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ARROW 2

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By author DESIGN STUDY ON

AVCS

Date MOBILE GROUND POWER UNITS

30 Sept

Signature Report 72/GEQ/1

PBS

Unit / Rank / Organization

Avro Aircraft Ltd.

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ARROW 2

DESIGN STUDY

ON

MOBILE GROUND POWER UNITS

ANALYZED

Report No. 72/GEQ/1.

November 1957.

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1. ABSTRACT

1.1 Introduction

1.1.1 Authority for Work

In accordance with R.C.A.F. Specification AIR 7-4 Issue 3, "Supersonic All-Weather Interceptor Aircraft Type CF-105", special ground handling equipment which is peculiar to the aircraft, shall, subject to the approval of the Department of National Defence, be developed by AVRO Aircraft Ltd. and delivered as specified by the Department.

As a part of this work, the Company issued early in 1955 a preliminary report, LOG/105/8 "CF-105 General Requirements for Mobile Ground Power Equipment". That report outlined the basic requirements for engine starting, electrical power, hot air, cool air, and inter-communication between cockpit occupants and ground equipment operators. The report was circulated to a number of firms specializing or interested in the design and manufacture of such equipment and the vendors were asked to submit design proposals for equipment to meet our requirements. An analysis and appraisal of the submitted proposals was presented in AVRO report LOG/105/24 entitled "CF-105 Evaluation Study of Proposed Mobile Ground Power Equipment", which was issued in February 1956. As a result, the R.C.A.F. approved the placement of orders by AVRO with the Consolidated Diesel Electric Corporation of Canada for two interim "starting vehicles" and two interim "power/air conditioning vehicles" for the support of Arrow 1 aircraft stationed at Malton. It was agreed that the development of mobile ground power equipment for the support of Arrow 2 aircraft would be deferred until the services required from this equipment were more firmly established.

The present report represents the next step in the development of equipment for supporting Arrow 2 aircraft at Malton and other bases. It is intended that evaluation of this equipment under service conditions shall form the basis upon which squadron equipment will be procured by the R.C.A.F.



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1.1.2 Nature of Equipment

Arrow 2 incorporates the Astra 1 electronic system which requires considerable more electrical power and approximately 50% more cooling air than the originally specified MX-1179 electronic systems. In addition, the electrical power for Astra 1 is derived from the aircraft electrical system, whereas the MX-1179 system had its own generators in the aircraft driven by an air turbine. Consequently the electrical power and cooling capacity required from the ground source has increased and hot medium pressure air from that ground source for driving a turbo-generator in the aircraft is now no longer needed.

Arrow 2 is powered by Orenda "Iroquois" engines instead of the Pratt and Whitney J-75 engines used in Arrow 1. However, in Avro report LOG/105/24, page 43, evidence was presented that indicated that this would not necessitate a change in the requirements of the hot medium pressure air for starting the engines from a ground source. This has since been proven to be the case and details of tests conducted by Orenda Engines Ltd. are included in the following text.

Subsequent to approving the placement of the orders for Arrow 1 equipment, the R.C.A.F. made known to the Company the design concept upon which further development of this equipment must be based. Details of this may be found in the minutes of the 21st meeting of the Arrow Maintenance Subcommittee.

Summarizing, the mobile ground power equipment which is the subject of this report consists of two units:

Unit No. 1 shall be capable of supplying the following services to one Arrow 2 aircraft:

- (a) Hot medium pressure air for starting the "Iroquois" engines in the aircraft in sequence.
- (b) Electrical power to energize certain of the aircraft circuits and the engine electrical circuits.



1.1.2 Nature of Equipment (Continued)

- (c) Telephonic inter-communication between aircrew and ground crew.

This unit shall consist of a self-contained package capable of being fitted on to a standard half ton truck, and embodying mounting pads for castoring wheel assemblies for the purpose of conversion to a trailer. The package may be used in any of the following configurations:

- Stationary (package only)
- Trailer (Castors fitted to base plate)
- Self-propelled (mounted on a half ton truck)

Unit No. 2 shall be capable of supplying the following services to one Arrow 2 aircraft:

- (a) Electrical power to energize the aircraft electrical and electronic systems.
- (b) Cool low pressure air to ventilate and cool the aircraft cockpit, armament bay and electrical and electronic equipment compartments.
- (c) Telephonic inter-communication between aircrew and ground crew.

This unit may consist of a self-propelled vehicle, the propulsive power unit of which may be used to supply any or all of the above services when the vehicle is stationary. Packaging of components for purposes of maintenance shall be a design objective.

1.1.3 Scope of Report

The Company's previous report on the subject, LOG/105/24, evaluated the merits of widely different types of equipment to supply the required services for engine starting, electrical power and cooling air.

In view of the important changes in the services required from the ground equipment supplying power



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1.1.3 Scope of Report (Continued)

and cooling air, all the conclusions arrived at in that report do not necessarily apply any longer.

The purpose of this report is therefore, to present the R.C.A.F. with the results of a further study aimed at determining the best equipment to meet the Arrow 2 requirements for electrical power and cold air. In carrying out this work, AVRO has received valuable assistance from the following Companies:

John Inglis Company Ltd.
Godfrey Engineering Company Ltd. of Canada
The Hussman Refrigeration Company
C.G. Hokanson Company Inc.
The Garrett Corporation
Blackburn and General Aircraft Ltd.
Stratos Division of Fairchild Engine and
Airplane Corp.

1.2 Discussion and Summary

From the investigations carried out during the design of Arrow 1 mobile ground power units and from the present studies, it is concluded that a gas turbine compressor is the most satisfactory type of unit for supplying hot, medium-pressure air for starting the engines in the Arrow 2. Such units are small, light, use the same type of fuel as the aircraft, and are well suited to this duty cycle since they can be started quickly and loaded fully without delay under all conditions of weather. Several gas turbine compressors that are now in production are capable of meeting our requirements for engine starting and should have a satisfactory overhaul life. These include the following engines:

AiResearch GTC 85-20
Blackburn Palouste 500
Blackburn Artouste 510
Solar Jupiter Mk. 1



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1.2 Discussion and Summary (Continued)

In the mobile power/air conditioning unit, it would be desirable to use identical gas turbine engines to supply shaft power for driving electrical generators and to supply bleed air to an air cycle refrigeration system and thereby provide the necessary power and cooling air to the aircraft. However, it has been shown that no single gas turbine compressor now in production is capable of supplying all of the shaft power and bleed air that is required. The unit must, therefore, be designed around two or more engines. Moreover, it is shown that with the bleed air pressure available from existing gas turbine compressors, an air cycle refrigeration system gives marginal performance under the humid environmental conditions specified. Since all of the entrained moisture cannot be removed from the air, some free moisture will likely be delivered to the aircraft on humid days, unless the delivery air temperature is raised above the 55°F temperature specified.

It was concluded therefore, that the requirements for the power/air conditioning unit could only be met fully by using freon refrigeration. Since time would not permit the development of small, light freon equipment, the major items in the system would have to be commercial units that are now in production. These factors result in a gasoline powered package that is 14' long, 8' wide, 4'-7" high, and weighs about 9000 lb. without fuel. This is considerably larger and heavier than comparable air cycle equipment and is, in fact, too heavy to be used as a "package" with castors. For this reason a specially designed trailer is recommended so that the power and air conditioning equipment can be arranged to give a minimum overall height.

Since the R.C.A.F. may consider that some relaxation in the performance requirements is acceptable in order to keep the size and weight of the unit to a minimum (or for other reasons), various schemes have been evaluated and the assessment is shown in Table A.

For this evaluation a "Figure of Merit" has been devised in order to access the advantages and disadvantages of each scheme. This "Figure of Merit" has been obtained in the manner outlined below:

TABLE A APPRAISAL OF FEASIBLE SCHEMES

No.	System	Size			Estimated Weight (lb)	Estimated Cost (Prototype)	Figure of Merit						Remarks
		Length	Width	Height			Performance (25)	Logistics (25)	Mobility (20)	Cost (20)	Availability (10)	Total (100)	
1	Freon system; "Packette" engines.	14'	8'	4'-7"	9000	\$55,000.00	23	20	10	18	10	81	
2	<u>Air Cycle Refrigeration Systems</u> 1 AiResearch GTC 85-20 & 1 GTCF 85-20; "Bootstrap" system.	10'	4'-6"	5'	2500	\$65,000.00	5	20	18	13	10	66	Insufficient Power.
3	2 AiResearch GTC 85-20 & 1 GTCF 85-20; "Bootstrap" system.	12'-2"	7'-9"	4'-3"	3100	\$90,000.00	18	12	15	8	10	64	3 engines used.
4	2 AiResearch GTCF 100-50; Simple or "Bootstrap" system.	9'	7'-9"	4'-3"	3200	\$110,000.00	25	15	20	4	0	64	Engines not Available
5	2 Solar Jupiter Mk. 1's; "Bootstrap" system.	12'	7'-9"	4'-3"	4900	\$110,000.00	25	15	15	4	7	66	Control problems not known with bleed air outputs paralleled.
6	2 Solar Jupiter Mk. 2's; "Bootstrap" system.	12'	7'-9"	4'-3"	4900	\$110,000.00	25	15	15	4	5	64	Engine Controls not developed.
7	1 Solar Jupiter Mk. 2 (uprated) 1 GTCF 85-20; Simple or "Bootstrap" system.	11'	7'-9"	4'-3"	4150	\$95,000.00	16	10	16	7	5	54	Engine controls not developed; insufficient bleed air.
8	2 Blackburn Palouste 500's; 1 GTCF 85-20; "Bootstrap" system.	12'-2"	7'-9"	4'-3"	3250	\$95,000.00	25	10	15	7	7	64	3 Engines Used.
9	2 Blackburn Artouste 510's; "Bootstrap" system.	9'	7'-9"	4'-9"	2800	\$75,000.00	18	15	20	11	5	69	Control problems not known with bleed air outputs paralleled.



1.2 Discussion and Summary (Continued)

(a) Performance & Growth Potential - 25 Points.

This factor represents the ability of the system to meet the performance requirements for electrical power, delivery air flow, delivery air temperature, and delivery air moisture content. It also includes 5 points for the capability of the system to be started quickly and easily, and to be loaded without delay under all environmental conditions.

(b) Logistics and Maintainability - 25 points

This factor is an appraisal of the serviceability and durability which can be expected from each system. It reflects our opinion concerning the following items:

(1) The number, variety, and cost of spare items of equipment to support operations. The suitability of the engine for use as an engine starter is also considered.

(2) Overhaul life of major components.

(3) Maintenance time and maintenance skills required. It is expected that gas turbine engines will require less attention in the field than piston engines. Moreover, for the lightweight piston engines that are considered, it is expected that the maintenance skill level required will be as high as that needed for gas turbine engines.

(4) Field experience with similar equipment.

Where similar items of equipment are being used widely at the present time, replacement items and overhaul facilities should be readily available, thereby simplifying the logistic problems.

(c) Mobility - 20 points

This factor, based on the size and weight of the power air conditioning unit, is a measure of the effort that will be expended in moving the unit



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1.2 Discussion and Summary (Continued)

(c) Mobility - 20 points (Continued)

from one place to another - particularly from one base to another by air.

(d) Cost - 20 points

This figure represents our opinion of the relative overall cost of using each system. In the case of gas turbine engines and air cycle refrigeration packages, the figure is based solely on initial cost, since it is expected that all units would have comparable overhaul lives so that operating and overhaul costs would be proportional to initial cost. The freon system is rated higher because of its lower initial cost, much higher efficiency (resulting in lower fuel consumption), lower engine overhaul cost, and longer overhaul life on items excluding the engines.

(e) Availability - 10 points

This factor represents our opinion concerning the possibility of obtaining proven equipment for the system in time for the Arrow 2 development programme. Thus, engines that are still in the design or development stages are considered a poor risk.

Total = 100 points.

Programming

Under the current list of ground support equipment contained in AVRO report 70/GEQ/1, issue 1, the Company is authorized to procure one Arrow 2 engine starting unit and one Arrow 2 power/air conditioning unit. This is inadequate for the support of development aircraft beyond aircraft #8 and delivery lead times are such that AVRO's initial purchase order must cater for an adequate quantity of this equipment so as not to embarrass the development programme planned by the R.C.A.F. The quantity of G.S.E. necessary to support the 37 aircraft development programme will be called out in issue 2 of AVRO



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1.2 Discussion and Summary (Continued)

Programming (Continued)

report 70/GEQ/1. Early R.C.A.F. agreement on the initial quantity of this equipment to be purchased by AVRO is therefore necessary.

1.3 Recommendations

Engine Starting Unit

It is recommended that the Arrow 2 engine starting unit use the AiResearch GTC 85-20 gas turbine compressor, provided that the engine starting times under extreme environmental conditions are considered acceptable by the R.C.A.F. The Arrow 2 "Scramble" time as defined in AIR 7-4, Issue 3, para. 3.4.1, is calculated to be 1 minute and 4 seconds at 3500' with 120°F ambient temperature using this unit. If this time is not acceptable to the R.C.A.F., the Blackburn Palouste 500 engine is recommended, which would reduce the above time to approx. 44 seconds.

It is recommended that the engine starting unit be designed as a self-contained package incorporating the following features:

- (a) Fuel for 1 hour of continuous running at maximum power.
- (b) Two 3-1/2" diameter flexible hoses 45' long terminating in automatic quick-disconnect couplings.
- (c) An electrical cable 50' long to supply the following services to the aircraft:
 - (1) 50 amperes at 27.5V D.C.
 - (2) 500 V.A. at 115V, 400 cps, 1-phase A.C.
 - (3) Intercommunication signals between cockpit occupants and ground crew.
 - (4) 27.5V D.C. signals to permit the air flow valves on the starting unit to be controlled from within the aircraft.



1.3 Recommendations (Continued)

Engine Starting Unit (Continued)

Power for these services is to be obtained from the gas turbine engine.

- (d) Batteries for starting the gas turbine compressor.
- (e) Storage for air hoses and electrical cables.

Mobile Power/Air Conditioning Unit

It is recommended that the Arrow 2 mobile power/air conditioning unit be a trailer powered by two Continental "Packette" gasoline engines - one driving a 60 K.V.A. 400 cps, 3-phase A.C. generator and a 28V D.C. generator; the other driving air blowers and a freon refrigeration compressor.

It is recommended that the mobile power/air conditioning unit incorporate the following features:

- (a) Tandem Miehle-Dexter 5516 air blowers, or equivalent.
- (b) Self-mobility at approximately 1 mph on level ground for a distance of 100' on battery power, or for an indefinite distance provided that the engine which drives the generators is running.
- (c) A height not in excess of 5 ft. 6 inches.
- (d) Two 3-1/2" diameter air delivery hoses 45' long and terminating in automatic, quick-disconnect couplings.
- (e) An electrical cable 50' long to supply 400 cps, 3-phase A.C. power to the aircraft.
- (f) Protective circuits to prevent electrical power from being supplied to the aircraft if the delivery air temperature exceeds 55°F or if the delivery air pressure is below 6.3 psig at the outlet of the air conditioning unit.
- (g) A convenient, central panel for all controls and instruments.



1.3 Recommendations (Continued)

Mobile Power/Air Conditioning Unit (Continued)

- (h) Convenient storage for air hoses and electrical cables.
- (i) Light alloy construction wherever possible in order to keep the weight to a minimum.
- (j) Cooling air flow velocities up to 1500 ft/minute in order to keep all heat exchangers as small as possible.
- (k) Provision for intercommunication between the cockpit occupants and the ground crew.

Procurement Authorization

It is recommended that AVRO be authorized to procure an adequate quantity of Arrow 2 engine starting units and mobile power/air conditioning units so as not to embarrass the Arrow development programme planned by the R.C.A.F.



2. INTRODUCTION

2.1 Authority for Work

In accordance with R.C.A.F Specification AIR 7-4 Issue 3, "Supersonic All-Weather Interceptor Aircraft Type CF-105", special ground handling equipment which is peculiar to the aircraft, shall, subject to the approval of the Department of National Defence, be developed by AVRO Aircraft Ltd. and delivered as specified by the Department.

As a part of this work, the Company issued early in 1955 a preliminary report, LOG/105/8 "CF-105 General Requirements for Mobile Ground Power Equipment". That report outlined the basic requirements for engine starting, electrical power, hot air, cool air, and inter-communication between cockpit occupants and ground equipment operators. The report was circulated to a number of firms specializing or interested in the design and manufacture of such equipment and the vendors were asked to submit design proposals for equipment to meet our requirements. An analysis and appraisal of the submitted proposals was presented in AVRO report LOG/105/24 entitled "CF-105 Evaluation Study of Proposed Mobile Ground Power Equipment", which was issued in February 1956. As a result, the R.C.A.F. approved the placement of orders by AVRO with the Consolidated Diesel Electric Corporation of Canada for two interim "starting vehicles" and two interim "power/air conditioning vehicles" for the support of Arrow 1 aircraft stationed at Malton. It was agreed that the development of mobile ground power equipment for the support of Arrow 2 aircraft would be deferred until the services required from this equipment were more firmly established.

The present report represents the next step in the development of equipment for supporting Arrow 2 aircraft at Malton and other bases. It is intended that evaluation of this equipment under service conditions shall form the basis upon which squadron equipment will be procured by the R.C.A.F.



2.2 Nature of Equipment

Arrow 2 incorporates the Astra 1 electronic system which requires considerably more electrical power and approximately 50% more cooling air than the originally specified MX-1179 electronic systems. In addition, the electrical power for Astra 1 is derived from the aircraft electrical system, whereas the MX-1179 system had its own generators in the aircraft driven by an air turbine. Consequently the electrical power and cooling capacity required from the ground source has increased and hot medium pressure air from that ground source for driving a turbo-generator in the aircraft is now no longer needed.

Arrow 2 is powered by Orenda "Iroquois" engines instead of Pratt and Whitney J-75 engines used in Arrow 1. However, in Avro report LOG/105/24 page 42, evidence was presented that indicated that this would not necessitate a change in the requirements of the hot medium pressure air for starting the engines from a ground source. This has since been proven to be the case and details of tests conducted by Orenda Engines Ltd. are included in the following text.

Subsequent to approving the placement of the orders for Arrow 1 equipment, the R.C.A.F. made known to the Company the design concept upon which further development of this equipment must be based. Details of this may be found in the minutes of the 21st meeting of the Arrow Maintenance Sub-Committee.

Summarizing, the mobile ground power equipment which is the subject of this report consists of two units:

Unit No. 1 shall be capable of supplying the following services to one Arrow 2 aircraft:

- (a) Hot medium pressure air for starting the "Iroquois" engines in the aircraft in sequence.
- (b) Electrical power to energize certain of the aircraft circuits and the engine electrical circuits.
- (c) Telephonic intercommunication between aircrew and ground crew.



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2.2 Nature of Equipment (Continued)

This unit shall consist of a self-contained package capable of being fitted on to a standard half-ton truck, and embodying mounting pads for castoring wheel assemblies for the purpose of conversion to a trailer. The package may be used in any of the following configurations:

- Stationary (package only)
- Trailer (Castors fitted to base plate)
- Self-propelled (mounted on a half-ton truck)

Unit No. 2 shall be capable of supplying the following services to one Arrow 2 aircraft.

- (a) Electrical power to energize the aircraft electrical and electronic systems.
- (b) Cool, low pressure air to ventilate and cool the aircraft cockpit, armament bay and electrical and electronic equipment compartments.
- (c) Telephonic inter-communication between aircrew and ground crew.

This unit may consist of a self-propelled vehicle, the propulsive power unit of which may be used to supply any or all of the above services when the vehicle is stationary. Packaging of components for purposes of maintenance shall be a design objective.

2.3 Scope of Report

The Company's previous report on the subject, LOG/105/24, evaluated the merits of widely different types of equipment to supply the required services for engine starting, electrical power and cooling air.

In view of the important changes in the services required from the ground equipment supplying power and cooling air, all the conclusions arrived at in that report do not necessarily apply any longer.

The purpose of this report is therefore, to present the R.C.A.F. with the results of a further study aimed at determining the best equipment to meet the Arrow 2



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2.3 Scope of Report (Continued)

requirements for electrical power and cold air. In carrying out this work, AVRO has received valuable assistance from the following Companies:

John Inglis Company Ltd.
Godfrey Engineering Company Ltd. of Canada
The Hussman Refrigeration Company
C.G. Hokanson Company Inc.
The Garrett Corporation
Blackburn and General Aircraft Ltd.
Stratos Division of Fairchild Engine and Airplane Corp.

The report first establishes the design requirements for the mobile ground power units in Chapter 3. This is followed in Chapter 4 by a preliminary design investigation of two basically different refrigeration systems for the cooling air. In Chapter 5 some practical solutions based on these different methods of approach are discussed. The selection of equipment for engine starting is outlined in Chapter 6 and in Chapter 7 we have attempted to summarize our findings in a comprehensive manner by focussing attention on the major advantages of deficiencies. Chapter 8 contains the Company's recommendations regarding the next steps to be taken in the development of adequate mobile ground power equipment for Arrow 2 aircraft.



3. DESIGN REQUIREMENTS

3.1 Aircraft Requirements

3.1.1 Electrical Power

The Arrow 2 has two completely independent and self-contained electrical systems, one being powered from each aircraft engine. Each system obtains its power from a 40 K.V.A., 200/115V, 3 phase, 400 c.p.s. generator which is driven by its aircraft engine through a constant-speed drive unit. Under conditions of steady load and engine speed the frequency is controlled to 400 cps $\pm 1\%$, and during load transients or variation of engine speed the frequency deviation does not exceed $\pm 5\%$. The transient recovers to 63% of its initial value within 0.5 seconds. The voltage is maintained within $\pm 1.5\%$ from zero to full load by regulators of the magnetic amplifier type. The response is such that the voltage recovers to within $\pm 1.5\%$ of its preset value within 0.2 seconds after full load is applied or removed.

Direct current at 27.5V is obtained from two 4.5 K.W. transformer-rectifier units, each energized from one of the main A.C. systems. The D.C. outputs are paralleled to feed a single D.C. system. The transformer-rectifiers, voltage regulators and generator control panels are packaged as complete units and rely on air from the air conditioning system for cooling whenever the A.C. or D.C. systems are energized.

For ground operation, both main A.C. systems can be paralleled and supplied with power from an external source through a receptacle under the fuselage behind the armament pack. There is no provision for energizing the main D.C. systems directly from an external D.C. source, although the emergency and battery busses can be energized through a receptacle on the nose undercarriage leg to permit such functions as canopy actuation, intercommunication, and engine starting. Thus, for most maintenance functions the D.C. systems must be powered from the transformer-rectifiers in the aircraft which, in turn, are energized from an external



3.1.1 Electrical Power (Continued)

A.C. source. The loads for ground operation of the Arrow 2 have been analysed and presented in Avro report LOG/105/5, Issue 4, "CF-105 MK.2, Estimate of Electrical Power to be Supplied by Ground Power Units". That report indicates that the load will probably not exceed 31.4 K.V.A., but recommends that the ground support equipment incorporate a 40 K.V.A. generator to allow for possible increases in load as the aircraft is developed. It is recommended that the characteristics of the power meet the requirements of Avro-can Specification E-500, although the generator need not be the same as the ones used in the aircraft.

3.1.2 Cooling Air

The Arrow 2 air conditioning system uses air which is bled from the compressors of the Iroquois engines when they are running. This air is cooled by passing it through an air-to-air heat exchanger, a water evaporator and an expansion turbine. The cold air thus obtained is then mixed with hot air to obtain the desired temperature. It is then used to condition the cockpits and to cool the electrical and electronic equipment throughout the aircraft.

For ground operation, air at the desired temperature can be injected into the system through two 3-1/2" diameter automatic quick-disconnect couplings which are mounted under the fuselage just ahead of the armament pack. From these couplings 3-1/2" diameter ducts lead to the main 6" distribution duct downstream from the cooling turbine. Although a pressure of only 1 psig is required in the main duct to ensure adequate distribution of the air to all equipment, a pressure of 4.5 psig is required at the aircraft couplings to cater for the pressure drop in the couplings and small ducts.

The total flow of air required is 150 lb/minute (minimum) and this is divided into two sub-systems in the aircraft as shown in Fig. 1.28 lb/minute goes to the cockpits and from there to the armament bay where it is exhausted around the missiles. The remaining 122 lb/minute passes through an oil-to-air heat exchanger to cool the hydraulic fluid from the antenna drive system and the liquid from the magnetron cooling system. It is then ducted to the



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3.1.2 Cooling Air (Continued)

electrical and electronic equipment throughout the aircraft. R.C.A. engineers have recommended that the temperature of the air entering their electronic equipment should not exceed 70°F. Therefore, since this air is heated approximately 15°F in the oil-to-air exchanger, it is necessary to supply the air to the aircraft at not higher than 55°F. Also, since the heat load from the oil-to-air heat exchanger will not necessarily be present whenever cooling air is supplied to the aircraft, the ground air conditioning system must be capable of supplying this 55°F air with no free moisture.

It is recommended that two 3-1/2" diameter hoses, 45' long, be used to duct the air from the ground power vehicle to the aircraft, since larger size hoses are cumbersome to handle and more difficult to store. It is estimated that these will incur a pressure drop of 1.8 psi. Also, a temperature rise of 5°F in hot weather and a temperature drop of 10°F in cold weather may be expected, due to heat conduction losses through the walls of the delivery air hoses. Thus the mobile power/air conditioning unit must be capable of supplying a minimum of 150 lb/minute of air at 50°F and a pressure of 6.3 psig. The moisture content of this air must be such that a dewpoint of 55°F is not exceeded.

3.1.3 Engine Starting

The Arrow 2 is fitted with two Orenda "Iroquois" engines which are started by air turbine systems. These starters have been selected because of their reliability and low installed weight, but require a supply of hot, medium pressure air from a ground source as detailed below:



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3.1.3 Engine Starting (Continued)

	<u>Normal Case</u>	<u>Maximum Case</u>
Ambient Pressure	14.7 psia	14.7 psia
Ambient Temperature	60°F	- 65°F
Delivery air pressure (minimum)	50 psia	60 psia
Delivery air temperature	325 to 500°F	225 to 500°F
Delivery air flow (per engine)	112 lb/minute	148 lb/minute

In the normal case defined above, the "Iroquois" will be accelerated to idling speed (3000 R.P.M.) within 20 seconds. This approaches the minimum time feasible with 2-spool engines (approximately 15 seconds), since the low-pressure spools are not driven from the starting motors and therefore, tend to lag and restrict the flow of air through the engine if the high-pressure spool is accelerated too quickly. The starting times for other environmental conditions will depend on the characteristics of the air source. If a gas turbine compressor is used for the supply, its output decreases as the air density decreases so that the starting time is increased. However, since the aerodynamic drag (and torque) of the Iroquois engine also decreases, starting times of less than 30 seconds are feasible at 3500' altitude with an ambient temperature of 120°F, thereby permitting the scramble requirements to be met.

Engine starting air is fed to the starters through two automatic quick-disconnect couplings and the flow is controlled electrically by valves on the ground supply unit. These valves may be opened by selecting "start" or "motor" on the engine starting switches in the front cockpit of the Arrow 2 and will be closed automatically by centrifugal switches when the engines reach a pre-set speed. Two 28V D.C. signal wires are brought to an automatic quick-disconnect coupling on the nose under-carriage leg for this purpose. This coupling also has provision for supplying the following additional services to the aircraft.



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3.1.3 Engine Starting (Continued)

- (a) Up to 50 amperes at 28V D.C. for operating the canopies, fire extinguishing circuits, intercommunication system, and engine starting circuits.
- (b) Up to 500 V.A. at 115V, 400 cps, 1 phase A.C. for warming the amplifiers in the "Iroquois" fuel flow control units.
- (c) Intercommunication between aircrew and ground crew.
- (d) Intercommunication between aircrew and an Operations' Controller via land telephone line.

The power for services, a, b, c above must be supplied by the engine starting unit when the aircraft is operated in the open.

3.2 Environmental Requirements

During the design of mobile ground power units for Arrow 1 aircraft, an analysis of Canadian and world-wide operating conditions was made and reported in Avro Report No. LOG/105/13, dated July 1955. This report recommended that mobile engine starting, ground power and air conditioning equipment be designed to give rated performance under the following conditions:

EXTREME CLIMATIC CONDITIONS QUOTED IN REPORT NO. LOG/105/13

Altitude (ft)	Temperature (°F)		Barometric Pressure (In. Hg.)		Dew Point (°F)	
	Hot Atmosphere	Cold Atmosphere	Hot Atmosphere	Cold Atmosphere	Hot Atmosphere	Cold Atmosphere
130		-65	29.92	29.92	75	-70
124		-65	28.93	28.57	73	-70
118		-65	27.98	27.32	70	-70
112		-65	27.04	26.17	67	-70
106		-65	26.14	25.09	64	-70
100		-65	25.25	24.05	61	-70

Provision must also be made for enclosed air temperature, due to solar radiation, of up to 160°F.



