CONFIDENTIAL TR.114-60/07

PROGRAM PLANNING REPORT
FOR
CANADIAN GOVERNMENT PROGRAM
FOR THE AVROCAR

10/ENG PLAN/7

AVRO AIRCRAFT LIMITED

SALES ORDER NO. 5429
ISSUE 2
DATE 25 SEPT./60

CHARGE TO Canadian Government (IDP) SHIP TO

CUSTOMER'S
CONTRACT NO. 9BXO-8 (TB No. 570345) ESTIMATE NO. 22-21-0/1
REQ. NO. (C.D.)
SERIAL NO. SALES TAX LIC.
CONTRACT DATE Yet to be established. P.O. SERIES

ITEM	QUANTITY	DESCRIPTION	MAN HOURS	DOLLARS
		Attached hereto is a copy of the "Program Planning Report for the Canadian Government Program for the Avrocar" No. 10/ENG PLAN/7 dated 25th July 60. All work is to proceed in accordance with the requirements of the Statement of Work under part. 2.0 and Appendices 1 and 2 and within the Funding and Time Schedule Allowances quoted in the above noted document. For Program reporting purposes, Avro Aircraft expenditures are to be collected in accordance with and under Work Order numbers noted in the tabulated Labour and Cost Summary. Orenda Engines Limited is to proceed with work in subject Program in accordance with Para. 2.1.6, Appendices 1 and 2 and within the time schedule on page 25 of the above referenced Planning Report. The price Avro Aircraft Ltd. shall pay Orenda Engines Ltd. for accomplishing this work inclusive of testing done, for or by Orenda Engines Ltd. shall be $71,500. The customary boiler plate clauses including those covering patent rights, royalties, progress claims etc. are to be introduced into our Purchase Order when these conditions have been agreed upon between Avro Aircraft Ltd. and the Canadian Government.		

MATERIAL SUPPLIED BY

RELEASE NOTES REQUIRED

SHIPPING INSTRUCTIONS

AVRO AIRCRAFT LIMITED

SALES ORDER NO. 5429 ISSUE 2 DATE 25 Sept./60

ITEM	QUANTITY	DESCRIPTION	MAN HOURS	DOLLARS
		You will be advised of these conditions in due course. The terms with Orenda will be no more nor no less favourable than those which Avro accepts from the Canadian Government. Work under the Program is unclassified but dissemination of information or data relative thereto is still limited to Government authorized recipients in Canada and the United States.		

CONFIDENTIAL

PROGRAM PLANNING REPORT

FOR

CANADIAN GOVERNMENT PROGRAM

FOR THE AVROCAR

10/ENG PLAN/7

25 July 1960

Issued by:

Avro Aircraft Limited

Malton, Ontario, Canada

The number of pages in this report including the Security Warning, Title page and Table of Contents is 37.

SECURITY WARNING

This document is intended solely for the recipient and such persons as have been delegated to use it in the course of their duty, and may be used in connection with work performed for or on behalf of the Governments of Canada and the United States.

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To -

Date -

Copy No. -

TABLE OF CONTENTS

1.0 INTRODUCTION

This report outlines the program to be undertaken by Avro Aircraft Limited in the conduct of studies on the Avrocar concept and also the examination of the merits and feasibility of the Ground Effect Take-Off and Landing concept.

1.1 PHASE I (AVROCAR CONCEPT)

During the past year, Avro Aircraft Limited has conducted approximately 30 hours of flight test work on the Avrocar in the ground cushion, together with static rig development of the aircraft and full scale wind tunnel tests at the NASA Ames Research Center. This work has brought to light certain shortcomings of the aircraft as it now stands. The object of Phase I of the program is to investigate some of these problems and to project an improved aircraft of the same general form as the Avrocar based on development information now available. The aircraft evolved from this study will not be a research tool but will represent an aircraft with useful economics, and having the potential for meeting the requirements laid down in the Statement of Work.

Present planning calls for the Avrocar to undergo its second series of tests in the Ames Wind Tunnel late in 1960, and that the analysis of the results be completed by the end of March 1961. This Phase I program of the Canadian Government work is intended to be ready at the same time to permit the findings to be used for evaluation of the requirements of the next stage of development of the Avrocar principle.

1.1 PHASE 1 (AVROCAR CONCEPT) (cont'd)

There are some limitations in the program, an obvious one being that the findings of the second series of tests at Ames Research Center will come too late to be fed into this study. It is also possible that the speed, endurance and load capability of the aircraft that is specified in the Statement of Work may not be met fully because of engine availability, as it is not intended to consider 'paper' engines but only those which will be available in the immediate future. The studies on aircraft stability are limited mainly to static conditions and, although the Avrocar simulator will be used for some dynamic work, the limitations of this must be recognized.

1.2 PHASE 2 (G.E.T.O.L. CONCEPT)

The purpose of this phase is to examine the merits and feasibility of the Ground Effect Take-Off and Landing (G.E.T.O.L.) concept in sufficient detail to enable a general specification to be written for such a vehicle when applied to a specific freighter type mission. This vehicle (or vehicles) will then be compared with Short Take-Off and Landing (S.T.O.L.) aircraft using conventional undercarriage support, helicopters and fixed wing aircraft. The comparison will be made largely on an economic basis, but in a summary report, brief comments will be made on such topics as operating techniques, useful life, maintenance periods, adaptability to other missions, and any other points that are considered pertinent. To do this adequately it will be necessary to conduct preliminary investigation of numerous configurations. However, in view of the limited manhours available, it is intended to narrow the field to 2 or 3 promising types

1.2 PHASE 2 (G.E.T.O.L. CONCEPT) (cont'd)

as rapidly as possible. It should be noted that it will not be possible to optimize these configurations and it is felt that optimization is beyond the scope of this program.

In a program of this nature where the field of investigation is very broad, it is inevitable that certain assumptions will have to be made early in the program and the results produced can only lead to fairly general conclusions. Thus in Phase 2 of the program, 9 configurations will be reduced to 2 or 3, by a process of elimination, these being considered the better vehicles to perform the specific mission, but not necessarily shown in their best, optimized form. It is possible that the presented comparisons between these configurations and other types of aircraft, could be improved if an optimization program was adopted for one or more of the Avro configurations. It must also be emphasized that during this study, certain of the assumptions made and theorized would benefit by having a test program to back them up.

These comments refer mainly to the complex region of transition from ground cushion made to free flight, but also in mind are certain forms of thrust augmentation that are in the early stages of development. The application of partial stabilization by gyroscopic action of large fans will also be investigated.

Thus in general conclusions to this program, the merits and feasibility of the G.E.T.O.L. concept will be presented together with indications on how a particular design could be improved and comments on areas that would benefit by test programs and further development.

