AVROMOBILE

AVROCAR

VZ-9AV

program planning REPORT

AVRO AIRCRAFT LIMITED

I.D. No. 58RDZ-11206 - 24

PROGRAM PLANNING REPORT

AVROCAR 1

UNITED STATES ARMY DESIGNATION VZ-9AV.

Prepared in accordance with the Preliminary Statement of Work - Avrocar Vehicle dated 1 May 1958

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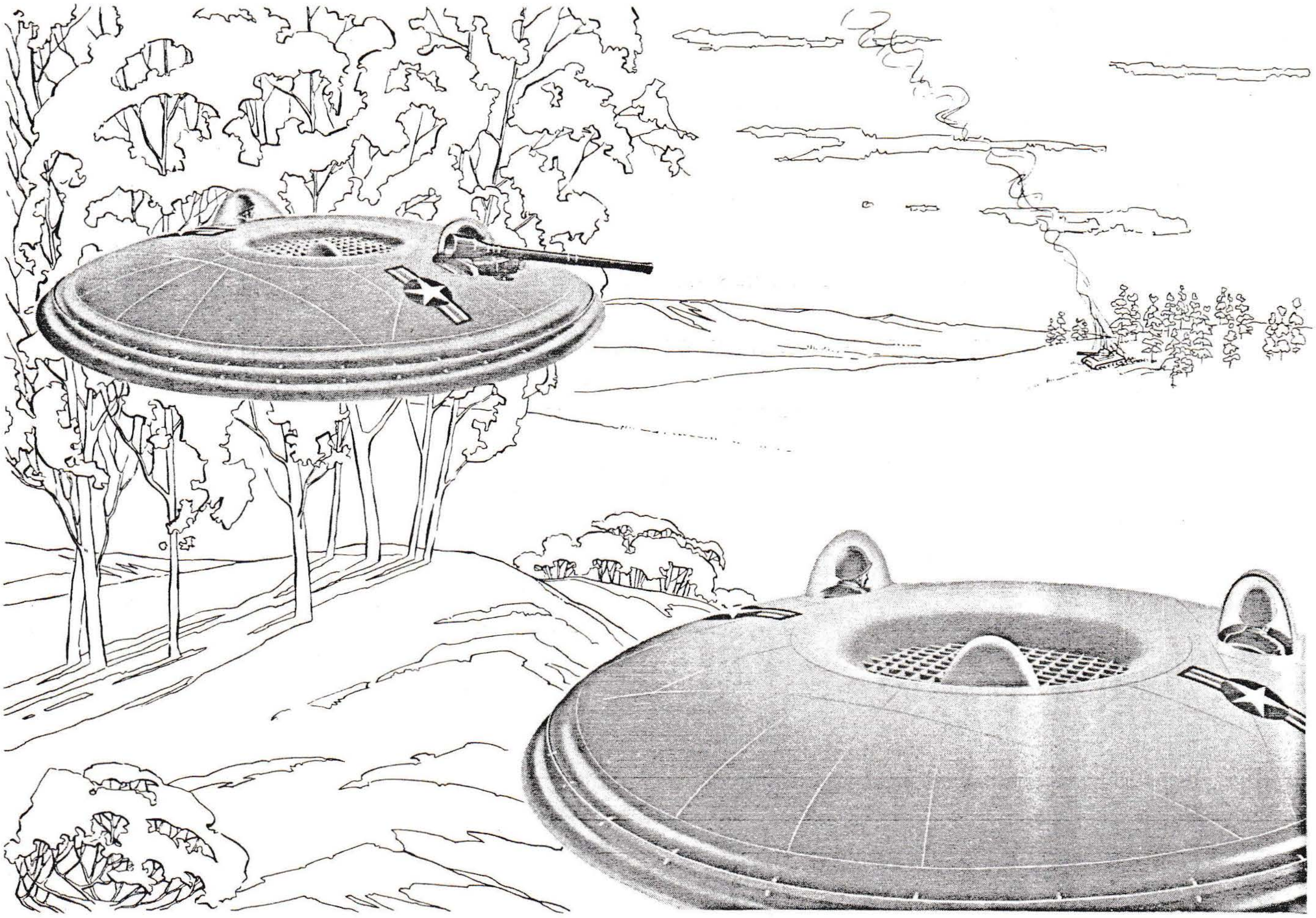

AVROCAR 1

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1. SUMMARY

This document details a planned program for the Avro Aircraft Limited AVROCAR first phase development with accompanying cost estimates and scheduling.

The first phase consists of the manufacture of one prototype vehicle according to the approved Model Specification for Avrocar I (Army VZ-9AV) dated 20 May 1958, issued by the Contractor and the carrying out of certain wind tunnel and other tests directed to this endeavour.

The program is prepared in accordance with the requirements set forth in the Preliminary Statement of Work Avrocar Vehicle (Army VZ-9AV) identified 58RDZ-12743 dated 1 May 1958 and the Request for Proposal identified 58MCXH-12357 dated 18 March 1958. Two items of work, namely the 1/5 scale AVROCAR model and simulation studies which form part of the USAF System 606A program re-directed to support the AVROCAR program, are included for programming and scheduling but are not included in the cost estimates.

A brief description of the AVROCAR is given in the Introduction, but for a comprehensive account of the proposed prototype, the model specification may be referred to. Some further detail is given in para 3. 1. 1 in order to clarify the design planning. Following the Introduction, the Engineering and Manufacturing of the prototype vehicle are described with detail scheduling through all phases. Separate sections describing models and tests supported with schedules and cost estimates are also included.

It is the Contractor's intention to subcontract the design, manufacture and development of the AVROCAR turborotor to Orenda Engines Limited, a subsidiary of the A. V. Roe Canada Limited Group. Planning and cost for this item is included in Appendix I of this report.

The funds required to carry out the program amount to $2,102,197 US. This sum includes $65,000 for one (1) additional complete set of vehicle parts, $15,520 for one (1) complete 16mm color film with sound track and $561,295 for a package first phase turborotor development by Orenda Engines Limited.

The first vehicle is expected to begin its tethered flight program not later than one year from date of contract; that is by June 1959.

The following items are not included in the cost analysis shown in this report:

(1) Equipment items requested as GFAE, now CFE

(2) Landing Wheels

(3) Fire Extinguisher System

(4) Amendments to the approved model specification (dated 20 May 1958) originating from USAF or US Army which increase the scope of work beyond the program defined herein.

All the above will be the subject of separate cost estimates.

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2. INTRODUCTION

The AVROCAR is a new type of air vehicle suitable for operating close to the ground and capable of VTOL, flight to 10,000 ft. altitude and speeds in excess of 200 mph.

The design is derived from a supersonic aircraft with VTOL/STOL capability projected by Avro Aircraft Limited.

Considerable research and development performed for the supersonic aircraft is directly applicable to the subsonic AVROCAR. Because the latter is a subsonic vehicle of simple design, it is considered entirely feasible to complete a prototype within twelve months.

This program involves the design and manufacture of an AVROCAR vehicle in accordance with the details outlined in the approved Model Specification for Avrocar I (Army VZ-9AV) dated 20 May 1958.

Manufacture of the vehicle will run concurrently with a series of model tests and simulation studies. The latter two items are included to assist refinement of the concept and determine the exact characteristics for controls development.

A general layout of the AVROCAR is illustrated in Figs. 1 through 6.

Fig. 1 is a three-view general arrangement of the vehicle. The vehicle is an all wing design of circular planform and is approximately 18 feet in diameter. In section the wing is a cambered ellipse with thickness to chord ratio of approximately 20%.

The wing section is symmetrical about the vertical centerline, resulting in a very simple radial structure. The vehicle stands approximately 5 inches off the ground, has an overall height of 4.8 feet and will take off vertically at a weight of 5650 lb. which includes a payload of 2000 lb. and fuel for over 100 miles flight.

Three Continental J69-T-9 turbojets - 927 lb. S. L. static thrust, 27 inch overall diameter, 364 lb. weight - are symmetrically disposed in plan with their exhausts directed inboard (ref. Fig. 2). The exhaust is collected in a cochleate chamber and directed through nozzle guide vanes to impinge upon turbine blades attached at the outer edge of the turborotor assembly.

The turborotor (ref. Fig. 3) draws in air through a circular intake from the wing upper surface and forces it radially outwards through diffuser ducts in the main structure (ref. Fig. 4). Some of the air forced out by the turborotor is directed back to feed the turbojets, but the main flow is expelled from an annular nozzle at the wing periphery. A continuous ring

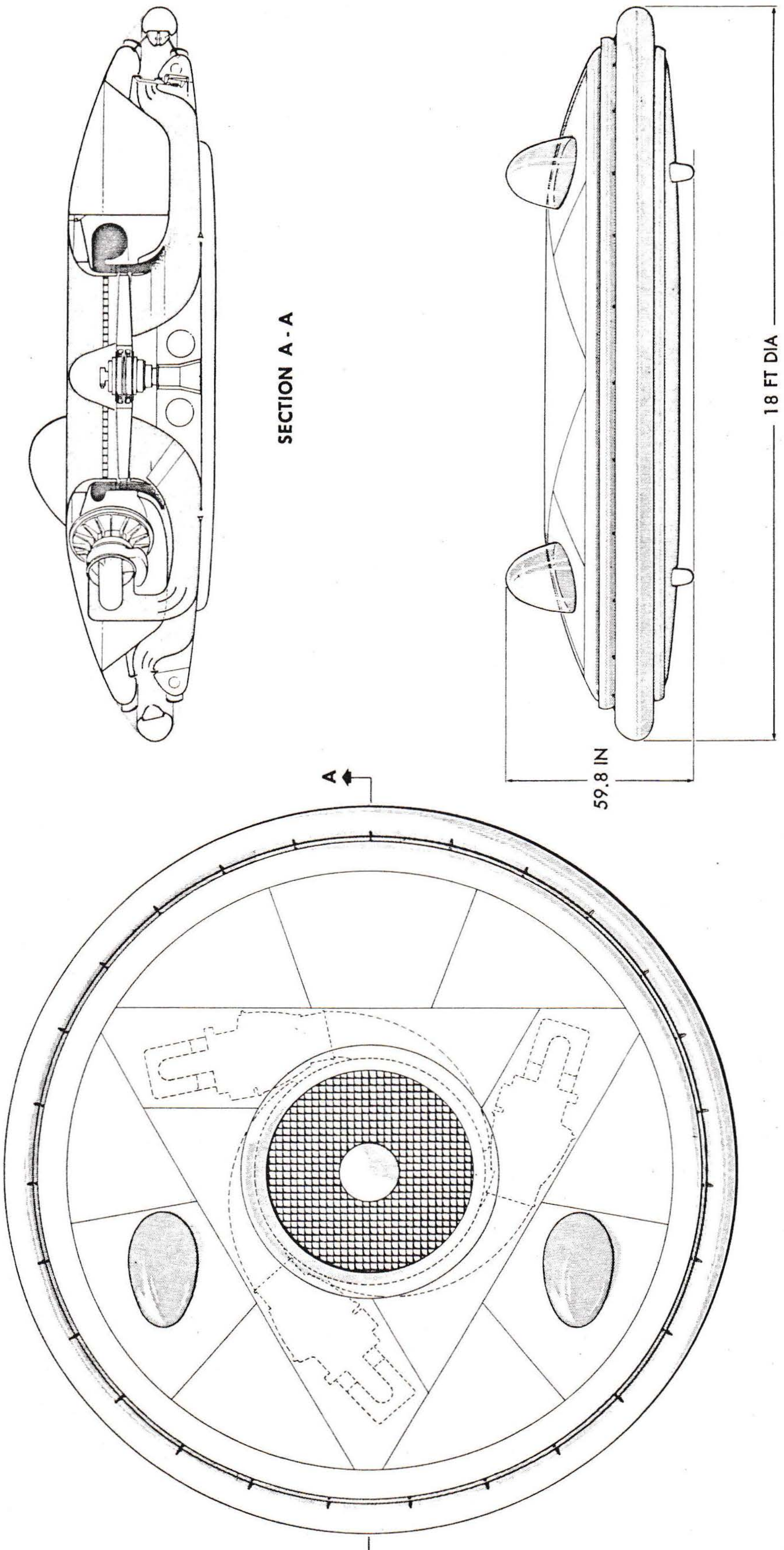

FIG 1 GENERAL ARRANGEMENT

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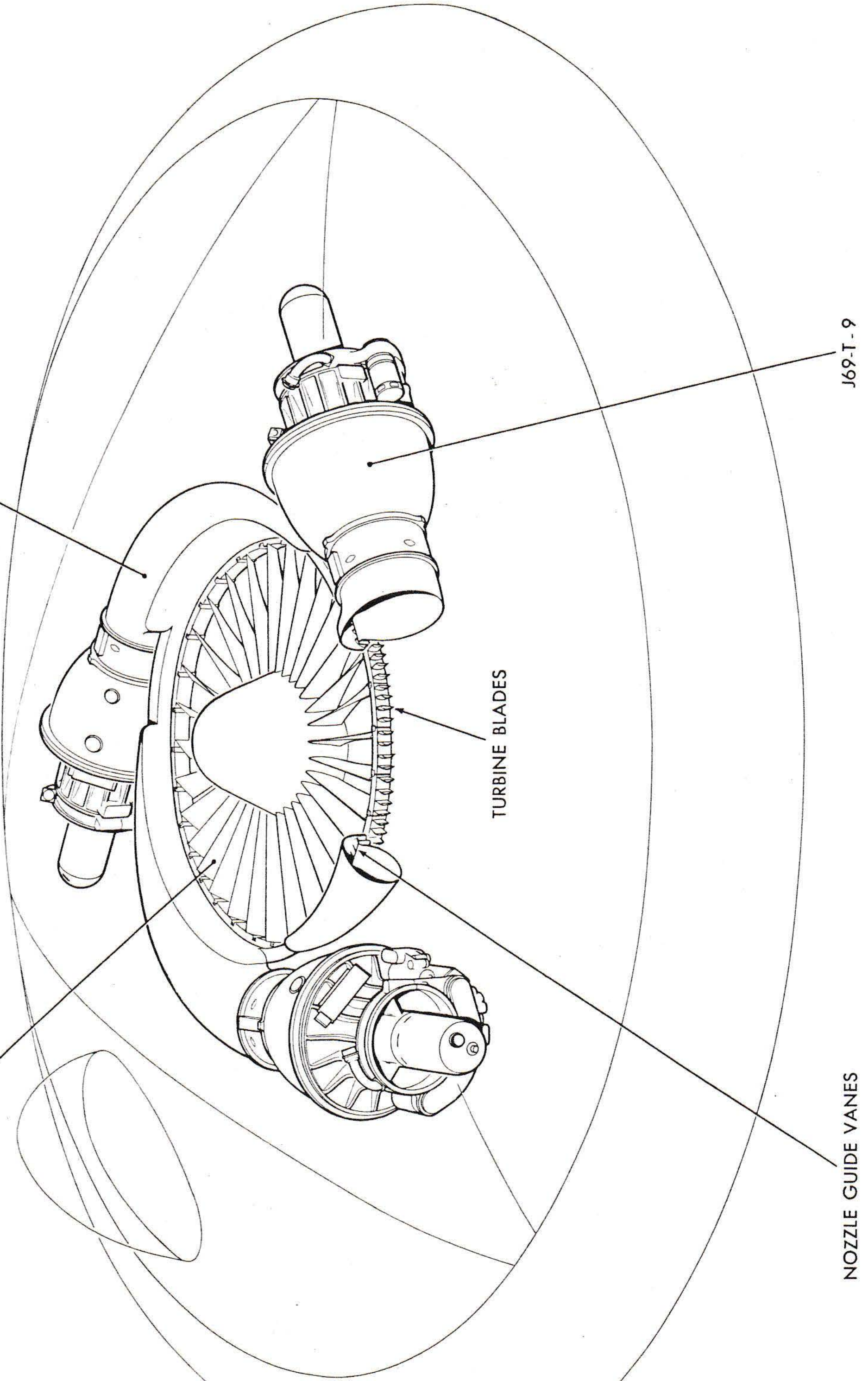