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3.2 Environmental Requirements (Continued)

Although this world-wide environment had been accepted by the R.C.A.F., further discussions with R.C.A.F. personnel and with vendors and manufacturers of air conditioning equipment indicated that these conditions might be unnecessarily severe. A review of current specifications and environmental requirements was made and reported in an addendum to report no. LOG/105/13, issued July 1957. This recommended the following "hot atmosphere" ambient conditions:

HOT ATMOSPHERE - ADDENDUM TO REPORT LOG/105/13				
Altitude (Ft)	Pressure (lbs/ft ² abs)	Dry Bulb Temp (°F)	Wet Bulb Temp (°F)	Specific Volume (ft ³ /lb)
0	2116	130	85	14.86
1,000	2041	126.5	85	15.33
2,000	1968	123	85	15.80
3,000	1897	119.5	85	16.30
4,000	1828	116	85	16.80
5,000	1761	112.5	85	17.32

Discussions with certain vendors were based upon these conditions. Report No. LOG/105/13 and its addendum had been submitted to the R.C.A.F. for approval in the meanwhile.

Subsequently the R.C.A.F. advised Avro in letter S36-38-105-13 (ACE-1), dated 21st August, 1957 that, notwithstanding the recommendations of Report No. LOG/105/13 and its addendum, the R.C.A.F. would require the mobile ground power and air conditioning unit for the Arrow 2 to give rated performance under the following extreme ambient conditions:

R.C.A.F. REQUIREMENTS - LETTER S36-38-105-13 (ACE-1)			
Case	Dry Bulb Temp. (°F)	Wet Bulb Temp. (°F)	Altitude (ft)
"a"	120	76	0 - 3,500
"b"	100	85	0 - 3,500
"c"	-65	-	0 - 3,500



3.2 Environmental Requirements (Continued)

The calculations presented in this report for the ground power and air conditioning unit are based on these conditions.

In the case of the engine starting unit, the environmental conditions have not been specified in detail. It is assumed, therefore;

- (a) that the aircraft scramble requirements must be met for ambient temperatures from -65°F to $+120^{\circ}\text{F}$ at altitudes from sea level to 3500'.
- (b) that identical engine starting units will be used as mobile starters and in readiness hangar applications. For mobile applications, however, the aircraft engines will be started in sequence using a single starting unit.

Under the worst environmental condition above, (3500', 120°F), the take-off for the Arrow 2 requires approximately 19 seconds to unstick and 29 seconds to reach a height of 50'. Using the ground run time of 19 seconds, and allowing 7 seconds for engine acceleration for idling speed to maximum thrust, then an engine starting unit must be capable of accelerating an engine to idling speed within 34 seconds.

3.3 Configuration

The optimum configuration for the mobile ground power units is, to a large extent, governed by the operational role for which the equipment is intended. In this regard, R.C.A.F. Specification AIR 7-4, Issue 4 is used as a guide and the following extracts are from that document:

Para. 3 Concept of Operations

3.1 General

For purposes of detail design of components and procedures the operational concept of the Arrow weapon system shall be as noted in the following sub-paragraphs.



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3.3 Configuration (Continued)

Para. 3 Concept of Operations (Continued)

3.1.1 Object

The object in the operation of the Arrow weapon system in time of war will be the attainment of the highest possible operational potential at all times. In time of peace the operation of the weapon system will be concerned primarily with attaining and maintaining a high degree of proficiency in the all weather role.

3.1.2 Battle State

The concept is based on one or more squadrons, of 12 operational plus 2 training aircraft each, at a prepared all-weather base. With 50% of the aircraft undergoing minor maintenance each squadron will be required to maintain 2 aircraft at the state of readiness or standby at all times, and as many of the remainder as possible in a state that can be changed to available within 3 hours.

3.1.3 Forward Base

In exceptional circumstances, the squadron may be required to operate from a forward base to which the aircraft will be flown in a fully operational state. They will be serviced and brought up to "Available" or "Readiness" on arrival, but normally will return to the main base when scrambled. Should they be required to land back at the forward base only sufficient facility to prepare them for return to the main base is required. This is a detached operation which the main base must be capable of supporting up to a maximum of 50% unit establishment. Individual aircraft will not normally remain on the forward base longer than the time between primary inspections. The servicing



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3.3 Configuration (Continued)

Para. 3 Concept of Operations (Continued)

3.1.3 Forward Base (Continued)

equipment required to prepare aircraft at a forward base for return to the main base must be air transportable, with trained personnel, to carry out the required operations, in a C-119 or similar transport airplane.

3.1.4 Building Facilities

For each squadron, the airfield shall include the following structures:

- (a) Hangar(s) to house two aircraft at readiness or standby.
- (b) Shelter(s) to house five aircraft undergoing turn-around or first line maintenance.
- (c) Hangars to house seven aircraft undergoing second or third line maintenance.

3.2 Time Limits

3.2.2 Serviceability

The aircraft is to be capable of being maintained at the states of readiness and for the time periods as follows:

<u>State</u>	<u>Time Period</u>
Available (15 min)	Indefinitely
Available (5 min)	Indefinitely
Standby (2 min)	Random periods of not more than 30 min.

3.2.4 Utilization

The aircraft together with the support of the ground support equipment and the R.C.A.F. shall be capable of a utilization of not less than 20 hours per month when operated as described in this section.



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3.3 Configuration (Continued)

In the concept quoted above, it is noted that most maintenance work at the main Arrow base will be carried out in hangars when electrically-powered equipment normally will be used. On this basis it is assumed that the mobile equipment will be used primarily to support aircraft:

- (a) . operating from advance bases.
- (b) at the main base if the electrically-powered equipment or power supplies should fail.
- (c) at the main base if the electrically-powered equipment should be inadequate. This could occur in a tactical situation where all serviceable aircraft had to be brought to the "Standby" condition simultaneously to cope with a mass attack.

Based on these factors the utilization of the mobile power/air conditioning equipment is assessed as follows:

Squadron establishment	14 aircraft (including two trainers)
Aircraft at advanced bases	7 aircraft (including two trainers)
(50%)	
Aircraft at "Readiness" at main base	2 aircraft (including two trainers)
Operational Aircraft	9

Since all 9 operational aircraft could require power and cooling air at the same time, it is assumed that each squadron will require 9 serviceable mobile power/air conditioning units plus 1 spare unit. Further, it is assumed that each operational aircraft will fly 20 hours per month and that the mobile power/air conditioning unit will be run for 3 hours per hour of flying. This figure allows for servicing the aircraft and maintaining it at readiness at an advanced base. With these assumptions the average utilization is;

$$\frac{9 \times 20 \times 3 \times 12}{10} = 648 \text{ hours per year.}$$



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3.3 Configuration (Continued)

With this utilization an overhaul life of 1000 hours is considered acceptable, although a longer period obviously is desirable.

Since the mobile ground power units are to be transportable by air in a C-119 aircraft, size and weight are considered to be important factors in the design of the equipment. Although truck, trailer, and package concepts all merit consideration, it appears from the concept of operations that the requirements for air transportability should outweigh any considerations for self-mobility around air bases. In this regard the R.C.A.F. indicated its preference at the 21st meeting of the Arrow Maintenance Sub-Committee on October 16, 1956, as follows:

- Para. 3 (a) "A standard range of trailers would not be developed for mobile items of G.H.E.; rather a standard range of lockable castoring wheel assemblies would be used on all mobile non-self propelled items of G.H.E."
- (b) "The following G.S.E. items are to have the configuration indicated below:
- (2) Starter: a packaged unit embodying mounting pads for the wheel assemblies noted in para. 3 (a), and capable of fitting on a standard 1/2 ton truck. Thus, the package could be used in any of the following configurations.
- (a) Fixed (package only).
(b) Mobile (castoring wheel assemblies installed)
(c) Self-Propelled (mounted on a standard 1/2 ton truck)

The R.C.A.F. indicated a preference for a similar approach for the mobile power/air conditioning unit, but it was pointed out by AVRO that the size and weight of the equipment might make such an arrangement impractical. It was thus agreed that the development of an integrated vehicle would be considered for this unit. However, component packaging for maintenance is a firm requirement.



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3.3 Configuration (Continued)

In this report the various schemes have been compared primarily as self-contained packages. However, studies have been made to investigate integration of the systems with truck and trailer chassis, and the probable variations in size and weight are noted in the report. Also, it is recommended that the units be made low enough to pass under the wingtips of the Arrow 2 with the ailerons fully deflected. This limits the height to 66 inches (maximum).



4. PRELIMINARY DESIGN OF POWER/AIR CONDITIONING UNIT

4.1 General

In this chapter of the report the performance of possible systems is calculated in order to establish the total requirements for power and the approximate sizes of the components in the systems. Typical engineering values are used for the efficiencies of compressors, turbines, generators, heat exchangers, etc., and are noted on the appropriate sketches, Fig. 2, 3. Two basic schemes for cooling the air have been considered:-

- (a) a vapour cycle refrigeration system using Freon 12 as a refrigerant.
- (b) an air cycle refrigeration system.

4.2 "Freon" System

4.2.1 Description

In this type of system the charge air is compressed to a pressure just high enough to allow for pressure losses in the cooling coils and ducting. It is then cooled to the desired temperature by being passed over cooling coils through which the refrigerant is circulated. An air-to-air heat exchanger may also be added between the blower and the refrigeration coil. The Freon circuit consists basically of the cooling coil, an expansion valve, a condensing coil and a pump. A schematic diagram of a cooling air supply using a Freon system is shown in Fig. 1.

4.2.2 Power Requirements

Preliminary power requirements for the system for the specified environmental conditions are given in Table 1. These requirements have been calculated using the values noted below.

- (a) It was recommended in Chap. 3 that the power/air conditioning unit be capable of supplying up to 40 K.V.A. of 3 phase, 400 cps. A.C. power to the aircraft at load factors from 0.75 to 1.0. Assuming 85% for the efficiency of the generator, the power required is

$$\frac{40 \times 1}{.746 \times .85} = 63 \text{ H.P.}$$

TABLE I
ESTIMATED PERFORMANCE - FREON SYSTEM

	ENVIRONMENTAL CONDITION				
	Sea Level 100°F D.B. 85°F W.B.	Sea Level 120°F D.B. 76°F D.B.	3500' 100°F D.B. 85°F W.B.	3500' 120°F D.B. 76°F W.B.	Sea Level - 65°F
Ambient Pressure (p.s.i.)	14.7	14.7	12.93	12.93	14.7
Density (lb/cu ft.)	.0709	.0685	.0624	.0603	.1005
Moisture Content (grains/lb.)	159	64	187	84	--
<u>Electrical Power</u> - Aircraft (H.P.)	63	63	63	63	63
- Controls, lights (H.P.)	5	5	5	5	5
Blower - Volume Flow (C.F.M.)	2120	2190	2410	2490	1950
- Power Required (H.P.)	83.5	86	92.5	95.5	77
- Air Delivery Temperature (°F)	200	223	208	231	+19
<u>Air-to-Air Heat Exchanger</u>					
- Air Delivery Temperature (°F)	110	130	111	131	+19
- Heat Transfer (B.T.U./Min)	3100	3340	3400	3280	---
- Cooling Air Flow (600 lb/min) (C.F.M.)	8480	8760	9640	9960	---
- Power Required (H.P.)	9.5	9.8	10.3	10.6	---
<u>Cooling Coil</u>					
- Air Delivery Temperature (°F)	50	50	50	50	70
- Refrigeration Load (B.T.U./min)	4400	3000	3000	3500	-1836
- Tons Refrigeration	22	15	25	17.5	---
- Power Required (D.C.P. = 4) (H.P.)	26	18	30	20	---
<u>Condensing Coil</u>					
- Cooling Air Flow (lb/min)	8480	8760	9640	9960	---
- Power Required (H.P.)	9.5	9.8	10.3	10.6	---



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4.2.2 (a) (Continued)

Additional electrical power may also be required within the power/air conditioning unit for operating controls, fans, lights, etc. This may vary from 5 to 40 H.P. depending on the method of driving the heat exchanger fans.

- (b) Blower An adiabatic efficiency of 0.7 was assumed for the blower and a delivery pressure of 7.3 p.s.i.g. was used to cater for a pressure drop of 1.0 p.s.i. in the heat exchanger, cooling coil and internal ducting. A temperature rise of 100 to 110°F is encountered when the air is compressed to this pressure.
- (c) Air-to-Air Heat Exchanger - Power is required for drawing cooling air through the air-to-air heat exchanger. The figures in Table 1 were based on an effectiveness of 0.9, a ratio of 4 for cooling air flow to charge air flow and a pressure drop of 0.25 p.s.i. to cater for pressure losses through filters and the heat exchanger. This power requirement can vary considerably and will depend on the size and shape of the heat exchanger and cooling flow velocity. A compromise is required between the size and weight of the heat exchanger and the power required by the fan.
- (d) Refrigeration - The refrigeration load is based on cooling the air from approximately 100°F. above the ambient temperature to 50°F and condensing sufficient water vapour to lower the dewpoint to 55°F. The system needs a 25 ton refrigeration system which, using a coefficient of performance of 4, requires 30 H.P. to drive the Freon compressor.
- (e) Freon Condenser - The heat absorbed by the Freon in the cooling coil must be transmitted to the atmosphere in the condensing coil. As a first approximation the cooling air flow was assumed to be the same as that for the air-to-air heat exchanger.



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4.2.2 Power Requirements (Continued)

- (f) Engines - The power requirements from Table 1 are summarized below in order to estimate the total power needed for the power/air conditioning unit:

	Sea Level 100°F D.B. 85°F W.B.	Sea Level 120°F D.B. 76°F W.B.	3500' 120°F D.B. 85°F W.B.	3500' 120°F D.B. 76°F W.B.
Electrical - Aircraft	63 H.P.	63 H.P.	63 H.P.	63 H.P.
- Controls	5	5	5	5
Heat Exchanger Fan	9.5	9.8	10.3	10.6
Refrigeration Compressor	26	18	30	20
Condensing Fan	9.5	9.8	10.3	10.6
Blower	83.5	86	92.5	95.5
Total	196.5 H.P.	191.6 H.P.	211.1 H.P.	204.1 H.P.

In order to develop 211 H.P. on a 100°F day at 3500' altitude, an engine rated at 259 H.P. under sea level standard conditions is required.

The effect of deleting the air-to-air heat exchanger has also been investigated and is summarized below for the 3500', 100°F case.

	<u>Power Required</u>	
	With Heat Exchanger	Without Heat Exchanger
Electrical - Aircraft	63	63
- Controls	5	5
Blower	92.5	87
Heat Exchanger Fan	10.3	-
Refrigeration Compressor	30	50.5
Condenser Fan	10.3	20.6
	211.1 H.P.	226.1 H.P.

Since engine power, refrigeration pump capacity, and condenser coil size are all increase, it is concluded that an air-to-air heat exchanger should be included in the system.



4.2.2. Power Requirements (Continued)

- (g) Heater - It is noted in Table 1 that in cold weather the heat of compression is not sufficient to meet our requirements. This can be overcome by adding a choke heater and recirculating access air that is available, or by adding a heater. The capacity required is approximately 110,000 B.T.U./hour.

4.3 Air Cycle System

4.3.1 Description

In an air cycle cooling system the charge air is compressed to a pressure considerably above that required at the outlet from the power/air conditioning unit. It is then cooled to a temperature slightly above ambient in an air-to-air heat exchanger and is then further cooled by passage through an expansion turbine. The power developed by the turbine may be used to drive cooling fans, compressors, electrical generators or other equipment. A schematic diagram of an air cycle cooling system is given in Fig. 3. A mechanical water separator is required in this system since there are no cold coils on which the moisture can condense.

4.3.2 System Performance

- (a) Water Separator - This unit normally consists of a cone in the air stream upon which the water droplets impinge and collect to form drops large enough to be separated from the air by centrifugal or inertial action. As noted in Table 1, the 100°F, 3500' case causes the greatest refrigeration load, largely because of the amount of moisture which must be removed. This is calculated below for this environmental condition:

Initial moisture content of air = 187 grains/lb dry air
Required maximum moisture content = 66 grains/lb dry air
(corresponding to dewpoint of 55°F)

Water to be removed 121 grains/lb dry air



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4.3.2 System Performance (Continued)(a) Water Separator (Continued)

Since the water separator is not likely to remove more than 80% of the free moisture, the free water content at the turbine exit must be at least

$$\frac{121}{.80} = 151 \text{ grains/lb. dry air}$$

Thus, the air delivered from the water separator will contain 30 grains of free moisture and 36 grains of water vapour per lb. of dry air. This corresponds to a turbine outlet temperature of 40°F. A pressure loss of 1.5 p.s.i. may be expected in the water separator.

- (b) Refrigeration Turbine - The turbine outlet temperature is dependent upon the turbine inlet temperature, pressure ratio, and the moisture content of the air. The turbine inlet pressure that is required in order to obtain water separation as noted above has been calculated for 100°F, 3500' altitude cases with different humidity conditions using:

Turbine adiabatic efficiency 85%
Turbine inlet temperature 120°F
Enthalpy change with humid air = enthalpy change for dry air.

The inlet pressures required are shown in Fig. 4. This curve indicates that a pressure of 68 p.s.i.a. is required for the specified ambient condition - 3500' altitude, 100°F dry bulb temperature, 85°F wet bulb temperature. This pressure is considerably higher than that available from existing gas turbine compressors. It could, however, be obtained by using a bootstrap system whereby the turbine drives a compressor to boost the pressure of the air delivered from the gas turbine. Lower pressures might also be feasible if the extracted water is used to help cool the air-to-air heat exchanger.



4.3.2 System Performance (Continued)

- (c) Compressor - As was explained in Avro report LOG/105/24 at some length, gas turbine compressors are considered to be the best source of compressed air for use with an air-cycle refrigeration system because of their low weight and small size. The performance characteristics and suitability of all known gas turbine compressors have been considered for this application; these are discussed in Chapter 5.

It should also be noted that gas turbine compressors are recommended as engine starters for the Arrow 2. Therefore, for logistic reasons, it would be desirable to use the same type of engine for the power/air conditioning unit should an air cycle refrigeration system be selected.

5. DESIGN INVESTIGATION - MOBILE POWER/AIR CONDITIONING UNIT

5.1 General

Using the preliminary analysis noted above as a basis, AVRO contacted the manufacturers of components in the equipment fields involved in order to survey a wide range of possible designs for a mobile power/air conditioning unit for the Arrow 2. Different manufacturers were asked to supply information concerning the size, weight and performance of their products and, in addition, their views were sought concerning installation of the equipment into a mobile package. The scope of the discussions with equipment manufacturers and the results of their investigations are outlined in the paragraphs below.

5.2 Freon Systems

5.2.1 Investigation by John Inglis Co. Ltd.

In 1956 the John Inglis Co. Ltd. had co-operated with AVRO in making proposals for fixed installations to supply cooling air to Arrow 2 aircraft in readiness and maintenance hangars. At the time they also expressed an interest in designing and



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5.2.1 Investigation by John Inglis Co. Ltd. (Continued)

supplying equipment for mobile use. Because of this, they were approached and asked to submit information concerning the sizes and weights of commercial-type equipment for a freon cooling system to meet our requirements. They were also requested to advise us regarding controls for the system and the installation of the components into a package in order to estimate the overall size and weight of the unit. At our suggestion, their proposal centred around a Packette engine and a Miehle-Dexter blower since, to our knowledge, these were the lightest and most compact units available.

The Inglis proposal is outlined in detail in App.1 of this report. It results in a package 12' x 6'6" x 6' weighing 7500 # excluding any chassis or running gear.

Features of their system included a heat exchanger to cool the charge air from the blower prior to its flow through the freon cooling coil. This reduced the refrigeration load from approximately 42 tons to 25 tons, resulting in a saving of 15 horsepower. The capacity of the system was based on giving rated performance at ambient temperatures up to 100°F, and supplementing the performance by spraying the freon condensing coils with water under more severe conditions. The freon system was based on 40°F evaporating temperature and 130°F condensing temperature, using suction pressure variation as the method of controlling the system.

Their proposal appeared to be based on conventional commercial practices regarding flow velocities, materials and equipment with the result that the package is large and heavy. The power requirements for the cooling flows seem low and the heat exchanger sizes are large. Subsequent discussions with other manufacturers indicated that the Inglis proposal for packaging the equipment could be improved upon. It was therefore concluded that a suitable unit using commercial equipment and practice could be built, but it would be large and heavy. In addition, considerable design and development work would be required in packaging the equipment.



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5.2.2 Investigation by Godfrey Engineering Co. Ltd.

Godfrey Engineering Co. Ltd. of Canada was known to have contacts in both the airborne air cycle and airborne freon refrigeration fields through its affiliation with Sir George Godfrey and Partners, Ltd. England and the Stratos Division of the Fairchild Engine and Airplane Corporation in the United States. Consequently it was suggested to this Company that they investigate the feasibility of a small, light freon design using aircraft-type freon compressors, air blowers and heat exchangers. The Continental "Packette" engines were suggested as prime movers.

This study indicated that Lysholm (spiral lobe) blowers and freon compressors are under development but will not likely be available, in the sizes which we require, in time for the Arrow 2 development programme. The alternative is to use commercial equipment and the Godfrey Co. thought that, while this would be quite feasible, it would not compete with air cycle equipment because of its size and weight. It was estimated that a package using commercial equipment would be about 18' long, 8' wide and 5' high. The cooling equipment would cost approximately \$14,000. and the complete package about \$45,000.

The Godfrey Co. report indicated that one Packette engine would not have enough power to meet all of our requirements and therefore a second prime mover is needed. Like the Inglis proposal, it included a water spray system to cool the condenser coil during operation at high ambient temperatures. In addition, it was recommended that a 60 cps generator be included in the equipment so that commercial controls could be used, since these are readily available and also are much cheaper.

5.2.3 Investigation by Hussman Refrigerator Co.

The Hussman Refrigerator Co. of St. Louis, Missouri, and Brantford, Ontario approached AVRO to discuss an electrically-driven air conditioning unit of their design which they had built for Convair. When our requirements were discussed they asked for per-



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5.2.3 Investigation by Hussman Refrigerator Co. (Continued)

mission to submit a preliminary proposal based on commercial Freon components.

This proposal included a single Packette engine with toothed-belt drives to tandem Miehle-Dexter blowers, a generator, refrigerator compressor and the condenser fans. No air-to-air heat exchanger was used, so that all cooling was done as the air passed through the refrigeration coils. The overall package was 15' long and 7'8" wide and the layout is shown in Fig. 15.

Examination of their drawing showed that there was not sufficient power available from a single engine and that a second "Packette" would be required.

5.2.4 Discussions with C.H. Hokanson Co. Inc.

This company had advertised a mobile air conditioning unit capable of supplying 125 lb/min of air at a pressure of 8.0 p.s.i.g. and a temperature of 30°F. Further information was obtained by correspondence and the unit appeared to come close to meeting our requirements for cooling air. Consequently, their plant was visited and the design was discussed in detail.

Their Model 707 air conditioning unit uses two Packette engines - a PE-150 driving two Miehle-Dexter blowers in tandem, and a PE-90 driving a 50 ton refrigeration compressor. An air-to-air heat exchanger is used to reduce the load on the refrigeration system and a gasoline heater rated at 200,000 B.T.U./hour is fitted to heat the air to about + 100°F in cold weather. The equipment is mounted on a special trailer chassis, giving an overall weight of 16,000 lb. It is 14' -2" long, 7'-3" wide and 7' high. The cost was \$60,000 per unit (10 units built), of which \$30,000 represented the cost of materials and bought-out parts. This overall cost might be reduced considerably on a production contract.



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5.2.5 Recommendations Concerning Freon Systems

From the investigations outlined above it is apparent that a suitable power/air conditioning unit can be developed to meet our performance requirements using a freon refrigeration system. It is also evident, however, that compact lightweight equipment will not be available in time and that such a unit will therefore have to be designed using some existing commercial equipment and practices. AVRO has, therefore, analysed the information submitted by the manufacturing firms noted above and the following scheme is presented as the lightest and most compact "package" arrangement likely to be attained at this time.

The proposed unit is shown in Fig. 5. It is powered by two Continental Packette engines, - a PE-150 driving a 60 K.V.A., 400 c.p.s. A.C. generator, and a PE-200 driving the blower and freon compressor. The excess electrical power is used to drive the cooling air fans and for operating the controls in the system. As a self-contained package, the unit will be approximately 14' long, 8' wide, and 4' - 7" high and will weigh about 9000 lb. The estimated weights and sizes of the equipment items are given in Table 2 and the equipment is described in more detail below:-

TABLE 2
ESTIMATED WEIGHTS AND SIZES AND FREON EQUIPMENT

<u>Item</u>	<u>Weight</u>	<u>Length</u>	<u>Width</u>	<u>Height</u>
Blower	760 lbs	49 in.	20 in.	16 3/8 in.
Heat Exchanger, Air-to-Air	205	40	13	48
" " Freon Liquid/suction	140	24	24	48
Cooling Coils	525	33	33	48
Condenser	500	48	24	48
Freon Compressor	1300	24	24	24
Generator, engine, and gearbox	1010	66	36	36
Fans and Motors	160	-	-	-
Expansion Valve	100	24	12	12
Blower engine (PE-200)	975	60	36	36
Gearbox	200	42	12	24



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TABLE 2 (Continued)

<u>Item</u>	<u>Weight</u>	<u>Length</u>	<u>Width</u>	<u>Height</u>
Pipework	300	-	-	-
Dusting	200	-	-	-
Freon Tank	50		IN BASE OF UNIT	
Fuel Tank (70 gal.)	195		IN BASE OF UNIT	
Instrument Panel	200	48	12	48
Fire Extinguisher	30		EXTERNAL	
Mounting base and body	1880			
Total Dry Weight	8730			
Fuel (2 hours operation)	500			
Freon 12 liquid	150			
Total	9380			

Engines

The Continental Packette engines have been selected as being the lightest and most compact that are available. Moreover, they are qualified for military applications under world-wide operating conditions and should therefore give satisfactory performance in a power/air conditioning unit. Discussions with U.S.A.F. personnel indicated that although the overhaul life of these engines is listed as 1000 hours, some sizes are currently being operated from 2000 to 2500 hours between overhauls. New engines are not requisitioned by the operating establishments until 1500 hours have been accumulated. The cost of a new PE-150 engine is \$4100.00 and overhaul costs are approximately \$750.00. Although these figures are somewhat higher than those for industrial engines, the initial cost includes the gearbox, governor, accessories and winterization kit. If industrial gasoline or diesel engines were used, it is estimated that the weight of the complete package would be increased by 5400 lb. and 7600 lb. respectively.



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5.2.5 Recommendations Concerning Freon Systems (Continued)

Generator

A 60 K.V.A., 400 cps. AC. generator has been selected in order to supply electrical power to the aircraft and to drive the cooling air fans in the refrigeration system. A transformer-rectifier unit will also be installed to provide power at 28V D.C. for relays and controls.

Blower

Tandem Miehle-Dexter 5516 blowers are proposed for compressing the charge air in the unit. These blowers are of the positive-displacement type and are used widely in applications similar to the Arrow 2 power/air conditioning unit. They are of aluminum construction and are among the lightest and most compact blowers of this type that are available commercially.

Freon Compressor

A 25 ton commercial compressor is used since small, lightweight units will not be available in time for the Arrow 2 development programme. Freon 12 is the refrigerant used.

Air-to-Air Heat Exchanger

This is a two-pass cross-counterflow aluminum unit of tubular construction. The charge air makes two passes through the tubes while the cooling air makes a single pass over the tubes. In order to minimize the size, a flow velocity of 1500 ft/min. is used for the cooling air. This is considerably higher than standard commercial practice but is satisfactory for heat transfer. Higher flow velocities would require more power for operating the fans.

Cooling Coil and Condenser

The unit has been based on the use of copper fins sweated onto copper tubes in order to ensure satisfactory heat transfer and long life. Brazed aluminum units might also be used, but would be more expensive



5.2.5 Recommendations Concerning Freon Systems (Continued)

Cooling Coil and Condenser (Continued)

as this practice is not in common use. However, up to 700 lb. weight could be saved on these two units by using aluminum alloys.

Frame and Body

The mounting frame and enclosure have been based on the use of aluminum alloys. The freon 12 storage tank and the fuel tanks would be mounted within the base and provision would be made for slinging the complete package. All instruments and controls would be in a convenient location adjacent to the delivery air connections and hose storage compartments.