2.0 STATEMENT OF WORK

2.1.0 PHASE 1

2.1.1 Scope

The purpose of Phase 1 is to show the maximum potential with respect to performance and general operation that is possible with the Avrocar in its existing general form. The outcome of this phase of the program will be a proposal for a tip turbine driven fan type aircraft of circular planform, employing an annular jet. Vertical take-off is desirable but not essential at maximum weight.

The general characteristics of the aircraft will be as follows:

(a) speed capability from hovering to 300 knots

(b) endurance to be maximum possible and aimed at four hours

(c) load capability of two men and 1000 lbs. of useful load at 10 lb/cu.ft.

The program will be concluded by March 1961 at which time the results in the form of reports will have been despatched by Avro Aircraft Limited to the Defence Research Board Project Officer.

2.1.2 Review of Powerplants

Preliminary design work to examine the installation feasibility of alternative powerplants will be carried out and their influence on weights, general design layout and aircraft performance in and out of the ground cushion will be examined. In the first instance, the gas generator portion of the General Electric T-58 will be considered; other engines will be included as agreed with the Project Officer (D.R.B.).

2.1.3 External Geometry

Theoretical investigations will be made into the effects of the following:

(a) camber, with particular attention to trimming in forward flight, influence on empennage design and compatibility with (b).

(b) lower surface contouring, with reference to the critical height in the ground cushion.

(c) section, including thickness ratio and LE radius; effect on internal volume, drag, and weight.

(d) small variations in geometric aspect ratio or equivalent aerodynamic effects obtained by suitable control of the jet efflux at the lateral edges in cruising flight to improve cruising efficiency.

Design work to assess the structural and performance implications of the findings applied to the Avrocar.

2.1.4 Stability and Control

Model tests will be conducted to assess the effects of varying the central jet strength relative to the peripheral jet strength over a wide range, with particular reference to stability and controllability in the ground cushion. Design work also will be carried out to study the feasibility of the indicated

2.1.4 Stability and Control (cont'd).

central jet strength including turning the central jet in cruise to provide a thrust component. Studies will be conducted of the feasibility of direct gyro stabilization as a substitute for or adjunct to aerodynamic or jet stabilization.

Methods of achieving control in and out of the ground cushion will be reviewed.

2.1.5 Performance Evaluation.

Estimate the performance and economics of the modified Avrocar and compare with other vehicles. The primary comparison shall be made against the 2-man helicopter. GETOL as well as VTOL operation shall be considered.

2.1.6 Turborotor and Internal Aerodynamics.

2.1.6.1 Statement of Requirements.

Avro will prepare and provide to Orenda Engines Limited, Malton, Ontario, a statement of the requirements on which the Orenda Engines Limited study, as detailed in para 2.1.6.2 is to be based. Within one month of date of initiation of work on the contract, the statement of requirements shall be agreed upon with the D.R.B. Project Officer, then transmitted to Orenda Engines Limited.

The statement shall specify:

(a) engine characteristics

2.1.6.1 Statement of Requirements (cont'd)

(b) approximate fan and other dimensional limitations

(c) performance requirements

(d) weight limitations

(e) angular momentum required for stabilizing purposes under different flight conditions

(f) requirements associated with the exit nozzle, proportion of mass flow exhausted at the center and at the pheriphery will be included.

Where any item cannot be determined by the due date, a range of values is to be given with an indication of the preferred value.

2.1.6.2 Execution of Study

Avro Aircraft Limited shall sub-contract to Orenda Engines Limited work, based on the requirements of para 2.1.6.1 above, as follows:

(a) Theoretical and experimental study of inlet flow conditions and the requirement for flow control devices for the fan intake. Preliminary design of such device, if required.

(b) Study of compatibility of rotor angular momentum requirements under different flight conditions with power requirements.

(c) Design of fan and turbine compatible with Avro requirements and covering the range of feasible pressure ratios and mass

2.1.6.2 Execution of Study (cont'd)

flows and anticipated duct losses. Design shall be taken far enough to provide dimensions, weights, on-and-off design performance. An attempt shall be made to reduce fan sensitivity to duct pressure losses by designing for steep characteristics.

(d) Study of ducting design to minimize pressure losses.

2.2.0 PHASE 2

2.2.1 Scope

Avro Aircraft Limited will conduct a parametric design study of G.E.T.O.L. (Ground Effect Take-Off and Landing) subsonic aircraft to determine the merits of the concept. Configurations will be derived and compared with S.T.O.L. (Short Take-Off and Landing), helicopter and fixed wing aircraft of similar load capacity and performance. In-service date of 1965 shall be taken as the period for comparison.

2.2.2 Mission

The basic mission assumed for these studies shall be:-

Logistic supply mission, involving the transportation of personnel, supplies and equipment from airhead to Divisional area.

Radius of Action:	300 nautical miles without refuelling at outward end.
Payload:	4 tons outward, 2 tons return.
Cruise Speed:	To be selected, preferably not less than 200 knots.
Cruise Altitude:	Not greater than 10,000 ft.
Field Length:	Distance to clear a 50' obstacle (T.O. and landing) 1,000 ft. or less, at sea level under standard conditions
Ferry Range:	1600 nautical miles (2500 n.m. preferred) - any altitude. Use may be made of overload tanks and runway take-off if required.
Reserves:	10% of cruise fuel plus three minutes at take-off power.
Cargo Space:	Volume to be based on cargo density of 10 lb/cu.ft. A rectangular box cargo space with end loading is preferred.
Satety:	Rate of climb available after failure of one engine in cruise shall be positive. Under any flight condition it shall be possible, as a minimum, to retain full control of altitude and heading after failure of

2.2.2 Mission (cont'd).

Safety: (cont'd) one engine or of any hot highly stressed component, and to make a controlled landing with minimum damage to the aircraft.

2.2.3 Parameters.

During the program, the following parameters will be studied:

(a) General configuration - essentially the configuration will center around two (2) basic shapes:

(a) discus and distorted discus

(b) more conventional aircraft configurations employing the ground effect. Included in the configuration studies will also be comparisons of type and size of powerplant; various means of providing augmentation (fans, ejectors, heat, etc.); various ways of providing the lifting and forward flight power including the use of a "straight - through" propulsive jet for cruise; different approaches in providing stability and control for the various shapes including the use of aerodynamic surfaces.

(b) Feasibility and penalties, if any, of providing for V.T.O.L. (Vertical Take-Off and Landing) at the outward end of the mission. In addition, the overall implications for each configuration of G.E.T.O.L. compared with V.T.O.L. will be studied.

(c) Analytical and simulator studies will be carried out to demonstrate stability and control during the ground cushion, transition and free flight phases.

2.2.4 Data Reported

As appropriate to each promising configuration, reports on the results of the study will include the following:

(a) G.A. drawings of configurations

(b) Weight breakdown for each

(c) Payload range characteristics including fuel arrangements.