FIG. 2 ENGINE INSTALLATION

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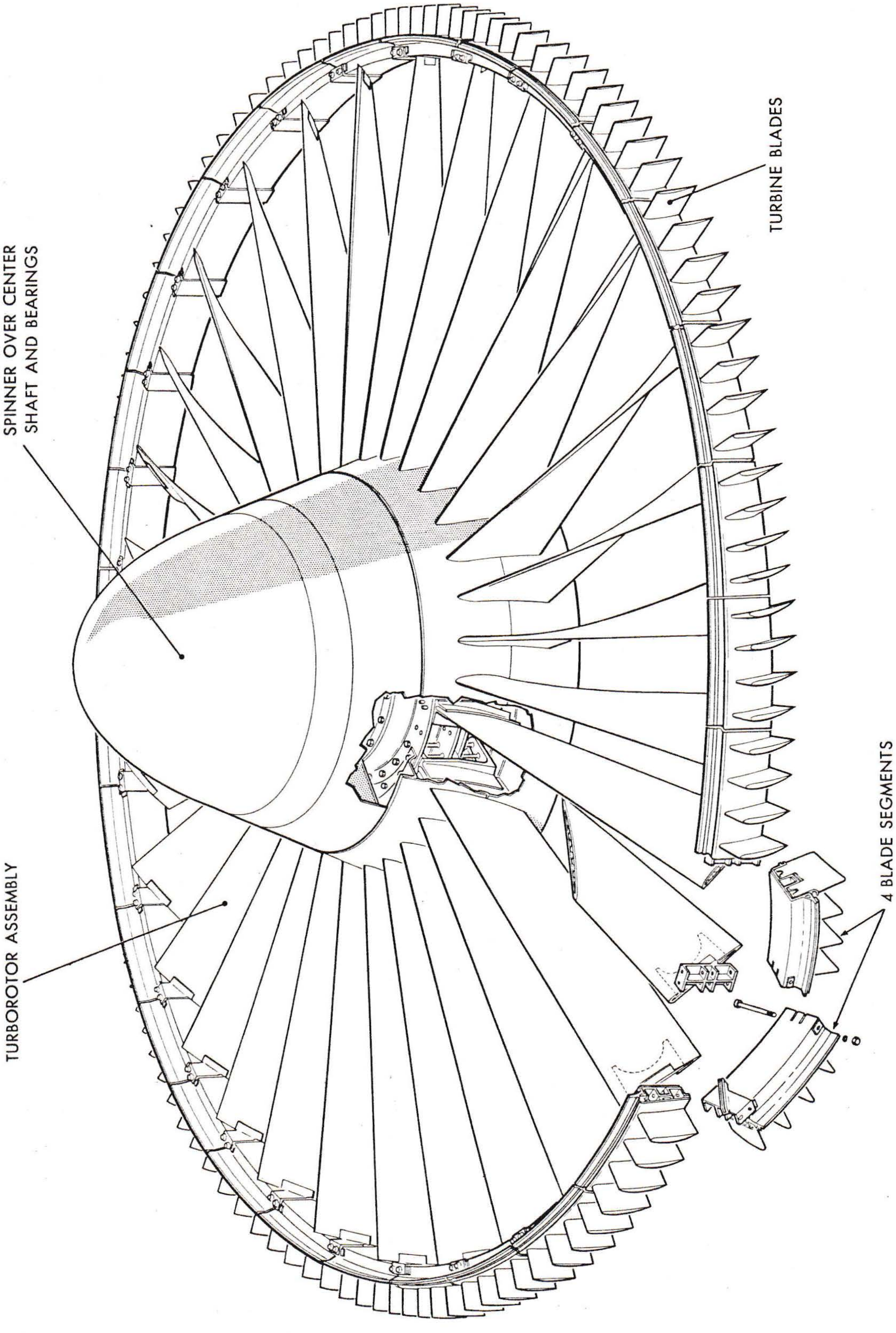

FIG. 3 TURBOROTOR ASSEMBLY

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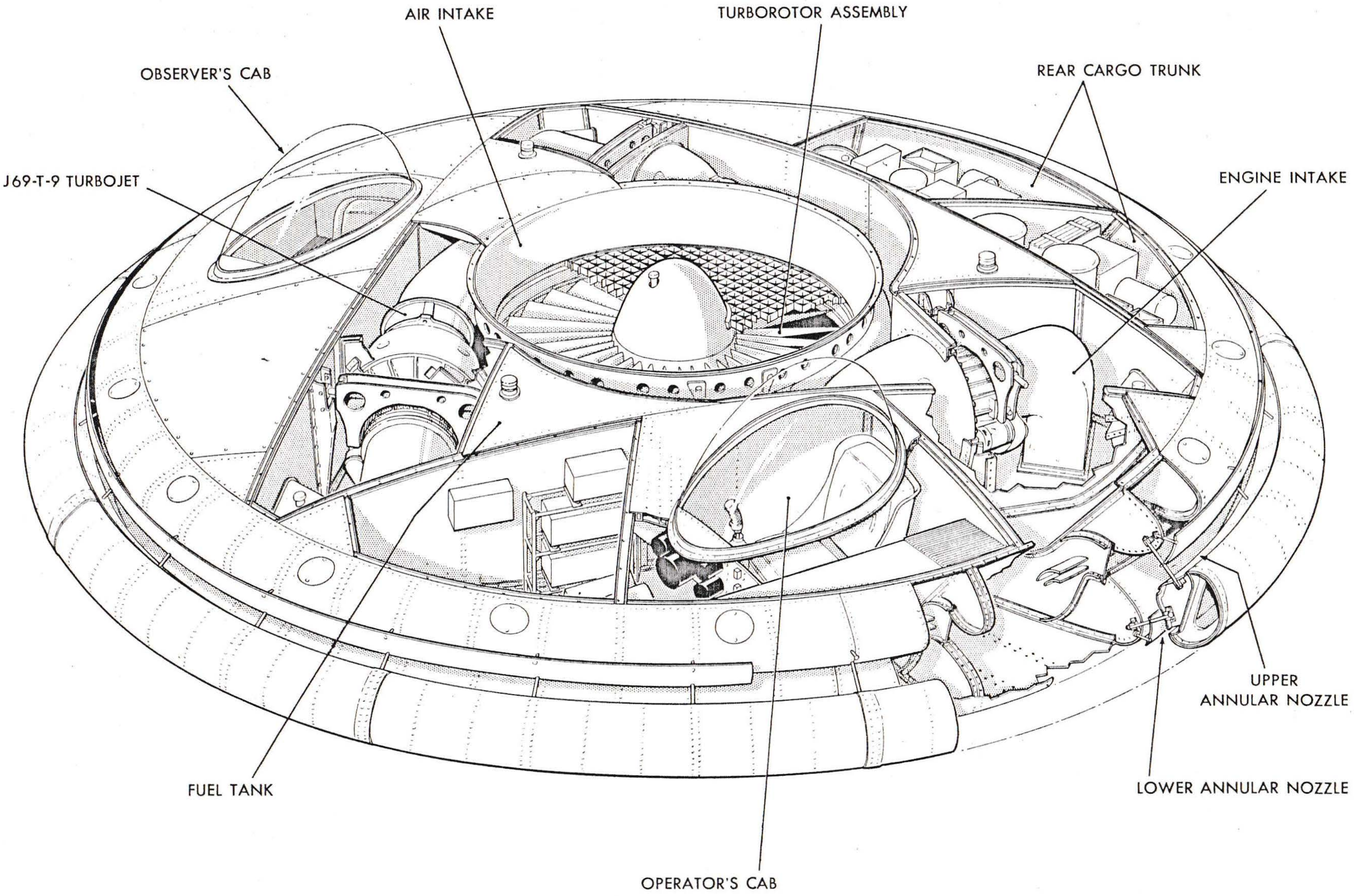

FIG. 4 STRUCTURE CUTAWAY

forming a small spoiler is fitted in the throat of the annular nozzle above and below (ref. Fig. 5). The projection of the spoilers controls the direction of the jet efflux; if both project equally the jet emerges radially; if both are lowered together, the upper spoiler will project further than the lower spoiler, and this inclines the jet progressively downward to exhaust partly through the radial propulsion nozzle and partly through the lower nozzle. When the spoiler is flush with the nozzle, the jet is bent to emerge completely from the lower nozzle in a vertical curtain of air. Similarly the jet can be bent upwards. In this way, the spoilers control the jet to raise the vehicle vertically off the ground or to propel it in forward flight. In the same manner, the spoilers are used to control and maneuver the aircraft by bending the jet differentially over opposing sectors of the periphery.

The operator controls the spoilers by means of a conventional control stick. The total movement of the spoilers is small (0.15"). They are flexure mounted and very light in weight and the jet responds almost immediately to the spoiler position so that a very rapid response is possible. This feature is an asset as the vehicle is stabilized by means of the controls. The stabilizer must not compromise safe operation of the controls and therefore a simple direct system is used which depends principally upon the turborotor acting as a gyro. In fact, the turborotor is allowed to pitch and roll a very small amount within the vehicle. The relative motion is stepped up with a mechanical linkage into a control post and this is connected directly to the spoilers through a number of cables. The operator's controls also act on the post through pneumatic bellows. Thus when the aircraft is pitching or rolling, a correction is applied by the controls but the control stick can always obtain maneuver by overriding the stabilizer. The change in jet direction as the vehicle pitches performs the same function as the fixed stabilizer of a conventional aircraft.

To take-off, the peripheral jets are directed downwards by means of a screw jack which lowers the spoilers collectively and produces the vertical curtain of air referred to above. This jet-around-wing configuration results in a powerful ground cushion effect (ref. Fig. 6) so that the lift near the ground is several times the reactive nozzle thrust. The effect increases the closer the vehicle is to the ground; a considerable magnification is realized within 12 feet of the ground.

The vehicle may be operated to hover or move within the ground cushion. Transition to forward flight is effected by gradually deflecting some of the jet flow backwards through the propulsion nozzle. The vehicle accelerates forward, and is inclined upward. The jet sheet at the rear of the wing induces a very large lift coefficient which, together with the low wing loading, enables the entire weight of the vehicle to be supported at a speed of 45 mph.

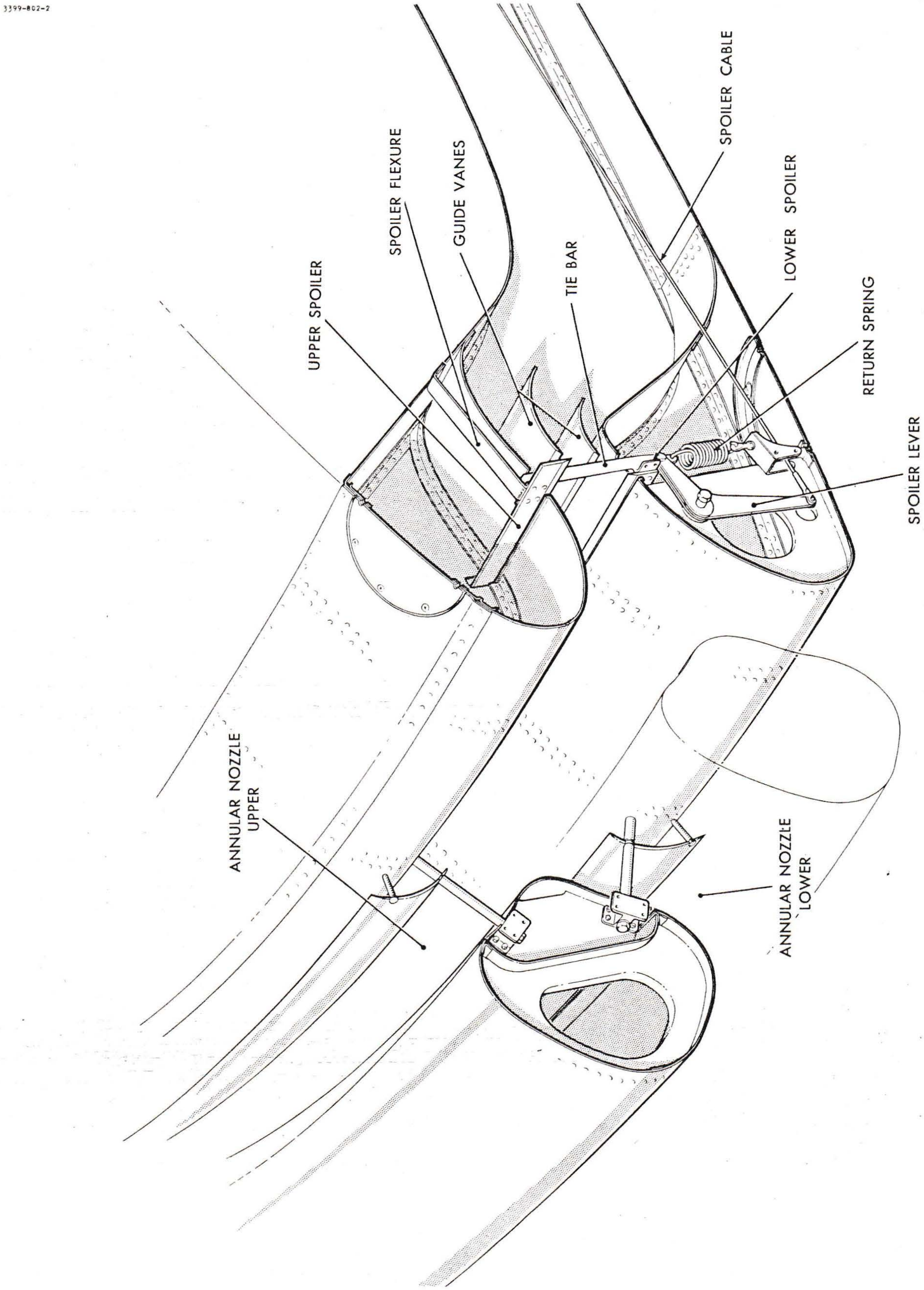

FIG. 5 CONTROL NOZZLE MECHANISM

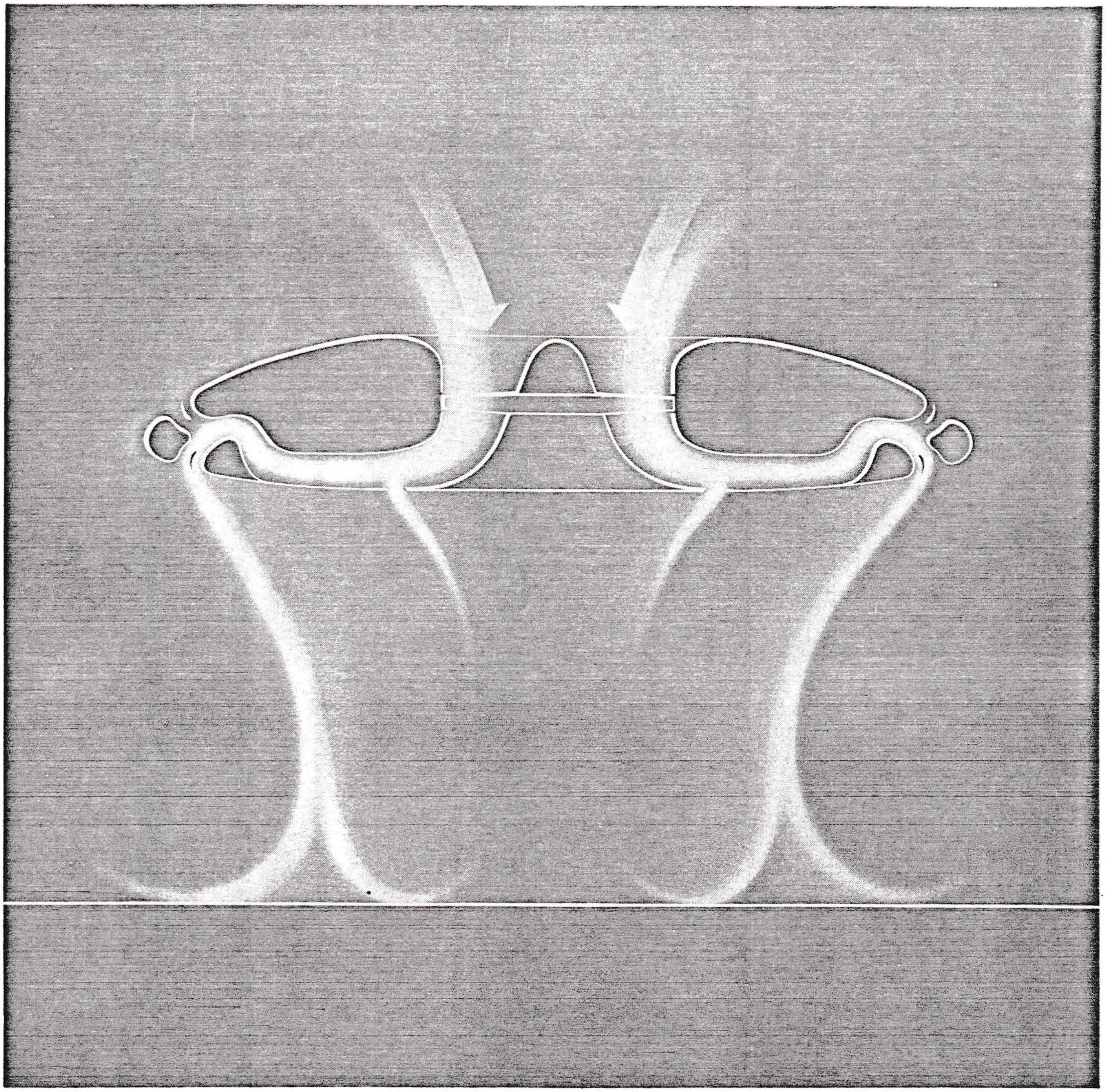

FIG 6 FLOW DISTRIBUTION - HOVERING & GROUND CUSHION

In landing, descent is made at constant power until the presence of the ground is sensed as the vehicle enters the ground cushion. The throttle is then progressively closed to settle the vehicle onto the ground.