Although this scheme is outlined as a self-contained package, it is too heavy for use with standard castors. For this reason a trailer concept is recommended with provision for self-mobility at walking speed. Some rearrangement of components is necessary in order to keep the height below 66 inches and the overall weight would be 10,800 lb., or 1400 lb. heavier than the package. If the system was integrated into a specialized truck with the generator driven by the truck engine through a power take-off rather than by a "Packette" engine, the unit would weigh in excess of 13,000 lb. A special chassis and cab would be required in order to keep the height under 66 inches and the overall length would be approximately 20 ft.

The estimated cost of a prototype unit as outlined above is \$55,000.00 and production units would probably cost between \$45,000.00 and \$50,000.00. The overhaul life should be between 1500 and 2000 hours and would be limited by the Packette engines. All other components should have a much longer overhaul life.

5.3 Air Cycle Systems

5.3.1 Compressors

5.3.1.1 General

From the analysis in Chapter 3, it was concluded that a turbine inlet pressure of



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5.3.1.1 General (Continued)

68 p.s.i.a. would be required under our worst environmental condition (3500', 100°F. Dry Bulb, 85°F Wet Bulb) so that enough water could be removed from the air to ensure that no free moisture would enter the aircraft. This represents a compression ratio of 5.25 : 1 for the compressor - considerably higher than that available directly from current gas turbine compressors. It is, however, feasible to use the air bled from existing units in conjunction with a "Bootstrap" cooling system wherein the air is further compressed by a compressor driven by the refrigeration turbine. Such a system is shown schematically in Fig. 3. Separate medium pressure compressors driven by gasoline or diesel engines have not been investigated. Since about 400 H.P. would be required to drive such a compressor, the units would be so large and heavy that the advantages of an air cycle system would be nullified.

In considering gas turbine compressors the following units have been evaluated:

- (a) Airesearch GTC 85-20
- (b) Airesearch GTCP 85-20
- (c) Airesearch GTCP 100-50
- (d) Solar Jupiter Mk.1
- (e) Solar Jupiter Mk.2
- (f) Solar Jupiter Mk.2 (uprated)
- (g) Blackburn Palouste 500
- (h) Blackburn Artouste 510
- (i) Blackburn Turmo 600
- (j) Boeing 514-4



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5.3.1.1 General (Continued)

The performance of each engine with respect to delivery air flow, pressure, and temperature is shown in Fig. 6-9 and the application of each engine is discussed in the following paragraphs.

5.3.1.2 AiResearch GTC 85-20

This gas turbine compressor is in production and has had wide use in the U.S.A.F. as a source of hot, medium-pressure air for starting jet engines, driving turbo-generators, air conditioning and airborne applications. From the performance curves in Fig. 6 it is apparent that two engines would be needed to meet our flow requirements. Such an arrangement would provide a 10% reserve against possible growth in the flow requirements. Since there is no provision for extracting shaft power from the engine, a third prime mover would be required in the power/air conditioning package to drive an electrical generator. No difficulty is foreseen in paralleling the outputs from two of these engines and this is, in fact, done by the U.S.A.F. in some applications.

The bleed air pressure from this engine is too low for use with a simple air cycle refrigeration system and AiResearch has proposed a "Bootstrap" system which consists mainly of components now in production. However, analysis indicates that approximately 0.5 lb/minute of free moisture would be delivered to the aircraft under ambient conditions of 3500', 100°F. dry bulb temperature, 85°F. wet bulb temperature. To re-evaporate this free moisture the delivery air temperature would have to be raised from 55°F to 70°F.



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5.3.1.2 AiResearch GTC 85-20 (Continued)

Current U.S.A.F. field reports indicate that these engines are giving satisfactory performance in the squadrons. At present the hot end is overhauled in the field after 1200 starts and the complete engine is overhauled after 2000 starts. A development programme is now under way and it is expected that the overhaul life will be increased to 3000 starts before the end of 1957. Thus it is anticipated that in our application this engine would have an overhaul life of at least 1000 hours, since the duty cycle would entail fewer starts and more running at reduced power output.

The AiResearch GTC 85-20 is also a satisfactory gas turbine compressor for starting the engines on the Arrow 2. Although Orenda Engines Limited has indicated in its report, Mech 9, "Evaluation of Ground Power Units," that the engine starting motor should be capable of being uprated by at least 15% over present requirements to allow for further growth, this is not applicable to the Arrow 2. It would imply an increase in air mass flow through the Iroquois engine, resulting in a larger compressor and bigger air intake ducts.

The initial cost of a GTC 85-20 is approximately \$16,000 as a bare engine and \$21,000 with an enclosure and controls. The cost of a complete overhaul is about \$5000. On this basis the GTC 85-20 is considered satisfactory for use on the Arrow 2 power/air conditioning unit.

5.3.1.3 AiResearch GTCP 85-20

This gas turbine is basically a GTC 85-20 with the addition of a gearbox so that shaft power and bleed air can both be extracted at the same time. Its performance with 0 and 63 S.H.P. (to drive a 40 K.V.A. generator)



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5.3.1.3 AiResearch GTCP 85-20 (Continued)

extracted is shown in Fig. 6. These curves indicate that two GTCP 85-20 units or one GTCP 85-20 and one GTC 85-20 will not meet our present flow requirements, let alone cater for any growth of the requirements in the future. The engine could, however, be used to drive an aircraft-type generator and thereby form a compact, light source of electrical power for both the aircraft and the power/air conditioning unit. This gas turbine is a current production unit although it has not been used in service as much as the bleed air machine.

5.3.1.4 AiResearch GTCP 100-50

This engine has been designed to supply 210 lb/minute of bleed air at a pressure ratio of 5.24 : 1 or 190 shaft horsepower under standard conditions at sea level. Its performance is shown in Fig. 7. Although the bleed air flow is slightly less than that required at 3500' and 120°F, the pressure ratio is high enough to work with a simple air cycle refrigeration system, and a good margin would be available with a "Bootstrap" system. However, it is understood that the prototype engine has only just started running so that a fully developed engine is not likely to be available for some time to come. This engine, therefore, can not be recommended at this time.

5.3.1.5 Solar Jupiter Mk.1

This engine has a 10-stage axial flow compressor and is designed to supply bleed air or shaft power, or a combination of both. Its performance is shown in Fig. 8. It is apparent from these curves that one engine cannot supply sufficient air, and no tests have been conducted to determine whether or not two units can be paralleled, particularly if some shaft power is extracted from one engine. The bleed air pressure is not high enough to make a simple air cycle refriger-



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5.3.1.5 Solar Jupiter Mk.1 (Continued)

ation system satisfactory, but a "Bootstrap" system could be used.

To date only a few of these engines have been delivered to the U.S.A.F. so that there is practically no field experience. The engine has, however, passed a qualification test comprising 1000 starts and 500 hours of operation. After this test the engine was operated for a further 400 hours. The initial cost of this engine is approximately \$40,000. and no figures are available concerning operating and overhaul costs. Because of the high cost of this unit and the small amount of field experience with it, the Jupiter Mk.1 engine is not recommended.

5.3.1.6 Solar Jupiter Mk.2

This gas turbine has been developed from the Jupiter Mk.1 but uses a redesigned compressor to deliver more air at a higher pressure. Also, in order to increase its overhaul life, the turbine inlet temperature has been reduced from 1520°F. (Jupiter Mk. 1 rating) to 1500°F. Its performance is shown in Fig. 8. These curves indicate that two engines would be needed to meet our flow requirements under all environmental conditions, even when no shaft power is extracted. Therefore, for our purpose it has no advantage over the Jupiter Mk.1. In addition, although the engine has been run with the new compressor, the control system is not yet developed. This may require considerable time and will depend largely on the support given to this engine by the U.S.A.F. and U.S. Navy. In this regard the U.S.A.F. has indicated that it has no requirements for this engine at the present time.



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5.3.1.7 Solar Jupiter Mk.2 (Uprated)

This engine is the Solar Jupiter Mk. 2, operated at a maximum turbine inlet temperature of 1520°F. Its performance is shown in Fig. 8. These curves show that if no shaft power is extracted this engine can meet our flow requirements at sea level with ambient temperature up to 120°F. and at 3500' with temperatures up to 104°F. At 3500' with 120°F. the flow is reduced to 141 lb/min.

The pressure available from this engine makes a simple air cycle refrigeration system marginal and calculations indicate that the delivery air temperature would have to be 65°F. to prevent free moisture from entering the aircraft under the worst environmental condition (3500', 100°F. dry bulb temperature, 85°F. wet bulb temperature). The engine could, however, be used in conjunction with a "Bootstrap" system. Electrical power for the aircraft and power/air conditioning unit would have to be obtained from a generator driven by a second engine. This could be a second Jupiter engine, an AiResearch GTCP 85-20 gas turbine, a Continental Packette gasoline engine or a truck engine. If two Jupiter engines are considered, the Mk.2 (Uprated) has no advantage over the Mk.1, and since the bleed air flow from one Mk.2 (Uprated) engine is marginal, this gas turbine compressor is not recommended. The development status of this engine is as noted for the Jupiter Mk. 2.

5.3.1.8 Blackburn Palouste 500

This engine supplies bleed air only and its performance is shown in Fig. 9. Two units would be required in order to meet our flow requirements and the delivery pressure is too low to be used with a simple air cycle refrigeration system. It could, however, be used



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5.3.1.8 Blackburn Palouste 500 (Continued)

with "Bootstrap" system but a third prime mover would be required to drive a generator to supply electrical power.

The Palouste engine has had more than 4300 hours of running time on development and in the field, two units having been in service with Orenda Engines Limited for starting Iroquois engines. Orenda has accumulated a total of 2700 starts with these units and their experience with the Palouste is outlined in their report Mech-9, "Evaluation of Ground Power Units". It is concluded that this gas turbine is satisfactory for consideration for the Arrow 2 engine starter. It would also be suitable for use in the mobile power/air conditioning unit. The cost of a Palouste is approximately \$15,000.00 and the current overhaul life is 1000 hours. It is expected, however, that the overhaul life can be increased to 2000 hours if a short warm-up period can be tolerated after the engine is started.

5.5.1.9 Blackburn Artouste 510

The Artouste 510 gas turbine can supply a combination of bleed air and shaft power. It is identical to the Palouste 500 except that a gearbox has been added to drive mechanical equipment. Its performance while driving a 40 K.V.A. generator is shown in Fig. 9. These curves show that two Artouste 510 engines can supply sufficient shaft power and bleed air to meet our requirements with a comfortable margin under all environmental conditions. The bleed air pressure is too low for use with a simple air cycle refrigeration system so that a "Bootstrap" system would be required.

At present this gas turbine is being developed in conjunction with a 12,000 R.P.M. 400 c.p.s. A.C. generator for use as an airborne



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5.5.1.9 Blackburn Artouste 510 (Continued)

power package. It has had 380 hours of running to date, but the experience on the Palouste engine should also be recognised. Thus it is anticipated that an overhaul life of 2000 hours can be achieved in our application, since maximum power is not required under normal environmental conditions. The initial cost of an Artouste 510, complete with gearbox, generator and controls, is approximately \$22,000.00.

To date no tests have been conducted to determine whether the bleed air from two Artouste engines can be paralleled, particularly when varying amounts of shaft power are extracted from either engine. An investigation of this problem is under way at the present time. Provided that the results of these tests are satisfactory, the Artouste gas turbine would be suitable for the Arrow 2 mobile power/air conditioning unit. It would also be well suited for use as an engine starter.

An alternative scheme has been proposed by Blackburn and General Aircraft Ltd., using two Artouste engines. This system would use one Artouste to drive a 40 K.V.A. generator and supply bleed air, the other to drive a geared up version of an existing high pressure supercharger in addition to supplying bleed air. This would deliver the air at a 5.8 : 1 pressure ratio and could be used with simple air cycle refrigeration system. However, since this scheme might involve considerable development work, and since two unsupercharged Artouste 510 engines could be used with a "Bootstrap" refrigeration system, this scheme is not recommended.

5.1.1.10 Blackburn Turmo 600

This engine is another version of the Palouste series and incorporates a free turbine to provide shaft power. Bleed



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5.3.1.10 Blackburn Turmo 600 (Continued)

air is not available from the compressor of this unit. Two schemes have been suggested by Blackburn and General Aircraft Ltd. using this engine.

This first would comprise a redesigned gearbox suitable for mounting a 40 K.V.A. generator and a two stage centrifugal compressor. Such a unit could provide 180 lb/minute of air at 5.8 : 1 pressure ratio at sea level with an ambient temperature of 130°F. This could be used with a simple air cycle refrigeration system but considerable design and development work would be required on the compressor and drive system.

In the second system, the Turmo 600 would be used to drive a Howden-Lysholm positive displacement compressor. This would give 135 lb/minute of air at a pressure ratio of 5.8 : 1 at sea level with an ambient temperature of 130°F. This system is larger, heavier and less efficient than the first scheme and would require further development work. Neither scheme using the Turmo 600 is recommended for use on the Arrow 2 mobile power/air conditioning unit at this time.

5.3.1.11 Boeing 515-4

This engine is currently under development and is expected to pass a 50 hour type test before the middle of 1958. It is a combination shaft power/bleed air machine designed to deliver 188 lb/minute of air at 5.5 : 1 pressure ratio or 100 shaft horsepower under sea level standard conditions. This engine is not recommended for use with the Arrow 2 power/air conditioning unit as it is not likely to reach a satisfactory development state in time for the Arrow development programme.



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5.3.2 Refrigeration Systems

5.3.2.1 Investigations by the AiResearch Manufacturing Division of the Garrett Corporation.

Since AiResearch manufactures gas turbine compressors, air cycle refrigeration equipment and airborne freon refrigeration equipment, this Company was asked to a proposal for a complete power and air conditioning system to meet our requirements. Two schemes were submitted, both based on their GTC 85-20 and GTCP 85-20 gas turbine compressors and a "Bootstrap" air cycle refrigeration system using for the most part equipment now in existence. These proposals are included in Appendix "E" of this report.

The first scheme was submitted before our environmental requirements were finalized. It was powered by two GTCP 85-20 gas turbine compressors, one of which drove a 60 K.V.A., 400 c.p.s. A.C generator in addition to supplying bleed air. The excess electrical power was used to drive the fans in the two heat exchangers of the refrigeration system. With this arrangement, the delivery air flow was less than that required and AiResearch was asked to estimate the performance using one GTC 85-20 gas turbine compressor and one GTCP 85-20 driving a generator and supplying bleed air. For this investigation the aircraft electrical load was reduced to 30 KW, and the environmental requirements were revised in line with the R.C.A.F. requirements. This system still would not meet the requirements for air flow under all environmental conditions and the AiResearch report also indicated that considerable free moisture would be delivered to the aircraft under humid ambient conditions. At 3500', 100°F, dry bulb temperature, 85°F wet bulb temperature, this system would deliver 0.73 lb/minute of free water to the aircraft with the air



5.3.2.1 Investigations by the AiResearch Manufacturing Division of the Garrett Corporation
(Continued)

delivery temperature at 55°F. The delivery temperature would have to be raised to 67° to re-evaporate this free moisture. The cooling capacity could also be increased by using different gas turbine compressors having a higher deliver air pressure.

The AiResearch proposals were based on the use of "Bootstrap" refrigeration turbines and water separators that are now in production. Thus, the only design and development work that is required is for the heat exchangers and the package for installation of the equipment. Although this proposal shows all of the equipment mounted within one large enclosure, it would be equally feasible to package the air conditioning equipment separately and to use "podded" engines. The overall size of the power/air conditioning unit would be increased slightly, but maintenance work would be simplified considerably. The initial cost of a prototype "Bootstrap" refrigeration package is estimated to be \$20,000.00. The overhaul life is estimated below:

Cooling turbine	-	1000 hours
Fan	-	2000 hours
Heat Exchanger	-	5000 hours
Water Separator	-	500 hours

5.3.2.2 Investigation by the Stratos Division of the Fairchild Engine and Airplane Corporation

Stratos manufactures a light, self-contained air cycle refrigeration package known as the GEA-120. This unit was designed for use with a Solar Jupiter Mk. 1 gas turbine compressor and incorporates a simple air cycle refrigeration system. It is claimed that the heat



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5.3.2.2 Investigation by the Stratos Division
of the Fairchild Engine and Airplane
Corporation (Continued)

exchanger is 97% effective and that the water separator removes 80% of the free moisture from the air.

Since the standard GEA-120 will not pass 150 lb/min. of air with the pressure available from existing gas turbine compressors, Stratos engineers were asked if the unit could be modified to handle our rated flow with two Solar Jupiter Mk. 1 engines, two Palouste 500's or two AiResearch GTC 85-20's. Their analysis indicated that the temperature and flow requirements could only be met with the Jupiter Mk. 1 engines. However, under humid conditions free moisture would be delivered to the aircraft.

The performance of the standard GEA-120 package was also estimated (by AVRO) when used with the Solar Jupiter Mk. 2 engine operated at a turbine inlet temperature of 1520°F. At 3500' altitude, 100°F dry bulb temperature, 85°F wet bulb temperature, 0.57 lb/minute of free moisture will be delivered to the aircraft with the cooling air. The delivery air temperature would have to be raised to 65°F to re-evaporate this free moisture.

The GEA-120 cooling unit has been produced in small quantities for the U.S.A.F. at a production cost of \$13,000 per unit. Its overhaul life is not known at present, but it has passed a 500 hour endurance test in accordance with U.S.A.F. exhibit WCL-876.

It should also be noted that Stratos has developed "Bootstrap" refrigeration turbines and airborne freon refrigeration systems which might be considered for use in the Arrow 2 power/air conditioning unit. As with the AiResearch system, the Stratos "Bootstrap" system would require the design



5.3.2.2 Investigation by the Stratos Division
of the Fairchild Engine and Airplane
Corporation (Continued)

of heat exchangers and would have to be packaged into a self-contained cooling unit. This could be done within the time that is available. Their existing airborne freon systems are too small for our purpose (4 to 10 tons capacity) and larger units are not likely to be available in time for the Arrow 2 development programme.

5.3.3 Recommendations Concerning Air Cycle Refrigeration
Systems

From the investigations outlined above, it is concluded that an air cycle refrigeration system based on major equipment items that are now in existence will give marginal performance under the most adverse environmental conditions that have been specified. However, because of the gas turbine compressors, air cycle systems have certain advantages, including the following:

- (a) smaller size
- (b) lower weight
- (c) quick, easy starting in cold weather
- (d) they use a fuel that is available on the flight line
- (e) similar engines will be used as engine starting units.

Since the R.C.A.F. may consider that some relaxation in the performance requirements is acceptable because of these factors, several possible systems have been analysed and are outlined below.

Scheme "A" (AiResearch Report AAC-2772-R, Rev.1)

This proposal is included as Appendix "E" of this report and is shown in Fig. 19. It consists of a "Bootstrap" refrigeration system supplied by air from one AiResearch GTC 85-20 gas turbine compressor



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5.3.3 Recommendations Concerning Air Cycle Refrigeration Systems (Continued)

and one GTCP 85-20 which also drives a 60 K.V.A., 400 c.p.s. A.C. generator. This unit is the smallest, lightest, and cheapest of the air cycle systems and results in a package 10' long, 4' - 6" wide, and 5' high. It would weigh approximately 2500 lb. empty and 3850 lb. with fuel for two hours of continuous running at maximum power. The estimated cost of this package is \$65,000.00 for a prototype and \$55,000.00 for a prototype and \$55,000.00 for production units. An overhaul life of at least 1000 hours should be feasible for this system.

The performance capabilities of this system are noted below:

Altitude	Sea Level	Sea Level	3500'	3500'
Ambient Air				
Temperature				
Dry Bulb (°F)	120	100	120	100
Wet Bulb (°F)	76	85	76	85
Conditioned Air				
Flow (lb/min)	145	150	123	134
Conditioned Air				
Temperature (°F)				
Dry Air Rated (°F)	-22	-44	-20	-37
Dry Bulb (°F)				
(minimum)	+18	+41	+30	+53
Conditioned Air				
Moisture Content	26	65	38	87
(grains /lb.dry air)				
Moisture Content for				
55°F Saturated Air	49	49	54	54
(grains /lb.dry air)				
Conditioned Air Dew-	38	63	45	68
point				
Electrical Power to Air-				
craft (KW)	30	30	30	30

Even with the electrical load reduced from 40 KW to 30 KW this system does not meet the air flow requirements at the high ambient temperatures specified. In addition, although it meets the delivery air temperature requirements under all conditions,



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5.3.3 Recommendations Concerning Air Cycle Refrigeration Systems (Continued)

considerable free moisture would be delivered to the aircraft on humid days. This system is, therefore, considered to be too small.

Scheme "B"

This arrangement comprises four packaged units as shown in Fig. 10. One AiResearch GTCP 85-20 gas turbine driving a 60 K.V.A., 400 cps A.C. generator is used as a lightweight power supply for both the aircraft and the power/air conditioning unit. Two GTC 85-20 gas turbine compressor packs are used to supply bleed air to a "Bootstrap" refrigeration system which forms the fourth pack. This unit would be 12' -2" long, 7' -9" wide, and 4'3" high. It would weigh approximately 3100 lb. empty and 5100 lb. with fuel for two hours of operation at maximum power. Its performance is outlined below:

Altitude	Sea Level	Sea Level	3500'	3500'
Ambient				
Temperature				
Dry Bulb (°F)	120	100	120	100
Wet Bulb (°F)	76	85	76	85
Conditioned Air				
Flow (lb/min.)	150+	150+	150+	150+
Conditioned Air				
Temperature				
Dry Air Rated (°F)	-28	-47	-17	-36
Dry Bulb (°F)	+14	+39	+32	+57.5
Conditioned Air				
Moisture Content				
(grains/lb.dry air)	24	71	39	89
Moisture Content for				
55°F Saturated Air				
(grains/lb.dry air)	49	49	54	54
Conditioned Air				
Dewpoint	37	66	46	69
Electrical Power	40	40	40	40
to A/C (KW)				



5.3.3 Recommendations Concerning Air Cycle Refrigeration Systems (Continued)

It is noted that this scheme meets the air flow, air temperature and electrical power requirements, but would deliver free moisture to the aircraft under the humid conditions specified. This could be overcome by raising the deliver temperature to 66°F and 69°F at sea level and 3500' respectively, with ambient temperature of 100°F D.B. and 85°F W.B. Conversely, the system could deliver air at 55°F with no free moisture for wet bulb temperatures up to 80° and 78°F for 100°F ambient temperature at sea level and 3500' respectively.

A prototype unit of this type would cost approximately \$90,000. and the overhaul life should be at least 1000 hours.

Scheme "C"

This arrangement uses two Blackburn "Artouste" 510 engines, each driving a 40 K.V.A. 400 cps A.C. generator and supplying bleed air to a "Bootstrap" refrigeration package. The complete unit would be 9' -0" long, 7' -9" wide, and 4' -3" high. It would weigh approximately 2800 lb. empty and 3500 lb. with fuel for two hours of operation at maximum power. This system meets the flow and power requirements with an adequate margin under all of the environmental conditions specified, but cannot meet the temperature and moisture content requirements under the humidity conditions that are specified. Its performance is outlined below and the proposed arrangement is shown in Fig. 11:

Altitude	Sea Level	Sea Level	3500'	3500'
Ambient Air Temp.				
Dry Bulb (°F)	120	100	120	120
Wet Bulb (°F)	76	85	76	85
Conditioned Air Flow (lb/min. minimum)	150+	150+	150+	150+
Conditioned Air Temp.				
Dry Air Rated (°F)	-33	-46	-24	-43
Dry Bulb (°F)	+10	+40	+27	+58



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5.3.3 Recommendations Concerning Air Cycle Refrigeration Systems (Continued)

Altitude	Sea Level	Sea Level	3500'	3500'
Conditioned Air				
Moisture Content (grains/lb dry air)	24	65	36	82
Moisture Content of 55° saturated air (grains/lb dry air)	49	49	54	54
Conditioned Air Dew- point (°F)	36	63	45	67
Electrical Power to Aircraft (KW) 40	40	40	40	40

It is noted from the table that the delivery air temperature would have to be raised from 55°F to 63°F 67°F respectively to eliminate free moisture with ambient conditions of 100°F dry bulb temperature, 85°F wet bulb temperature at sea level and 3500'. Conversely, the system could meet the delivery air requirements for all wet bulb temperatures up to 80°F at sea level and 78°F at 3500' for 100°F dry bulb temperatures.

A prototype unit of this type will cost approximately \$75,000 and the overhaul life should be at least 1000 hours. However, this scheme cannot be recommended until it has been demonstrated that two Artouste engines can be operated and controlled satisfactorily with their bleed air outputs paralleled and with varying amounts of shaft power (due to electrical loads) extracted from each engine.

Scheme "D"

This arrangement involves the use of two types of gas turbines, - a Solar Jupiter Mk.2 (uprated) supplying bleed air to a "Bootstrap" or "Simple" air cycle refrigeration package, and an AiResearch GTCP 85-20 driving a generator to provide electrical power. This unit would be 11' long, 7' -9" wide, and 4' -3" high. It would weigh approximately 4150 lb. empty and 5650 lb. with fuel for two hours of operation at maximum power. Its performance is outlined below when used with a Stratos GEA-120 "Simple" air cycle refrigeration package:



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5.3.3 Recommendations Concerning Air Cycle Refrigeration Systems

Scheme "D" (Continued)

Altitude	Sea Level	Sea Level	3500'	3500'
Ambient Air Temp.				
Dry Bulb (°F)	120	100	120	100
Wet Bulb (°F)	76	85	76	85
Conditioned Air Flow (lb/min)	150-	150-	141	150-
Conditioned Air Temp.				
Dry Air Rated (°F)	-4	-19	+4	-12
Dry Bulb (°F)	+31	+54	+41	+64
Conditioned Air Moisture Content (grains/lb. dry air)	26	66	39	89
Conditioned Air Dew-point (°F)	39	63	46	69
Electrical Power to Aircraft (KW)	40	40	40	40

It is noted that this scheme does not meet the air flow requirement at 3500' altitude at temperatures above 105°F and that free moisture is delivered to the aircraft under the humid day conditions at sea level and at 3500'. The delivery air temperature would have to be raised to 63°F and 69°F respectively, or conversely, the delivery air requirements could be met at wet bulb temperatures up to 80°F and 78°F at sea level and 3500' respectively with 100°F dry bulb temperature. Also, the refrigeration capabilities could be improved by using a "Bootstrap" system, but it is not feasible to increase the flow of bleed air from this engine.

The estimated cost of a prototype unit of this type is \$95,000.00 and the overhaul life should be at least 1000 hours.

Other Schemes

Other schemes are feasible in a package concept, but involve the use of engines that are at a less advanced stage of development. If a truck concept is



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5.3.3 Recommendations Concerning Air Cycle Refrigeration Systems

Other Schemes (Continued)

considered instead of a self-contained package, the electrical power could be obtained from the truck engine through a power take-off. However, the increased size and weight would then partially offset the advantages of the air cycle system. The minimum dimensions likely to be attained using a truck are 15' in length, 7' -9" in width, and 7' in height. The weight will be approximately 8000 lb. without fuel.



6. DESIGN INVESTIGATION - ENGINE STARTING UNIT

The general requirements for the engine starting unit have been outlined in para. 3.1.3 of this report. Design investigations outlined in AVRO reports LOG/105/24, "CF-105 Evaluation Study of Proposed Mobile Ground Power Units", and LOG/105/9, "Arrow 2 Readiness Facility" have concluded that the engine starting requirements can be met best by using gas turbine compressors to supply the hot, medium-pressure air that is needed. Also, it is considered desirable to use identical equipment to meet the "Scramble" and "Readiness" requirements as well as mobile applications, since this would simplify logistic support and crew training.

To meet the "Scramble" and "Readiness" requirements it is necessary;

- (a) to start both "Iroquois" engines simultaneously so that they reach idling speed within 34 seconds under the worst environmental condition.
- (b) to provide intercommunication between the aircrew in the cockpits and an Operations' Controller via land telephone line.

The first requirement involves the use of two gas turbine compressors, since no existing units are capable of starting both Iroquois engines simultaneously within the time allowed. For starting aircraft on the flight line when the "Scramble" requirement is not applicable, it is desirable to be able to start the engines in sequence using a single gas turbine compressor.

To accommodate both functions, the following arrangements are proposed:

- (a) Incorporate the following features in the engine starting package:
 - (1) Capability for starting one Iroquois engine so that it will reach idling speed within 34 seconds under the worst environmental condition (3500' altitude, 1200F).
 - (2) Two 3-1/2" diameter air delivery hoses, each 45' long and terminating in automatic, quick-disconnect couplings.