(d) Mission profiles, including ferry missions

(e) Operating costs

(f) Stability and control data

(g) Supporting data for propulsion and lifting systems considered necessary

(h) General performance data

(i) Landing and Take-Off performance

(j) Summary report of the study

Where available, experimental data shall be used to justify estimates made.

2.3.0 Photography

The following photographic coverage shall be provided:

(a) Two prints of still photographs of test model, instrumentation installations, etc. taken as required for reporting purposes.

2.4.0 Submission of Reports

2.4.1 Progress Reports

Before the forty-fifth day after initiation of work on the contract and every month thereafter, a monthly progress report shall be prepared and five (5) copies of it shall be despatched to the Directorate of Engineering Research, Cartier Square, Ottawa, Ontario; Attention Project Officer, D.R.B. and five (5) copies to Advanced Offensive Systems Office, Office of Advanced System Technology, ARDC, W.P.A.F.B., Dayton, Ohio, U.S.A. Attention of WWRPO.

The progress report shall present a summary of work performed, percentage of task accomplished, results obtained and a budgetary status of the program and work status of work called for in clauses 2.1.2, 2.1.3, 2.1.4, 2.1.5, 2.1.6, 2.2.0 and 2.3.0 of the Statement of Work and detailed in the Planning Report, para 2.4.2.

2.4.2 Planning Report

Before the day of execution of the contract, a planning report shall be prepared and approval of it shall be obtained from the Project Officer, D.R.B., Ten (10) copies of it shall be despatched to the Directorate of Engineering Research, Cartier Square, Ottawa, Ontario.

The planning report shall detail the objectives, work content, time and cost schedules for each item of work called for under paragraphs 2.1.2, 2.1.3, 2.1.4, 2.1.5, 2.1.6, 2.2.0, 2.3.0, 2.4.1 and 2.4.2.

2.4.3 Technical Reports and Specifications

During the program, as work is completed, formal technical reports and test specifications shall be prepared and five (5) copies of the technical reports and test specifications shall be despatched to the Directorate of Engineering Research, Cartier Square, Ottawa, Ontario; Attention Project Officer, D.R.B., and five (5) copies to Advanced Offensive Systems Office, Office of Advanced Systems Technology, ARDC, W.P.A.F.B., Dayton, Ohio, U.S.A. Attention of WWRPO.

The test specifications shall be despatched for approval by the Project Officer D.R.B., fifteen (15) days prior to commencement of tests to which they pertain.

Despatch of all reports will be completed by March, 1961.

2.5.0 Terms of Reference and Conditions

2.5.1 The Project Officer, D.R.B. will monitor progress.

2.5.2 . The progress reports will cover the progressive steps outlined in the Program Planning Report, to the extent stated under para 2.4.1 above.

3.0 WORK PROGRAM

3.1.0 PHASE I

This phase of the program is basically a group of studies on different aspects of the development of the Avrocar concept which will be brought together at the end of the program to present the best overall compromise. However, the inter-relation of these aspects on each other will be closely matched so that no undue sacrifice of a particular aspect is made for the sake of another.

Some of the events by which progress can be judged include, the statement of requirements to be given to Orenda Engines Limited for study of the turbo-rotor, which will be completed for duscussion with the D.R.B. Project Officer in mid July, 1960, and the submission of the test specifications, at the end of August 1960, for the Avro wind tunnel test series detailed in the Statement of Work. This specification will reflect work done in the early stages of the program as some theoretical and design work is required before the test specifications can be written.

3.1.1 Review of Powerplants

The first work that will be tackled will be the installation of the General Electric T-58 gas generator in the Avrocar as a replacement for the J-69. The reduction in depth and the effects of the differences in weight, thrust and specific fuel consumption will be compared. These data will be used to provide Orenda Engines Limited preliminary requirements for their turbo-rotor studies.

3.1.2 External Geometry

Examination of the surface pressures recorded on the Avrocar during the NASA wind tunnel tests, will be used as a basis for the theoretical study of camber, thickness/chord ratio and small changes in aspect ratio.

3.1.3 Stability and Control

Modifications may be possible to the existing 1/20th scale Avrocar model to adapt it to give a variable central jet with respect to the peripheral jet. Should this not be possible, a simple model to study this factor alone will be manufactured. The effects of the variation in strength of the annular jet on stability in the ground cushion will be investigated and where possible, the findings from the 'shape' models fed into the tests. A small amount of work has been done on the existing 1/20th scale model on the effect of contouring the undersurface on the 'critical height' in the ground cushion. This critical height where the jet changes from the 'focussed' flow to the 'curtain' type of flow, has limited the Avrocar flight test height and most of the trouble has been attributed to jet hysteresis. Various undersurface contours will be tried on this model - these will be simple turned shapes attached to the basic model.

The problem of installing into the aircraft the required central jet which appears best from the tunnel results will be investigated, together with the problem of deflecting the central jet aft for cruise. The effect of locating

3.1.3 Stability and Control (cont'd)

the aircraft center of gravity forward of the vertical axis of the rotor will be studied.

Simulator studies will be made to assess the size and feasibility of a direct gyro for stability and will be compared with jet deployment and aerodynamic surface means of stabilization.

3.1.4 Performance Evaluation

A continuous review of performance will be made through the program as the various parameters are investigated. However, a start will be made first on the general comparisons of fitting different engines in the existing Avrocar as a basis of comparison. Investigations into G.E.T.O.O. take-off characteristics, cruise performance at sea level, and altitude, duration, range, mission profiles, payload characteristics and economics will be conducted.

3.1.5 Turborator and Internal Aerodynamics.

See Appendix 2.

3.2.0 PHASE 2

The major stages to be undertaken in the conduct of Phase 2 studies are as follows:

3.2.1 Choice of Overall Layout

Fig. 2, gives an indication of the number of variables initially considered. It is intended to start with approximately 9 different layouts and from these extract 5 for further, more complete study. One or two of these 5 will also be chosen for assessing the implications of Vertical Take-Off and Landing, (V.T.O.L.) application.

3.2.2 Preliminary Layout Sizing

Preliminary sizing of the major components for the 5 designs selected for full study will be done on an approximate basis to obtain configurations on which to base further calculations. Such items as wing, fin, horizontal stabilizer, aerodynamic control surfaces (where applicable), powerplants, ground manoeuvring undercarriage, cargo hold and loading aperture, will be sized. Refinement and correction will be incorporated as the study proceeds, bearing in mind however that optimization of any particular design is not possible in the time.

3.2.3 Powerplant Selection

The types of powerplant considered will be mainly from the turbojet and turboprop group, using these gas generators either directly or indirectly when driving secondary fans or compressors, to provide the primary ground cushion and also to provide forward flight thrust. Various ways of diverting the ground cushion thrust to propulsive thrust will be studied, as for example, direction

3.2.3 Powerplant Selection (cont'd)

of the lifting jet either wholly or partially rearwards, or by the gradual bleeding of the lifting jet air into a propulsive nozzle(s) placed horizontally. In addition to these studies, separate powerplants to do each job will be considered.