Tests completed under previous USAF contracts have confirmed the feasibility of this new type of vehicle.

Every effort has been made to outline the proposed course of work in detail. Any changes to the planned program will be made only with the prior approval of the Project Officer and will be reported in the monthly Progress Reports required in accordance with Section 9. 2. 3 of the Preliminary Statement of Work.

Statement of Work Sub Parts

6.1.1

3.0 PROTOTYPE VEHICLE

3.1 ENGINEERING

3.1.1 DESIGN PROGRAM

This design schedule includes general assembly drawings for the prototype vehicle and installation drawings for the equipment and stores to be carried within it.

The design of the prototype is explained in the following itemized construction analysis. Fig. 7 is an exploded view diagram to assist in identifying structural components and Fig. 8 is a detailed drawing release schedule for the prototype vehicle. The Work Schedule Chart (ref. Fig. 24) provides an appreciation of the program as a whole.

3.1.1.1 Structure

Base Structure: The base structure is divided into four component assemblies to simplify manufacture and construction. These components consist of a centre base of circular planform to which are attached three equal segments jointed radially at the three engine intake ducts.

The centre base is designed to house the turborotor shaft in a centre casting which is supported in a box structure of radial ribs and external skins.

The three wing segments are constructed of radial ribs supporting the bottom skin and the floor skin.

Wing Tip: The wing tip is designed for assembly to the base structure in six detachable segments to permit access to the flight control mechanism.

Compartments: The space above the floor is divided into compartments by means of transverse partitions. The power system is segregated in the centre of the vehicle by a triangular enclosure.

The three remaining sectors are each divided by a partition to form two crew compartments and four stowage compartments [illegible]-802-1

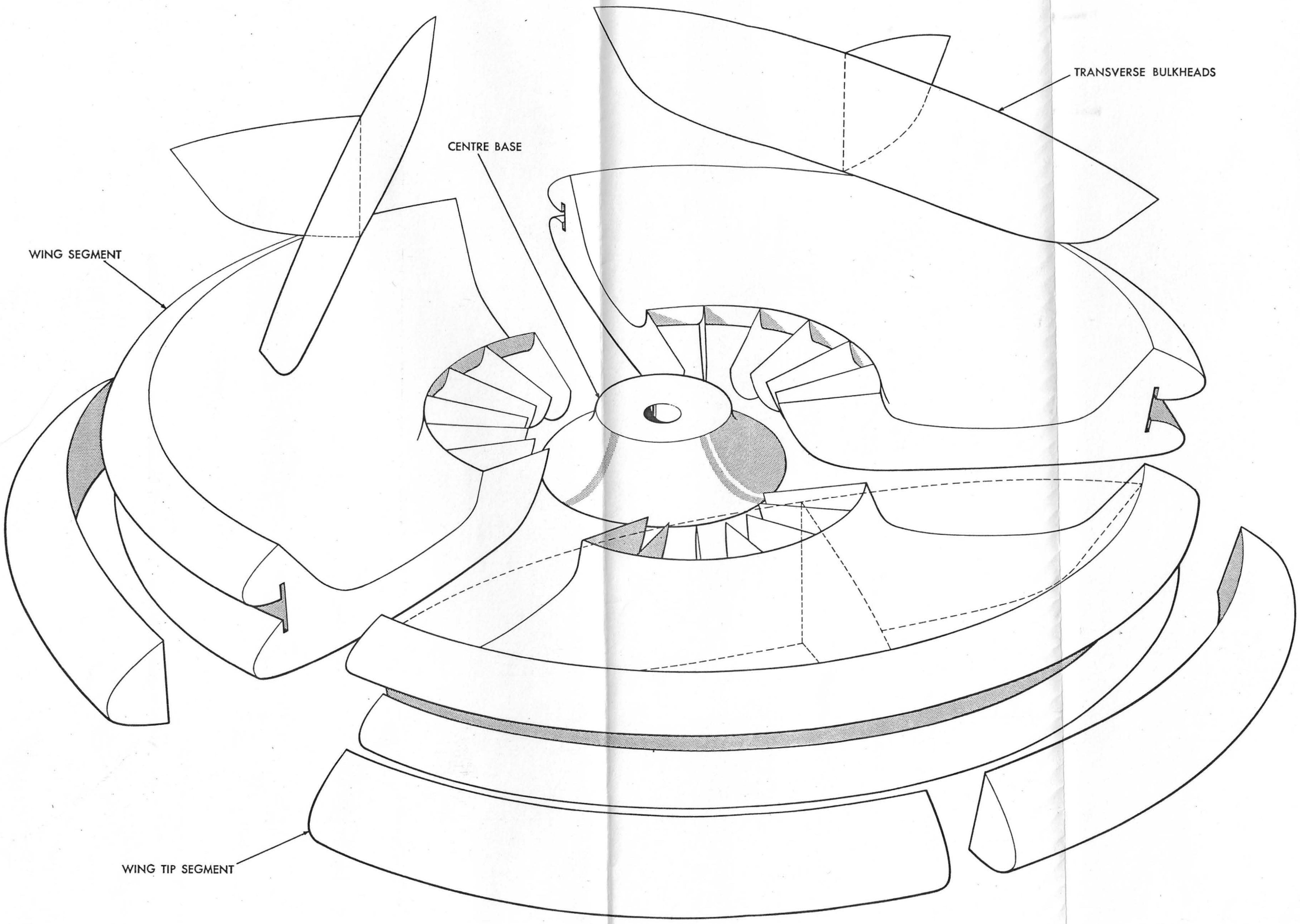

FIG. 7 STRUCTURE BREAKDOWN

Fig. 7 Structure Breakdown

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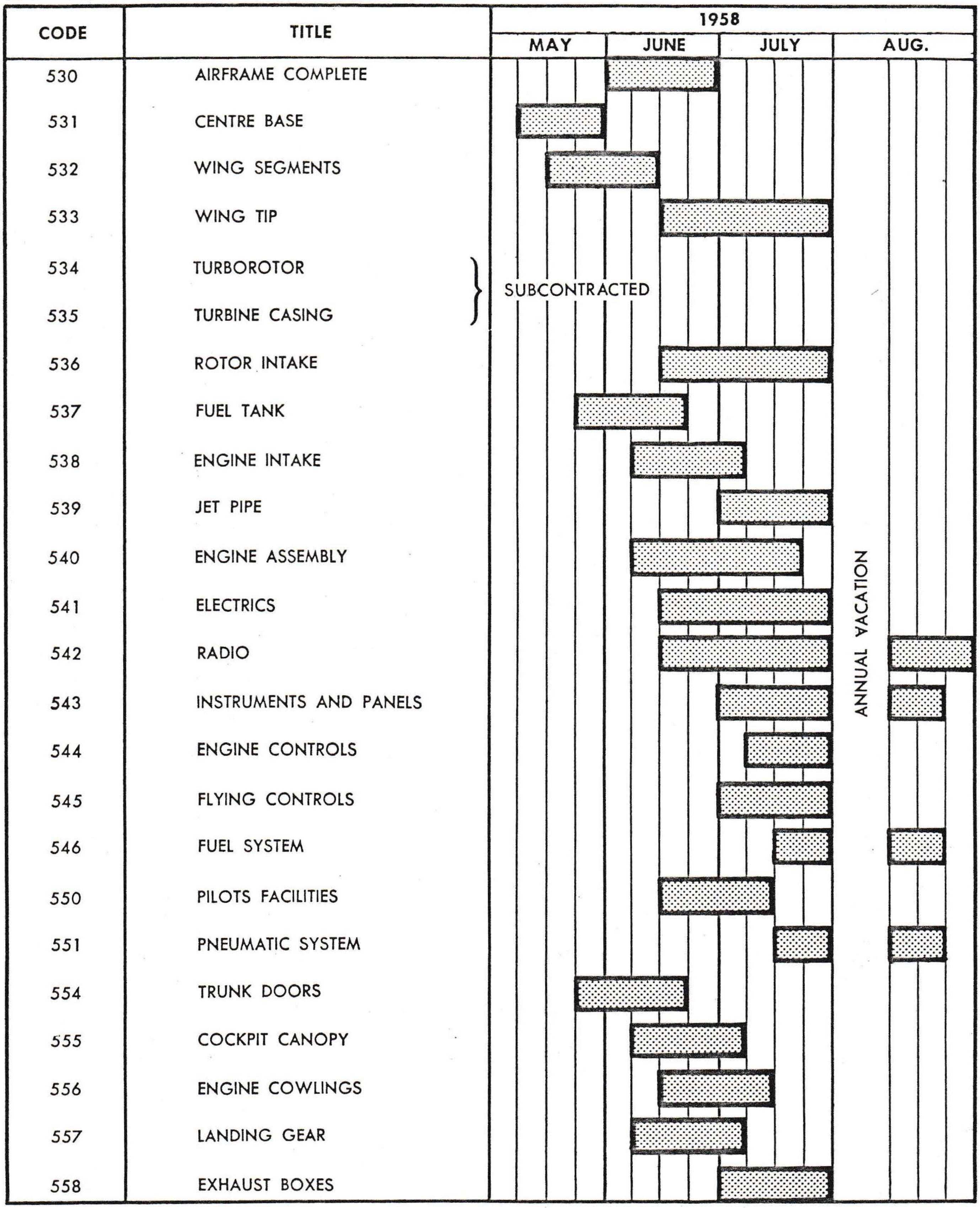

CODE	TITLE
530	AIRFRAME COMPLETE
531	CENTRE BASE
532	WING SEGMENTS
533	WING TIP
534	TURBOROTOR
535	TURBINE CASING
536	ROTOR INTAKE
537	FUEL TANK
538	ENGINE INTAKE
539	JET PIPE
540	ENGINE ASSEMBLY
541	ELECTRICS
542	RADIO
543	INSTRUMENTS AND PANELS
544	ENGINE CONTROLS
545	FLYING CONTROLS
546	FUEL SYSTEM
550	PILOTS FACILITIES
551	PNEUMATIC SYSTEM
554	TRUNK DOORS
555	COCKPIT CANOPY
556	ENGINE COWLINGS
557	LANDING GEAR
558	EXHAUST BOXES

FIG. 8 DRAWING RELEASE SCHEDULE - PROTOTYPE VEHICLE

3.1.1.2 Power System

Firewalls: The triangular power system enclosure is further subdivided by firewalls to segregate the engines and fuel tanks and to isolate the combustion and exhaust areas from the fuel control components.

Engine Mounts: The engines are anchored to the floor structure at the rear mounting point. The main trunnions are slung on a hinged yoke to permit longitudinal thermal expansion of the engine and a sliding housing provides for transverse expansion. Engine removal is facilitated by open access to the yoke hinges, while the pin at the rear mounting point is disengaged from an adjacent stowage compartment.

Engine Exhausts: The jet pipe is attached to the engine with a marman clamp and is supported on the turborotor casing with provision made for rearward expansion by means of a slide device.

Engine Intakes: Three radial ducts are provided in the base structure and these permit air from the turborotor to be fed to the engines while by-passing the residual exhaust gas into adjacent ducts. The final ducts to the engine compressor sections are provided with sealed sliding joints to permit longitudinal thermal expansion to the engines.

Compressor Intake: The flared intake to the turborotor in the top centre of the vehicle is designed to be supported at three attachment points on the triangular enclosure partitions to facilitate removal.

Turborotor: The turborotor consists of a centre hub and outer rim sustaining a single stage of radial compressor blades, with a single stage of turbine blades mechanically attached to the outer face of the rim. This assembly is mounted by means of two tapered roller bearings on a tubular shaft which locates in the centre casting of the base structure.

Turborotor Casing: The turbine blades are enclosed with a segmented casing mounted on the base structure. This casing provides support for the engine jet pipe, and carries a single stage of stator blades above the turbine blades with a gas seal to reduce leakage losses.

Exhaust Boxes: The residual exhaust gas from the turbine is conducted through exhaust boxes into the diffusion ducts in the base structure. These boxes are designed to provide mixing of the hot gas with the airflow from the compressor.

3.1.1.3 Controls

Peripheral Apertures: The radial airflow through the diffusion ducts in the base structure emerges at the wing tip where its path is controlled to perform flight maneuvers.

The airflow normally emerges horizontally, but a bifurcated by-pass permits the flow to be deflected either upward or downward.

Exit Louvres: At the front sector of the vehicle, normal emergence is at 30° to the wing edge, attaching to the wing surface and flowing backwards. At the left and right of the vehicle, deflection louvres are provided to turn the airflow rearward and at the rear of the vehicle open louvres are installed.

Shutters: To close off the exit louvres during hovering, a series of electrically actuated shutters are provided at the sides and rear. A small segment of shutters is provided at the left and right of the front sector for yaw control with pneumatic jacks.

Spoiler Rings: To control deflection of the airflow either upward or downward an upper and a lower spoiler ring are installed in the throat of the main diffusion duct. These rings are carried on flexures with a spring-loaded return, and are connected mechanically to a central control shaft.

Central Control Shaft: A central control shaft is mounted within the tubular turborotor shaft on flexural diaphragms. The lower end of the shaft picks up the mechanical leads to the spoiler rings and is also connected to three pilot-controlled pneumatic jacks. At the upper end of the shaft an electric actuator is installed with a connecting rod to the spoiler ring mechanism.

Hovering Control: The spoiler rings are actuated through the actuator on the central control shaft by means of a switch control in the cockpit to deflect the airflow downward; the shutters are also closed from the cockpit by switch control.

Transition Control: Shutters and spoiler rings are inched through the cockpit switch controls to effect the change from hovering to forward flight and vice-versa.

Pitch and Roll: Conventional movement of the pilot's stick operates the pneumatic jacks on the central control shaft to deflect the spoiler rings in a swash-plate action.

Yaw Control: A twist-grip on the pilot's stick operates pneumatically the small shutter segments at the left and right sides of the front sector.

Automatic Stabilizing: The flexural diaphragms on the central control shaft are designed to transmit stabilizing forces, utilizing the turborotor as a gyroscope, and to apply through the central control shaft, a corrective movement to the spoiler rings.

Statement
of Work
Sub Parts

3.1.2 MOCK-UP

7.1

The program additionally calls for the design and construction of a wooden mock-up of the vehicle to assist in refining Engineering design. A design has been determined and a mock-up is already in the process of assembly.

Fig. 9 presents a detailed drawing release schedule for the mock-up.

3.1.3 STRUCTURAL ANALYSIS

6.1.1

3.1.3.1 General

The requirements of MIL-S-5700 to MIL-S-5709 inclusive will be used as a guide in the structural analysis of the AVRO-CAR I in so far as they are considered applicable to this vehicle and as time permits. The analysis will be based on a limited number of flights cases for which air loads may be estimated. The structure will be examined in detail for the most critical of these cases. The analysis will not be supported by a structural test program at this time.

3.1.3.2 Load Analysis

A flight envelope based on MIL-S-5702 has been established for the AVROCAR I and is shown in Fig. 10. The cases under consideration are itemized in Fig. 11. The latter will be dealt with in more detail in a structural design criteria report.