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6. DESIGN INVESTIGATION - ENGINE STARTING UNIT (Continued)

- (3) An electrically-controlled air flow valve for each air delivery hose.
- (4) Provision for controlling these valves either remotely from the aircraft, or locally by switches on the control panel.
- (5) Provision for supplying up to 50 amp. at 27.5V D.C. to the aircraft through a 50' cable terminating in an automatic, quick-disconnect connector.
- (6) Provision for supplying up to 500 VA at 115V, 400 cps, 1-phase A.C. to the aircraft for warming the amplifiers in the fuel flow control units on the Iroquois engines.
- (7) Provision for intercommunication between the cockpit occupants and the ground crew.
- (8) Provision of power for items 5, 6, 7 from the gas turbine engine.
- (9) Batteries for starting the gas turbine compressor.
- (10) Fuel for 1 hour of continuous operation at maximum power.
- (b) Incorporate the following features in the "Readiness" Facility:
 - (1) An electrical junction box to accommodate the following inputs:
 - electrical cables from two engine starting units.
 - audio signals from the landline telephone system.

A single cable is then required from the hangar junction box to the receptacle on the nose undercarriage leg on the Arrow 2. Such an arrangement is shown on AVRO drawing 7-4427-113 and permits two Arrow 2 aircraft to be scrambled in succession using two engine starting units.

The engine starting times for the Iroquois engines have been calculated for different environmental conditions using various gas turbine compressors that could be available in time for the Arrow development programme.

6. DESIGN INVESTIGATION - ENGINE STARTING UNIT (Continued)

These times are based on data supplied by the manufacturer of the air turbine starter, and on torque and drag curves for the Iroquois engine as shown in Avrocan Specification E-540, corrected for variations in air density. The results are shown below:

Altitude Ambient Temp.	<u>Engine Starting Time</u>			
	Sea Level 59°F	Sea Level 100°F	3500' 100°F	3500' 120°F
AiResearch GTC 85-20	18.1 sec.	23.8 sec.	32 sec.	38.2 sec.
Blackburn Artouste 510	15.5 *	19.2	24.6	27.8
Blackburn Palouste 500	11.8 *	14.0 *	17.6	18.3
Solar Jupiter Mk. 1	9.7 *	11.4 *	14.2	15.9

* It must be noted that these times will not be attained in practice, since the low pressure spool of the Iroquois engine is not driven by the starter and will, therefore, tend to lag and restrict the flow of air through the engine. This has not been allowed for in the calculations, but limits the starting time to a minimum of approximately 15 seconds.

From the times noted above, it is seen that any of these gas turbine compressors will enable the Arrow "Scramble" requirement to be met under any environmental condition likely to be encountered in Canada. However, at 3500' with 120°F ambient temperature, the AiResearch GTC 85-20 unit becomes marginal and the calculated "Scramble" time is 1 minute and 4 seconds. If this is considered acceptable by the R.C.A.F., this engine is recommended because of its highly developed state, its wide application within the U.S.A.F., and its low cost.

If the starting times with the AiResearch GTC 85-20 unit under the extreme environmental conditions are considered unacceptable, then the Blackburn Palouste 500 engine is recommended. This engine has adequate performance, has given good service in starting Iroquois engines on the test beds at Orenda Engines Ltd., and is comparable in cost with the AiResearch GTC 85-20 engine. The Solar Jupiter MK.1 engine is not recommended because of its complexity and high cost, although its performance is adequate.



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6. DESIGN INVESTIGATION - ENGINE STARTING UNIT (Continued)

The AiResearch GTC 85-20 and Palouste 500 gas turbine compressors have both been used and evaluated by Orenda Engines Ltd. during their development tests on the Iroquois engine. The results of their study are presented in Orenda Engines Limited report Mech -9, "Evaluation of Ground Power Units". In that report is concluded that:

- (1) "Reliability of Field Aviation (Palouste) and AiResearch units appears to be of the same order, on the basis of the very limited experience available.
- (2) With the sonic throat in the Field Aviation ground power unit bleed port, starter performances using the two makes of unit are comparable.
- (3) The Field Aviation unit has a greater uprating potential than the AiResearch unit (i.e., by opening the sonic throat). With the sonic throat opened, it is possible to operate the unit (considering present power requirements) below the maximum design speed, which may increase the mechanical reliability of the unit".



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7. DISCUSSION AND SUMMARY

From the investigations carried out during the design of Arrow 1 mobile ground power units and from the present studies, it is concluded that a gas turbine compressor is the most satisfactory type of unit for supplying hot, medium pressure air for starting the engines in the Arrow 2. Such units are small, light, use the same type of fuel as the aircraft, and are well suited to this duty cycle since they can be started quickly and loaded fully without delay under all conditions of weather. Several gas turbine compressors that are now in production are capable of meeting our requirements for engine starting and should have a satisfactory overhaul life. These include the following engines:

AlResearch GTC 85-20
Blackburn Palouste 500
Blackburn Artouste 510
Solar Jupiter Mk. 1

In the mobile power/air conditioning unit, it would be desirable to use identical gas turbine engines to supply shaft power for driving electrical generators and to supply bleed air to an air cycle refrigeration system and thereby provide the necessary power and cooling air to the aircraft. However, it has been shown that no single gas turbine compressor now in production is capable of supplying all of the shaft power and bleed air that is required. The unit must, therefore, be designed around two or more engines. Moreover, it is shown that with the bleed air pressures available from existing gas turbine compressors, an air cycle refrigeration system gives marginal performance under the humid environmental conditions specified. Since all of the entrained moisture cannot be removed from the air, some free moisture will likely be delivered to the aircraft on humid days unless the delivery air temperature is raised above the 55°F. temperature specified.

It was concluded, therefore, that the requirements for the power/air conditioning unit could only be met fully by using freon refrigeration. Since time would not permit the development of small, light freon equipment, the major items in the system would have to be commercial units that are now in production. These factors result in a gasoline powered package that is 14' long, 8' wide, 4'-7" high, and weighs about 9000 lb. without fuel. This is considerably larger and heavier than comparable air cycle equipment and is, in fact, too heavy to be used as a "package" with castors. For this reason a specially designed trailer is recommended so that the power and air conditioning equipment can be arranged to give a minimum overall height.



7. DISCUSSION AND SUMMARY (Continued)

Since the R.C.A.F. may consider that some relaxation in the performance requirements is acceptable in order to keep the size and weight of the unit to a minimum (or for other reasons), various schemes have been evaluated and the assessment is shown in Table 3.

For this evaluation a "Figure of Merit" has been devised in order to access the advantages and disadvantages of each scheme. This "Figure of Merit" has been obtained in the manner outlined below:

(a) Performance & Growth Potential - 25 Points

This factor represents the ability of the system to meet the performance requirements for electrical power, delivery air flow, delivery air temperature, and delivery air moisture content. It also includes 5 points for the capability of the system to be started quickly and easily and to be loaded without delay under all environmental conditions.

(b) Logistics and Maintainability - 25 Points

This factor is an appraisal of the serviceability and durability which can be expected from each system. It reflects our opinion concerning the following items:

- (1) The number, variety, and cost of spare items of equipment to support operations. The suitability of the engine for use as an engine starter is also considered.
- (2) Overhaul life of major components.
- (3) Maintenance time and maintenance skills required. It is expected that gas turbine engines will require less attention in the field than piston engines. Moreover, for the lightweight piston engines that are considered, it is expected that the maintenance skill levels required will be as high as that needed for gas turbine engines.
- (4) Field experience with similar equipment.

7. DISCUSSION AND SUMMARY (Continued)

(b) (Continued)

Where similar items of equipment are being used widely at the present time, replacement items and overhaul facilities should be readily available, thereby simplifying the logistic problems.

(c) Mobility - 20 Points

This factor, based on the size and weight of the power air conditioning unit, is a measure of the effort that will be expended in moving the unit from one place to another - particularly from one base to another by air.

(d) Cost - 20 Points

This figure represents our opinion of the relative overall cost of using each system. In the case of gas turbine engines and air cycle refrigeration packages, the figure is based solely on initial cost, since it is expected that all units would have comparable overhaul lives so that operating and overhaul costs would be proportional to initial cost. The freon system is rated higher because of its lower initial cost, much higher efficiency (resulting in lower fuel consumption), lower engine overhaul cost, and longer overhaul life on items excluding the engines.

(e) Availability - 10 Points

This factor represents our opinion concerning the possibility of obtaining proven equipment for the system in time for the Arrow 2 development programme. Thus, engines that are still in the design or development stages are considered a poor risk.

Total = 100 points.

TABLE - 3

APPRAISAL OF FEASIBLE SCHEMES

No.	System	Size			Estimated Weight (lb)	Estimated Cost (Prototype)	Figure of Merit						Remarks
		Length	Width	Height			Performance (25)	Logistics (25)	Mobility (20)	Cost (20)	Availability (10)	Total (100)	
1	Freon system; "Packette" engines.	14'	8'	4'-7"	9000	\$55,000.00	23	20	10	18	10	81	
<u>Air Cycle Refrigeration Systems</u>													
2	1 AiResearch GTC 85-20 & 1 GTCP 85-20; "Bootstrap" system.	10'	4'-6"	5'	2500	\$65,000.00	5	20	18	13	10	66	Insufficient Power.
3	2 AiResearch GTC 85-20 & 1 GTCP 85-20; "Bootstrap" system.	12'-2"	7'-9"	4'-3"	3100	\$90,000.00	18	12	15	8	10	64	3 engines used.
4	2 AiResearch GTCP 100-50; Simple or "Bootstrap" system.	9'	7'-9"	4'-3"	3200	\$110,000.00	25	15	20	4	0	64	Engines not Available
5	2 Solar Jupiter Mk. 1's; "Bootstrap" system.	12'	7'-9"	4'-3"	4900	\$110,000.00	25	15	15	4	7	66	Control problems not known with bleed air outputs paralleled.
6	2 Solar Jupiter Mk. 2's; "Bootstrap" system.	12'	7'-9"	4'-3"	4900	\$110,000.00	25	15	15	4	5	64	Engine Controls not developed.
7	1 Solar Jupiter Mk. 2 (uprated) 1 GTCP 85-20; Simple or "Bootstrap" system.	11'	7'-9"	4'-3"	4150	\$95,000.00	16	10	16	7	5	54	Engine Controls not developed; Insufficient bleed air.
8	2 Blackburn Palouste 500's; 1 GTCP 85-20; "Bootstrap" system.	12'-2"	7'-9"	4'-3"	3250	\$95,000.00	25	10	15	7	7	64	3 Engines used.
9	2 Blackburn Artouste 510's "Bootstrap" system.	9'	7'-9"	4'-9"	2800	\$75,000.00	18	15	20	11	5	69	Control problems not known with bleed air outputs paralleled



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7. DISCUSSION AND SUMMARY (Continued)

Procurement Authorization

Under the current list of ground support equipment contained in AVRO report 70/GEQ/1, issue 1, the Company is authorized to procure one Arrow 2 engine starting unit and one Arrow 2 power/air conditioning unit. This is inadequate for the support of development aircraft beyond aircraft #8 and delivery lead times are such that AVRO's initial purchase order must cater for an adequate quantity of this equipment so as not to embarrass the development programme planned by the R.C.A.F. The quantity of G.S.E. necessary to support the 37 aircraft development program will be called out in issue 2 of AVRO report 70/GEQ/1. Early R.C.A.F. agreement on the initial quantity of this equipment to be purchased by AVRO is, therefore, necessary.



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8. RECOMMENDATIONS

8.1 Engine Starting Unit

8.1.1 It is recommended that the Arrow 2 engine starting unit use the AiResearch GTC 85-20 gas turbine compressor, provided that the engine starting times under extreme environmental conditions are considered acceptable by the R.C.A.F. The Arrow 2 "Scramble Time" as defined in AIR 7-4, Issue 3 para. 3.4.1 is calculated to be 1 minute and 4 seconds at 3500' with 120°F ambient temperature using this unit. If this time is not acceptable to the R.C.A.F., the Blackburn Palouste 500 engine is recommended, which would reduce the above time to approximately 44 seconds.

8.1.2 It is recommended that the engine starting unit be designed as a self-contained package incorporating the following features:

- (a) Fuel for 1 hour of continuous running at maximum power.
- (b) Two 3-1/2" diameter flexible hoses 45' long terminating in automatic quick-disconnect couplings.
- (c) An electrical cable 50' long to supply the following services to the aircraft.
 - (1) 50 amperes at 27.5V D.C.
 - (2) 500 V.A. at 115V, 400 cps, 1-phase A.C.
 - (3) Intercommunication signals between cockpit occupants and ground crew.
 - (4) 27.5V D.C. signals to permit the air flow valves on the starting unit to be controlled from within the aircraft.

Power for these services is to be obtained from the gas turbine engine.

- (d) Batteries for starting the gas turbine compressor.
- (e) Storage for air hoses and electrical cables.



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8.2 Mobile Power/Air Conditioning Unit

- 8.2.1 It is recommended that the Arrow 2 mobile power/air conditioning unit be a trailer powered by two Continental "Packette" gasoline engines - one driving a 60 K.V.A., 400 cps, 3-phase A.C. generator and a 28V D.C. generator, the other driving air blowers and a freon refrigeration compressor.
- 8.2.2 It is recommended that the mobile power/air conditioning unit incorporate the following features:
- (a) Tandem Miehle-Dexter 5516 air blowers, or equivalent.
 - (b) Self-mobility at approximately 1 mph on level ground for a distance of 100' on battery power, or for an indefinite distance provided that the engine which drives the generators is running.
 - (c) A height not in excess of 5 ft. 6 inches.
 - (d) Two 3-1/2" diameter air delivery hoses 45' long and terminating in automatic, quick-disconnect couplings.
 - (e) An electrical cable 50' long to supply 400 cps 3-phase A.C. power to the aircraft.
 - (f) Protective circuits to prevent electrical power from being supplied to the aircraft if the delivery air temperature exceeds 55°F, or if the delivery air pressure is below 6.3 psig at the outlet of the air conditioning unit.
 - (g) A convenient, central panel for all controls and instruments.
 - (h) Convenient storage for air hoses and electrical cables.



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8.2.2 (Continued)

- (i) Light alloy construction wherever possible in order to keep the weight to a minimum.
- (j) Cooling air flow velocities up to 1500 ft/minute in order to keep all heat exchangers as small as possible.
- (k) Provision for intercommunication between the cockpit occupants and the ground crew.

8.3 It is recommended that AVRO be authorized to procure an adequate quantity of Arrow 2 engine starting units and mobile/power air conditioning units so as not to embarrass the Arrow developed programme planned by the R.C.A.F.



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9. REFERENCES

1. R.C.A.F. Specification Air 7-4, Issue 3, "R.C.A.F. Specification for Supersonic All-Weather Interceptor Aircraft Type CF-105".
2. R.C.A.F. Specification Air 7-4, Issue 4, "R.C.A.F. Specification for Arrow Weapon System.
3. AVRO Aircraft Limited Report LOG/105/8, Amendments 1 and 2, "CF-105, General requirements for Mobile Ground Power Equipment."
4. AVRO Report LOG/105/13, (& Add. 1), "Environmental Requirements for Mobile Ground Power Units".
5. R.C.A.F. Letter S36-38-105-13 (ACE-1) dated Aug. 21, 1957.
6. AVRO Report LOG/105/24, "CF-105, Evaluation Study of Proposed Mobile Ground Power Equipment."
7. AVRO Report LOG/105/9, "Arrow 2 Readiness Facility."
8. AVROCAN Specification E-540, "Pneumatic Starter for Iroquois Engines."
9. AVRO Drawing 7-4427-113, "Schematic Diagram- Engine Starting for Arrow Aircraft in the Readiness Hangar."
10. Orenda Engines Limited Report Mech-9, "Evaluation of Ground Power Units."

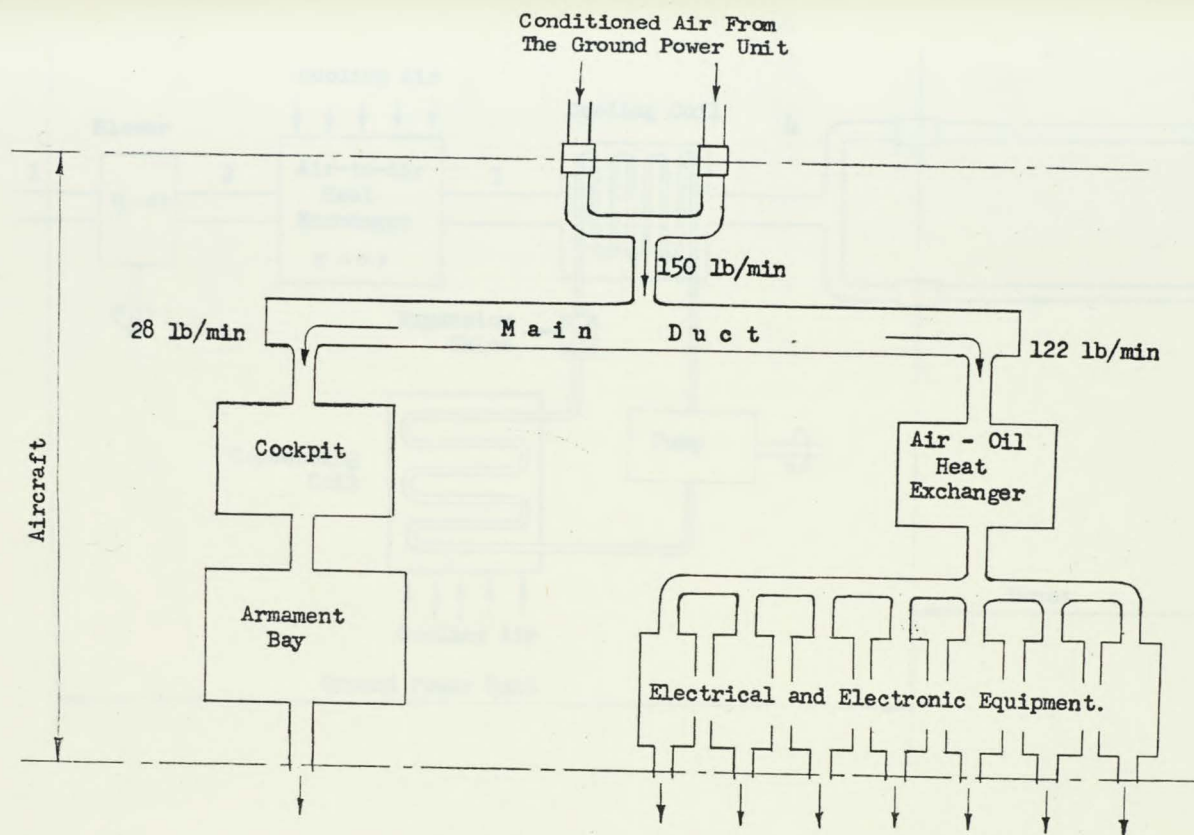


FIG. 1.

COOLING AIR FLOW WITHIN ARROW 2

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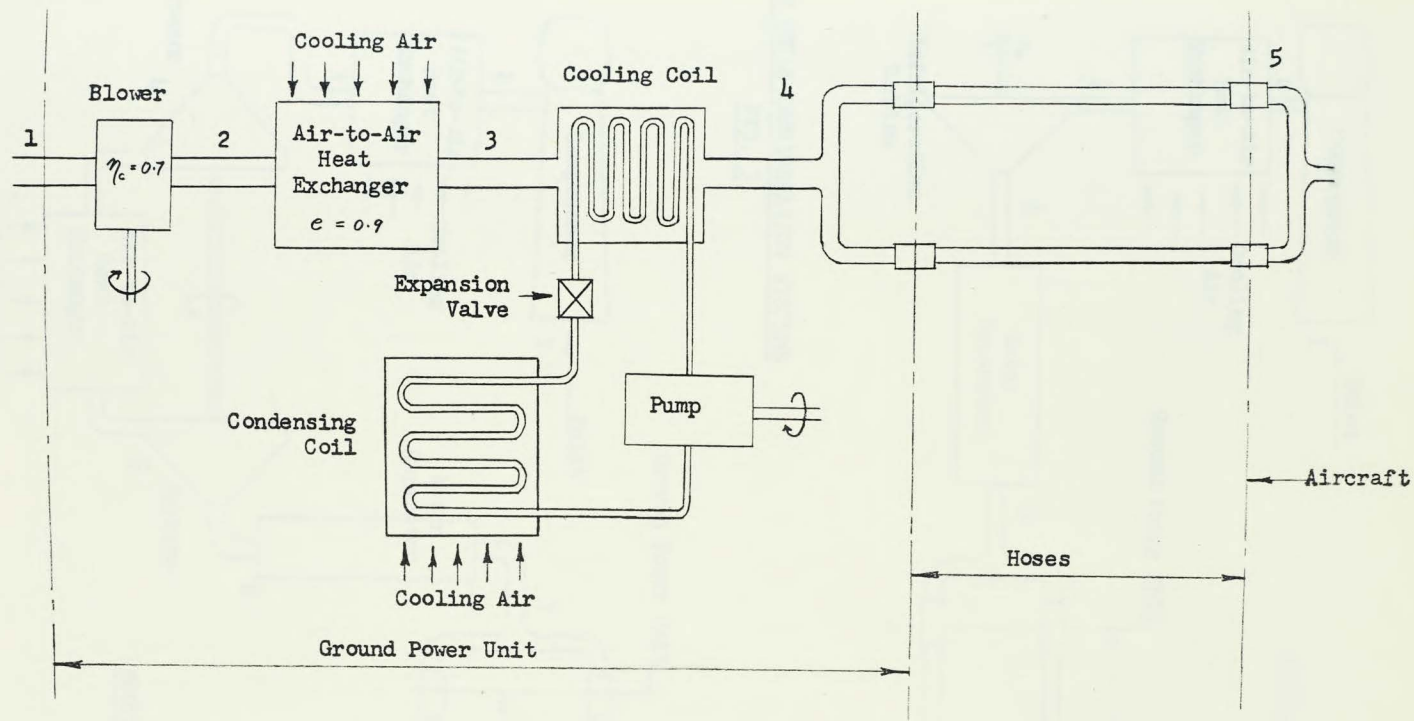
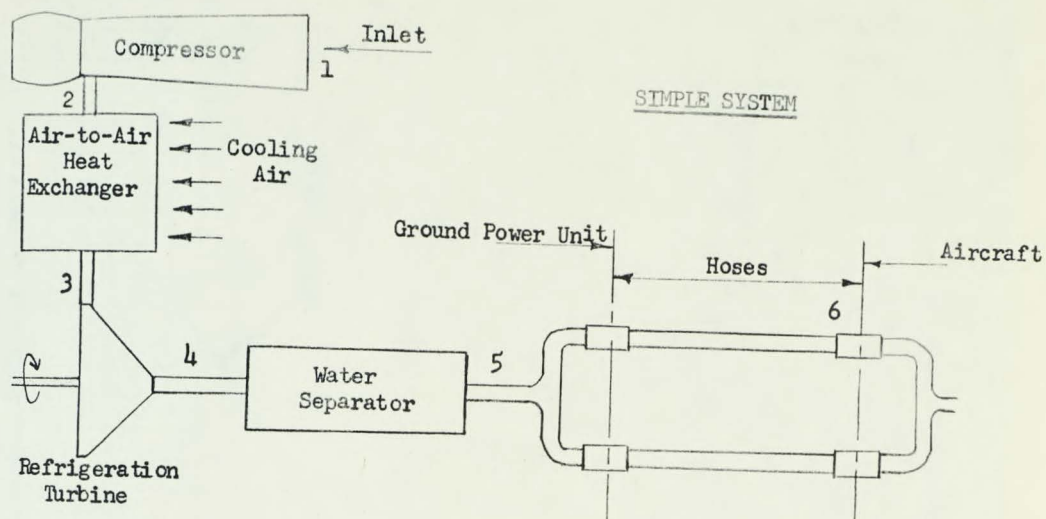


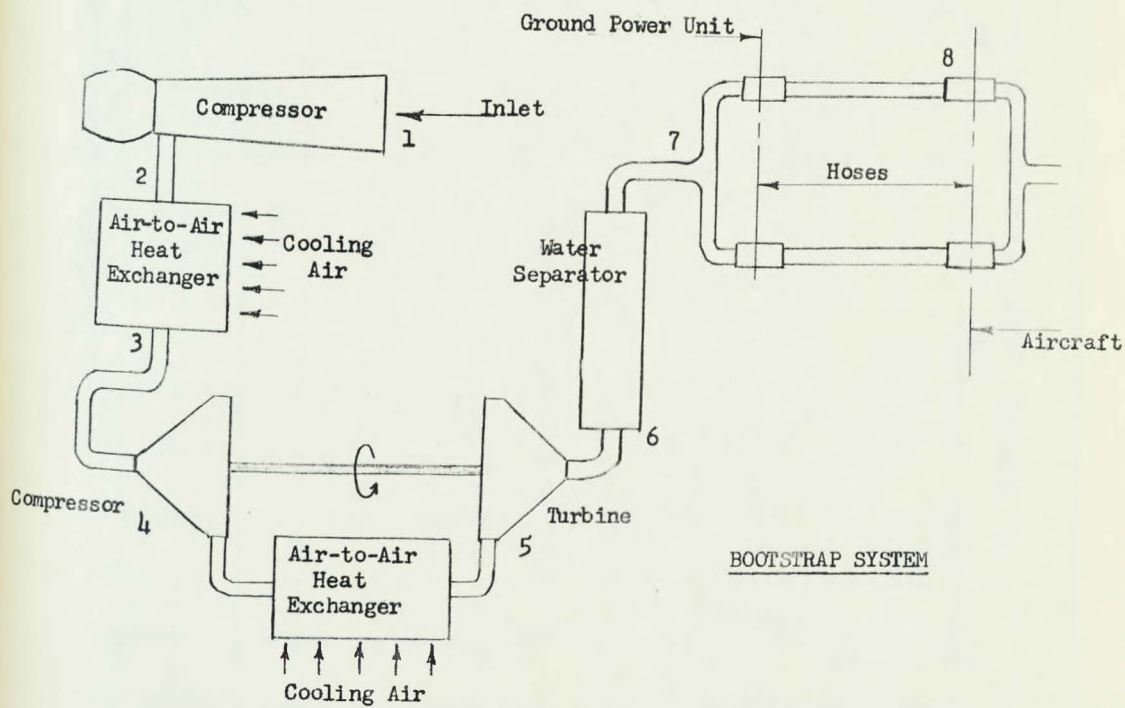
FIG. 2.

GROUND AIR CONDITIONING SYSTEM USING FREON.