3.2.4 Weight and Strength Investigation

Preliminary weight estimation will be done on an empirical basis, but where necessary the stress department will assist with rough sizing as a preliminary to weight estimates. Structures of an unconventional nature will probably require this approach. Refinements to these estimates will be made as the study proceeds.

3.2.5 General Performance Analysis

A general investigation of ground effect take-off and landing techniques will be made. This will include study of thrust/weight ratio, wing loading and lift coefficient required to meet the 1000 ft. objective; study of thrust required to support and accelerate the different types of aircraft; study of jet deflection, aircraft attitude and control in acceleration and transition; study of longitudinal stability in this phase, using analytical and/or analogue computer techniques. Existing work on annular jet deflection, variation of lift with forward speed in ground cushion, etc., will be used to back-up this study.

The technique will be centered around the sea level standard day requirements as specified in para 2.2.2 of the Statement of Work. This work will be applied to estimate transition profiles for the five configurations mentioned above.

3.2.5 General Performance Analysis (cont'd)

On a selected configuration or configurations, the feasibility and penalties of providing for Vertical Take-Off and Landing (V.T.O.L) at the outward end of the mission will be investigated. This should give a reasonable indication of what to expect from other configurations.

General performance calculations including range, payload, fuel consumption, economical altitude and speed, L/D ratios, rate of climb, ferry missions, etc., will be done in order to provide a basis for comparison with other aircraft. In view of the number of variables, use will be made of IBM 704 computing facilities wherever expedient.

The stability and control investigations will be centered around two approaches. One, the conventional approach, employing aerodynamic control surfaces and stabilizers. Two, employing partial stabilization by the gyroscopic action of the large fans or compressors proposed for the discus and elliptical shapes. Control by thrust vectoring or reaction will both be considered. It is expected to make use of the simulator during the studies of the configurations employing partial gyro stabilization, whereas on the conventional approach stability derivatives for 3 or 4 configurations will be calculated possibly employing computer aids.

3.2.6 Configuration Refinement

As a result of these investigations there will be changes required to improve the various configurations. This will be conducted while item 3.2.7. is in progress. It could also involve the elimination of some configurations.

3.2.7 Economic Analysis

Prediction of direct operating costs for Avro configurations will be based on established ATAA and SBAC methods, but in compiling the data on other aircraft for comparison purposes, assistance may be required from D.R.B.

3.2.8 Comparison with other Configurations

Areas of comparison could be listed approximately as follows:

(a) Economy of operation

(b) Feasibility of operation

(c) Geographical sphere of operation

(d) All weather operation

(e) Amount of usefulness, expected life, maintenance aspects.

(f) Adaptability to various missions

(g) Restrictions in use

4.0 REPORTING.

A progress report covering the month's work will be issued at the end of each month. The Financial Statement for this month will be issued at the end of the month following the month being reported. It is estimated that a total of 12 technical reports will be issued to cover Phase 1 of the program, including test specifications. All the applicable drawings giving the design details of the developed Avrocar will be included in the technical reports after reduction to standard report size.

Approximately ten (10) technical reports will be issued to cover Phase 2 of the program, including 6 aerodynamic reports, two design reports, a configuration comparison report and a Design Summary report. Applicable general arrangement drawings for all configurations actively considered in the study and sufficient area drawings to describe any significant design points for a particular configuration, will also be made available.

AVRO AIRCRAFT LIMITED

ESTIMATE #3004/21/1 - d/6/16/60

AVROCAR - CANADIAN GOVERNMENT PROGRAM - Page 1

Work Order No.	Item No.	STATEMENT OF WORK Description	Manhours		Labour	Labour Overhead	Material & Direct Charges	Sub-Total	15% Admin. Overhead	Total
	1.	COMPLETE PROGRAM								
506XX		Engineering	25,527	$	84,222	92.643	76,500	253,365	37,999	291,364
507XX		Manufacturing	720		1,678	2,181	288	4,147	622	4,769
508XX		Publications	567		1,519	1,672	40	3,231	485	3,716
509XX		Photography	19		48	53	30	131	20	151
			26,833	$	87,467	96,549	76,858	260,874	39,126	300,000
	2.	REVIEW OF POWER PLANTS								
50601		Engineering	4,565		15,065	16,570	-	31,635	4,740	36,375
50801		Publications	12		34	37	-	71	11	82
			4,577	$	15,099	16,607	-	31,706	4,751	36,457
	3.	EXTERNAL GEOMETRY								
50603		Engineering	530		1,747	1,921	-	3,668	550	4,218
50803		Publications	15		41	45	-	86	14	100
			545	$	1,788	1,966		3,754	564	4,318
	4.	STABILITY & CONTROL								
50604		Engineering	4,795		15,830	17,413	1,000	34,243	5,136	39,379
50704		Manufacturing	720		1,678	2,181	288	4,147	622	4,769
50804		Publications	18		50	55	-	105	16	121
50904		Photography	19		48	53	30	131	20	151
			5,552	$	17,606	19,702	1,318	38,626	5,794	44,420
	5.	PERFORMANCE EVALUATION								
50605		Engineering	1,737		5,700	6,270	1,000	12,970	1,946	14,916
50805		Publications	6		17	19	-	36	5	41
			1,743	$	5,717	6,289	1,000	13,006	1,951	14,957
	6 & 7	TURBOROTOR & INTERNAL AERODYNAMICS Requirements (6)								
50606		Engineering	1,900		6,280	6,909	-	13,189	1,978	15,167
50806		Publications	6		17	19	-	36	5	41
			1,906	$	6,297	6,928	-	13,225	1,983	15,208

Work Order No.	Item No.		Manhours	Labour	Labour Overhead	Material & Direct Charges	Sub-Total	15% Admin. Overhead	Total
		Study (7)							
50606X XXXX?		Sub contracts - (Orenda)	-	-	-	71.500	71.500	10.725	82.225
	8.	RETOL. DESIGN STUDY							
50602		Engineering	12,000	39,600	43,560	3,000	86,160	12,924	99,084
50802		Publications	300	772	850	40	1,662	249	1,911
			12,300	$ 40,372	44,410	3,040	87,822	13,173	100,995
	9.	PHOTOGRAPHY							
-		See Items 4 - Photography	-	-	-	-	-	-	-
	10.	REPORTS							
		PART 1 - PROGRESS REPORTS							
50807		Publications	200	$ 560	616	-	1,176	176	1,352
		PART 2 - PLANNING REPORTS							
50808		Publications	10	$ 28	31	-	59	9	68

Rates Used in this Estimate:

Engineering	-	$3.30 per hour	110% overhead
Manufacturing	-	2.33 " "	130% overhead
Publications	-	1.70 to 2.80 per hour	110% overhead
Photography	-	2.50 " "	110% overhead 15% Admin. O/H

Issued: July 15, 1960
Revised: July 29,1960
Re-issued: Aug. 25,1960

AIRCRAFT
A.U.W.