Aerodynamic loads for these cases will be estimated and shown in an aerodynamic load data report. These estimates will be compared with the results of surface pressure tests now being conducted on a 1/6 scale model of P.V. 704 under the System 606A program and with the limited surface pressure data to be obtained on the proposed 1/5 scale AVROCAR model (ref. para. 4.3). Revisions will be made if considered essential in the light of these results

The aerodynamic data report will serve as the basis of an external load report. This report will cover the entire vehicle as the wing and fuselage cannot be separated and there are no ailerons nor empennage to consider. Control loads

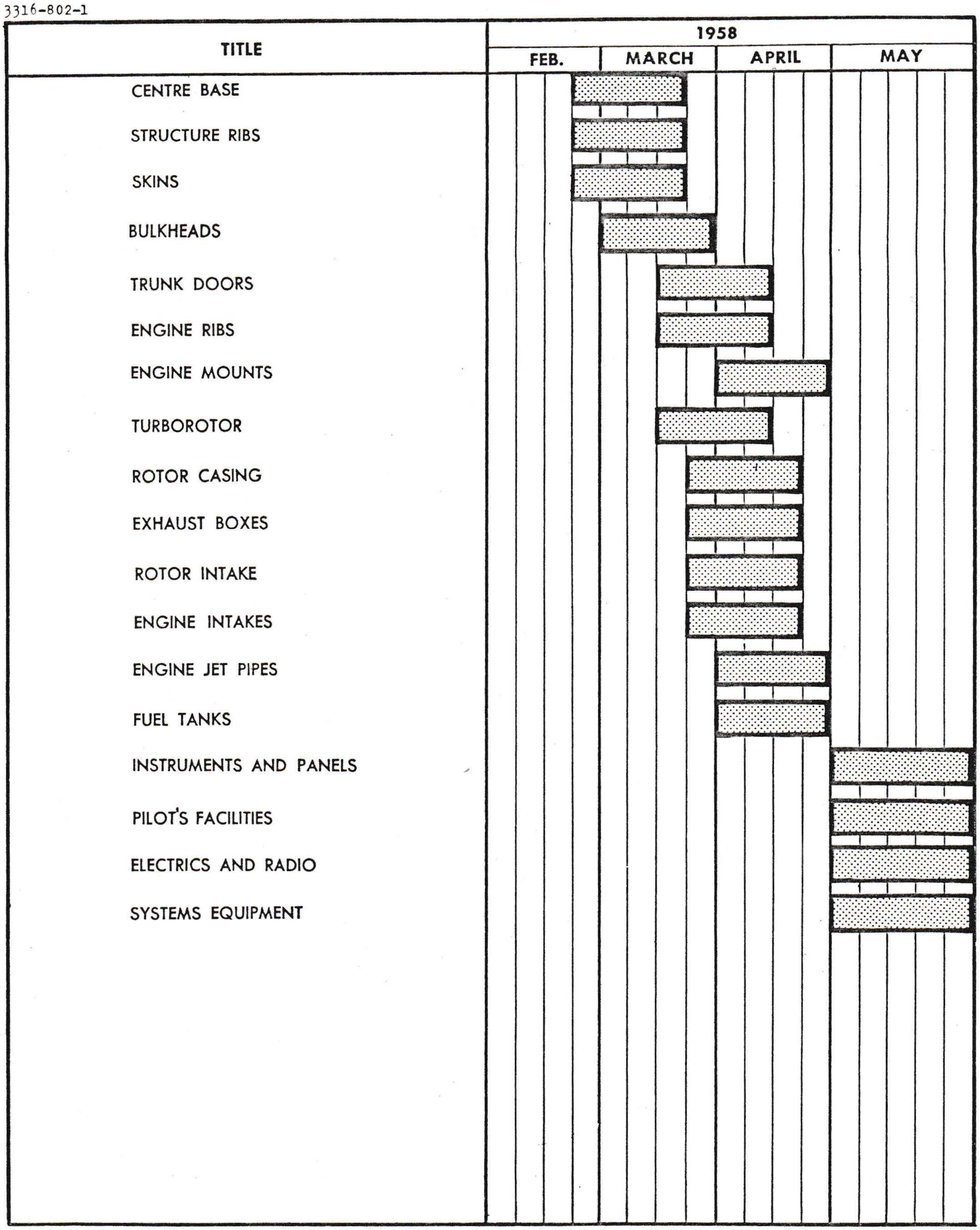

FIG. 9 DRAWING RELEASE SCHEDULE - MOCKUP

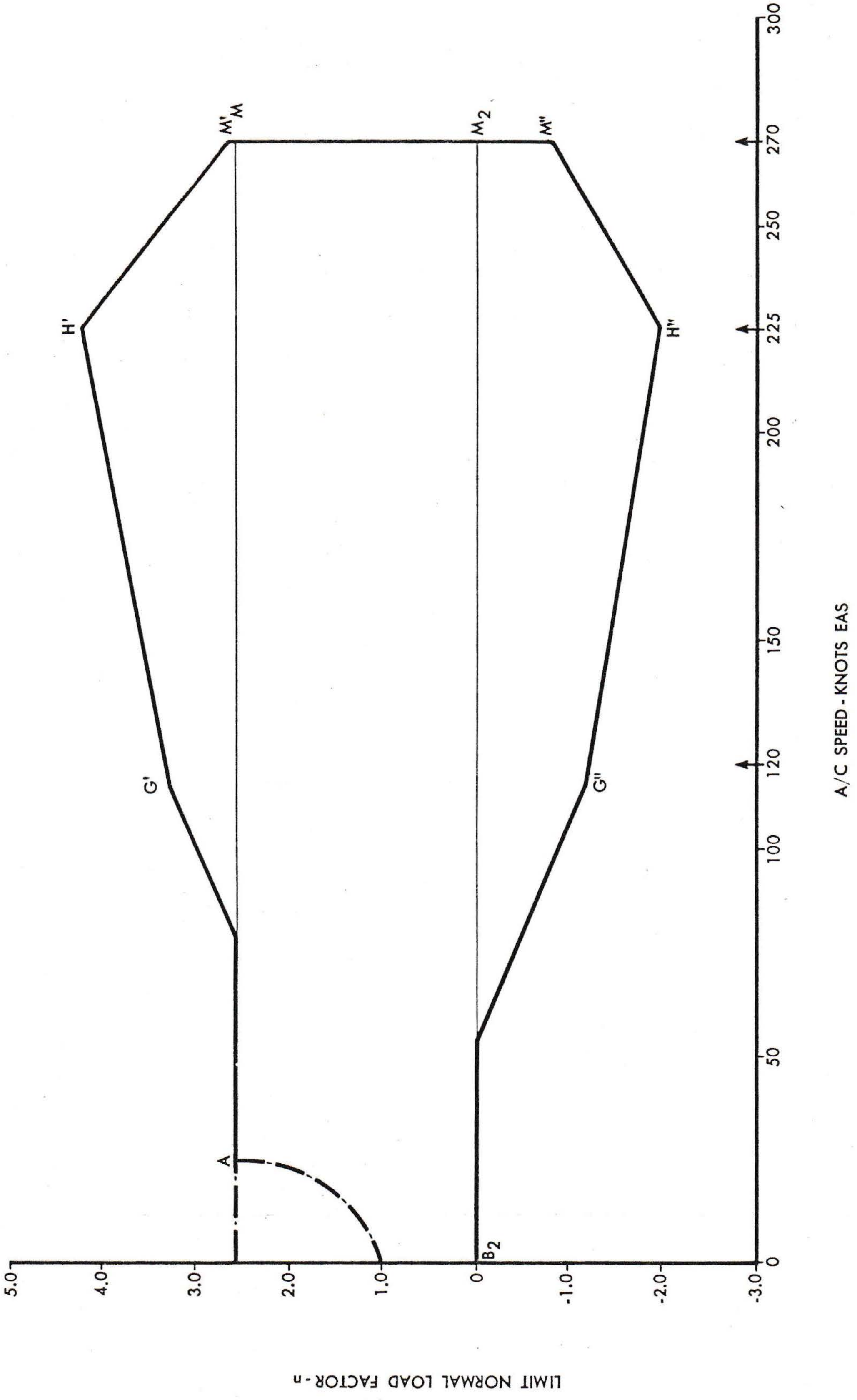

FIG. 10 DESIGN FLIGHT ENVELOPE

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CASE	CONDITIONS	RANGE OF LOAD FACTORS			ROLLING		PITCHING	
		VERTICAL	FWD	SIDE	VEL. RAD./SEC.	ACCEL. RAD./SEC.^{2}	VEL. RAD./SEC.	ACCEL. RAD./SEC.^{2}
BALANCED MANEUVER	SELECTED WEIGHTS AND SPEEDS	-2.0 TO + 4.0	—	± 1.0	—	—	0 TO 2.0	—
ABRUPT PITCHING MANEUVERS	SELECTED WEIGHTS AND SPEEDS	-2.0 TO + 4.0	—	± 1.0	—	—	0 TO 2.0	TO BE CALC.
UNSYMMETRICAL MANEUVER	SELECTED WEIGHTS AND SPEEDS	3.0	—	± 1.0	0 TO 2.0	TO BE CALC.	—	—
SYMMETRICAL GUST	SELECTED WEIGHTS AND SPEEDS	-2.02 TO + 4.02	—	—	—	—	—	TO BE CALC.
UNSYMMETRICAL GUST	SELECTED WEIGHTS AND SPEEDS	-1.64 TO + 3.64	—	—	—	TO BE CALC.	—	TO BE CALC.

FIG. 11 FLIGHT CASES FOR STRUCTURAL ANALYSIS

and ground loads will be considered in the stress analysis of the control system and landing gear respectively. A separate report on engine loads will be presented.

3.1.3.3 Weight and Balance Estimation and Control

The initial weight estimate appears in the Model Specification for Avrocar I. This estimate will be revised as necessary throughout development of the design. A continual check will be made of the weight, centre of gravity position and moments of inertia for the complete vehicle and for each service installed therein. A report summarizing this work will be issued at intervals.

3.1.3.4 Structural Reports

The structural reports will be divided into groups as indicated below. These are, in principle, the groups called out in MIL-S-5709. The reports will be issued according to the schedule shown in Fig. 12.

Group I Basic Reports

- Structural Design Criteria
- Airplane Weights and Moments of Inertia

Group II External Loads Reports

- Aerodynamic Data
- External Load Analysis
- Power Plant Load Analysis

Group III Internal Loads Reports

- Internal Load Analysis

Group IV Stress Analysis Reports

- Thermal Effect due to Exhaust Gas Temperatures
- Primary Wing Structure
- Splitter Box and Wing Details
- Centre Base Structure
- Wing Tip Structure
- Main Intake Structure
- Super Structure Ribs
- Trunk Doors and Access Panels
- Cockpit Canopy and Deck
- Landing Gear
- Cargo Stowage Provisions

Engine Installation
Engine Intake Duct
Engine Exhaust Duct
Engine Firewall and Cowlings
Engine Oil System Installation
Engine Controls
Rotor Installation
Rotor Casing
Rotor Exhaust Duct
Fuel Tanks
Fuel System Installation
Flight Controls
Central Control Shaft
Hydraulic and Pneumatic Installations
Radio and Electrical Installations
Crew Furnishings
Instrument Installations
Equipment Installations

Group V Summary Reports

Stress Summary and Flight Limitations

3.1.4 PERFORMANCE ESTIMATION 6.1.1

Preliminary performance estimates appear in the Model Specification for Avrocar I. A preliminary substantiation report is being prepared and will be available by June 30. The estimates will be revised on completion of the wind tunnel test analysis of the proposed 1/5 scale AVROCAR model (ref. para. 4.3), and if the tests conform to schedule, a revised report will be available by December 1958 as indicated on the Aerodynamic and Propulsion Report Schedule (ref. Fig. 13).

This performance report will be based on:

(a) The above wind tunnel tests.

(b) The latest weight estimate, probably including a large proportion of weighed weight.

(c) The subcontractor's latest estimate of turborotor performance.

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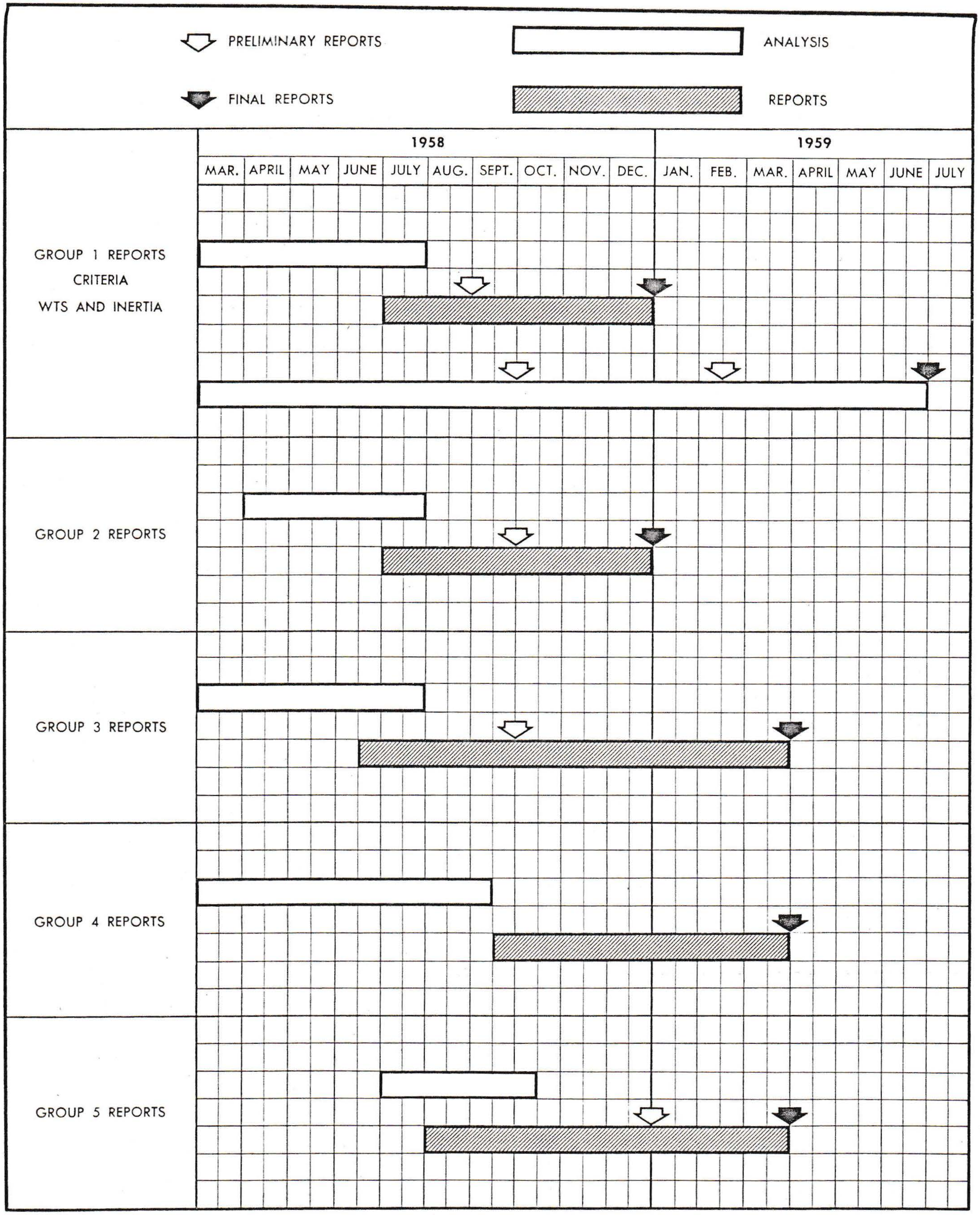

FIG. 12 STRUCTURAL REPORT SCHEDULE

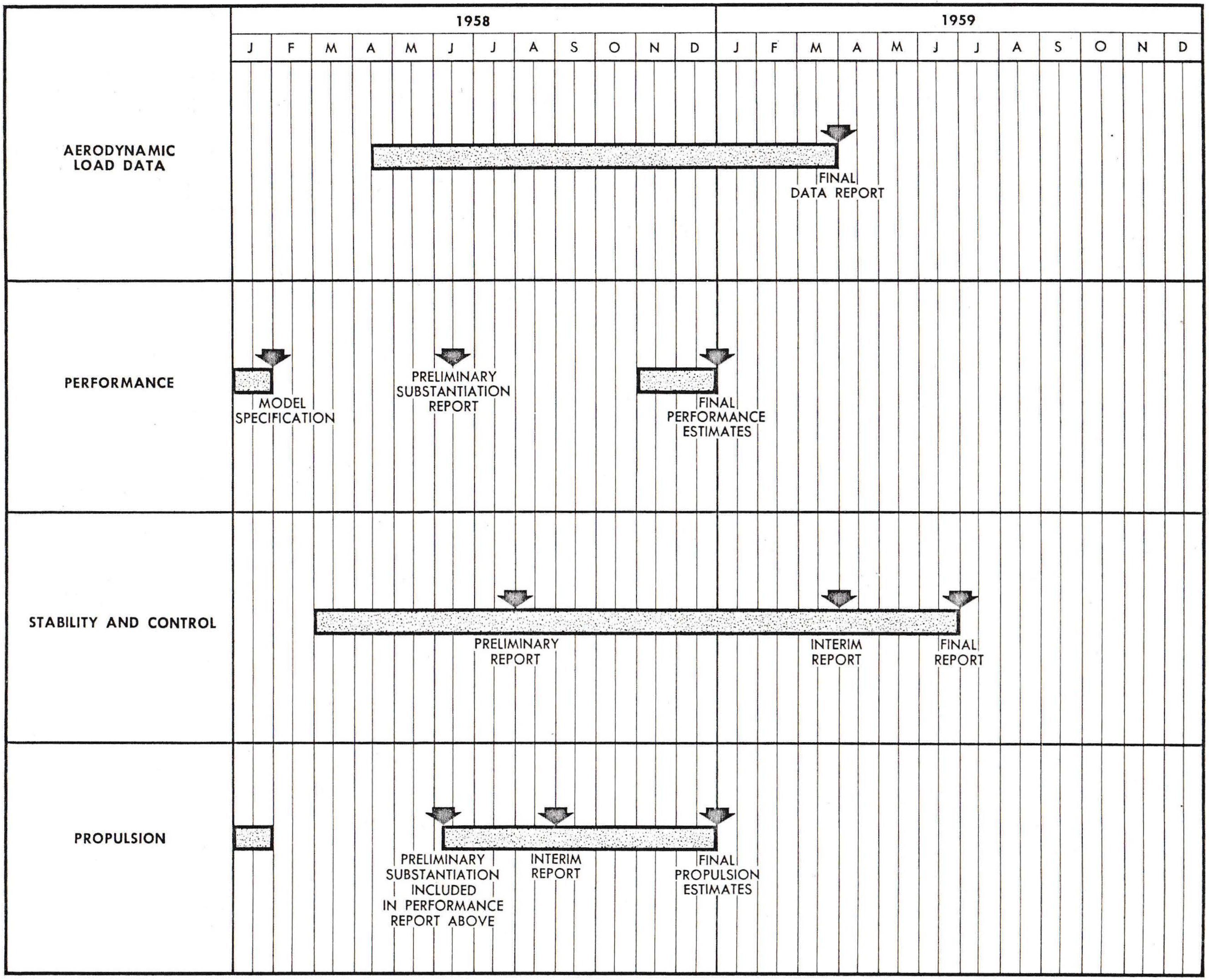

FIG. 13 AERODYNAMIC AND PROPULSION REPORT SCHEDULE

It will substantiate at least the following items of performance:

(a) Maximum level flight speeds.