AIR CYCLE REFRIGERATION SYSTEMS

FIG. 3



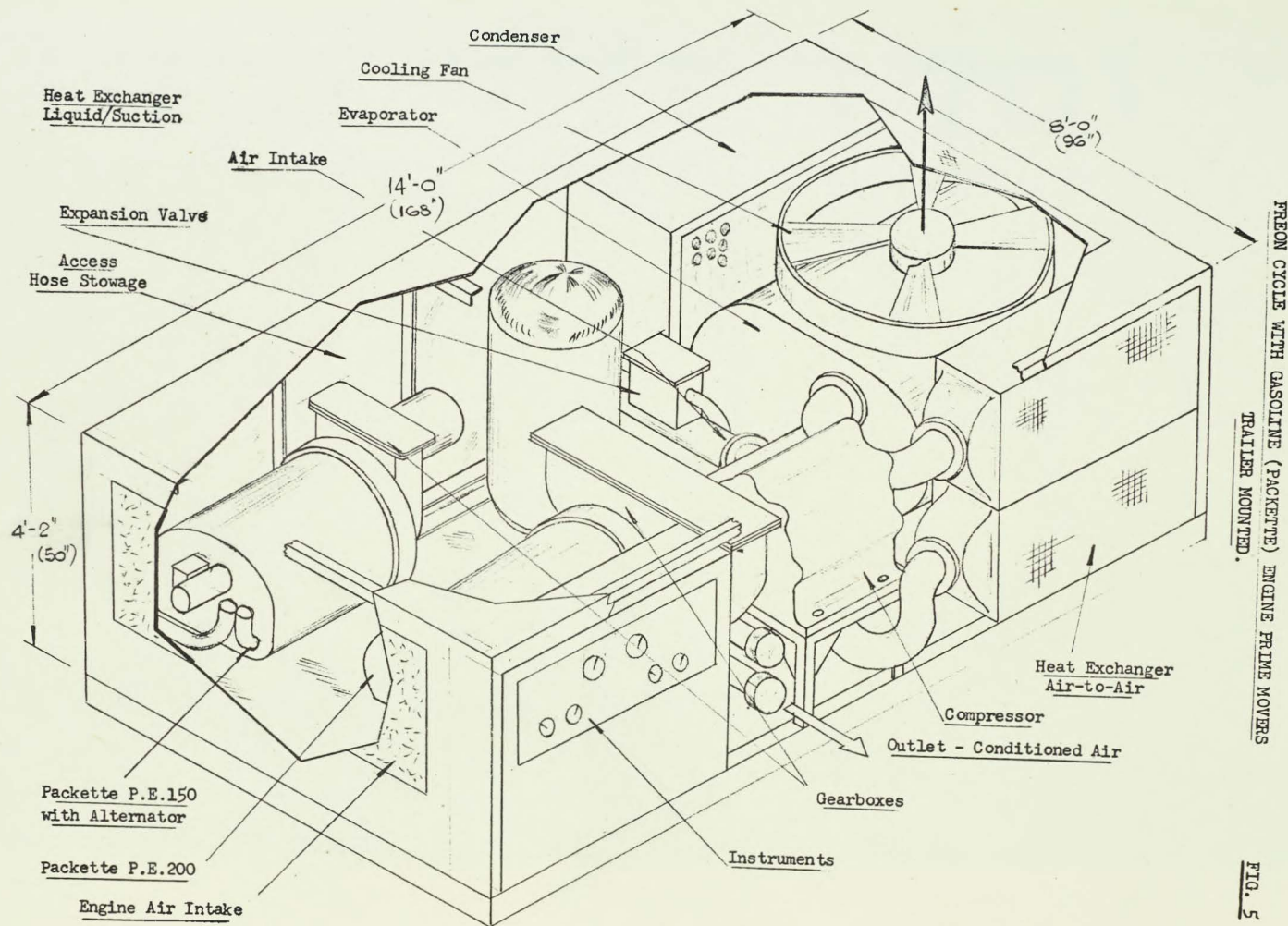


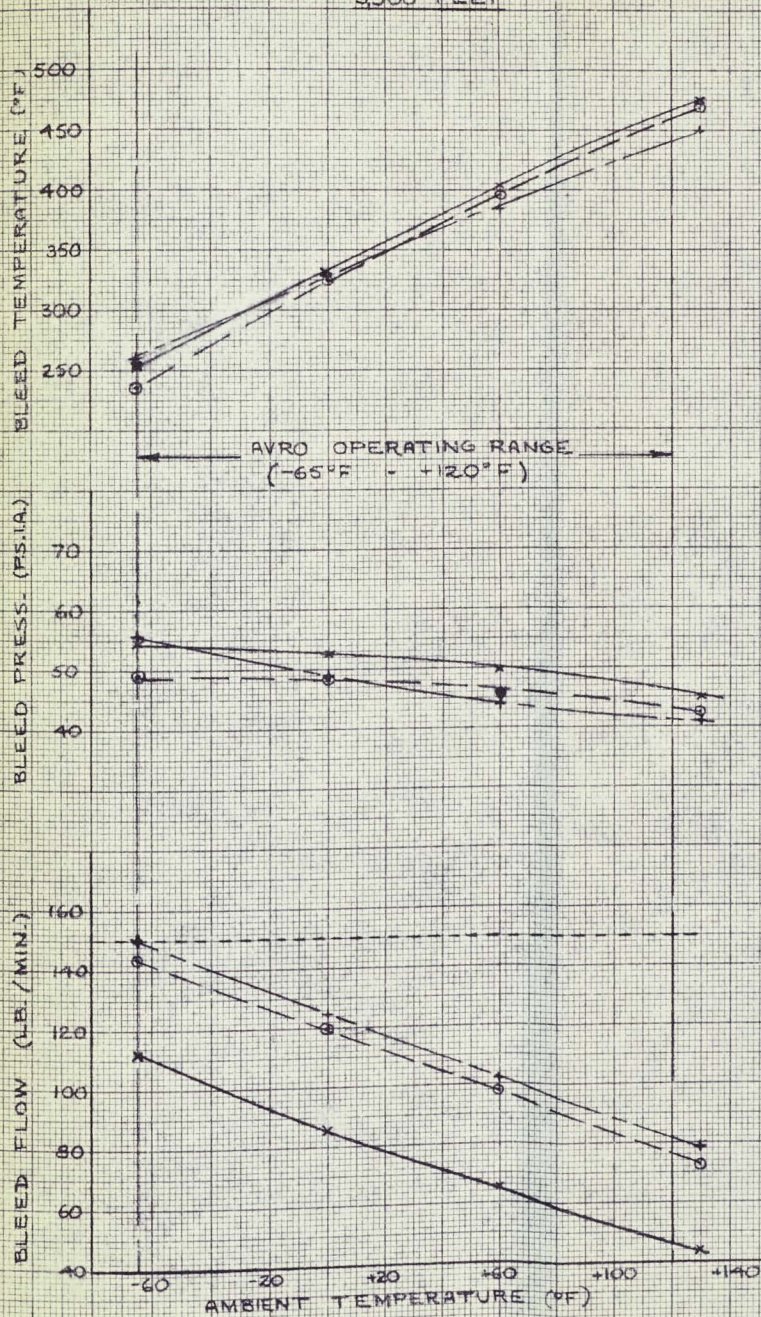
Fig. 6

CURVES FOR AIRESEARCH MODELS

C 85-20 & GTCP 85-20

DATA TAKEN FROM
AIRESEARCH PUBLICATIONS
SC-5022 & SC-5104

3500 FEET



IHM-17/10/57

Fig. 8

PERFORMANCE CURVES FOR SOLAR MODEL T-300U "JUN"

- LEGEND
- — MKI - ZERO SHP
 - x — MKI - 63 SHP
 - + — MKII - ZERO SHP
 - Δ — MKII (UPRATED) - ZERO SHP

SEA LEVEL

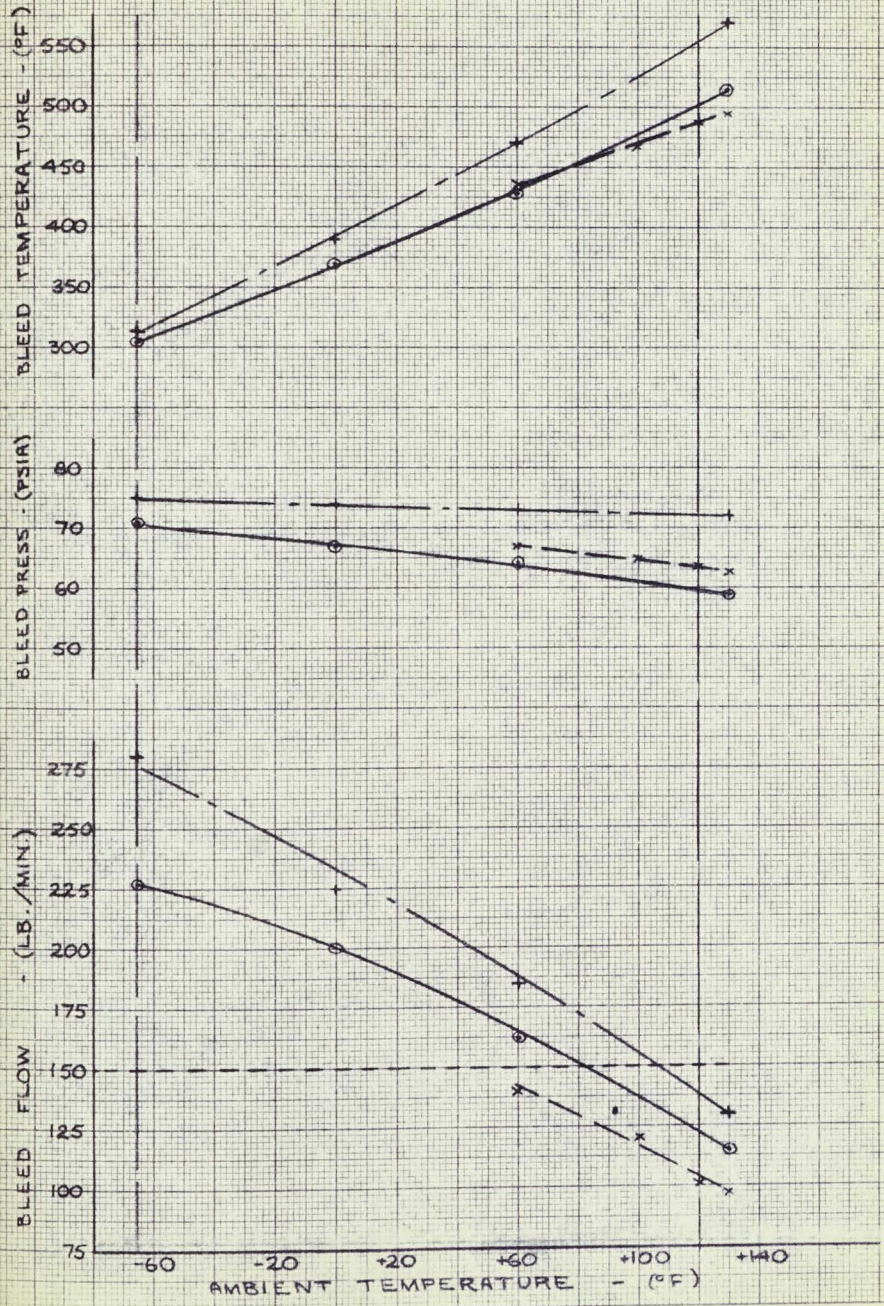


Fig. 9

LEGEND

○ — PALOUSTE 500 (ZERO S.W.P.)

x — ARTOUSTE 510 (80 S.H.P. GIVING 40 KVA WITH PLESSEY ELIBOS ALTERNATOR)

PERFORMANCE CURVES FOR PALOUSTE 500 AND

SEA LEVEL

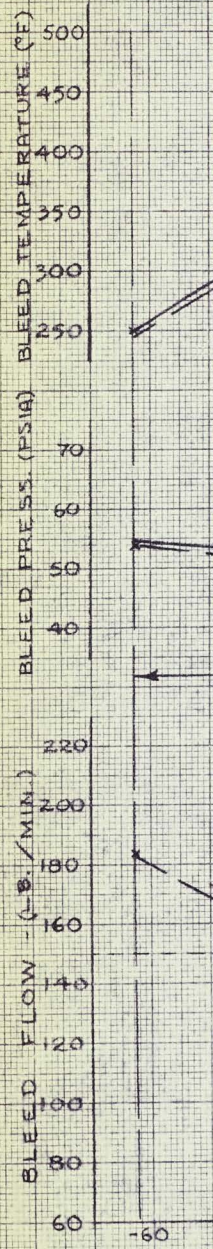
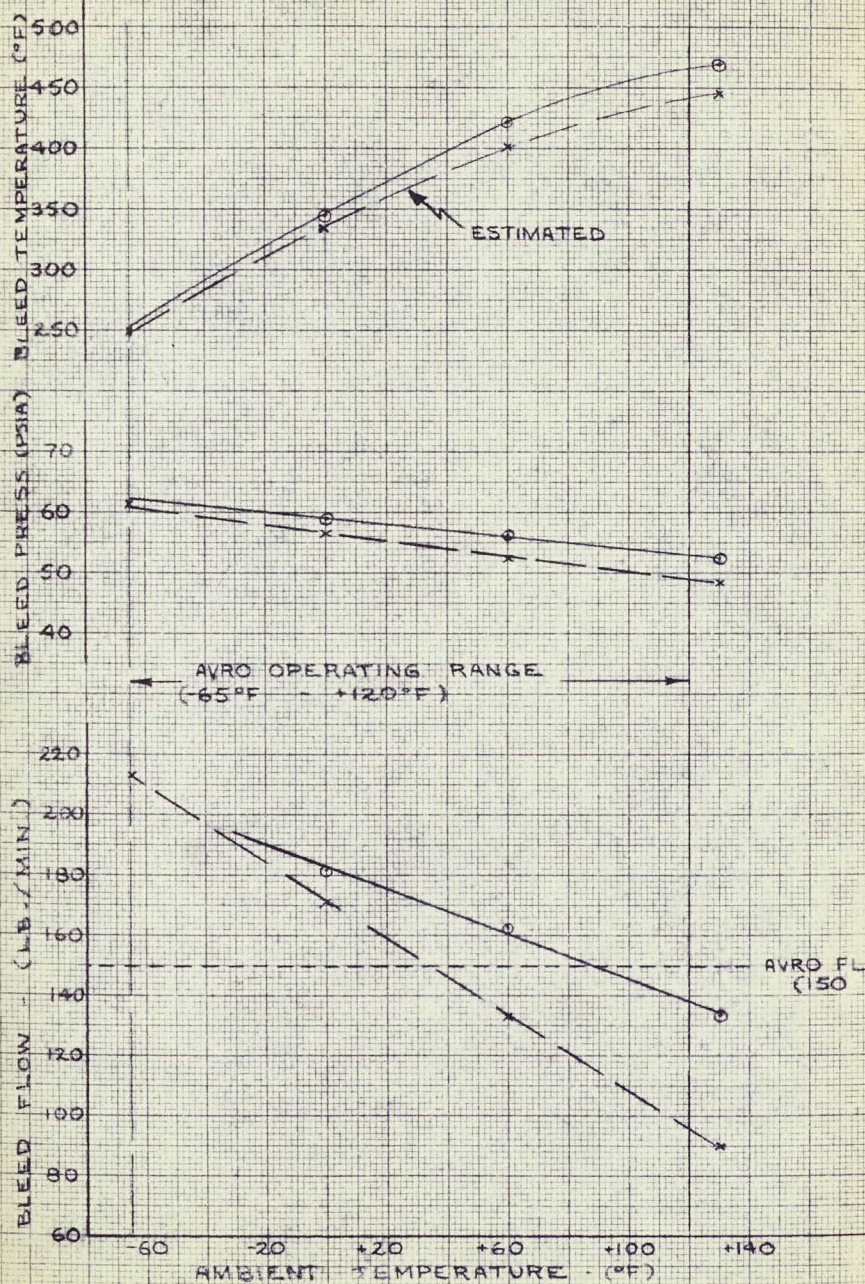
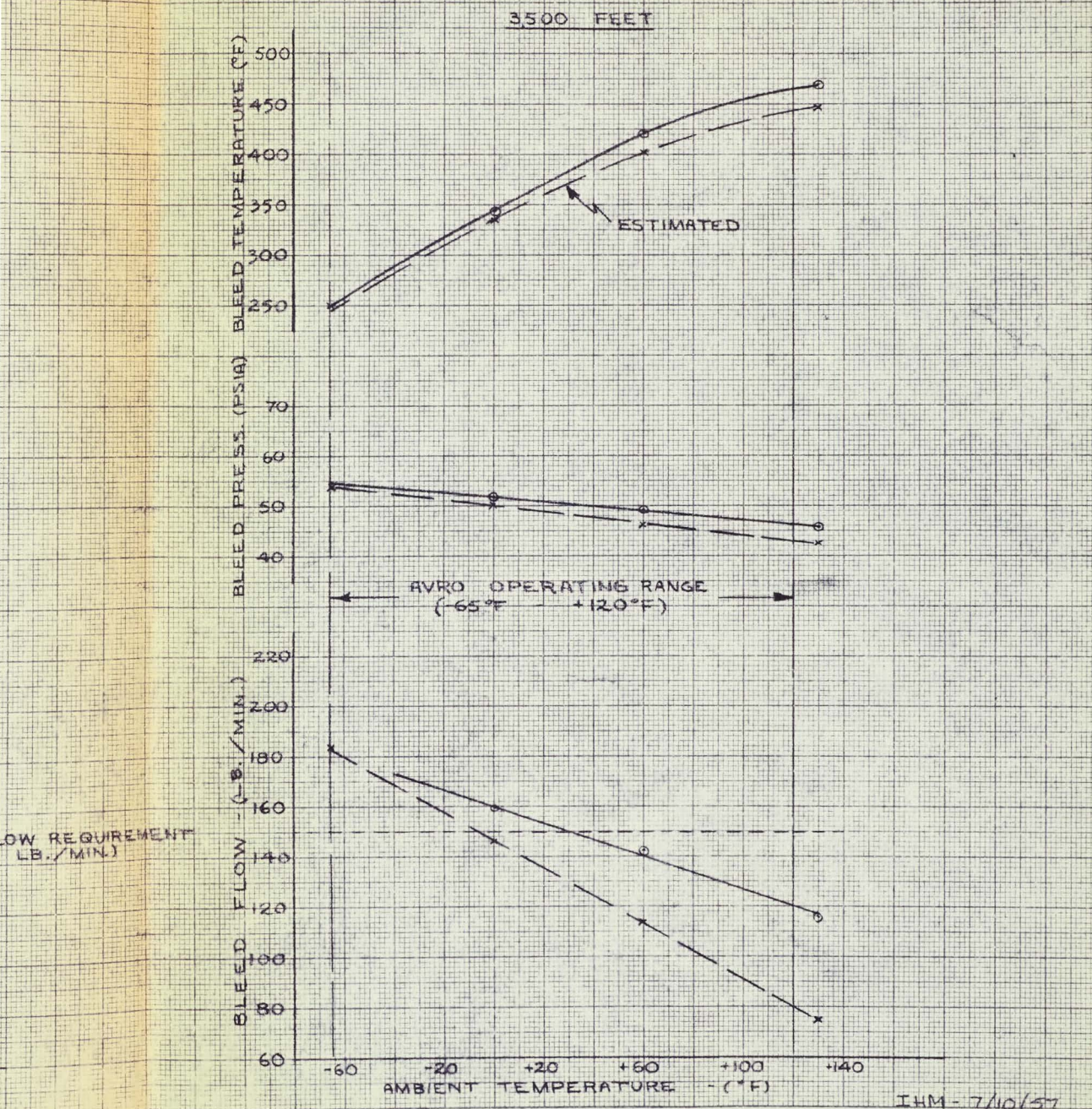


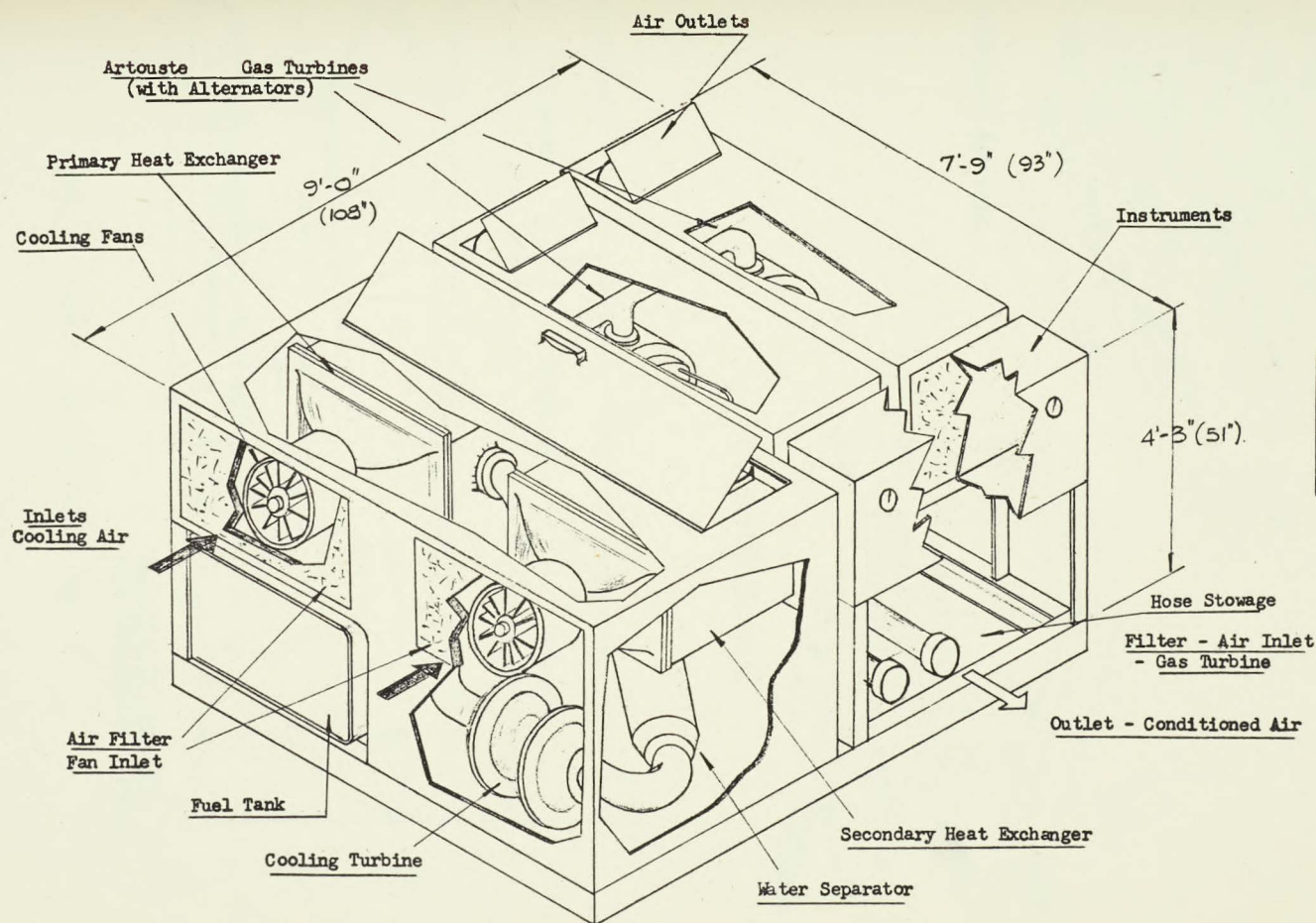
Fig. 9

CURVES FOR PALOUSTE 500 AND ARTOUSTE 510

DATA TAKEN FROM
BLACKBURN-TURBOMECA PUB.
NO. 100, ISSUE 2, AND BLACKBURN
AND GENERAL AIRCRAFT (ENGINE
DIV.) REPORT GR 119, PART "B."

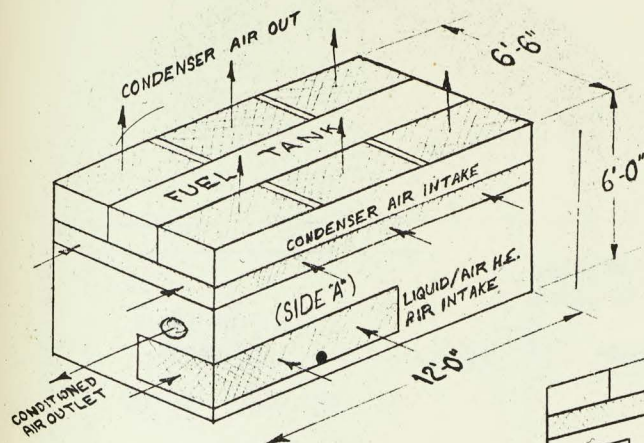
PLESSEY EL1808 ALTERNATOR)



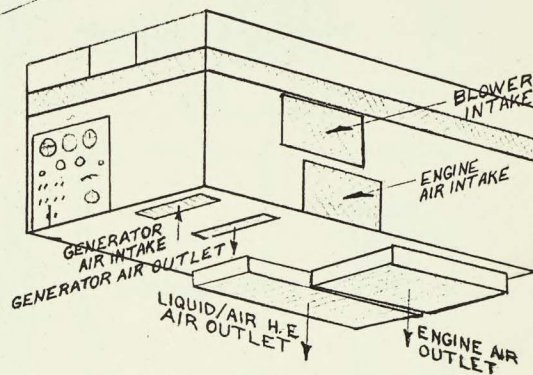


AIR CYCLE PACKAGE WITH ARTOUSTE ENGINES.
 TRAILER MOUNTED.

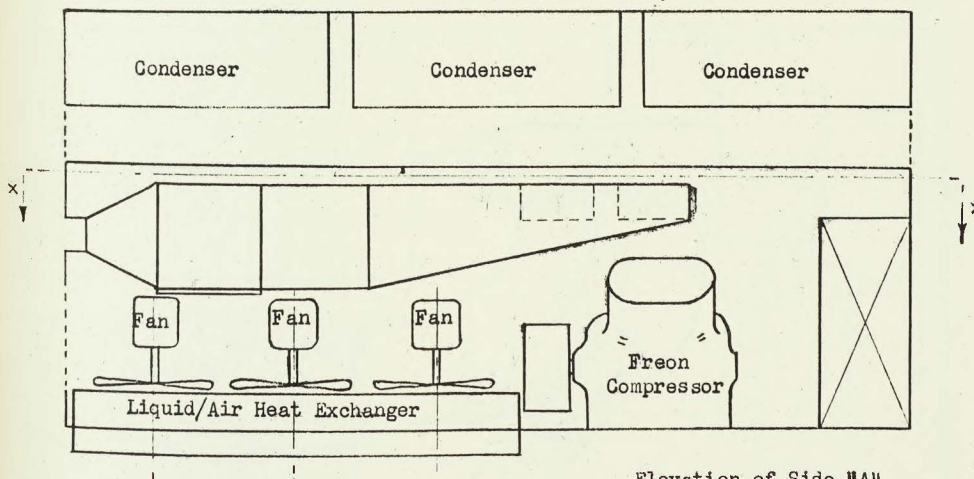
FIG. 11



"Southeast" Elevation

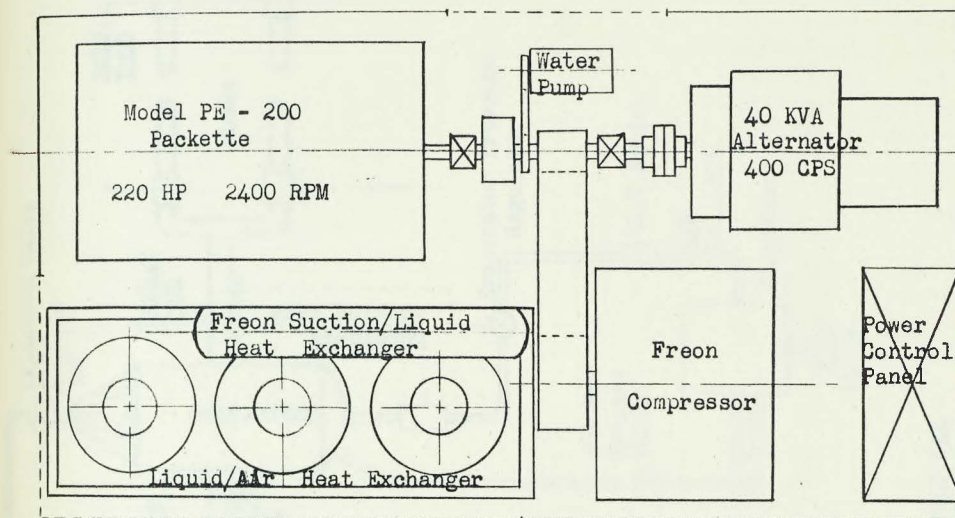


"Northwest" Elevation

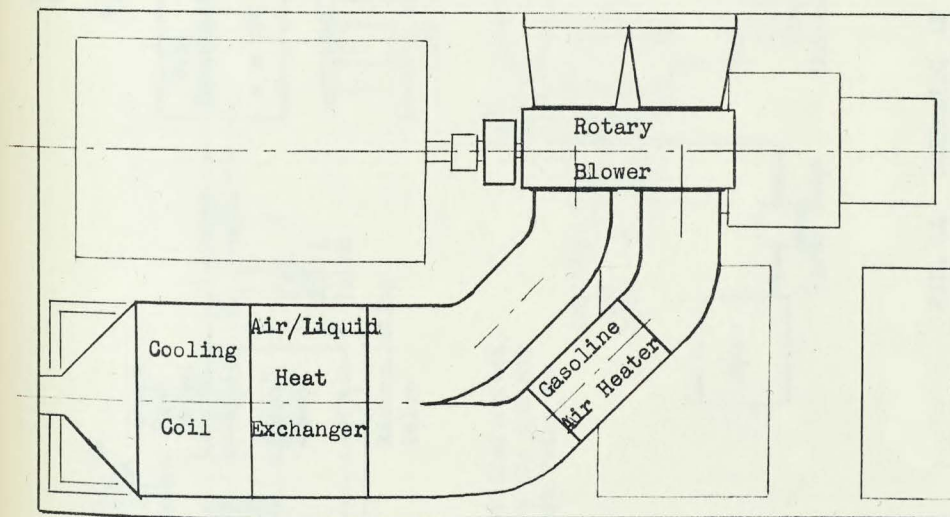


Elevation of Side "A"
with Side Panels Removed

FIG. 12 VIEWS OF PROPOSED INGLIS UNIT



Plan at Base Level



Plan at Level "X - X"