COMPONENT

SHEET NO. 25

DATE

REPORT NO. 10/ENG PLAN/7

PREP. BY

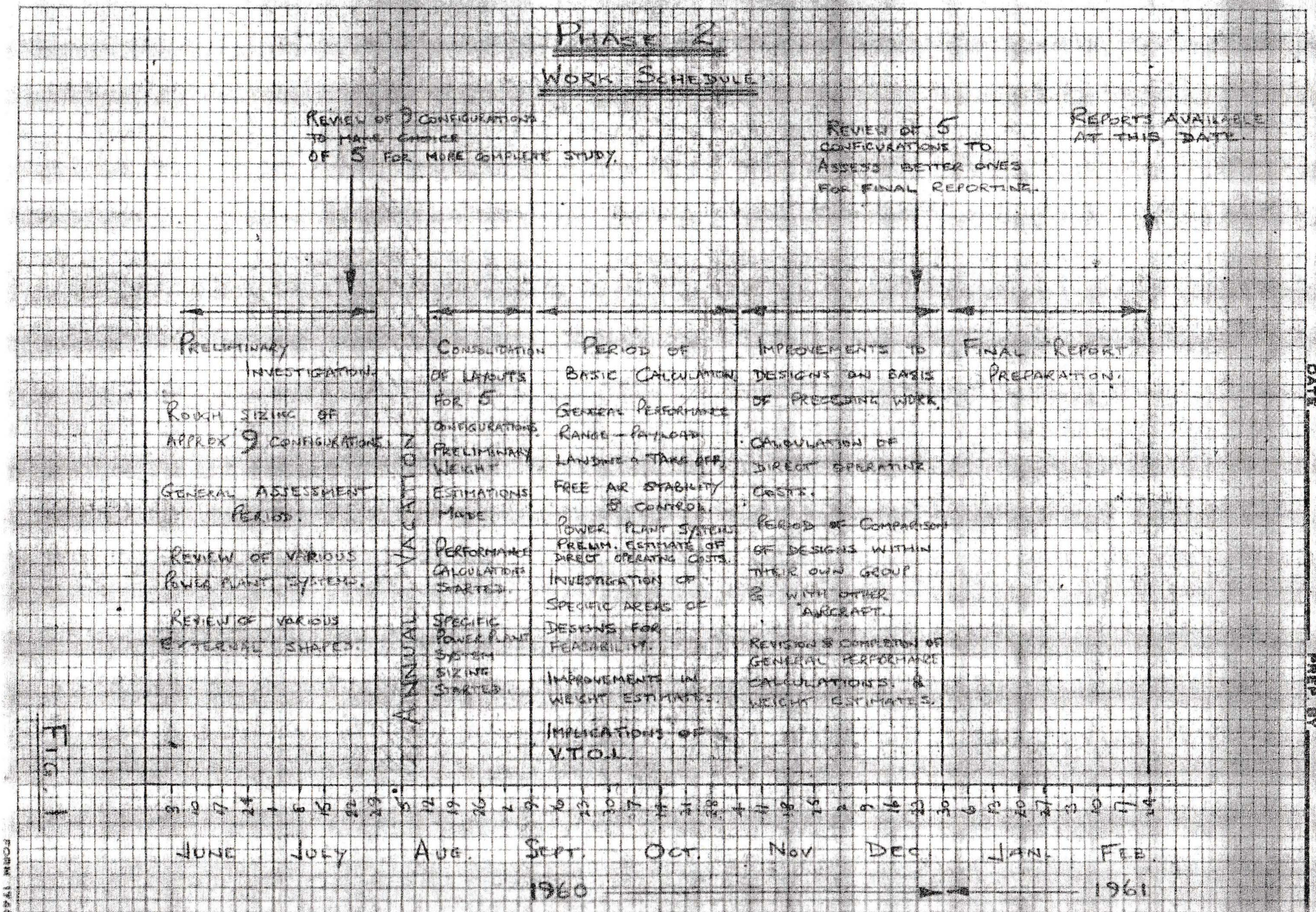


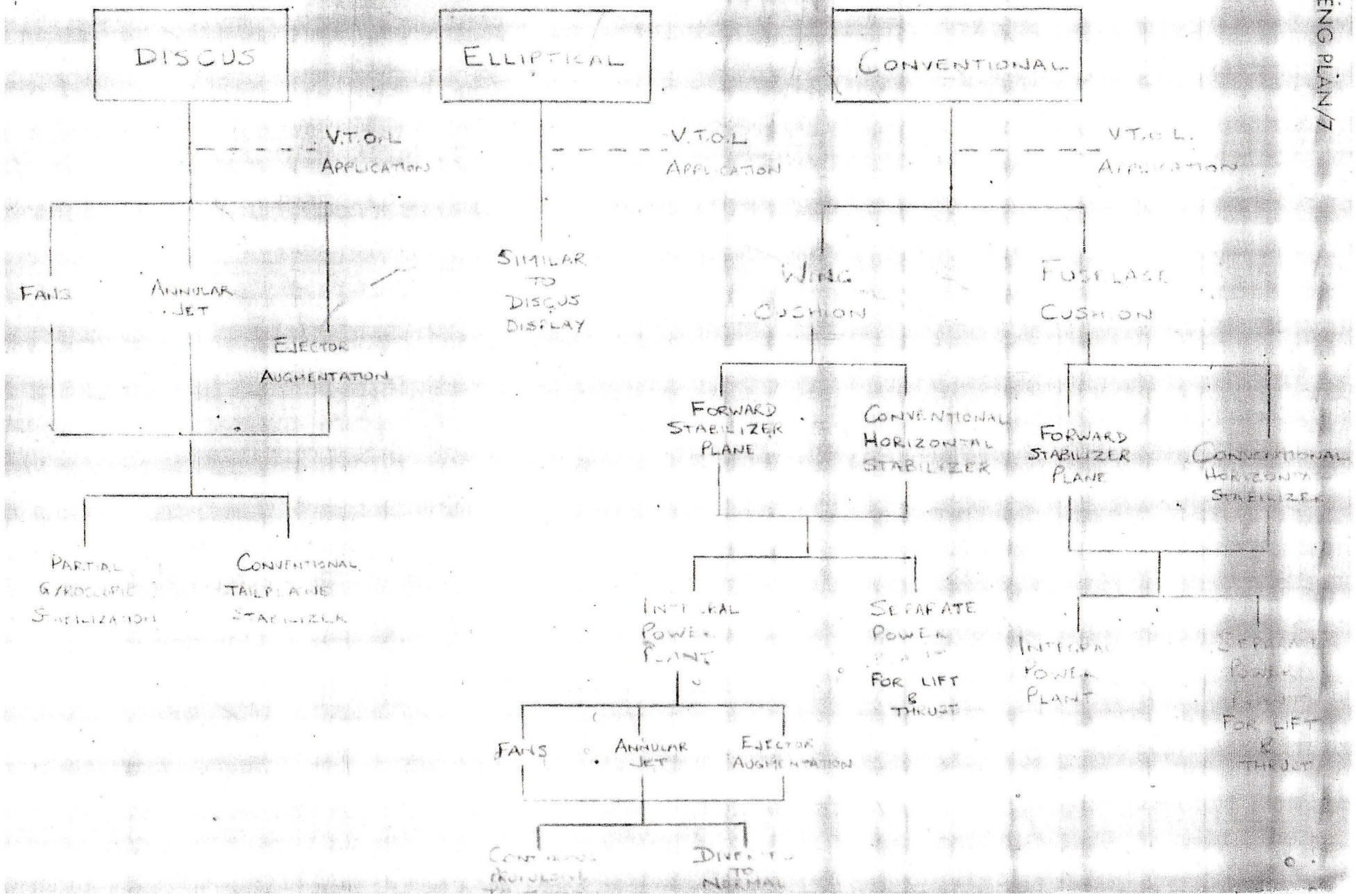
FIG. 1

FORM 1748

PHASE

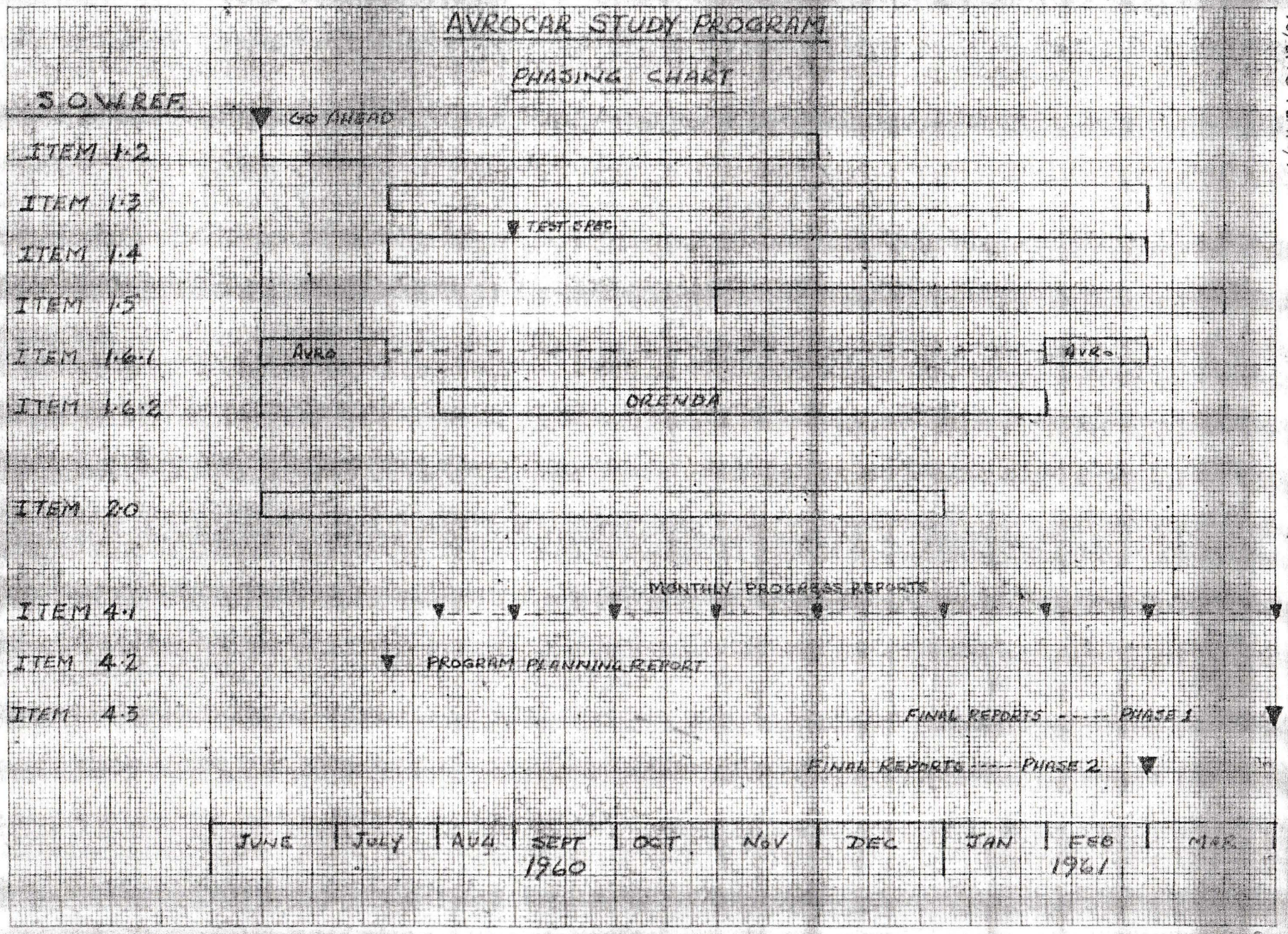
G.E.T.O.L. INVESTIGATION

DISPLAY OF INITIAL VARIABLES CONSIDERED

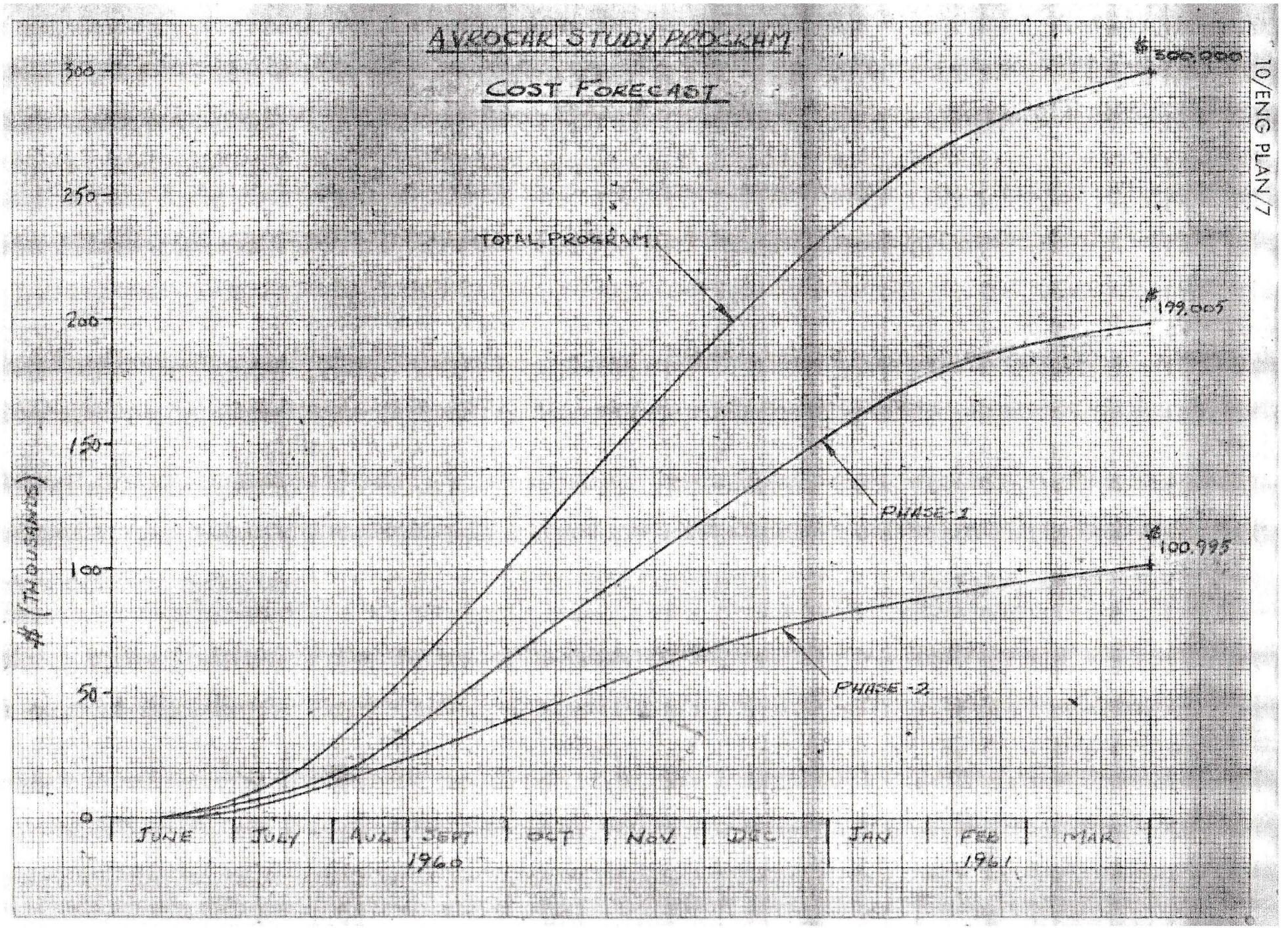


AVROCAR STUDY PROGRAM

PHASING CHART



10/ENG PLAN/7


AVROCAR STUDY PROGRAM
COST FORECAST
10/ENG PLAN/7
$ (THOUSANDS)
500
250
200
150
100
50
0
TOTAL PROGRAM
PHASE - 1
PHASE - 2
$300,000
$199,005
$100,995
JUNE
JULY
AUG.
SEPT.
1960
OCT.
NOV.
DEC.
JAN.
FEB.
1961
MAR.

APPENDIX 1.

REQUIREMENTS FOR ORENDA ENGINES LIMITED.

The turborotor and internal aerodynamics requirements given below are to satisfy para 1.6.1 of the Statement of Work of the Canadian Government Program on the Avrocar - Phase 1. These requirements detailed below are given in order to enable Orenda Engines to proceed with para 1.6.2 of the Statement of Work.

(a) Engine Characteristics

Turborotor driven by the exhaust of the gas generator section of the General Electric T-58. Two and three engine layouts are being considered with this engine. An alternative engine to be considered is the