(b) Hovering performance.

(c) Maximum rate of climb.

(d) Range with allowance for payload.

3.1.5 STABILITY AND CONTROL ANALYSIS 6.1.1

A short description of the proposed control system appears in Section 2. The stability and response of this system in the forward flight condition is being analyzed using wind tunnel test data obtained under the Project 1794 program which preceded that of the System 606A. The analysis is being worked out on an analog computer and the motions are being investigated with freedom in all conditions except yaw and sideslip. This will be followed with freedom of motion along and about all axes. As soon as satisfactory response and damping can be demonstrated, a preliminary report will be prepared and this will be available by 31 July 1958. On completion of the test analysis on the 1/20 scale AVROCAR model, a complete investigation into the stability response and handling characteristics in all phases of flight will be initiated. This will take the form of simulation studies on an analog computer with suitable parts of the AVROCAR flight control system incorporated as development proceeds. In addition, simple free flight models will be devised. These simulations are more fully described in para. 4.4. When the test results of the 1/5 scale AVROCAR model are available, the data will be compared with that of the smaller 1/20 scale model, and if necessary, adjustment to the assumed quantities will be made. At this stage a comprehensive interim report on the anticipated flight handling characteristics can be prepared. This will be issued by 31 March 1959 (ref. Fig. 13). A final report incorporating refinements or alterations to the interim report will be issued prior to the commencement of hovering trials.

Statement of Work Sub Parts

3.1.6 PROPULSION ANALYSIS 6.1.1

Estimates of static and forward flight thrust were made to provide the performance calculations in the Model Specification for Avrocar I As the design develops, these estimates will be refined.

Orenda Engines are estimating the turborotor characteristics (ref. Appendix). When the estimates are complete, a report will be prepared to substantiate the net thrust and specific consumption figures to be used in estimating the vehicle performance.

The report is scheduled for 1 September 1958. It will include data on duct and nozzle efficiency obtained from the P.V. 704 Six Viper Engine Test Assembly and from the Full Scale Wing Tip Segment described in para. 4.2.

3.2 MANUFACTURING

3.2.1 PROCESS PLANNING 6.1.2

Process Planning and Tool Design will be carried out in accordance with the Company's standard procedure for prototypes.

Preliminary investigations will be conducted during the initial design stages to determine the most economical method of tooling and manufacture. The basic method of manufacture, assembly procedure and tooling requirements will be established and closely co-ordinated with the design production economy throughout this stage.

3.2.2 MANUFACTURE OF JIGS AND TOOLS 6.1.2

The manufacture of jigs and tools will be carried out to process planning and tool design instructions.

Detail tooling will be utilized only if warranted by the number of parts to be produced or the nature of their complexity.

Assembly jigs will be held to a minimum, sufficient only to ensure meeting engineering specifications and points of control necessitating mating with adjacent assemblies. Gauging will be supplied to achieve the fitment between the airframe and the rotor.

3.2.3 MANUFACTURE OF PROTOTYPE VEHICLE 6.1

The manufacture of the first vehicle will be carried out to process planning instructions and the jigs and tools made available, in accordance with Company's procedure for prototypes.

Close co-operation will be maintained with the process planning department to achieve maximum economy.

Fig. 14 shows the flow of components required to achieve the production of the first vehicle in the time period specified.

Fig. 15 shows the manufacturing sequence and component breakdown to be used in producting the first vehicle.

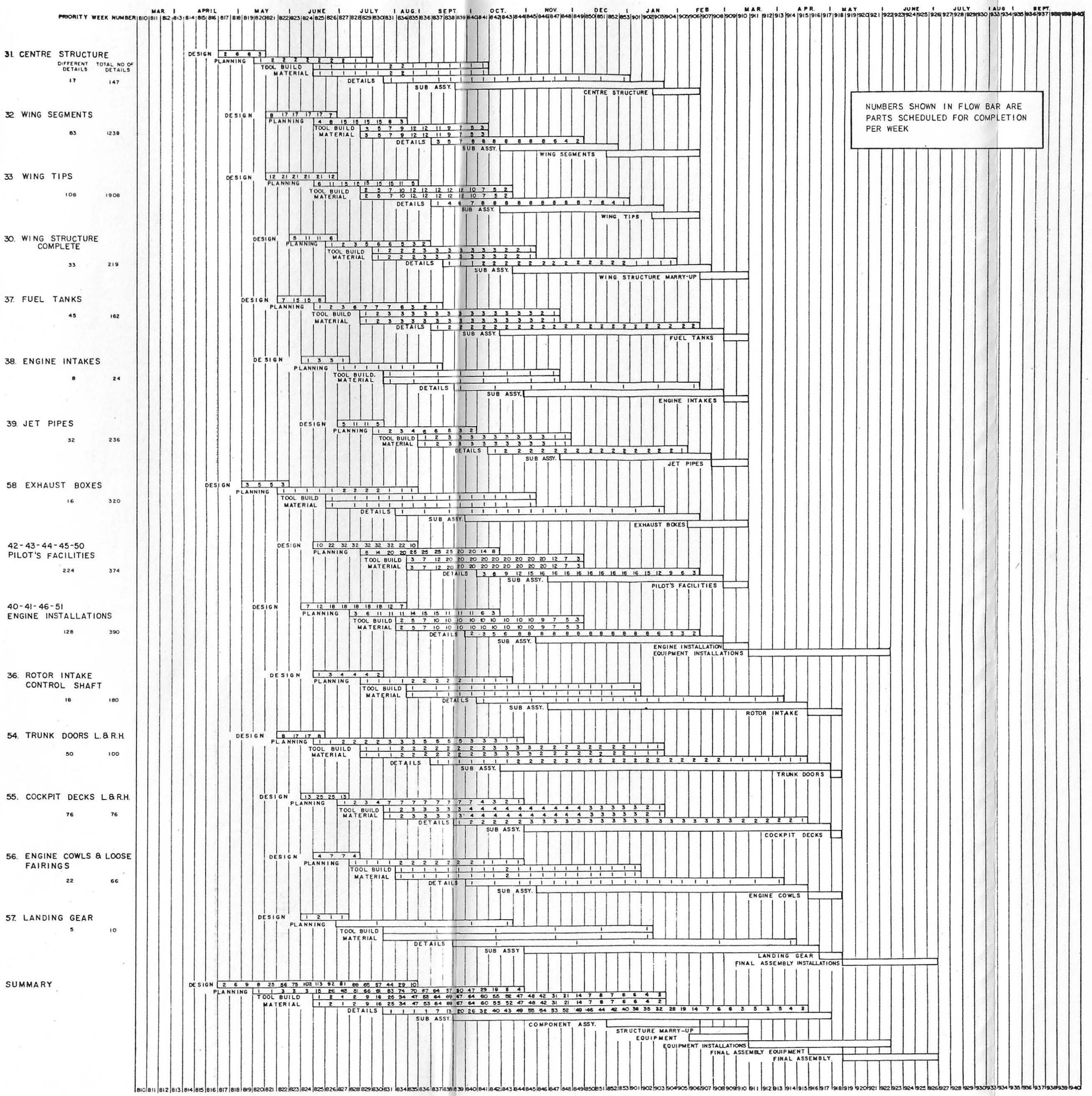

FIG. 14 COMPONENT FLOW CHART

Fig. 14 Component Flow Chart

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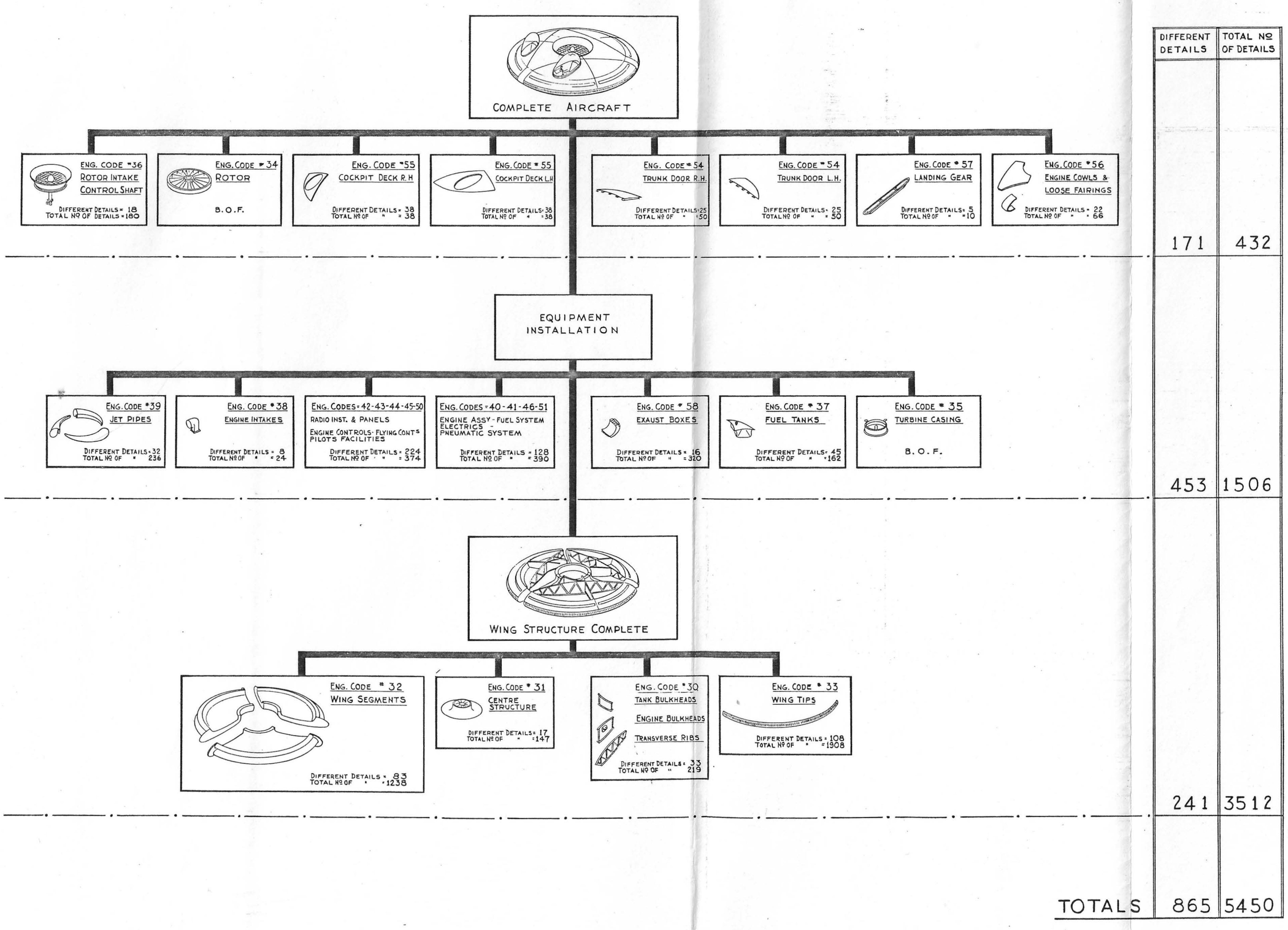


FIG. 15 MANUFACTURING SEQUENCE

Fig. 15
Manufacturing Sequence

4. MODELS AND TESTS

4.1 1/20 SCALE AVROCAR MODEL 8.1.1

Preliminary aerodynamic tests will be carried out on a 1/20 scale model of the AVROCAR in the 18 x 18 inch ejector tunnel at the contractor's facility. Fig. 16 is a photograph of this tunnel with a similar sized model installed. Fig. 17 illustrates the 1/20 scale model which is in the course of manufacture and testing is scheduled to start in June. A test specification for this model is almost complete and will be submitted before the tests begin.

The model incorporates both air intake and jet flow. To avoid the large pipes usually required for supply of intake and jet flows, an ejector is being used. In this way a relatively small volume of high pressure air is supplied and used to pump a much larger mass flow through the air intake of the model and out of the jets. As the volume of exhaust air from the jets will be greater than that drawn in through the air intake, the two flows will never be wholly compatible. Adequate representation is however anticipated.

The spoiler control system is represented and the control position can be set by adjusting three screws in the surface of the model.

The mosel is mounted on a five component balance giving lift, drag, pitching, rolling and yawing moments. The tests are designed to measure forces over the whole flight range including hovering for which condition the tunnel sidewalls are removed to avoid interference.

A data report with some analysis of results will be submitted at the conclusion of the first and major phase of testing. Sporadic testing of the model to confirm detail points will continue. If sufficient additional data is obtained another report will be issued. The work schedule chart (ref. Fig. 23) listing models and tests, indicates the proposed scheduling for the model.