FIG. 13 VIEWS OF PROPOSED INGLIS UNIT

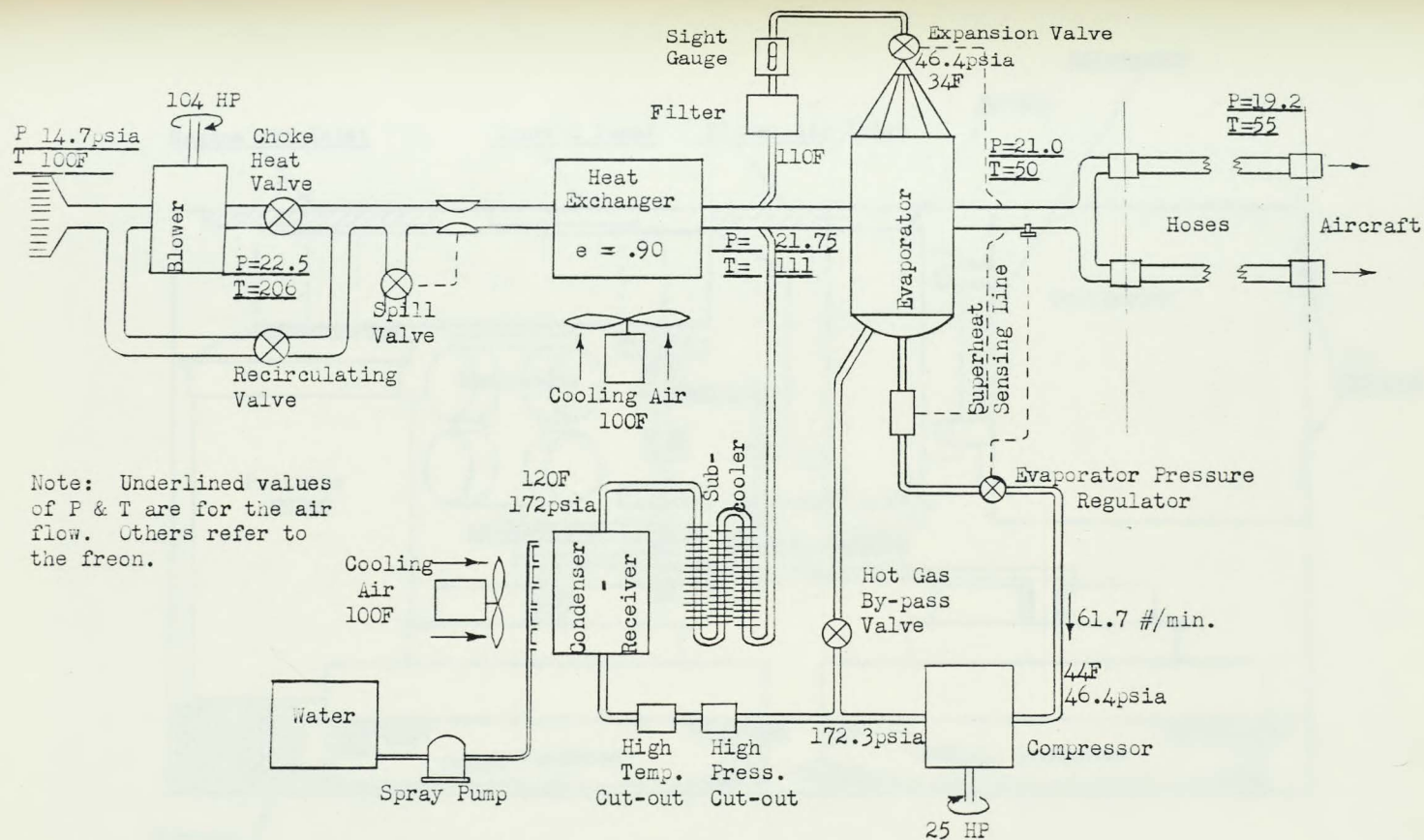


FIG. 14. SCHEMATIC OF GODFREY PROPOSAL

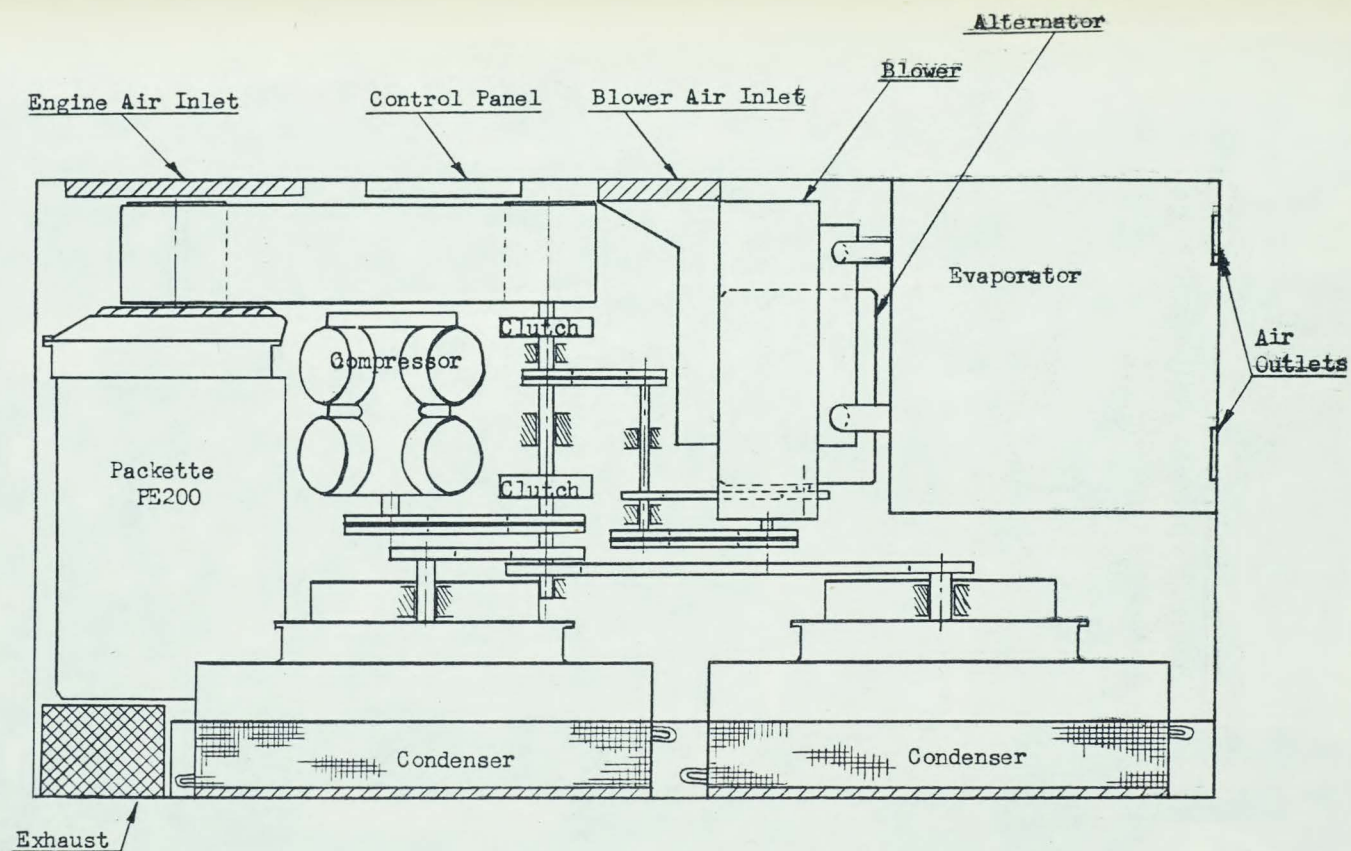


FIG. 15 PLAN VIEW OF HUSSMANN PROPOSAL

FIG. 17. HOKANSON MODEL 707 FREON AIR CONDITIONING UNIT

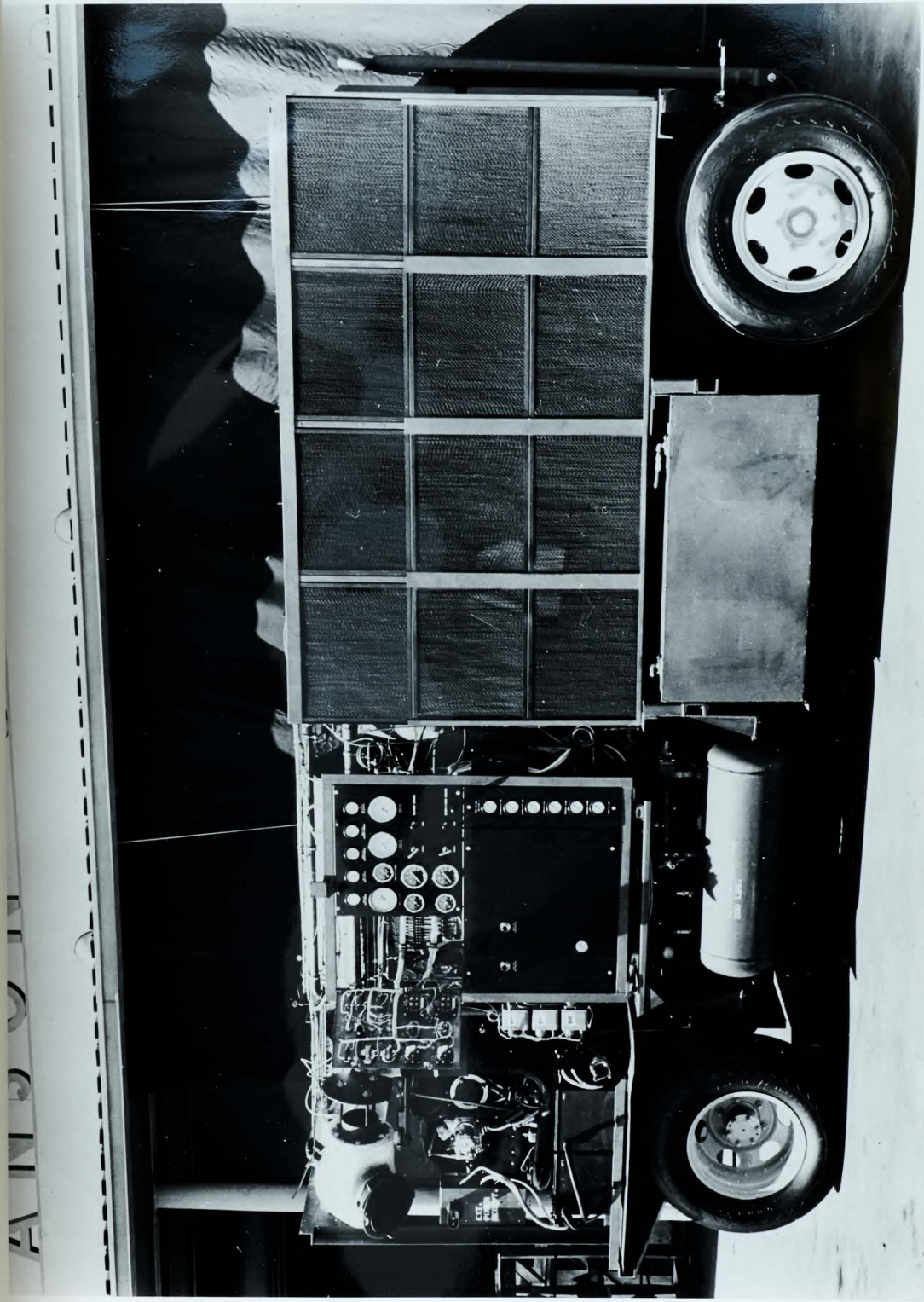


FIG. 16 HOKANSON MODEL 707 FREON AIR-CONDITIONING UNIT

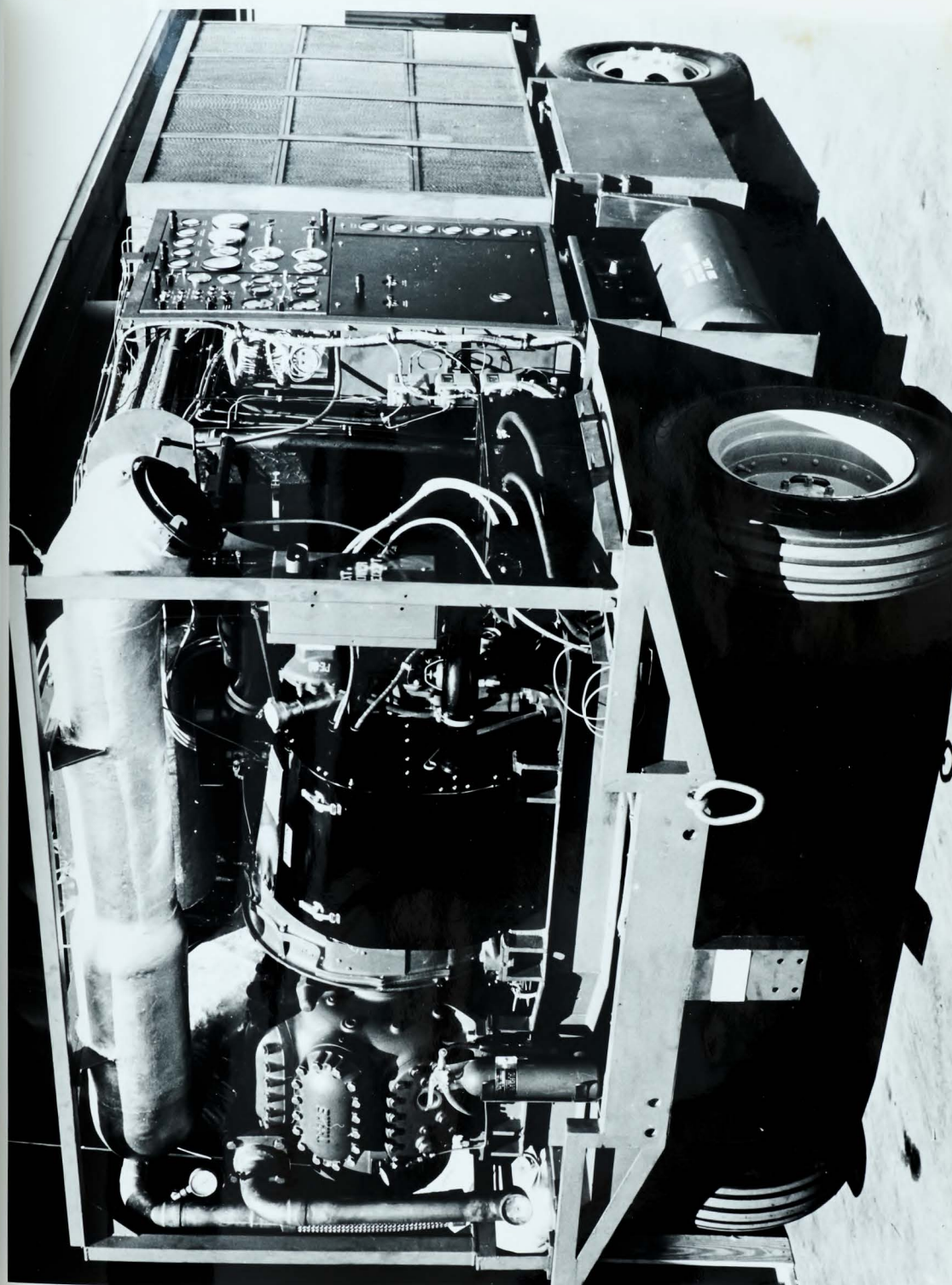


FIG. 17. HOKANSON MODEL 707 FREON AIR CONDITIONING UNIT

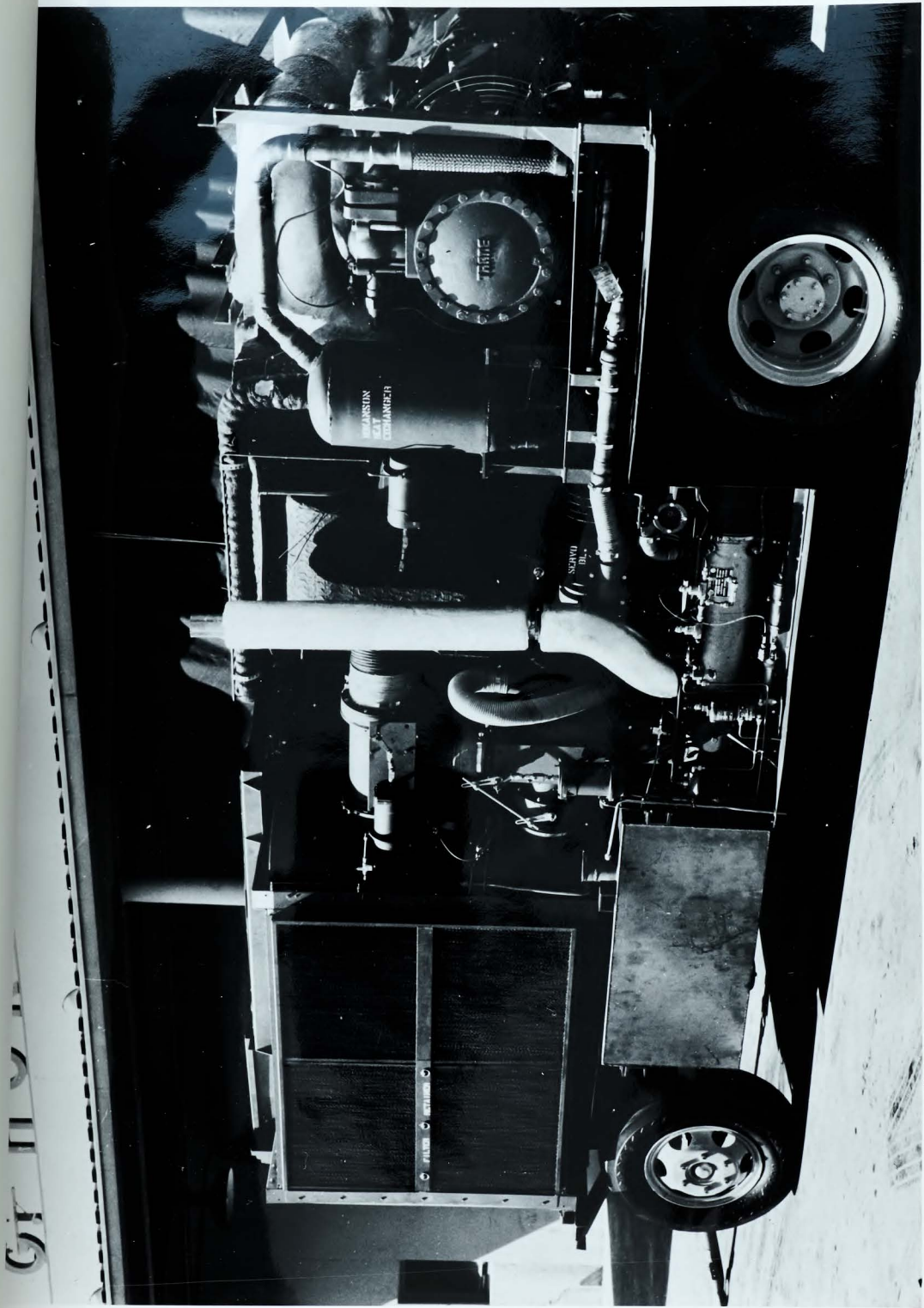


FIG. 18 HOKANSON MODEL 707 FREON AIR-CONDITIONING UNIT

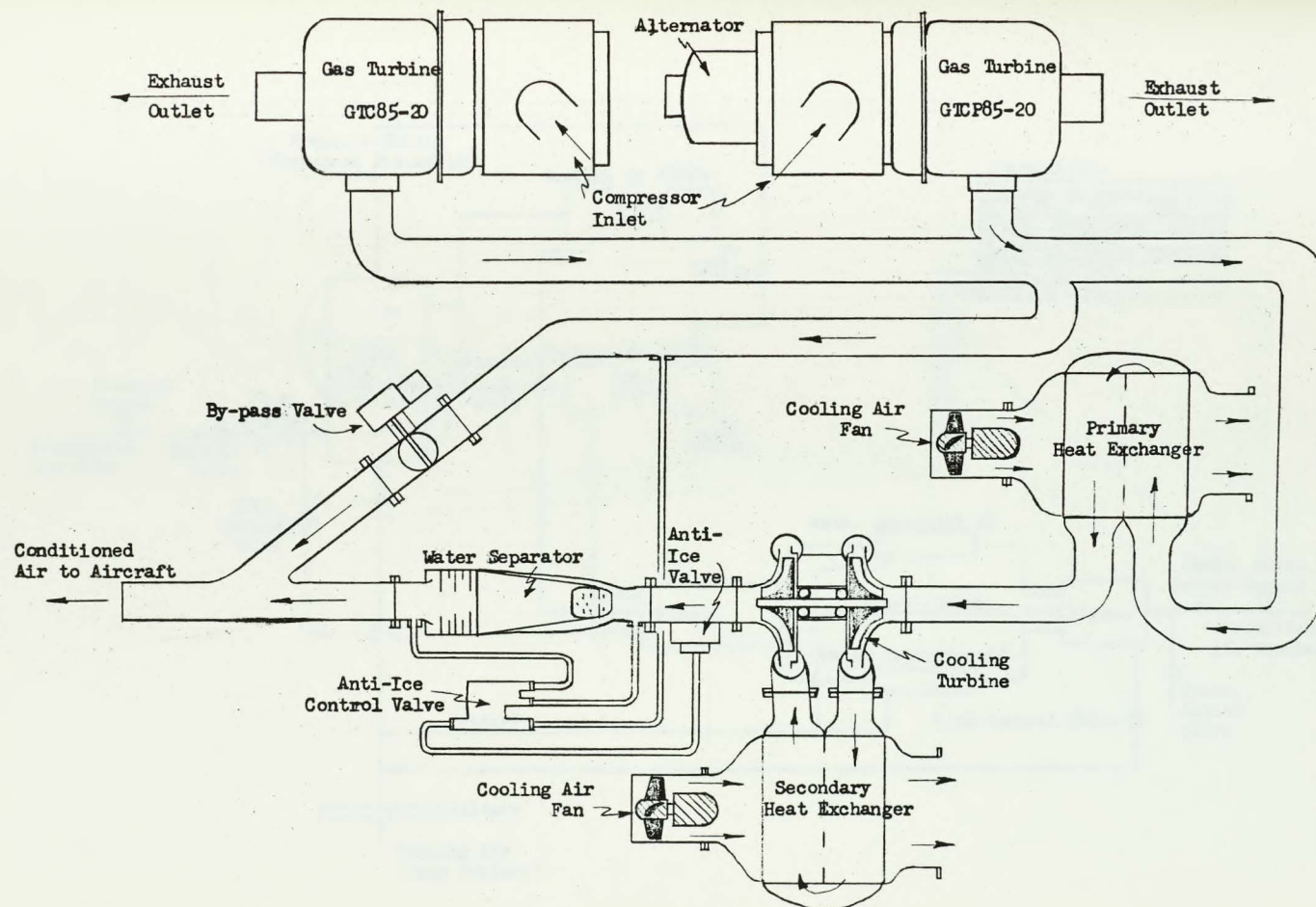


FIG. 20. SCHEMATIC DIAGRAM OF PROPOSED AIRESEARCH UNIT

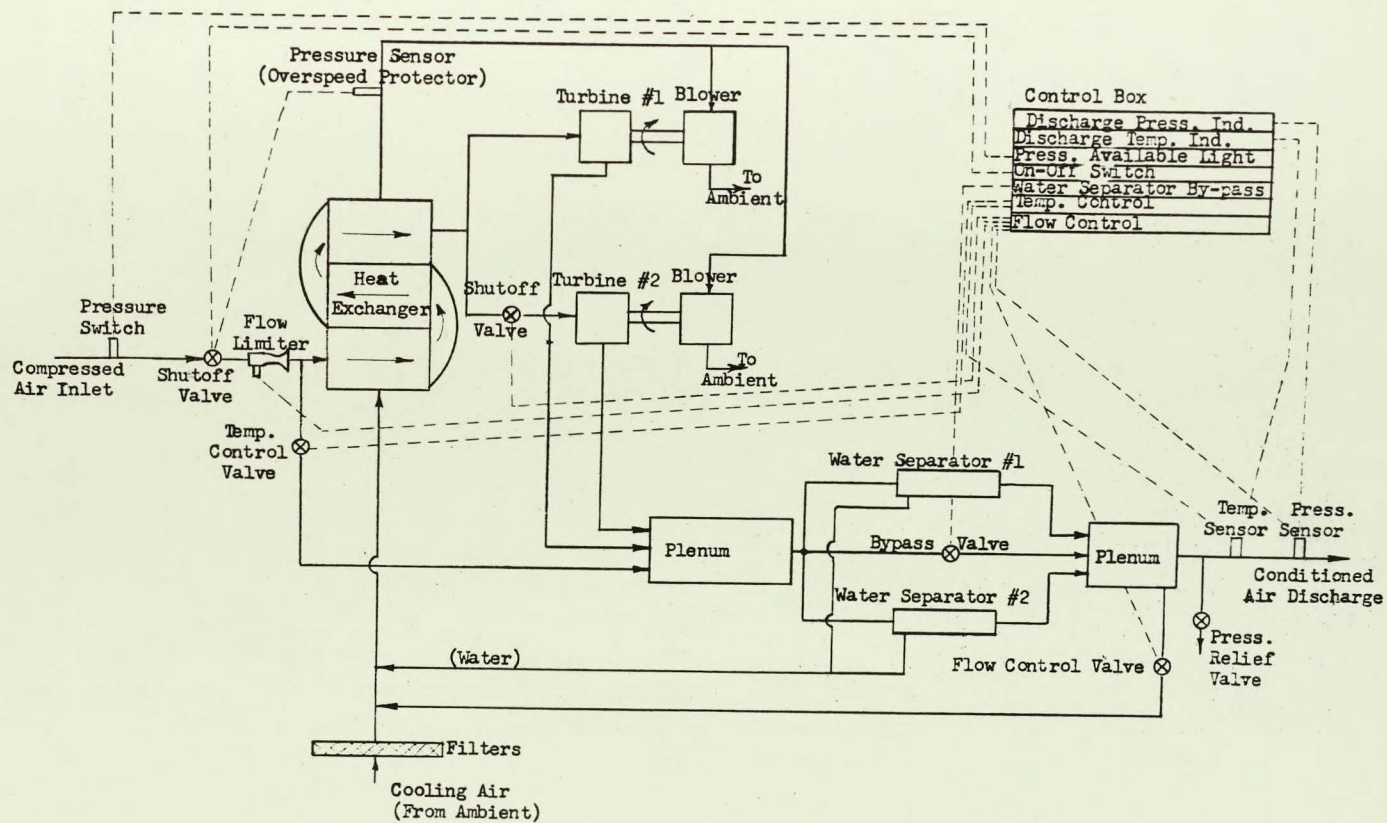


FIG. 21. STRATOS GEAL20-1 PACKAGE SCHEMATIC



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APPENDIX A

Information Contributed by John Inglis Co. Ltd.

As noted in the body of the report, the John Inglis Co. Ltd., was contacted and asked to submit information concerning the sizes and arrangement of components for a freon refrigeration unit based primarily on commercial equipment. At the time of the discussions the environmental requirements were not firm and their proposal was based on the use of air cooling for ambient temperatures up to 100°F, supplemented by water cooling at higher temperatures. Moreover, later analysis based on the current environmental requirements has shown that a single Packette engine has not sufficient power for the job and that two engines would be required. The overall size and weight of the package would therefore, also be increased. The layout of their proposed power/air conditioning package is shown in Fig. 12, 13 and their report appears below:

All power would be provided by a 220 B.H.P. Continental Packette Air-Cooled Gasoline Engine running at 2400 R.P.M. A 400 cycle, 115/200 volt, 3 phase supply would be obtained from a 40 KVA generator direct-coupled to this engine. The generator would require 50 B.H.P.

For compression of the supply air, a Miehle-Dexter Rotary Blower is included. This unit would deliver at 6.5 p.s.i.g. when running at 3600 R.P.M. and absorbing 101 H.P. and it is proposed to take a gear or chain drive for the blower from an extension shaft between the engine and generator.

Partial cooling of the supply air would be achieved by a liquid-cooled coil placed immediately upstream of the direct-expansion cooler. Liquid for the coil would be cooled by passing it through an air-cooled coil, mounted on the base of the trailer, utilizing ambient air. The fans for this latter cooler would require about 1 H.P. A centrifugal pump, absorbing about 1/2 H.P. would provide circulation in the closed liquid circuit. A V-belt drive for this pump can be taken from the engine shaft extension.