General Electric J-85, in this case two engines only will be used. The characteristics of the T-58 without the free turbine and the J-85 have been requested from Canadian General Electric Company, and these will be made available to Orenda Engines Limited when to hand, together with the J-85 Brochure.

(b) Approximate Fan and Other Dimensional Limitations.

Fans of 4 ft. 6 ins. to 7 ft. in diameter should be considered with the preferred figure of 6 feet. The hub size, distance between bearings are left open to Orenda's choice, but should be generally similar to the existing Avrocar. It is anticipated that the turborotor will not require to be tilted out of the rotational plane as is the existing Avrocar turborotor, but should the redesigned aircraft require such a means for control the tilting should be such that the angular displacement is $\pm$ 15 minutes.

Entry of the engine exhaust gases to the turbine will be over the rear 180 degrees of the turborotor only, (see attached sketches of proposed layouts).

Studies by Orenda under para 1.6.2 (a) of the Statement of Work should consider the case of a partial shut-down of the fan intake and exit, and the turborotor should be designed over a wide range so that the efficiency is not unduly affected at off-design conditions.

(b) Approximate Fan and Other Dimensional Limitations. Cont'd.

Data will be supplied by Avro Aircraft Limited of the Avrocar intake in the Ames Tests as soon as available together with any other information relevant to the proposed Orenda intake - Tests detailed in Appendix 2.

(c) Performance Requirements.

Under standard conditions the following is the desirable powerplant performance.

(i) Sea Level Static

Thrust 7000 to 9000 lb. (Net)

Specific fuel consumption 0.6 to 0.8 lb/lb/hr.

(ii) In-Flight Sea Level

Thrust 2500 lb. at M = 0.45 (Net)

Specific fuel consumption 0.75 lb/lb/hr at M = 0.275 and 1200 lb. of thrust.

The design should not be compromised too much in order to get down to the sea level static specific fuel consumption. Fan pressure recovery and engine inlet recovery to be estimated by Orenda Engines Limited.

The thrust figures are at the nozzle outlets and take into account duct losses but not losses due to jet focussing.

(d) Weight Limitations

The weight of turborotor, bearings, etc. and oil system, should not exceed 500 lb. and be aimed at the lightest possible.