4.2 FULL SCALE WING TIP SEGMENT 8.4.1

It is proposed to test a full scale 20° segment of the wing tip

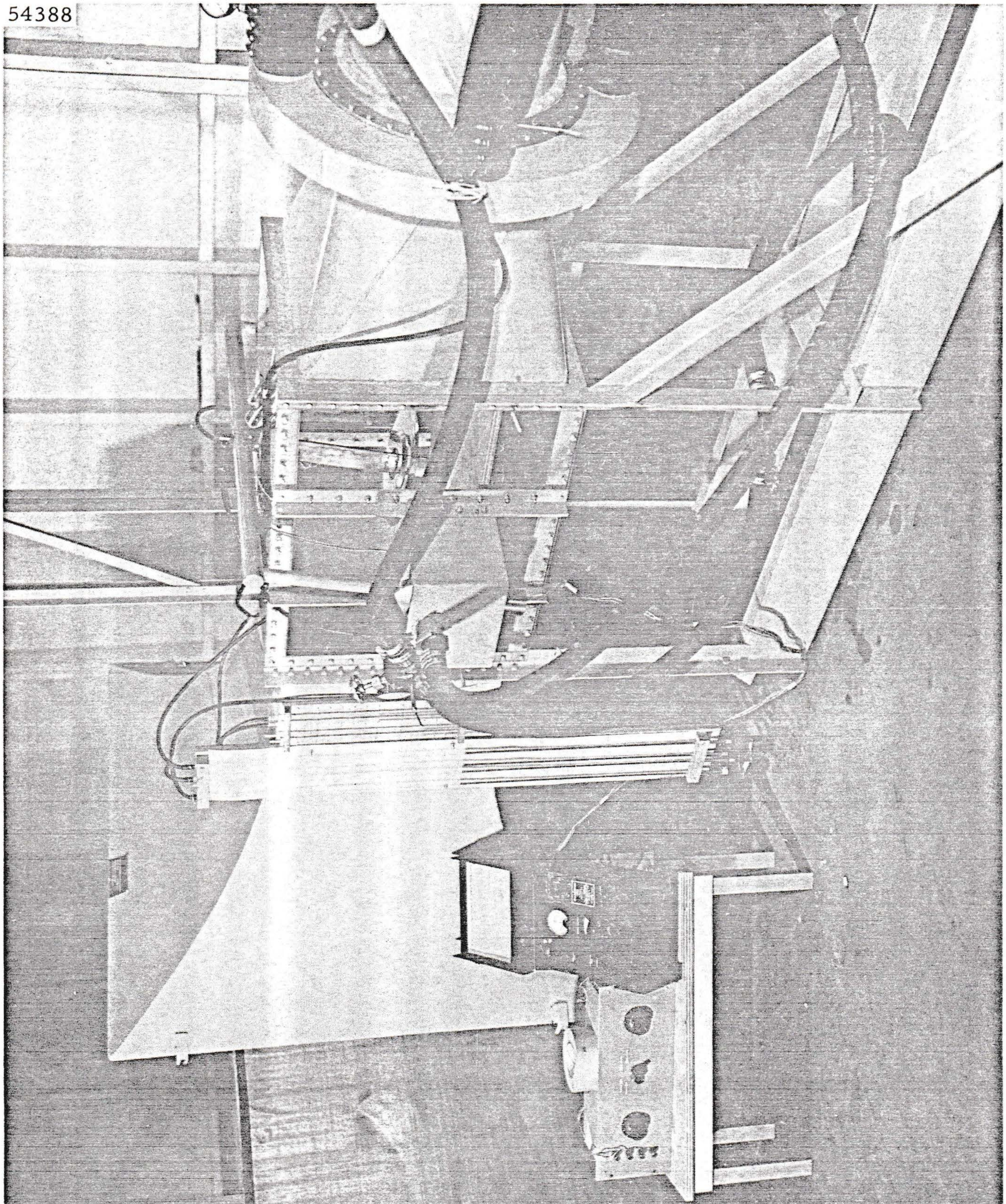


FIG. 16 MODEL INSTALLATION IN AVRO EJECTOR WIND TUNNEL

3201-802-4

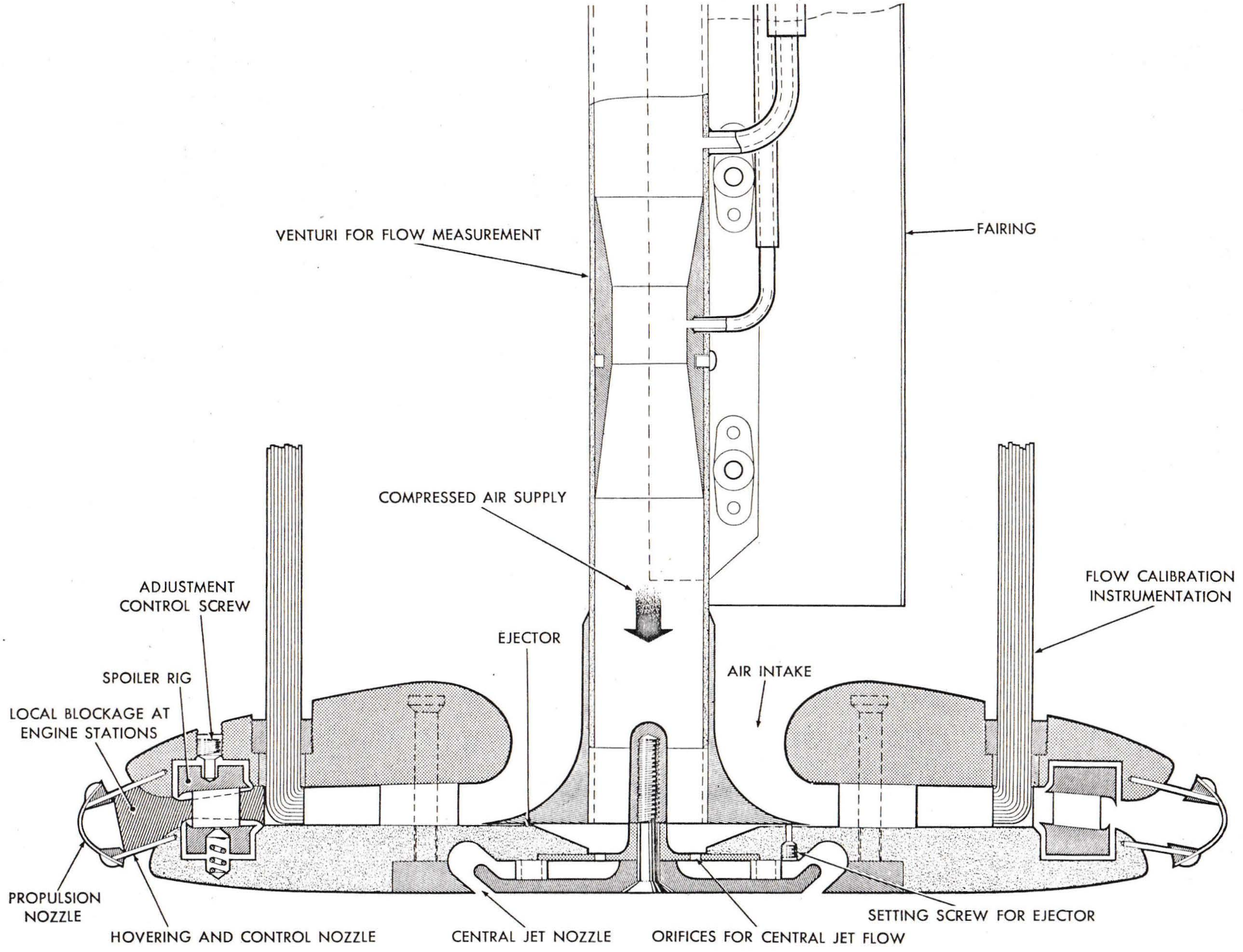


FIG.17 SECTION THROUGH 1/20 SCALE AVROCAR MODEL

control system. This requires a mass flow of approximately 30 lb./sec. at a total pressure of 16.5 psia. This mass flow is not available to the contractor by direct pumping capacity. The model will therefore be tested at the Orenda Engines Novel Facility where available compressors can produce a primary stream of 16 lb./sec. at 105 psia. There is thus little doubt that the required flow will be obtained.

Construction is about to start on the proposed rig illustrated in Fig. 18 The Work Schedule Chart (ref. Fig. 23) indicates the dates scheduled for test specification, development and production of data reports. The specimen will be mounted on the end of a 40 foot length pipe containing an orifice plate for flow measurement, and will be comprehensively instrumented for pressure survey.

For ease of manufacture, the nozzle has been represented as a straight portion but the spoiler control is faithfully reproduced. Successful testing of this model should give complete confidence in the satisfactory operation of the basic control which has already been tested at small scale on the rig illustrated in Fig. 19. This established the vital geometry of the nozzle and proved the proportionality of control and absence of hysteresis throughout the full 90° control range. This proportionality is illustrated by the graph in Fig. 20.

REDIRECTED SYSTEM 606A PROGRAM

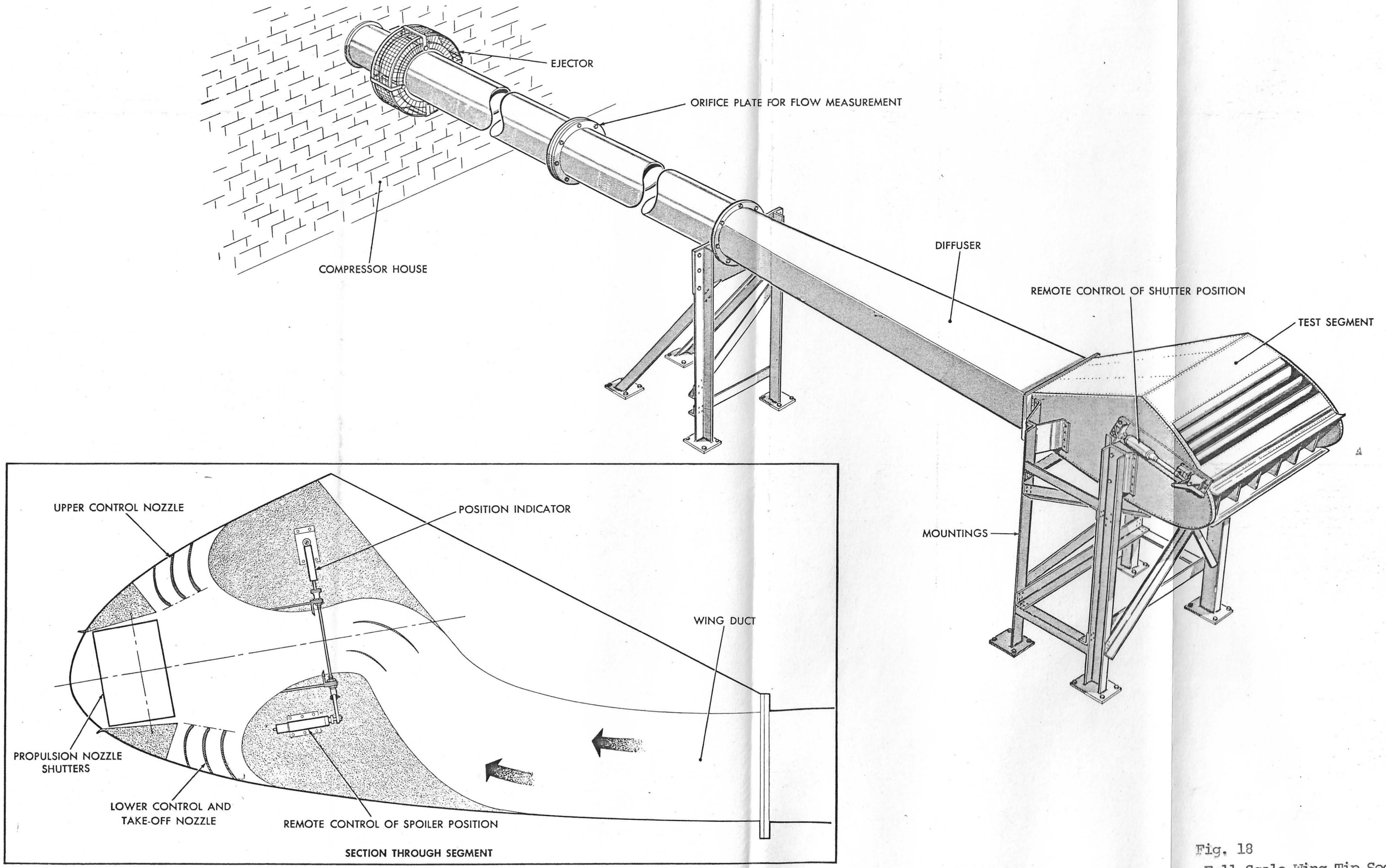
The following models and tests applicable to the AVROCAR form part of the redirected System 606A program. They are described to complete the requirement under Phase 1 of the AVROCAR Program.

4.3 1/5 SCALE AVROCAR MODEL

It is proposed to test a 1/5 scale force model of the AVROCAR with simulated intake and jet flow. The scale is chosen to match an existing balance and air supply constructed under the 606A Program for use in the Massie Memorial Wind Tunnel at W. A. D. C. Model and Balance are illustrated in Fig. 21.

This model will make use of the facility's scavenge system in the ten foot transonic wind tunnel. It will provide direct pumping capacity to supply the jet and suck the intake. A smooth accurately measured jet flow will thus be assured. This will confirm the results of the small model tests in which the ejected flow will probably be more difficult to assess accurately.

In other respects the large model will also be superior; the scale provides Reynolds nos. up to approximately 6×10^6 and allows for more accurate



SECTION THROUGH SEGMENT

FIG. 18 **FULL SCALE WING TIP SECTOR**

Fig. 18
Full Scale Wing Tip Sector

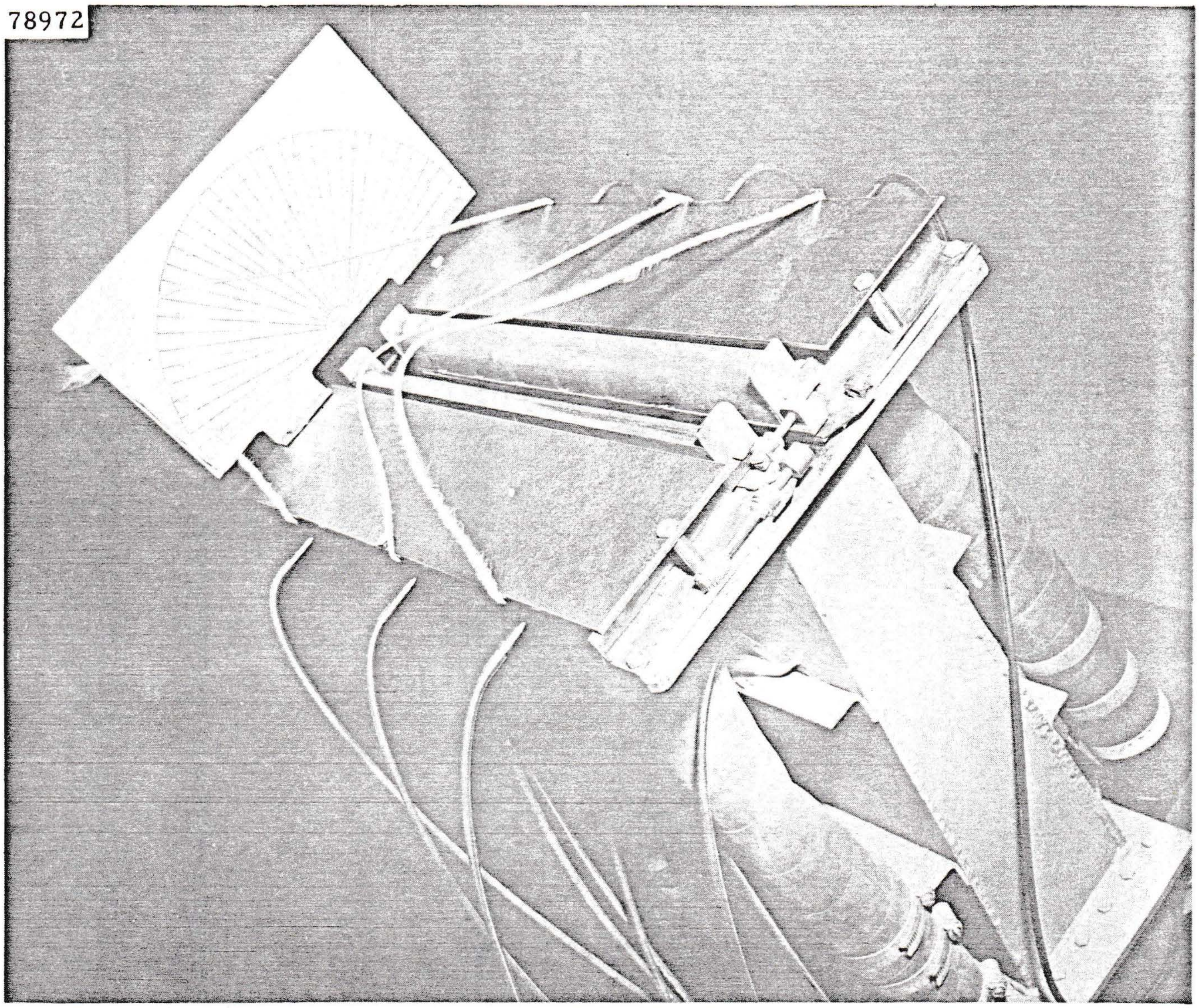
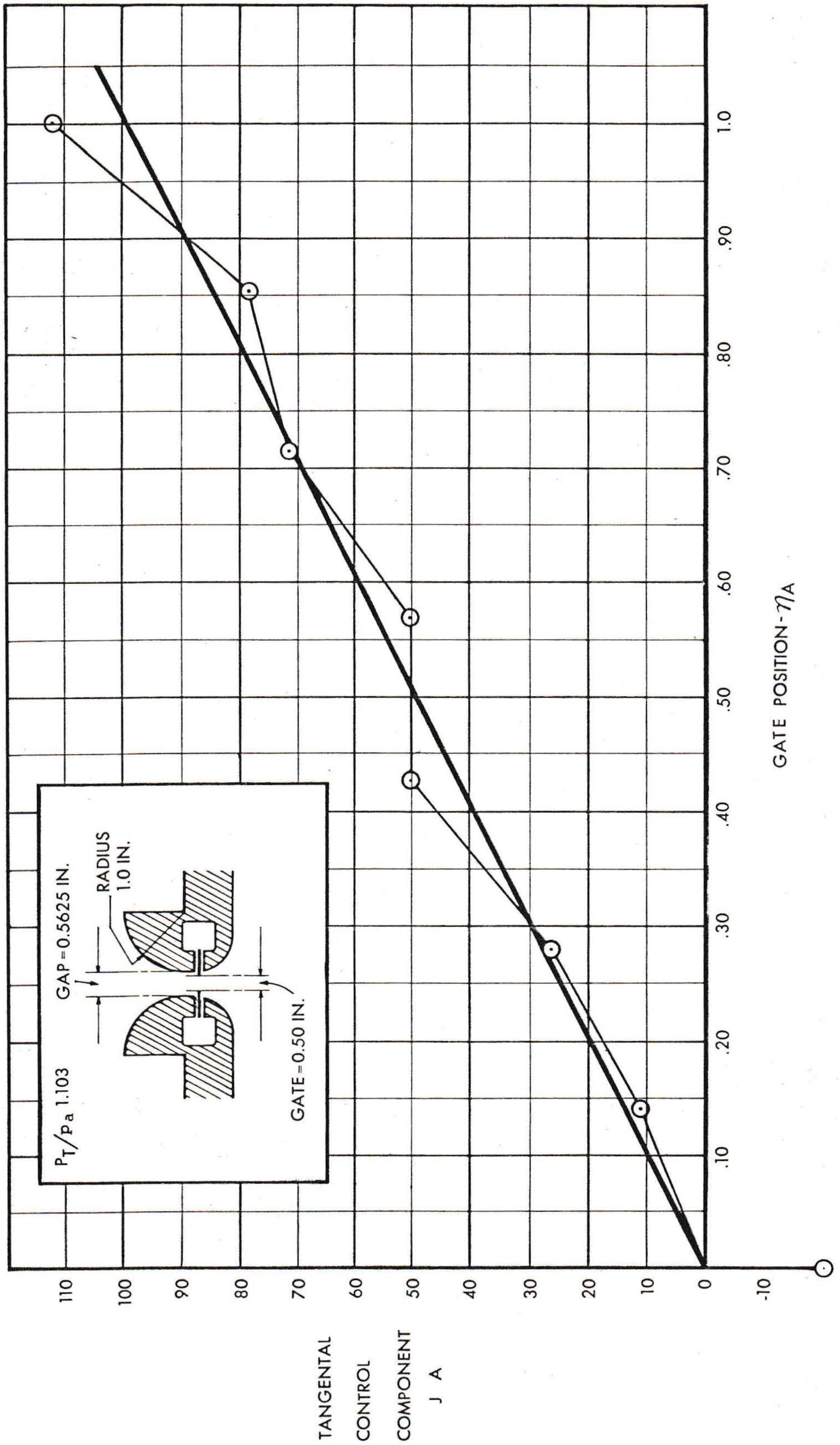


FIG. 19 JET NOZZLE CONTROL RIG

3179-802-2


110
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TANGENTAL CONTROL COMPONENT J A
.10
.20
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.40
.50
.60
.70
.80
.90
1.0
GATE POSITION - η/A
P_T/p_a 1.103
GAP = 0.5625 IN.
RADIUS 1.0 IN.
GATE = 0.50 IN.