APPENDIX A (Cont'd)

With the above heat-exchanger arrangement it is estimated that air to the direct-expansion cooler would be at a temperature of 130°F. The refrigeration load would then be approx. 25 T.R. For this duty a Worthington 4JF4 multi-cylinder compressor is proposed, requiring 38 B.H.P. with a V-belt drive taken from the engine shaft extension, with jockey-pulley tensioning. Presently, the refrigeration cycle is based on 40°F evaporating and 130°F condensing temperature.

A direct-expansion F-12 air-cooler with thermostatic expansion valve will provide the dehumidification and final cooling. Provision is made for a liquid/suction-gas heat exchanger.

To avoid reliance on availability of water, an air-cooled condenser is proposed for the Canadian climate, but supplementary water sprays will be necessary for d.b. temperatures higher than 100°F. On the accompanying sketches this is shown as a combination of two banks of three condensing units, each unit with its own 1/3 H.P. fan. These are mounted across the top of the trailer with a shallow air intake plenum immediately beneath, extending for the length and breadth of the trailer. The air from these units is discharged vertically.

It may be necessary to take steps to prevent the higher temperature air, discharged from the base of the unit, (from the liquid/air H.E. and engine-cooling system etc.), from being recirculated through the supply air system, condensers, engine liquid/air H.E. and generator. This might be achieved by a flexible skirt around three sides of the trailer base, deflecting discharged air to one end, where, if necessary, a retractable flap could be provided to carry this air away from the trailer.

For cold weather working, provision has been made for a gasoline type air-heater with a capacity of approx. 200,000 B.T.U./hr.



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APPENDIX A (Cont'd)WEIGHT ESTIMATEGROUND AIR CONDITIONER - ARROW 2

	#
200 H.P. Packette Engine	970
40 KVA Generator	950
Rotary Blower (5511-14)	705
* 20 T.R. Compressor	1145
* Air-cooled Condenser	932
* Cooling Coil H.E.	518
Air/Liquid H.E.	370
Liquid/Air H.E.	408
Liquid	100
Pump	50.
*F-12 Liquid/Suction H.E.	140.
Ducting	200.
*Pipework	200.
Casing	-
Power Panel	-
Fuel Tank	100.
Fuel (5 hours)	700. 7,488.

Excludes Chassis, Running
Gear.

Refrigeration Equipment only * 2,935



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APPENDIX B

Information Submitted by Godfrey Engineering Co. Ltd.

The Godfrey Engineering Co. Ltd. was asked to submit information concerning the use of light-weight freon refrigeration equipment and aircraft-type blowers for the Arrow 2 mobile power/air conditioning unit. At the time of the discussions, the environmental requirements were not firm, so the performance was analyzed for operation at temperatures up to 130°F at sea level and 100°F at 5000' altitude. The results are noted below in their report and show that two Packette engines are necessary. Since our requirements were not firm, Godfrey Engineering did not attempt to select equipment or lay out a package. Rough calculations indicated that the component sizes might be as follows:

Evaporating coil	24" x 20" x 5"
Condensing Coil	34" x 20" x 6"
Air-to-air heat exchanger	36" x 36" x 24"
Complete package (trailer)	18' x 8' x 5', weight from 12000 to 14000 lb.

The refrigeration system proposed by Godfrey Engineering is shown schematically in Fig. 14.



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APPENDIX B (Cont'd)

TABLE 1 - AMBIENT CONDITIONS

ALT.	TEMP OF	D.P. OF	psia	ft. ³ /cu.ft	ρ/ρ_0
SL	100°F	75°F	14.7 psia	.0708	.925
SL	130	75	14.7	.0673	.88
5000	82.4	61	12.2	.0609	.796
5000	100	61	12.4	.0597	.781
SL	-65	-70	14.7	1.005	1.31
5000	-65	-70	11.8	.0806	1.05

TABLE 2 - FLOW, TEMPERATURE, HORSEPOWER OF BLOWER

TEMP OF	FLOW #/min	p_2/p_1	T_2/T_1	$T_2 - T_{10F}$ (100%)	T_{20F} (70%)	HP (100%)	HP (70%)
100	174.5	1.533	1.132	74	206	72.9	104
130	174.5	1.533	1.132	78	241	72.9	104
82.4	150	1.635	1.153	82.5	200	70.3	100.5
100	147	1.635	1.153	87	224	70.3	100.5
-65	249	1.533	1.132	52	10	72.9	104
-65	200	1.635	1.153	61	22	70.3	100.5



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APPENDIX B (Cont'd)

TABLE 3 - REFRIGERATION LOAD

T1 °F	T2 °F	T3 °F	DRY LOAD BTU/MIN	WET LOAD BTU/MIN	TOTAL BTU/MIN	FLOW #/MIN	TH. H.P. HP	C.O.P. (Theor)
100	206	111	2200	1800	4000	61.7	17.5	5.4
130	241	141	3280	1800	5080	78.4	25.9	4.62
82.4	200	94	1580	687	2267			
100	222	112	2230	687	2917			

Refrigerant - Freon 12

Evaporator - Temp = 34°F
 - Pressure = 46.417 psia
 - Latent Enthalpy = 64.886 TSTU/LB.
 - Sp. Volume (10% Superheat) = .880 cu. ft./lb.

Condenser - Temp = 120°F (145°F with 130° ambient design)
 - Pressure = 172.35 psia (235 psia with 130° ambient design)

TABLE 4 - HORSEPOWER TABLE

		ENGINE		HORSEPOWER		
		PACKETTE	RATED	75%	SL 100°F	5000' 82.4°F
Blower	104					
H.E. Fan	15	PE 90	110	82.5	76.2	65.6
Compressor	25	PE 150	175	131	121	104.5
Cond. Fan	15	PE 200	220	165	152.5	131.5
TOTAL	159					



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APPENDIX B (Cont'd)

TABLE 5 - AVAILABLE HEATING

ALT. FT.	T ₁ °F	T ₂ °F	MASS FLOW #/MIN	HEAT INPUT BTU/MIN	M _{net} #/MIN	M _{recire} #/MIN	%M _{recire} %
SL	-65	10	249	4500	150	99	39.7
5000	-65	22	200	4170	139	61	30.5

TABLE 6 - MOISTURE REQUIRED FOR EVAPORATIVE COOLING AT 130°F

ALT.	TEMP	D.P.	MOISTURE REMOVED		MOISTURE REQ'D *-#/MIN			
FT.	°F	°F	gr/lb	Total #/MIN	H.E.	Cond.	Total	Net
SL	130	75	84	1.82	2.52	6.5	9.02	7.20
5000	100	61	32	.686				

*Moisture required to reduce T₂ to 100° S/L valve

$$= \frac{(241-206) \times .24 \times 150}{500} = 2.52 \text{ \#/Min (50\% Effective)}$$

Moisture required to condense Freon

$$= \frac{61.7 \times 52.59}{500} = 6.5 \text{ \#/Min}$$



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APPENDIX C

Information Submitted by Hussmann Refrigerator Co. Ltd.

This company submitted an equipment layout for a freon refrigeration system as shown in Fig. 15. It was done before the environmental requirements were established and was based on supplying 150 lb/minute of air at 50°F (to allow for a temperature rise of 5°F in the delivery hoses), under the following conditions:

Sea Level	130°F dry bulb, 75°F wet bulb.
5000'	100°F dry bulb, 61°F wet bulb.

These conditions were misinterpreted; the figures given them were from Avro report Log/105/13 as follows:

Sea Level	130°F dry bulb, 75°F dewpoint.
5000'	100°F dry bulb, 61°F dewpoint.

This proposal is based on a single Packette engine driving all of the equipment through a series of toothed rubber belts. Examination of their drawing showed that there was insufficient power available and that a second engine would be necessary. Their system does not include an air-to-air heat exchanger, so that all cooling takes place within the refrigeration coil.



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APPENDIX D

Information Obtained from C.G. Hokanson Co., Inc.

General

The C.G. Hokanson Co., Inc., was visited in order to discuss the design of their model 707 ground air conditioning unit for the B-58. This unit appeared to come closest to meeting the Arrow 2 requirements and, from pictures, appeared to show the best engineering approach using a freon refrigeration system.

The 707 unit supplies 125 lb/air at a temperature of 30 to 45°F and a pressure up to 8 psi gauge under standard conditions. It is a trailer 87" wide, 170" long and 84" high, weighing 16000 lb. It uses two Continental Packette engines - a PE-150 driving two Miehle-Dexter 5516 blowers in tandem at 2400 RPM and a PE-90 driving a 50 ton Trane refrigeration compressor. The fuel capacity is adequate for 10 hours of continuous operation. Pictures of the 707 unit are included as Fig. 16, 17 & 18 of this report.

Design

The frame consists of an angle iron chassis which is specially designed for mounting the various items of equipment. The blower engine is mounted longitudinally at one end of the trailer and drives the M-D 5516 blowers directly through flexible couplings.

The PE-90 and the freon compressor are mounted laterally across the opposite end of the chassis.

The cabinet is divided into three sealed zones, two of which have intake filters along each side. The charge air for the blowers and the carburettor and cooling air for the blower engine enter the center zone.

The zone above the PE-150 engine contains a two pass air-to-air heat exchanger on one side and the freon condensing coil on the other side, with cooling air drawn through each and exhausted vertically by a fan driven from the PE-150. A by-pass valve is fitted in the air line to by-pass the heat exchanger when it is not required and is used progressively to maintain the temperature out of

APPENDIX D (Cont'd)

the heat exchanger at 130°F. A Janitrol 200,000 BTU/hr. heater is also fitted to warm the air sufficiently to pre-heat the aircraft during very cold weather. Storage tubes for the 8" diameter hoses are also fitted in this zone.

The center zone contains the freon cooling coil and an intake silencer for each blower. The coils are made from copper fins and tubes sweated together by dipping in tin. Controlling the inlet temperature to the cooling coil at 130°F serves two purposes:

- (a) it maintains a uniform load on the refrigeration unit to the point where its controls are practically an "off-on" switch, and,
- (b) the first couple of rows of the cooling coil are used to dry the freon 12 vapour. A special heat exchanger has also been fitted to assist in drying the freon 12 vapour and a four-way valve is fitted in the charge air lines to reverse the flow of air through the cooling coils for de-icing the unit, since this machine is required to deliver air at 30°F.

The third zone contains the PE-90, refrigeration compressor and insulated delivery ducting. The complete unit is enclosed in a light angle iron frame with quick access doors. The door on top (covering the cooling fan) is electrically operated and must be opened before either engine can be started.

Controls

The B-58 uses a multitude of pneumatic actuators operating at pressures of 15-20 psi. Therefore, a 20 psi air supply was built into the 707 unit (driven from the blower engine) and most of the valves in the unit were made pneumatic. They have apparently been quite successful.

Convair required a number of automatic features and settings in the 707 (different delivery temperatures and pressures) and this has made the control system more complex than ours would need to be. Basically their control system works as below:-



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APPENDIX D (Cont'd)

- Flow is controlled by varying the speed of the blower engine.
- Air temperature into the cooling coil is thermostatically controlled to 130°F.
- Cooling coil refrigerant temperature is regulated by controlling the suction pressure to the compressor.

Mobility

A 28V DC generator is driven by the PE-150 engine and, along with batteries, energizes the electrical system of the unit (lights, instruments, engine starting, drive motor). The unit is self-propelled at 3 mph by a 28V DC motor and can be moved approximately 1000' using batteries only, or without limit if the PE-150 is running. No battery heaters are fitted.

Cost

The prototype unit cost approximately \$80,000 including engineering charges. Production units sold for about \$60,000, of which \$30,000 was the cost of materials and bought out parts.



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APPENDIX E

Information Submitted by the Garrett Manufacturing Corporation of Canada, Ltd.

The Garrett Manufacturing Corporation of Canada Ltd., was asked to submit a proposal for a complete power/air conditioning package to meet our requirements. At the time of discussions the environmental requirements had not been finalized and the cases used in their reports are more severe than the present requirements.

Report AAC-2772-R, dated July 30, 1957

I INTRODUCTION

The purpose of this report is to present the configuration and estimated performance of a ground service unit to provide ground cooling and 3-phase, 200/115-volt, 400-cycle power for the AVRO C-105 Mark II airplane.

The proposed ground service unit consists of two gas turbines which provide the required electrical power and compressed air along with an air-cycle refrigeration unit which cools the gas turbine supplied air. The two gas turbines differ in that one machine provides compressed air only while the other supplies air and drives a 60-kva, 3-phase, 200/155-volt, 400-cycle alternator. The refrigeration unit is the bootstrap type consisting of two air-to-air heat exchangers, a cooling turbine, and a water separator with anti-ice control. Cooling air for the heat exchangers is provided by two electric-motor-driven fans which operate from power supplied by the gas turbine alternator. All of the components in the proposed unit are production items or modifications thereof with the exception of the refrigeration unit heat exchangers.

The configuration of the unit presented should be considered preliminary in nature. The components selections were made on the basis of a preliminary problem statement supplied by AVRO Engineering, the design conditions of which are summarized below.



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APPENDIX E (Cont'd)I INTRODUCTION (Cont'd)

Altitude, feet

Sea Level 2000 5000

Ambient Air Temperature

Dry Bulb, °F

130 112 100

Dew Point, °F

75 67 67

Conditioned Air Flow, lb per min

150 150 150

Conditioned Air Delivery Pressure psig

6.5 6.5

Conditioned Air Delivery Temperature °F

54 54

Electrical Power, kva

40 40 40

II DESCRIPTION OF COMPONENTS

The proposed service unit component arrangement is shown in Sketch AAC-2772-SK1. Included also is Sketch AAC-2772-SK2 which shows a schematic arrangement of the components.

1. Gas Turbine (Two Required) GTCP85-20, 372440

This gas turbine is a dual-purpose type machine, the two functions of which are to supply high-pressure bleed air and shaft power through a gear-driven accessory pad. This particular gas turbine is a current AiResearch production unit. It is proposed that one of the gas turbines shall be equipped with a 3-phase, 60-kva, 200/115-volt, 400-cycle alternator to provide ground service electrical power and the electrical power for the cooling air supply fans. AiResearch Outline Drawing 372440 is attached to this report.

2. Cooling Turbine 205650 (Modified)

The cooling turbine is a bootstrap type turbine. The cooling turbine is identical, with the exception of the turbine nozzle, with a current production cooling turbine. An outline drawing of Cooling Turbine 205650 is attached to this report.

APPENDIX E (Cont'd)II DESCRIPTION OF COMPONENTS (Cont'd)

3. Water Separator

The water separator consists of an aluminum shell containing a condenser cone and swirl section. The cone coalesces the entrained moisture in the turbine discharge air into large droplets. The droplets thus formed enter a swirl section and then the collector section where the droplets are removed by centrifugal action. The water separator is equipped for the inclusion of the anti-ice protection described in Paragraph 6.

A relief valve is incorporated in the water separator, which opens in the event that the pressure differential across the condenser cone becomes excessive.

This water separator is similar to the unit shown in Outline Drawing 85640, which is attached to this report.

4. Cooling Air Fans (Two Required)

The fan is a compact, lightweight unit consisting essentially of a 11.5-inch diameter axial-flow impeller and a 4-pole squirrel cage induction type motor mounted on a common shaft. The motor operates on 200/115 volts, 400 cycles per second, three-phase alternating current.

The proposed unit is similar to the unit shown in Outline Drawing 49390 with the shutter assembly deleted and the housing shortened.

5. Primary and Secondary Heat Exchangers

The primary and secondary heat exchangers are to be new units. The same heat exchanger will be used for both applications. The heat exchanger is an aluminum unit of tubular construction, arranged in a two-pass cross-counterflow configuration. The bleed air makes two passes through the tubes, while the cooling air makes one pass over the tubes. The heat exchanger is a mechanically assembled unit with removable manifolding and return pan. This heat exchanger is shown, in this report, by Sketch AAC-2772-SK3.



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APPENDIX E (Cont'd)II DESCRIPTION OF COMPONENTS (Cont'd)

6. Anti-Ice Control

The anti-ice control considered is of the pressure differential type. Equipment incorporating this type of control on water separators, which would be suitable for this application, are currently in production. The selection of a particular unit has not been made at this time.

III ESTIMATED SYSTEM PERFORMANCE

The system performance was estimated on the basis of the design conditions summarized in the introduction section of this report. The estimated performance of the proposed system is as follows:

Altitude, feet	Sea Level	2000	5000
Ambient Air Temperature, F (Dry Bulb)	130	112	110
Conditioned Air Delivery Flow, lb per min.	132.5	125	117
Conditioned Air Delivery Temperature, Dry Air Rated, °F	23	15	12
Dry Bulb, °F	46	35	35
Conditioned Air Moisture Content, grains of moisture per lb.	69	53*	61
Electric Power Supplied, kva	40	40	40

The maximum available air-flow from the two gas turbines with the required electrical output will not satisfy the air flow requirements. The discharge temperatures of the air, however, are lower than the required 54°F, and it is believed that the air flows shown with the estimated discharge temperatures will satisfy the airplane cooling requirements.



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APPENDIX E (Cont'd)

IV ESTIMATED WEIGHT OF SYSTEM COMPONENTS

1. Gas Turbine GTCP85-20, 372440	<u>Weight-lb</u> 245
2. Gas Turbine GTCP85-20, 372440 (Alternator Equipped)	340
3. Cooling Turbine 205650	35.6
4. Water Separator 85040	11.5
5. Primary Heat Exchanger	205
6. Secondary Heat Exchanger	205
7. Cooling Air Fans (Two Required)	66
Estimated Total Weight	<u>1108.1 lb</u>

The component characteristics used in the preceding report were:

	<u>Seal Level</u>	<u>2000'</u>	<u>5000'</u>
Adiabatic efficiency, %			
Turbine	85.5	84.5	85.5
Compressor	71.6	71.5	71.8
Pressure Drop (in. Hg.)			
Primary Heat Exchanger	1.64	1.50	1.48
Secondary Heat Exchanger	0.75	0.76	0.77
Water Separator	1.8	1.77	1.57
Efficiencies			
Primary Heat Exchanger	.90	.885	.905
Secondary Heat Exchanger	.90	.885	.905
Water Separator	.63	.63	.62

Since the air flow rates in this analysis were considerably less than those required under adverse environmental conditions, the Garrett Manufacturing Corp., was asked to examine the performance using one GTC 85-20 gas turbine compressor and one GTCP 85-20 shaft power/bleed air machine. At the same time, the aircraft electrical load requirement was reduced to 30 KW. Their report appears below:



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APPENDIX E (Cont'd)Report AAC-2772-R, Rev. 1I. INTRODUCTION

The purpose of this report is to present the configuration and estimated performance of a ground service unit to provide ground cooling and 3-phase, 200/115-volt, 400-cycle power for the AVRO C-105 Mark II airplane.

The proposed ground service unit consists of two gas turbines which provide the required electrical power and compressed air along with an air-cycle refrigeration unit which cools the gas turbine supplied air. The two gas turbines differ in that one machine provides compressed air only while the other supplies air and drives a 60-kva, 3-phase, 200/115-volt, 400-cycle alternator. The refrigeration unit is the bootstrap type consisting of two air-to-air heat exchangers, a cooling turbine, and a water separator with anti-ice control. Cooling air for the heat exchangers is provided by two electric-motor-driven fans which operate from power supplied by the gas turbine alternator. All of the components in the proposed unit are production items or modifications thereof with the exception of the refrigeration unit heat exchangers.

The configuration of the unit presented should be considered preliminary in nature. The component selections were made on the basis of a preliminary problem statement supplied by AVRO engineering, the design conditions of which are summarized below.

Altitude, feet	Sea Level	Sea Level	3500
Ambient Air Temperature			
Dry Bulb, °F	120	100	101
Dew Point, °F	76	85	67
Conditioned Air Flow, lb per min	150	150	150
Conditioned Air Delivery Pressure, psig	6.5	6.5	6.5
Conditioned Air Delivery Temp. °F	55	55	55
Electrical Power, kva	30	30	30



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APPENDIX E (Cont'd)

II DESCRIPTION OF COMPONENTS

The proposed service unit component arrangement is shown in Sketch AAC-2772-SK1. Included also is Sketch AAC-2772-SK2 which shows a schematic arrangement of the components.

1. Gas Turbine GTCP85-20, 372440

This gas turbine is a dual-purpose type machine, the two functions of which are to supply high-pressure bleed air and shaft power through a gear-driven accessory pad. This particular gas turbine is a current AiResearch production unit. It is proposed that this gas turbine will be equipped with a 3-phase, 60-kva, 200/115-volt, 400-cycle alternator to provide ground service electrical power and the electrical power for the cooling air supply fans. AiResearch Outline Drawing 372440 is attached to this report.

2. Gas Turbine GTC85-20, 76400

This gas turbine is a single-purpose machine which supplied high-pressure bleed air. This gas turbine is a current AiResearch production unit. AiResearch Outline Drawing 76400 is attached to this report.

3. Cooling Turbine 205650 (Modified)

The cooling turbine is a bootstrap type turbine. The cooling turbine is identical, with the exception of the turbine nozzle, with a current production cooling turbine. An outline drawing of Cooling Turbine 205650 is attached to this report.

4. Water Separator

The water separator consists of an aluminum shell containing a condenser cone and swirl section. The cone coalesces the entrained moisture in the turbine discharge air into large droplets. The droplets thus formed enter a swirl section and then the collector section where the droplets are removed by centrifugal action. The water separator is equipped for the inclusion of the anti-ice protection described in Paragraph 6.

APPENDIX E (Cont'd)II DESCRIPTION OF COMPONENTS (Cont'd)

4. Water Separator (Cont'd)

A relief valve is incorporated in the water separator, which opens in the event that the pressure differential across the condenser cone becomes excessive.

This water separator is similar to the unit shown in Outline Drawing 85640, which is attached to this report.

5. Cooling Air Fans (Two Required)

The fan is a compact, lightweight unit consisting essentially of a 11.5-inch diameter axial-flow impeller and a 4-pole squirrel cage induction type motor mounted on a common shaft. The motor operates on 200/115 volts, 400 cycles per second, three-phase alternating current.

The proposed unit is similar to the unit shown in Outline Drawing 49390 with the shutter assembly deleted and the housing shortened.

6. Primary and Secondary Heat Exchangers

The primary and secondary heat exchangers are to be new units. The same heat exchanger will be used for both applications. The heat exchanger is a aluminum unit of tubular construction, arranged in a two-pass cross-counterflow configuration. The bleed air makes two passes through the tubes, while the cooling air makes one pass over the tubes. The heat exchanger is a mechanically assembled unit with removable manifolding and return pan. This heat exchanger is shown, in this report, by Sketch AAC-2772-SK3.

7. Anti-Ice Control

The anti-ice control considered is of the pressure differential type. Equipment incorporating this type of control on water separators, which would be suitable for this application, are currently in production. The selection of a particular unit has not been made at this time.



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APPENDIX E (Cont'd)III ESTIMATED SYSTEM PERFORMANCE

The system performance was estimated on the basis of the design conditions summarized in the introduction section of this report, with the exception of the ambient air temperature noted below. The estimated performance of the proposed system is as follows:

Altitude, feet	Sea Level	Sea Level Humid	3500
Ambient Air Temp.			
Deg. F. Dry bulb - from data	120	100	101
Deg. F. Dry bulb - used in analysis	115	100	90
Conditioned Air Delivery Flow lbs/min	150	160	150
Conditioned Air Delivery Temperature at Turbine Discharge			
Deg. F. D.A.R.	7	- 7	-11
Turbine Dist. Moisture Content			
GR./LB Dry Air	136	184	113
Moistured removed			
GR./LB Dry Air	59.5	84	59.5
Conditioned Air Temp.			



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APPENDIX E (Cont'd)

III ESTIMATED SYSTEM PERFORMANCE (Cont'd)

	Sea Level	Sea Level Humid	3500
At Water Separator Discharge Deg. F. D.A.R.	45	44	26
Entrained Moisture Content			
GR./LB Dry Air - Water Separator Discharge	25.5	36	25.5
Entrained Moisture Content Cabin			
Inlet Ambient Pressure GR./LB Dry Air	15	24.5	17.5
Free Moisture Entering Cabin			
LB/MIN	0.322	0.56	0.375

IV ESTIMATED WEIGHT OF SYSTEM COMPONENTS

	<u>Weight-lb</u>
1. Gas Turbine GTCP85-20, 372440 (Alternator Equipped)	340
2. Gas Turbine GTC85-20, 76400	225
3. Cooling Turbine 205650	35.6
4. Water Separator 85040	11.5
5. Primary Heat Exchanger	205
6. Secondary Heat Exchanger	205
7. Cooling Air Fans (Two Required)	66
Estimated Total Weight	1088.1 lb



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APPENDIX E (Cont'd)

Subsequent to the issue of Revision 1 of Report AAC-2772-R, the following data were provided:

"Since issue of revision 1 to Report AAC-2772-R, AiResearch have completed qualification testing of the proposed Water Separator. This Water Separator is scheduled for use in the Boeing 707 aircraft and as such qualification testing was required. As a result of tests carried out it is now possible to provide more factual information with respect to performance than is currently shown on Page 4 of the referenced report. It has been determined that the Water Separator efficiency will be 70 per cent for all cases checked."

Additional information concerning the cost and overhaul life of equipment was provided as follows:

"The AiResearch model GTC 85-20 Gas Turbine Engine has been designed for a minimum of 1000 hours between overhauls. At the moment the United States Air Force have established an overhaul frequency of this turbine on the basis of number of starts of the machine. A hot end overhaul being carried out after 1300 starts and a complete overhaul after 2600 starts. Experience is being rapidly accumulated of a considerable number of units in service and latest units going through overhaul at these figures show excellent results. AiResearch are confident that an overhaul program based upon the number of starts shown or on a 1000 hours between overhaul basis is quite realistic.

A program is underway at AiResearch aimed at increasing the number of starts between overhauls to 3000. Presumably this will also result in increasing the allowable running time between overhauls. The volume of units in operation should quickly verify the program now laid on.

With respect to overhaul life of the refrigeration package we can advise the following.

1. Cooling Turbine - 1000 hours
2. Fan - 2000 hours
3. Heat Exchangers - 5000 hours
4. Water Separator - 500 hours



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APPENDIX E (Cont'd)

IV ESTIMATED WEIGHT OF SYSTEM COMPONENTS (Cont'd)

In order to assist you in establishing broad budget figures we can advise approximate unit prices as follows:

1. Gas Turbine Compressor with Enclosure (GTCE 85-20) approximately \$22,000.00 each.
2. Refrigeration Package complete approximately \$20,000.00 each.

The prices shown are based upon small quantity release and not to be considered firm."



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APPENDIX F

Information Submitted by the Stratos Division of the Fairchild Engine and Airplane Corporation

"Stratos" manufactures a simple air cycle refrigeration package as described below and in Fig. 21. Performance curves were also submitted (at a later date) and a typical curve is reproduced in Fig. 22.

DESCRIPTIVE DATA

MODEL GEA120-1 GROUND AIR CONDITIONER

1. Introduction

The Stratos Model GEA120-1 is a compact, lightweight Type MB-1 air cycle ground air conditioner designed to the requirement of Air Force Exhibit WCL-876 dated 21 June 1955. It is suitable for installation as a component of Multi-Purpose Servicing Units, or individually on its own trailer. The required power supply is compressed air from a Type MA-2 Gas Turbine Compressor plus a maximum of 8 amperes of 28 volt DC power for the air conditioner controls. The air conditioner will also operate with the Type MA-1A Gas Turbine Compressor, at a somewhat lower output.

2. Description

The GEA120-1 is comprised of a number of aircraft quality components assembled within an aluminum enclosure 48" x 50" x 30" high, plus a separate control box and instrument panel from which all functions of the air conditioner may be controlled. A 15 foot electrical cable, supplied with the air conditioner, is the only connection between the air conditioner and the control box. The attached photograph shows the general appearance of the air conditioner, control box, and connecting cable. Other connections to the air conditioner itself are a 3½" compressed air supply connection and an 8" conditioned air (discharge) connection. The connector for 28 volt DC electrical power supply is located on the side of the control box.

Air from the gas turbine compressor entering the air conditioner passes through a fast acting shut-off valve and a flow limiting venturi, and then through a high effectiveness air-to-air heat exchanger in which the temperature is reduced to slightly above that of the ambient air. (Refer to the attached Schematic Flow and Controls Diagram). It then enters two expansion turbines in which a further reduction in temperature is achieved. Turbine



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APPENDIX F (Cont'd)

2. Description (cont'd)

work is absorbed by blowers which serve to draw ambient cooling air through the heat exchanger. The cold air then flows through a plenum chamber and from there through two water separators, where 80% of the liquid water in the conditioned air is removed, and thence through a second plenum to the discharge duct connection. The separated water is sprayed into the heat exchanger cooling air to increase heat exchanger effectiveness.