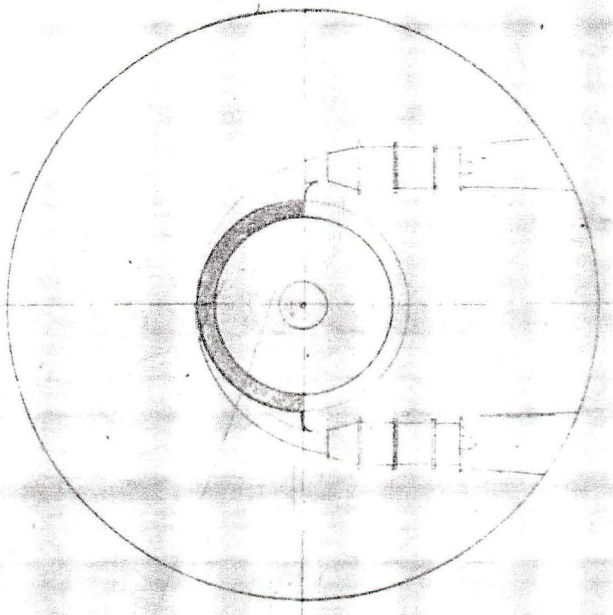
(e) Angular Momentum of the Turborotor

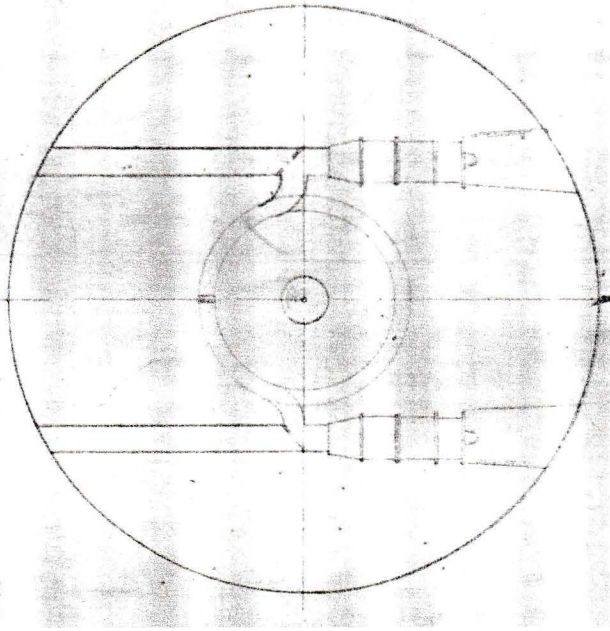
This information to be supplied at a later date when more work on this has been done by Avro Aircraft Limited. However, it is felt that we will increase the figure over and above the value that will result from the turborotor design for minimum weight.

(f) Requirements Associated With the Exit Nozzles and Proportions of Mass Flow Exhausted at the Center and Peripheral Jets.

The change in the effective fan outlet area, from hovering to full forward speed, may vary down to half of the hovering setting.

The mass flow from the respective central and peripheral nozzles is the subject of wind tunnel tests by Avro on a 1/20th scale model of the Avrocar, and the tests will establish this proportion. However, it is felt that no more than 80% of the total output of the turborotor will be ejected from the central jet in the hovering case and no less than 30%. The proportions will probably change with forward speed.


JET EXHAUSTING ON
REAR HALF OF
TURBINE
FWD


JET EXHAUSTING ON
REAR HALF OF TURBINE
FOR VTOL AND
DEFLECTED AFT FOR
FWD FLIGHT

APPENDIX 2

ORENDA PROGRAM & COST SUMMARY

Outline and estimate of work to be performed by Orenda as defined in Para. 2.1.6.2 of Phase 1 Statement of Work is detailed below:

SUB-PARAGRAPH (a)

Study of inlet flow conditions and the requirement for flow control devices. Preliminary design of such device if required. The study shall include:

a.1 A literature survey and an examination of any useful Ames tunnel data for the Avrocar. Some preliminary design of suitable flow control vanes.

a.2 Model tests of the Avrocar inlet in the NRC tunnel, first to establish the inlet flow configuration, its variation with angle of attach, etc. and then to check the effectiveness of flow control devices. (OEL will be responsible for the models and securing the testing facilities. NRC will do the testing and OEL will analyse the data as necessary to permit the design of control vanes and confirm their performance. Several trips to Ottawa will be required.)

a.3 Mechanical design to investigate more than one approach, fixed inlet vane and variable geometry inlet vane will require design investigation. Design of flow control devices.

a.4 A written report with recommendations.

Total Cost for Sub-paragraph (a) $17,463.00

N.B. The cost of using NRC equipment and personnel has not been considered in this estimate.

SUB-PARAGRAPH (b)

Study of compatibility of rotor angular momentum requirements under different flight conditions with power requirements. The study shall include:

b.1 A maximum of five flight conditions which shall be studied for compatibility of rotor angular momentum with power requirements.

b.2 A study of method of varying fan angular momentum without compromising performance and an investigation of rotor construction.

Total Cost for Sub-paragraph (b) $4,204.00

SUB-PARAGRAPH (c)

Design of fan and turbine compatible with Avro requirements and covering the range of feasible pressure ratios and mass flows and anticipated duct losses. The study shall include:

c.1 A preliminary examination of the fan and turbine requirements including attempts to select optimum fan flow and pressure ratio combinations for a range of expected duct loss coefficients.

Design considerations for steeper fan characteristics, and the design of fans and turbines for 3 flow and pressure ratio combinations.

Design of suitable turbine inlet ducting and scroll.

c.2 Mechanical design to assist c.1 and product layouts and arrangement of design approach in relation to the various pressure ratios under consideration.

c.3 A report with recommendations.

Total cost for Sub-paragraph (c) $18,248.00

SUB-PARAGRAPH (d)

Study of ducting design to minimize pressure losses. Model experiments may be required in this phase. The experimental program is to be agreed with the Project Officer (DRB). The study shall include:

d.1 An aerodynamic study of exhaust duct for fan and turbine including advice on Model.

d.2 Design of model, manufacture of model, instrumentation and required parts for installation including changes for two minor variants and assembly.

d.3 Set-up of model, check run, test program including cost of power.

Total Cost for Sub-paragraph (d) $18,825.00

Additional Items (e)

This shall include:
Project co-ordination, liaison, report compilation editing, proof reading, editing, collating etc. In this connection it is to be noted that:

(i) Orenda will maintain adequate and continuous liaison with Avro Aircraft Limited throughout the Program.

(ii) During the course of work, Orenda will provide monthly Progress Reports which will be prepared in such a way as to enable the inclusion of the report as Appendix 1 in the monthly report which Avro submits to the Canadian Government as Prime Contractor. The Progress Report shall present a summary of work performed, percentage of task accomplished, results obtained and the Budgetary Status and the Work Status of the Orenda Program. Fifteen copies of each monthly report shall be due in Avro Aircraft Limited on the 25th day of the month. For the month being reported, these reports shall cover the period extending from this day to the 25th day of the previous month except that the Budgetary Status and Work Status presentation shall be based on the Accounting Month just previous. The Budgetary Work Status presentations shall show, separately, the total expenditure for each of the four studies listed in para. 2.1.6.2 and of para. (e), Appendix 2 of the Planning Report.

(iii) Twenty-Five copies of the final Technical Reports, as noted under Sub-paragraphs a, b, c and d, in this Appendix, shall be prepared and submitted to Avro Aircraft Limited by the 31st of March 1961.

Total Cost for Additional Item $12,760.00

Total cost of the program outlined above is $71,500.00 excluding Fee.

N.B. The cost of using NRC tunnel and personnel has not been considered in this estimate.