3195-802-1

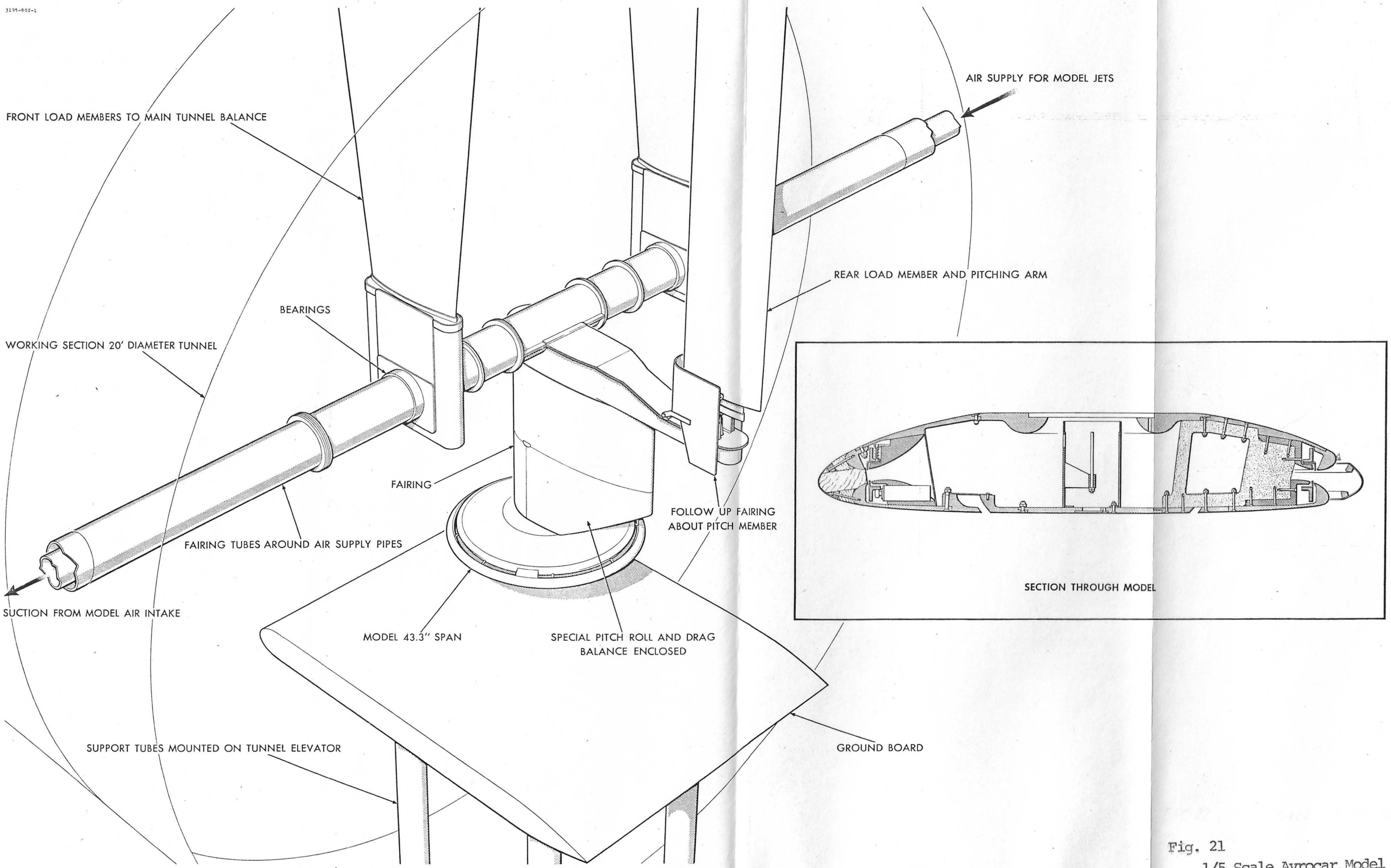

FIG. 21 1/5 SCALE AVROCAR MODEL

Fig. 21
1/5 Scale Avrocar Model

representation of the spoiler control. In addition the large model will be relatively much smaller with respect to the tunnel working section than the 1/20 scale model. As a result, indeterminate tunnel wall interference due to the jet flow, particularly in transition, will be minimized.

The ground will be mounted on the tunnel elevator and remotely controlled. The spoilers likewise will be remotely controlled in order to reduce the configuration change time unavoidable in earlier models. This will allow considerable improvement in test efficiency. A limited number of surface pressure taps will be fitted to provide a check on the surface pressure data obtained from the reflection plane model now being tested in the 606A program.

Tests are scheduled for mid July and the model will be ready for approval at the Contractor's plant on July 1st. Approximately five weeks testing is scheduled which should allow reasonable coverage of the unusually large number of test parameters involved. These include pitch and roll control, ground distance, transition control, jet strength, intake flow, angle of attack and tunnel speed. A report on the results, including a comparison with the 1/20 scale model test, is planned for completion in January 1959.

4.4 SIMULATION STUDIES

This item is also covered in the re-directed System 606A program, but is again referred specifically to the AVROCAR I.

The system of control and stability proposed for the AVROCAR I is described in para 3.1.1.3.

The following points are of paramount interest:

1. Control is by jet deflection in both hovering and forward flight conditions.

2. Due to the C of G position in the middle of the wing the vehicle is unstable in pitch in the forward flight condition without the stabilizer.

In view of these and the additional cases imposed by hovering and control in the powerful ground cushion and of transition to forward flight from the ground cushion and in free air, extensive simulation studies are proposed.

Simulation may be carried out either on representative mechanical models operating in free flight or with an electronic analog computer. The simulations will use as much actual control system hardware as is practicable.

Complete dynamical similarity is very difficult to achieve at small scale in a mechanical model, but it is believed that valuable work can be done with models which possess approximate similarity and limited freedom of motion. Two such models are presently planned and if possible, further similar models will be devised. The model illustrated in Fig. 22 is intended to combine the gyro system with jet control in free air hovering. No attempt is made to simulate the wing or the effect of ground upon it. The model illustrated in Fig. 22A is intended to be flown in the Contractor's wind tunnel by means of manual controls outside the tunnel. This represents the combination of a gyro stabilizing system with a circular planform in forward flight. However, flap type controls are used instead of jet controls.

The electronic analog does not suffer from the simulation difficulties inherent in mechanical models and is thus considerably more versatile and comprehensive. It is intended to carry out an analog program in several phases. The first phase is presently underway on two PACE units. This involves a preliminary study of the system in all degrees of freedom. From this, the effects of varying available design parameters to improve stability and response, and the accuracy of estimated derivatives necessary to predict response satisfactorily can be investigated. This phase relates to forward flight cases.

The second phase will be the introduction of a simple stick control, not designed to represent the actual pilot's controls, but enabling command input to the computer, and a simple display of pitch, roll and yaw on a standard cathode ray oscilloscope. This will enable the operator to assess the ease with which any long period motions can be controlled.

The third phase will be an analytical program to cover all régimes of flight including hovering and transition with the given system.

The program will develop with the introduction of a mock-up, operator's seat, stick and visual display. This will be followed with provision of as much of the control system hardware as it is practicable to incorporate and will be dependent upon the outcome of discussions with NACA Laboratory at Ames.