Automatic controls permit selection of flow rate and temperature of the conditioned air as desired. Temperature control is accomplished by bypassing hot supply air around the heat exchanger and expansion turbines, to the first plenum chamber, in proper proportion to effect the desired temperature at the discharge connection. A control on the control panel permits selection of any discharge temperature from 35 to 280°F. Flow control is accomplished by dumping conditioned air through a valve connected to the second plenum chamber, to reduce flow to the desired value. (The dumped air is ducted to the heat exchanger cooling air inlet, thereby affording a regenerative cooling effect). When less than 50 percent flow is desired, one of the expansion turbines is shut down completely to reduce the compressed air demand on the gas turbine compressor. In this condition, the control effects a change in the internal geometry of the flow limiting venturi at the package inlet, so that it limits total package flow to one-half of the rated value.

When separation of the entrained water in the conditioned air is not required cooling capacity of the air conditioner can be increased (through re-evaporation of the water content in the discharge) by opening a water separator bypass valve. This valve is controlled by a switch on the control box.

Instruments provided include indicators for temperature and pressure at the air conditioner discharge connection, and an hourmeter.

Installation details of the GEAL20-1 are shown on the attached drawing number 23000.

3. Performance

Estimated performance of the GEAL20-1 at the three conditions of Exhibit WCL-876 is as follows:



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APPENDIX F (Cont'd)

Ambient Conditions

		<u>Condition</u>		
		<u>1</u>	<u>2</u>	<u>3</u>
Temperature - DB	(°F)	130	100	-65
Temperature - WB	(°F)	76	76	-
Pressure	(psia)	14.7	14.7	14.7

Supply Conditions

Temperature	(°F)	600	550	200
Pressure Available	(psig)	50	53	65
Maximum Flow	(lbs/min)	110	125	200

Discharge Conditions

Pressure	(psig)	4	4	4
Airflow	(lbs/min)	*110	*125	***200
Temperature				
Dry Air Rated	(°F)	42	5	-
Actual	(°F)	** 49	** 45	***200
Moisture Content	(gr/lbs)	50	47	-

*With temperature selector set at full cold. Discharge airflow will increase slightly if higher temperature is selected.

**Corresponds to WB temperature at 4 psig back pressure.

***Condition 3 represents operation with the temperature control valve in the full open position. In this condition, there will be a small amount of airflow through the turbines and, consequently, a small amount of cooling airflow through the blowers. This flow will be so small as to practically negligible, however, and the package discharge temperature will be very close to supply temperature.

This company was asked to calculate the performance of its GEA-120 unit for the following conditions:

Environmental Conditions:

Sea Level	100°F dry bulb,	85°F wet bulb.
	130°F " "	85°F " "
	-65°F " "	
5000"	112°F " "	85°F wet bulb.

Outlet air Requirements (at unit):

Pressure	6.3	psi (gauge)
Temperature	50°F	
Flow	150	to 200 lb./min.



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APPENDIX F (Cont'd)Engine Performance:

- (a) Two Solar T-300 J-1 engines (one drawing a 40 KVA generator in addition to supplying bleed air).
Estimated compressor delivery conditions:

<u>Ambient</u>	<u>Pressure</u>	<u>Temperature</u>
Sea level, 130°F	64 p.s.i.a.	520°F
Sea level, 100°F	66 p.s.i.a.	490°F
5000', 112°F	53 p.s.i.a.	500°F

- (b) 2 Blackburn Palouste 500 Engines (derived from the same basic engine as the Continental Model 141).
Estimated compressor delivery conditions :

<u>Ambient</u>	<u>Pressure</u>	<u>Temperature</u>
Sea level, 130°F	55 p.s.i.a.	475°F
Sea level, 100°F	57 p.s.i.a.	455°F
5000', 112°F	45 p.s.i.a.	460°F

- (c) 2 AiResearch GTC 85-20 Engines.

<u>Ambient</u>	<u>Pressure</u>	<u>Temperature</u>
Sea level, 130°F	48 p.s.i.a.	455°F
Sea level, 100°F	50 p.s.i.a.	430°F
5000', 112°F	41 p.s.i.a.	435°F

In addition, if the air delivered in Case "A" is cold enough, AVRO would appreciate your opinions concerning the use of a single Solar T-300 J-1 engine supplying bleed air and driving an auxiliary blower to bring the total flow up to 150 lb/minute under adverse ambient conditions. For this case, the estimated supply conditions are:

<u>Ambient</u>	<u>Flow</u>	<u>Pressure</u>	<u>Temperature</u>
Sea level, 130°F	Solar 108 lb/min.	59 p.s.i.a.	515°F
	Blower 44 lb/min.	21 p.s.i.a.	240°F
Sea level, 100°F	Solar 133 lb/min.	62 p.s.i.a.	480°F
	Blower 17 lb/min.	21 p.s.i.a.	210°F
5000', 112°F	Solar 100 lb/min.	50 p.s.i.a.	495°F
	Blower 50 lb/min.	18.5 p.s.i.a.	220°F

The results are contained in their letter of August 2, 1957:



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APPENDIX F (Cont'd)

Engine Performance (Cont'd)

"We have calculated the performance of our GEAL20-1 ground air conditioner at the conditions stated in reference letter. This performance is reported on the attached table.

"Effective temperature" is the temperature of dry air of equivalent cooling capacity. It is somewhat lower than the wet bulb temperature and reflects the additional cooling which is obtained in the airplane due to evaporation of the small amount of liquid water present in the air conditioner discharge. "Effective temperature" should be used for T supply in the equation $Q = Wx C_p (T_{\text{cabin}} - T_{\text{supply}})$ to determine cooling capacity of the air conditioner.

We would like to caution you on the use of the performance figures in the enclosure. They are accurate if the flow we have indicated is compatible with the pressure you have given us for supply pressure. As you know, GTC performance at a given ambient temperatures is a curve wherein bleed pressure falls off as bleed airflow increases. Therefore our performance is meaningful if the GTC will flow as much air as we take at the pressure you have given. If it will not, the pressure will be lower than given and a balance point will be reached at some lower pressure and flow. Conversely, if it will flow more than we take, the bleed pressure may be higher than given, and the balance point will be at a flow and pressure higher than shown in the enclosure.

We hope this information will be of interest and will be glad to furnish additional details if required.

With regard to the idea of using an auxiliary blower to supplement the cooling air discharge flow, this might be practical in some cases, but with a 210 - 240°F air temperature it does not take much auxiliary flow to result in a very appreciable change in the temperature of the discharge air. For example, increasing the flow from 140 to 150 lbs/min. increases the temperature by something like 13°F."



APPENDIX F (Cont'd)

Altitude	S.L.			S.L.			5000'		
Ambient Dry Bulb Temp. °F	100			130			112		
Ambient Wet Bulb Temp. °F	85			85			85		
Compressor used	<u>Solar</u>	<u>Palouste</u>	<u>AiResearch</u>	<u>Solar</u>	<u>Palouste</u>	<u>AiResearch</u>	<u>Solar</u>	<u>Palouste</u>	<u>AiResearch</u>
Turbine Flow #/min	153.1	132.7	116.8	144.8	125.0	109.3	121.8	106.2	94.6
Exit DAR Temp. °F	- 8.5	2.5	14.8	17.8	30.2	44.2	8.7	29.9	32.4
Exit Wet Bulb Temp. °F	53.2	57.6	62.1	51.7	56.8	62.0	52.2	56.7	60.5
Exit Effective Temp. °F	40.9	46.6	52.6	44.9	51.5	58.4	43.5	49.5	54.9
Free Water lb/lb air	.003	.0026	.0023						



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APPENDIX F (Cont'd)

Since the delivered air flow was less than required under adverse environmental conditions with the standard package, "Stratos" was asked whether the unit could be modified to pass 150 lb/minute of air with a lower inlet pressure. Their analysis indicated that it would not be feasible using the AiResearch GTC 85-20 gas turbine and that the performance with the other engines would be as indicated below:

Altitude	Sea Level		Sea level		5000'	
Ambinet Temperature (°F)						
Dry Bulb	100		130		112	
Wet Bulb	85		85		85	
Specific Humidity (grains/lb/dry air)	159		107.5		157.5	
Engine	Solar Palouste		Solar Palouste		Solar Palouste	
Flow	187.6	186.8	177.8	176.3	149.4	149.3
Discharge Temperature (°F)						
Dry Air Rated	21.7	41	46.7	66.7	37.3	57.1
Wet Bulb	71.5	78.5	68.7	76	74.5	80.5
Effective	51.5	71	64.5	74	67	76



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APPENDIX G

Information Supplied by Blackburn & General Aircraft

GENERAL

The performance requirements originally specified have recently been revised, however, details are given in this part of the report which may be considered in relation to the original requirements. These details refer to the Artouste 510 APU which incorporates an engine basically the same as the Palouste 500 proposed for the air starting requirement. The Artouste 510 APU is shortly going into production, and no development would be specifically required for AVRO Canada. This course of action will allow AVRO, Canada to consider the possible use of this unit in association with alternative refrigeration systems, if it should prove impossible to find a suitable means of meeting the revised requirements in association with an air cycle refrigeration system.

PERFORMANCE

The attached set of performance curves, together with the associated covering notes give the details of the performance of the Artouste 510, these curves are drawn for the engine which is matched in such a way that surge is impossible with the type of control system which would be provided.

If it proves impossible to reduce the air conditioning air flow requirement then the use of two Artouste 510 APU's (the second without an alternator) may be considered. The coupling of the air output of two engines presents certain technical difficulties, but the design of a control system to overcome these is not expected to require the use of any heavy complicated or expensive equipment.

STATUS

The Artouste is one of a range of engines which have many components in common, notably the Gas Generator which is common to all engines in the range. The experience on all engines is, therefore, of direct significance in considering the status of the Artouste itself. The following running times both on development and in the field which have been achieved so far are, therefore, quoted to show the experience which has been built up on the engine range.



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APPENDIX G (Cont'd)

STATUS (Cont'd)

Artouste	-	<u>380</u> hours.
Palas	-	1,040 hours.
Palouste	-	4,300 hours.
Turmo	-	<u>930</u> hours.
Total		<u>6,650</u> hours.

It is emphasized that the unit proposed in this report is already under intensive development prior to production for the R.A.F. It incorporates an alternator (running at 12,000 R.P.M.) which is also under development prior to production.

In the event of a decision being made to use two units only the additional control gear necessary when coupling the output of two engines would require design and development.

ENGINEERING DETAILS

Engine Description

The Artouste 510 is a combination of an air bleed and a shaft drive engine; a reduction gear is driven by a forward extension of the rotating assembly. It is identical to the Palouste except for the modification required to accommodate the reduction gearbox.

The reduction gearbox is a single stage unit comprising a high speed pinion which drives an upper and lower gear. All gears are helical.

Fuel System

The fuel control system automatically meters the fuel supply to the engine to meet starting, idling, acceleration, maximum speed and deceleration requirements, at all ambient temperatures. Metered fuel passes through the hollow rotor shaft from which it is injected by a rotary atomiser to the combustion zone. For starting, fuel is supplied via a solenoid valve to a torch igniter.

Details of the fuel system are given in the manual attached to the first part of this report. Although this describes the Palouste fuel system, that on the Artouste would be identical except for detail changes necessary due to the fitment of the gear box on the front face of the engine.

APPENDIX G (cont'd)Fuel System (cont'd)

It is understood that the engine would be required to operate at a constant bleed flow and the variation of total engine power output with variation of electrical load from zero to 40 KVA would therefore be relatively small. It is therefore possible with the existing fuel system to say that the variation in engine speed with varying alternator load would always be within 1%. For very rapid variation in alternator load, say less than 1/4 second, the transitory speed change would be well within the 5% limit quoted.

Oil System

The oil system is completely self contained on the engine, the only external connection being one for a pressure gauge. Twin oil tanks are situated each side of the air intake passage and supply oil to the pump/filter unit. A gear type pressure pump supplies oil to the front bearing, rear bearing, accessory drives and reduction gearbox and a larger capacity scavenge pump returns the oil to the tanks. The oil system is fully described in the manual attached to part 1 of this report, but certain modifications are already under discussion for the M.O.S. air starting trolleys and these would automatically be incorporated in any engines for AVRO.

Electrical System

The ignition system consists mainly of two components, an ignition unit, battery supplied, and a high energy torch igniter.

An electrical starter, driving through a roller clutch is utilized to start the engine. The system is automatic in that a pressure switch cuts out the starter motor at a pre-determined speed. Hand Starting Gear is also provided.

For an installation requiring a self contained electrical system a Generator, a 50 AH, 24 Volt battery and a voltage regulator and cut-out and the associated wiring and panel can be provided. In addition to providing power for the self-contained unit the generator would have enough excess power to provide the 10 amps required for relay control on the aircraft.

The section of the manual attached to part 1 describing the electrical system in the existing trolley application is not yet issued, but a wiring diagram is shown on Fig. 2 of part 2, Section 3, Chapter 3 and from this the details can be inferred.

APPENDIX G (cont'd)Reduction Gearbox

The reduction gearbox is a light alloy casting which is secured to the front of the engine on two extensions to the air intake ducts. Two taper flange mounting faces are provided; the lower large one provides the mounting for the alternator and the smaller upper one a cooling fan. A duct from the fan to the end of the alternator provides blast cooling.

The gear ratio gives an alternator speed of 12,000 R.P.M. at the engine running speed of 33,230 R.P.M.

Air Delivery Valve

The two position air delivery valve is situated on the main casing and is electro-pneumatically operated. To prevent malfunctioning the two butterfly valves are interconnected and operated by a single pneumatic ram.

Fuel

The following fuels are approved by us for use on the Arouste 510.

Aviation Turbine Fuel JPI (i.e. DERD.2482 or MIL-F-5616).

Wide cut Gasoline. JP4 (i.e. DERD.2486 or MIL-F-5624A).

Aviation Kerosene
(High Flash Point). JP5 (i.e. DERD.2488 or MIL-F-5624C).
Aviation Gasoline
(Grades 91/96 & 100/130). DERD.2485 or MIL-F-5572

Diesel Oil. Specification ST 700-1C.

Oil

The following oils are approved by us for use on the Artouste 510.

DED.2487
DED.2479 (i.e. Esso Aviation Turbo Oil No. 35 or Allison Corporation EMS 35 or Esso Aviation oil EEL 3).

MIL-L-6082B. Grade 1065.

Esso Aviation Oil No. 57.

Aeroshell Turbine Oil No. 9.

Aeroshell Turbine Oil No. 9B.

Mobiloil Motrix 111 (Aero 57).

APPENDIX G (Cont'd)Accessories

The attached installation drawing of the Artouste 600 Engine gives details of the type of power and rotation direction, etc., of the accessory drive pads normally available. In the case of the Artouste 510 certain drive pads are blanked, and others are already in use. From the installation drawing and the schedule of accessories attached, details of the faces and drive power available for additional accessories can be deduced.

Contamination

Since there is no physical separation between the combustion air and the bleed air, certain tests are necessary in order to establish that the bleed air is free from toxic contamination. These tests are under way but are not yet complete, however it is confidently expected that they will show that no toxic contamination is present in the bleed air.

It is considered possible that certain precautions will have to be taken to avoid bleed air being supplied to the aircraft during the starting operation, but this can be made a normal function of the starting and control system.

Instruments

The only instruments necessary are an Engine Speed Indicator, an Exhaust Temperature Indicator, and an Oil Pressure Gauge. Fuel and Air delivery pressure gauges may also be needed, but are not essential.

Intakes and Exhausts

The design of the intake and exhaust system depends on the installation and details of the installation are, therefore, required before the design details for these units can be specified.

Noise

Since the Artouste 510 is practically identical to the Palouste 500, it is of interest to note the noise levels achieved in a sound proofed trolley incorporating this engine. A brochure describing this trolley which give details of the measured noise levels is attached to part 1 of this report.

APPENDIX G (Cont'd)Refrigeration Unit Inter Cooler Air Flow

It has been suggested that power to provide an air flow through the air cycle refrigeration unit inter cooler should be allowed for, and this has been done; see paragraph dealing with performance. Since no details of the flow required are available the method of achieving this cannot be suggested, but the provision of an inductor working on the exhaust duct or of a small fan driven from an auxiliary drive pad are both possibilities.

Alternators

The alternator fitted on the Artouste 510 is the Plessey type EL1808, this has a nominal continuous output of 43 KVA. and the present maximum overload output on a 5 minute rating is 50 KVA. The efficiency of the alternator is at present approximately 67% so that the horse power required at the specified output of 40 KVA is 80 h.p. It should be noted that if greater powers are required the alternator is under development and the gearbox is capable of taking 100 h.p.

The alternator operates at 400 cycles per sec., and has three phases at 208/120 volts. Full details are being obtained from the Plessey Co., and will be transmitted to AVRO's direct by them.

As mentioned under Fuel System heretofore the specified speed control of $\pm 1\%$ in the steady state can be achieved and 5% control under transient conditions is also possible.

The controls for the Generator are completely automatic, and over and under frequency control, and all the other necessary forms of protection would be provided.

Weights

The weight of the Artouste 510 complete with alternator, but excluding Intakes and Exhausts, and Controls etc. is approximately 348 lb.

Overhaul Life

At the maximum continuous rating shown on the performance curves the present overhaul life is 1,000 hours.

If two engines are used to meet the flow requirements, then they would be operating at substantially below the maximum continuous conditions and a significant increase in the overhaul life may therefore be expected, although quotation of this is not possible until more details are available of the proposed running conditions.



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APPENDIX G (Cont'd)

Overhaul Life (Cont'd)

It should be noted under this heading that a test is now being run on a Turmo Engine at approximately 400 h.p. with the object of increasing the overhaul life to 2,000 hours, and it will be appreciated that the experience gained on this test will to a large extent be directly applicable to the Artouste 510. Other tests, notably those on the Artouste 510 for airborne applications, are aimed at increasing the overhaul life of this engine, and it is confidently anticipated that an overhaul life of 2,000 hours at the lower output ratings will be achieved in the near future.

Delivery

It is understood that the first engines required to meet the AVRO specification will not be needed before the fall of 1958, and this requirement can be met without difficulty. Should earlier deliveries be required it is estimated that a batch of 10 engines could be delivered in the Summer of 1958, and that if necessary a prototype engine could be produced in the Spring of 1958. These dates are based on the assumption that the order for the engines is received before November 1st, 1957. Spares ordered with the engines would be delivered at the same time as the engines.

Should it be decided to use two Artouste 510 Units with the airflow coupled, then delivery of the first unit could be made within twelve months of receipt of the order.



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APPENDIX G (Cont'd)

Notes on the Performance of Artouste 510 for the
Air Conditioning Air Supply for the Avro Canada Arrow

The Artouste 510, comprises a gas turbine air compressor engine, (identical to the Palouste 500) fitted with a reduction gearbox, Plessey Alternator and cooling fan.

The performance curve E.T.D. 430/9 shows the horsepower and air bleed relationship for this engine under conditions of varying ambient temperature at sea level, and for various altitudes under I.S.A. conditions. The figures relate to a constant turbine inlet temperature for the maximum continuous rating. The constant engine speed of 33,230 R.P.M. corresponds to 12,000 R.P.M. for the 40 KVA - 400 c.p.s. alternator.

The existing reduction gearbox has a power limitation of 100 horsepower, but the performance curves have only been extended up to a power sufficient to meet the alternator and cooling fan requirements.

The performance figures given assume an intake and exhaust system similar to that now incorporated on the Blackburn MK. 11 L.P.A.S. Ground Starter Trolley. Allowance has been made for the power absorbed by the D.C. generator and the Fuel and Oil Pump and a further allowance of 8 H.P. has been made for the possible provision of an air supply for the refrigeration gear inter-cooler as requested by AVRO.

It will be seen that under extremely high ambient temperatures a single engine cannot meet the existing air flow requirements; approximately 1.6 lbs/sec. being available.

If another alternator, of similar output, but different rotational speed is considered, this would involve a change in the reduction gear ratio. Should this be the case then a different engine speed may be selected. Additional performance curves are included, (E.T.D. 431/9) corresponding to E.T.D. 430/9, but for rotational speed of 35,000 R.P.M.

In order to show the flexibility of the engine the curve E.T.D. 422/9 is included. This shows the performance of the engine without taking account of the gearbox limitation. It will be seen that for relatively low shaft powers, maximum air bleed is achieved at about 32,000 R.P.M. The performance over the extended speed range is presented for I.S.A. conditions at sea level.



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APPENDIX G (Cont'd)

For this application the compressor/turbine matching is such that surge is impossible under all conditions with the proposed control system, provided that there is no significant change in the effective orifice size of the system to which the engine is delivering air. Should it be considered necessary to provide against the possibility of a blockage in the aircraft or the refrigeration gear, an alternative matching could be provided which would make surge impossible with shaft power and no bleed flow.

The effect of the alternative matching would be to give a small reduction in available pressure for a given flow rate, together with a slight increase in fuel consumption. The change in performance is of course dependent upon the amount of horsepower required in the absence of air bleed.

AIR CONDITIONING AND GROUND POWER UNIT

Revised Requirements

INTRODUCTION

A preliminary investigation shows that the revised AVRO requirements for conditioning air require an input to the cold air unit of 80 to 85 p.s.i.a. with a minimum flow of 150 lb. per minute and a maximum which may rise as high as 200 lb. per minute.

The above air flows when taken in conjunction with the 40 KVA electrical requirement represent a need for about 650 h.p. for the high ambient temperature case of 130°F. This certainly cannot be met with any single engine of the Blackburn turbine range.

Consideration has been given to the various methods of meeting this requirement with a pair of engines. Discussion with cold air unit manufacturers, AVRO and the RCAF is needed at an early stage, but the present preliminary investigation may serve as a basis for talks on the best method of meeting the above requirement.

GENERAL CONSIDERATION OF SCHEMES

If a gas turbine engine is considered as the power supply to meet the above requirement it is reasonable to assume that weight and compactness are major considerations. If this is the case then almost certainly the necessary air supply should be produced with an aerodynamic type of compressor. The relatively low mass flow and high pressure ratio restricts the investigation to either a two stage centrifugal design driven by the gas turbine prime mover, or air bleed

APPENDIX G (Cont'd)GENERAL CONSIDERATION OF SCHEMES (cont'd)

from the latter "supercharged" through a centrifugal compressor driven by the gas turbine engine. These two schemes have been considered and brief details of their advantages and the development work involved are given in the next section.

Should weight and size be of less importance, a third scheme has been given brief consideration. This consists of a Blackburn Coupled Turmo engine driving a positive displacement compressor of the Howden-Lyholm type. The required pressure ratio of 5.8:1 is high for a single stage positive displacement compressor, but the manufacturers of this unit state that this can be attained, but efficiency is rather low. The main reason for this scheme being considered is one of availability rather than suitability to meet the requirement.

TECHNICAL APPRAISAL OF SCHEMES CONSIDERED(1) Two Blackburn Artouste 510 Air Bleed Gas Turbine Engines

One of these engines would drive a 40 KVA alternator and the other a geared up version of the existing high pressure supercharger. Air would be bled from both engines thus distributing the thermal load equally between the two identical engines.

Considering the 130°F ambient temperature case, approximate performance figures for continuous operation are as follows:

Bleed Flow.....	2.5 lb/sec.
Pressure Ratio.....	5.8:1
Air Delivery Temperature.....	640°F
Fuel Consumption.....	570 lb/hr.

The advantages of this scheme are:

- (a) Stage of development and availability of the Artouste 510.
- (b) Utilization of existing Plessey alternator and reduction gear box if required.
- (c) Size and compactness.
- (d) Fuel economy.

APPENDIX G (Cont'd)(1) Two Blackburn Artouste 510 Air Bleed Gas Turbine Engines (cont'd)

Disadvantages are as follows:

- (a) The possibility of contamination of the air bleed with the existing method of taking air from the engine.

Tests are being undertaken to establish the purity of the bleed air on existing engines and in the event of contamination being detected some redesign to the air bleed casing may be necessary.

- (b) Although tests are planned, no experience has so far been gained on two air bleed engines discharging air into a common manifold. This may lead to control problems, but the difficulties envisaged are not likely to be serious.

- (c) Flow marginal at extremely high ambient temperature.

(2) Blackburn Coupled Turmo free turbine engine driving a two stage centrifugal compressor.

This scheme would comprise the existing Coupled Turmo 600 engine with redesigned gearbox suitable for mounting a 40 KVA alternator and the two stage centrifugal compressor.

Approximate performance figures for the 130°F ambient temperature case at maximum continuous rating are as follows:

Bleed Flow.....3.0 lb/sec.

Pressure Ratio.....5.8:1

Air Delivery Temperature.....640°F

Fuel Consumption.....710 lb/hr.

The advantages of this scheme are:

- (a) Stage of development and availability of the existing basic Coupled Turmo 600.
- (b) Adequate performance for the high ambient temperature case.
- (c) Uncontaminated air supply.
- (d) Relatively light and compact.
- (e) Reasonable fuel economy.



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APPENDIX G (Cont'd)

- (2) Blackburn Coupled Turmo free turbine engine driving a two stage centrifugal compressor (cont'd)

Providing weight and size are not prohibitive this scheme has no direct technical disadvantage except that a fair amount of design work is involved, particularly with respect to the two stage centrifugal compressor. Cost may be deciding factor.

From mechanical considerations no serious development problems are envisaged and aerodynamically the matching of two compressors in series should be reasonably straight forward since the overall pressure ratio is relatively low.

- (3) Blackburn Coupled Turmo, driving a Howden-Lysholm positive compressor.

As with scheme (2) the existing Coupled Turmo 600 would be used with redesigned gearbox suitable for mounting a 40 KVA alternator and the Howden-Lysholm compressor.

Approximate performance figures at 130°F for maximum continuous rating are as follows:

Bleed Flow.....2.25 lb/sec.

Pressure Ratio.....5.8:1

Air Delivery Temperature.....720°F

Fuel Consumption.....660 lb/hr.

The main advantage of this scheme is that the two major items, the prime mover and the compressor have both reached a reasonable stage of development. A further advantage is that as with scheme (2) there would be no contamination problems.

The disadvantages of this scheme are:

- (a) Size and weight.
- (b) Performance is inadequate. It should be mentioned however, that future development on the Howden-Lysholm compressor may enable the flow rate to be increased. Since the efficiency of this compressor is somewhat low and since it is not likely to increase with increasing flow rate, the maximum flow is likely to be limited by the power available from the Coupled Turmo. Based on the foregoing the development potential does not seem very great.

APPENDIX G (Cont'd)

- (c) Low overall efficiency compared with scheme (1) and (2).
- (d) High air delivery temperature.

EFFECT OF AMBIENT TEMPERATURE VARIATION OF THE THREE SCHEMES

Generally speaking, the effect of ambient temperature variation on scheme (1) and (2) will be much the same as that shown in part (A) of this report for the Palouste 500. With reducing ambient temperature the flow rate, pressure ratio and fuel consumption will increase. An accurate assessment cannot be made without a knowledge of the discharge system and the individual component characteristics.

For the positive displacement compressor, running at constant speed, the flow rate will vary inversely as the absolute ambient temperature. The effect on pressure ratio will be dependent upon the method of control of the discharge.

SUMMARY OF SCHEME (1), (2) AND (3)

A table is appended which summarises the relevant information for the above schemes.

CONCLUSIONS

This preliminary investigation is not intended to confine selection of a suitable scheme to the three outlined above. Other schemes are being considered and further details are necessary from the user and air unit manufacturer before a detailed investigation can be undertaken and the most suitable method decided upon.

If the performance of the three methods reviewed is considered adequate, scheme (1) undoubtedly seems the one which requires least development, is the most compact and economical.

SCHEME	BLEED FLOW (LB/SEC.)	DELIVERY TEMP. (F)	FUEL FLOW (LB/HR.)	ENGINE R.P.M.	APPROXIMATE DIMENSIONS			
					WEIGHT (LB)	LENGTH	WIDTH	HEIGHT
Two Artouste 510 and Supercharger	2.5	640	570	34,000/ 33,230	750	5'-6"	3'-6"	1'-6"
Coupled Turmo 600 and 2 Stage Centrif.	3.0	640	710	33,500	1,000	6'	3'-6"	1'-6"
Coupled Turmo 600 and Howden-Lysholm	2.25	720	660	32,900	1,900	7'	3'-6"	2'

APPENDIX G (Cont'd)

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