3199-802-4

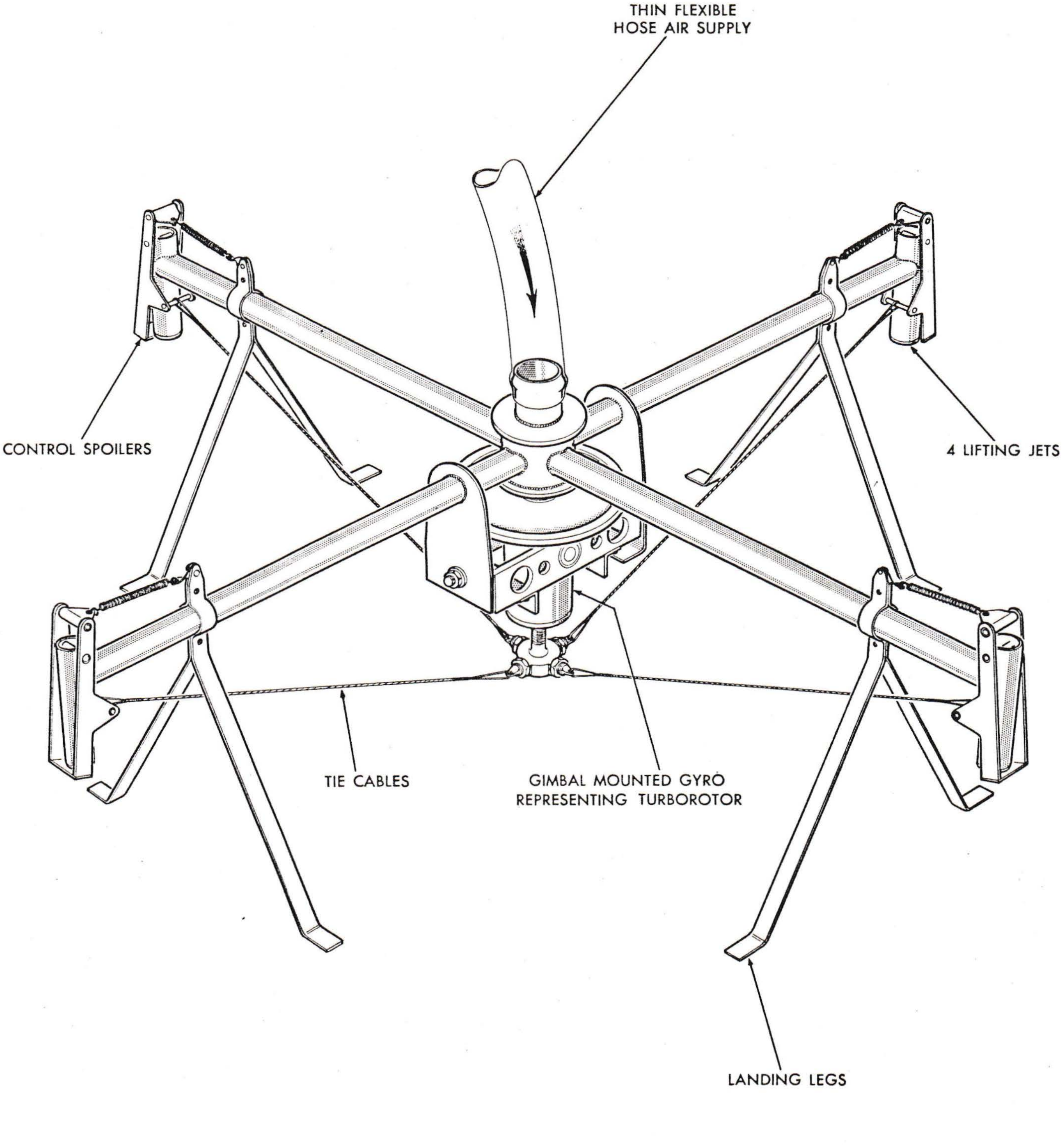

FIG. 22 SIMULATION MODEL FOR HOVERING

3324-802-3

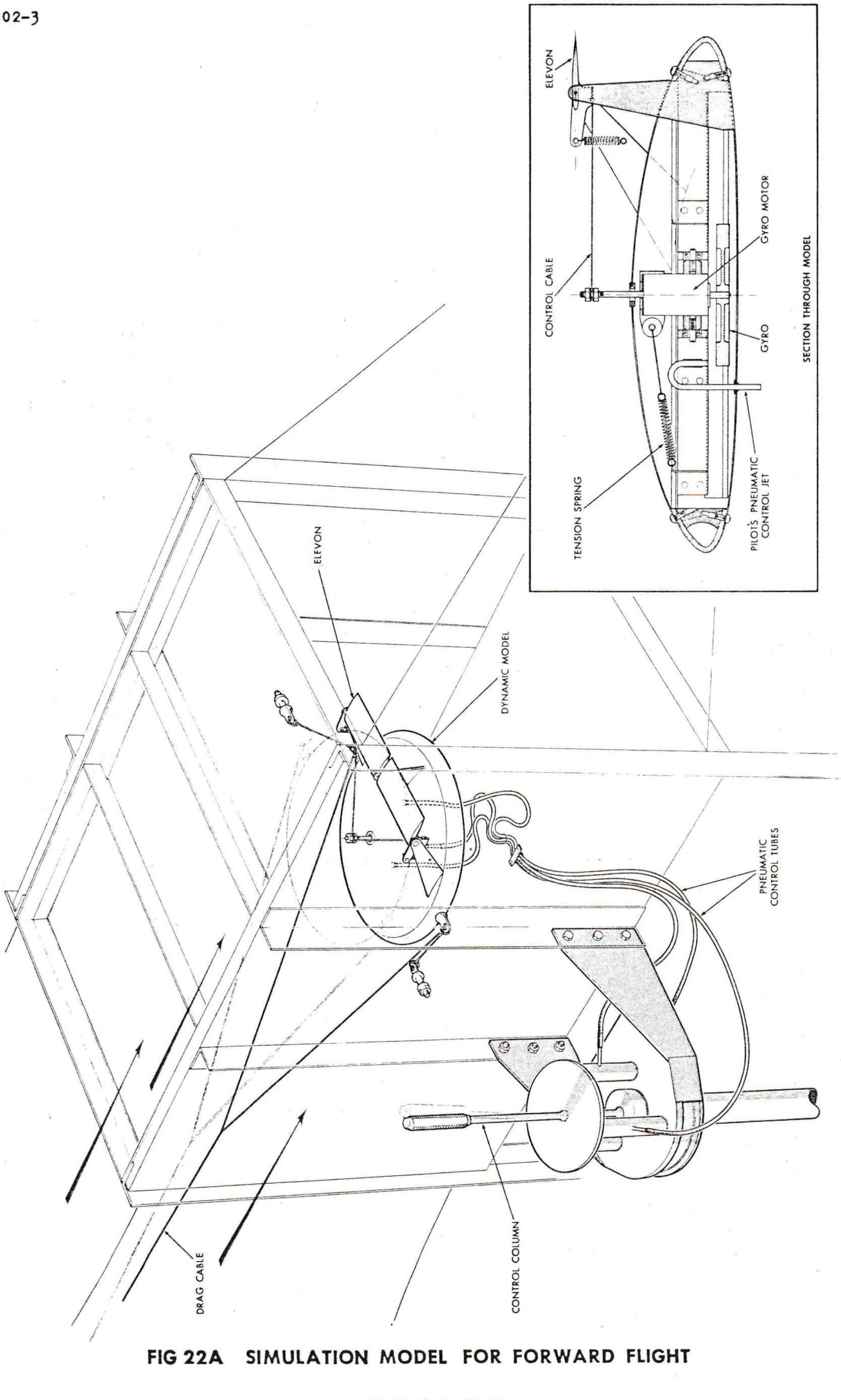

FIG 22A SIMULATION MODEL FOR FORWARD FLIGHT

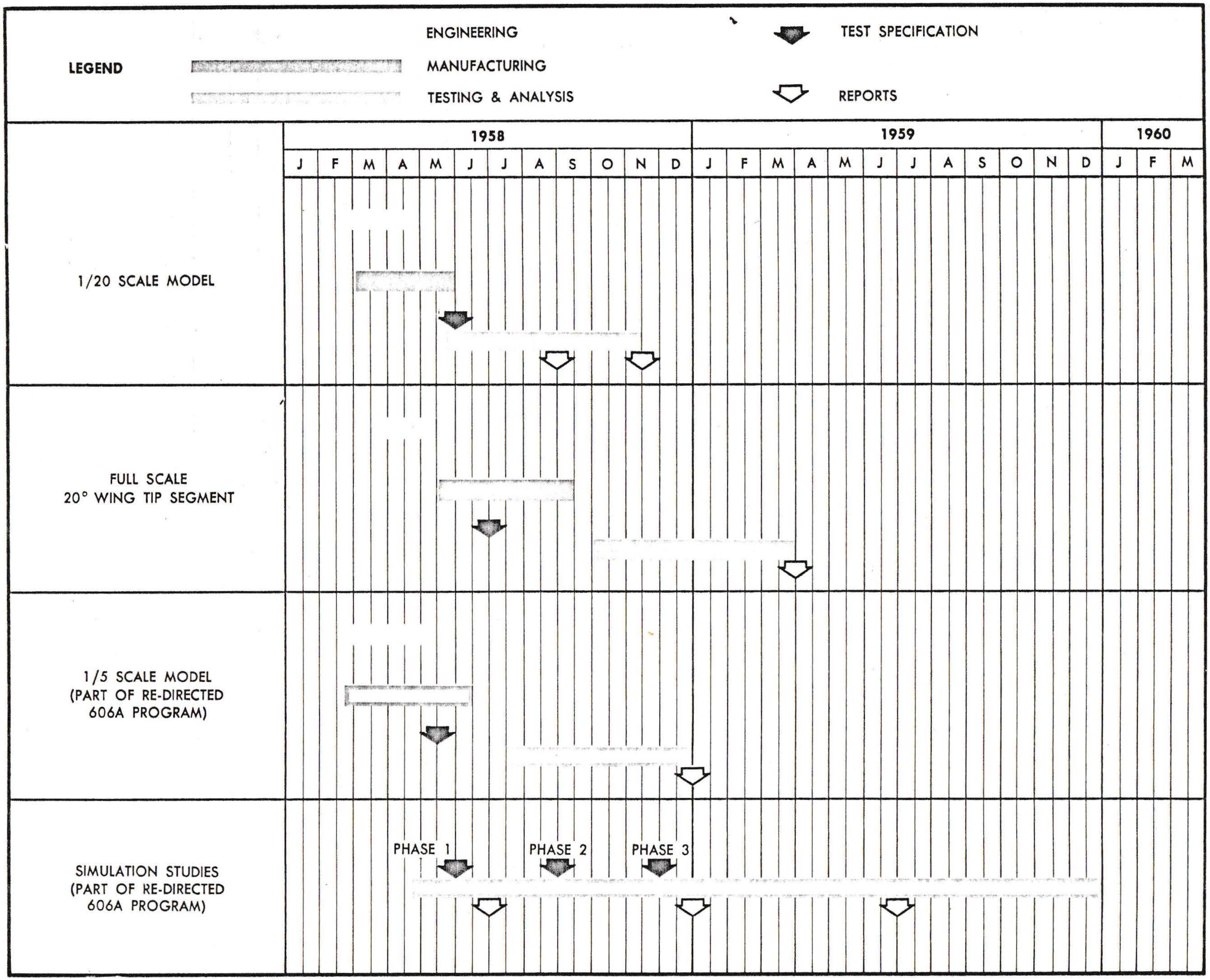

FIG. 23 WORK SCHEDULE CHART - MODELS AND TESTS.

3197-802-3

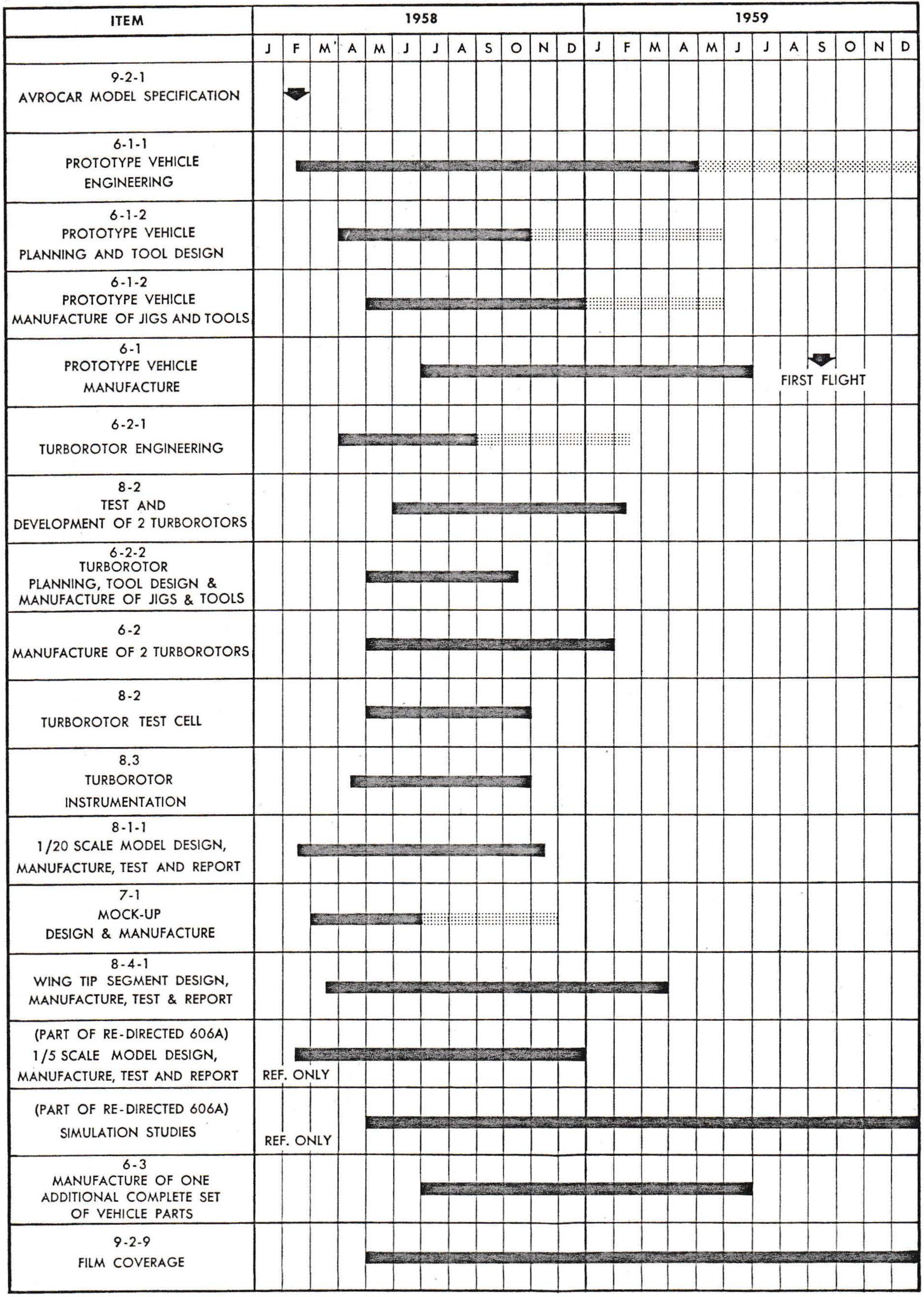

FIG. 24 WORK SCHEDULE CHART - ENGINEERING AND MANUFACTURING

Statement
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5. DATA REQUIREMENTS

5.1 PROGRAM PLANNING REPORT 9.2.2

Fifteen copies of this Program Planning Report are now submitted to the Commander, Hq. Air Research and Development Command, ATTENTION: RDZSXA, Wright-Patterson Air Force Base, Ohio.

5.2 MONTHLY PROGRESS REPORTS 9.2.3

Twenty-five copies of a Monthly Progress Report will be furnished by the thirtieth day of the month following the reported one month period. This will present a summary of the following items:

(a) Work performed

(b) Percentage of task accomplished

(c) Results obtained

(d) Problems encountered

(e) Budgetary status of the program.

Alternate reports will be in letter form.

These reports will be delivered to Hq. ARDC, ATTENTION: RDZSXA and such other places designated by the Procuring Contracting Officer.

5.3 TEST SPECIFICATIONS 9.2.6

Ten copies of detailed specifications of tests to be accomplished under item 8 of the Preliminary Statement of Work identified 58RDZ-12743 dated 1 May 1958 will be submitted to Hq. ARDC, ATTENTION: RDZSXA, for approval. The test specifications will provide the following information:

(1) Test objectives

(2) Facility requirements

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of Work
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(3) Model characteristics

(4) Test conditions

(5) Instrumentation requirements

(6) Data collection and reduction etc.

Test specifications will be furnished in accordance with the Work Schedule Chart of the approved Program Planning Report.

5.4 TECHNICAL REPORTS AND SUMMARY

9.2.7 &
9.2.8

Twenty copies of technical reports presenting results of tests accomplished under item 8 and covering other work accomplished, will be submitted in accordance with the Preliminary Statement of Work and as indicated in the Schedule Charts contained within this report.

Twenty-five copies of a Summary Report will be submitted containing:

(1) An introduction which includes historical background and statement of purpose or objectives.

(2) Discussion of the design concept.

(3) Presentation of the important results.

(4) Evaluation and interpretation of these results.

(5) Conclusions

(6) Recommendations

5.5 PROJECT REVIEWS

9.1

Three project reviews of the program will be given by the Company at times and places mutually established by the Contracting Officer and the Contractor.

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5.6 FINANCIAL REPORTS

9.2.4

Ten copies of a Quarterly Financial Status Report of Contract (D.D. Form 1097) will be compiled and sent to: Hq. ARDC, ATTENTION: RDZSXA.

5.7 FILMS

9.2.9

One partially edited 16 mm color film together with a written description of subject matter will be submitted quarterly to cover significant events such as mock-ups, engine test stand runs, wind tunnel tests etc.

One composite 16 mm color film with sound track covering the development of the AVROCAR program will be submitted on completion of the contract.

5.8 DRAWINGS AND DATA

9.2.10

One complete set of detail drawings and data covering the AVROCAR vehicle will be delivered on completion of the contract.

6. COST AND MANHOUR ESTIMATES

6.1 ANALYSIS OF ESTIMATED COSTS BY SUB PARTS

Sub Parts			Hours	Direct Labour Rate	Direct Labour Cost	Labour Over Head Rate	Labour Over Head Cost	Material & Direct Charges	Sub-Total	Admin Over Head Rate	Admin Over Head Cost	Sub-Total	10% Fee	Sub-Total	3% Exchange	Total	
6.1.1	Engineering	Prototype Vehicle	73,533	$3.10	227,952	120%	273,543		501,495	8.5%	42,627	544,122	54,412	598,534	17,956	616,490	
6.1.2	Production Manufacturing	Prototype Vehicle Planning & Tool Design	11,447	$2.80	32,051	120%	38,461		70,512	8.5%	5,994	76,506	7,651	84,157	2,525	86,682	
6.1.2	Production Manufacturing	Prototype Vehicle Jigs & Tools	45,147	$2.30	103,838	120%	124,605	29,757	258,200	8.5%	21,947	280,147	28,015	308,162	9,245	317,407	
6.1	Production Manufacturing	Prototype Vehicle	39,924	$2.10	83,840	120%	100,608	15,921	200,369	8.5%	17,031	217,400	21,740	239,140	7,174	246,314	
8.1.1	Engineering	1/20 Scale Model	4,201	$3.10	13,023	120%	15,628		28,651	8.5%	2,435	31,086	3,109	34,195	1,025	35,220	44,353
8.1.1	Experimental Manufacturing	1/20 Scale Model	1,255	$2.30	2,887	140%	4,042	500	7,429	8.5%	632	8,061	806	8,867	266	9,133	
7.1	Engineering	Mock-up	2,100	$3.10	6,511	120%	7,814		14,325	8.5%	1,218	15,543	1,554	17,097	513	17,610	85,023
7.1	Experimental Manufacturing	Mock-up	9,100	$2.30	20,931	140%	29,303	4,605	54,839	8.5%	4,661	59,500	5,950	65,450	1,963	67,413	
8.4.1	Engineering	Wing Tip Segment	4,201	$3.10	13,023	120%	15,628		28,651	8.5%	2,435	31,086	3,109	34,195	1,025	35,220	64,113
8.4.1	Experimental Manufacturing	Wing Tip Segment	3,623	$2.30	8,334	140%	11,669	3,500	23,503	8.5%	1,998	25,501	2,550	28,051	842	28,893	
6.3	Production Manufacturing	One (1) Additional complete set of vehicle parts	8,570	$2.10	18,000	120%	21,600	13,275	52,875	8.5%	4,495	57,370	5,737	63,107	1,893	65,000	
9.2.9	Engineering	Film Coverage	1,680	$2.50	4,200	120%	5,040	3,385	12,625	8.5%	1,073	13,698	1,370	15,068	452	15,520	
																1,540,902	
6.2 8.2 8.3	Orenda Engines Ltd. Subcontract								456,595	8.5%	38,811	495,406	49,540	544,946	16,349	561,295	

GRAND TOTAL $ 2,102,197 US

Subcontractor's portion of total funds is 26%

Analysis of estimated cost by sub parts

6.2 MANHOUR AND DOLLAR GRAPHS

The following graphs present a breakdown of the time and cost elements of the Preliminary Statement of Work by sub parts.

3198-802-2

3321-802-1

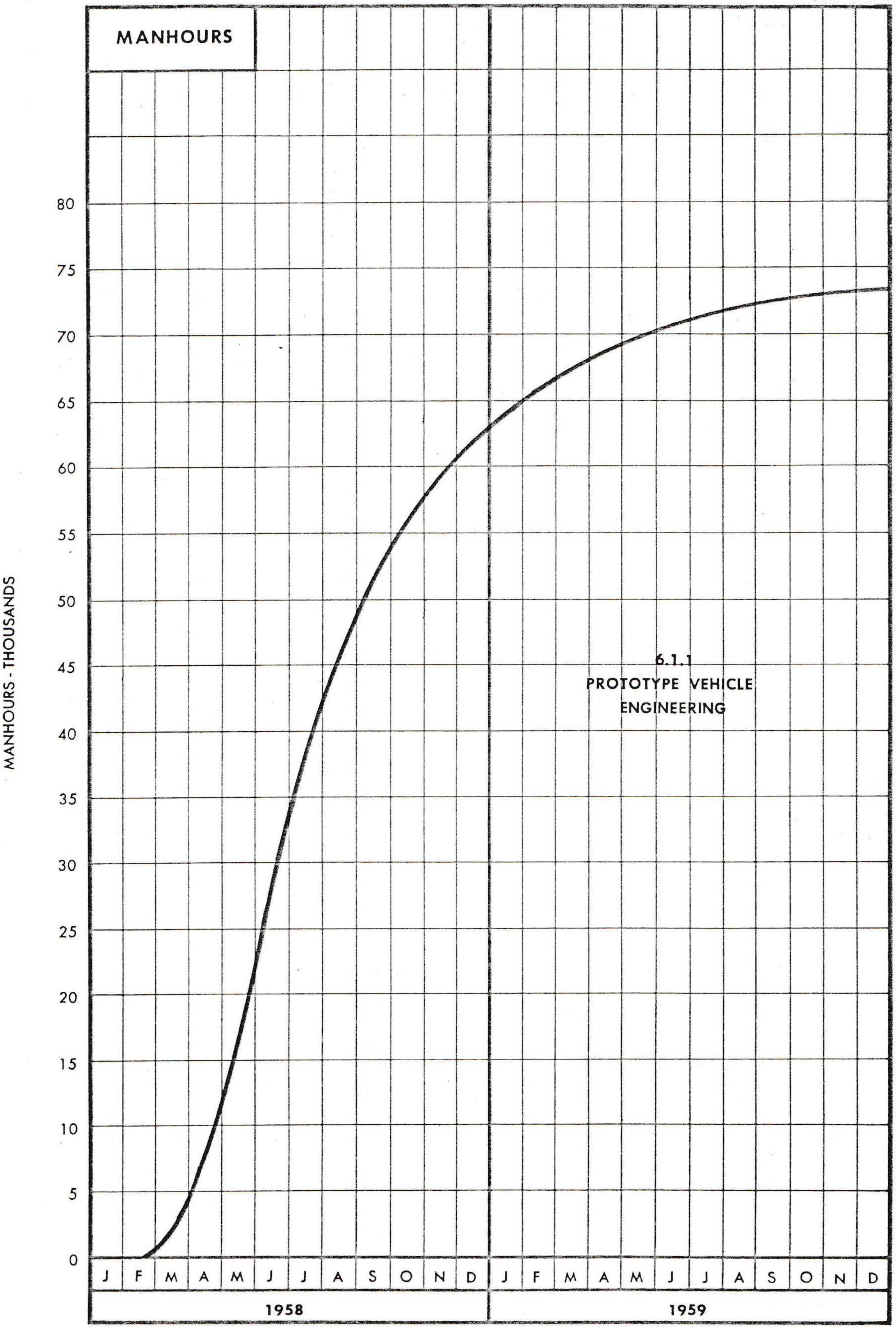

FIG. 25 PROTOTYPE VEHICLE ENGINEERING - MANHOURS - CUMULATIVE

3206-802-2

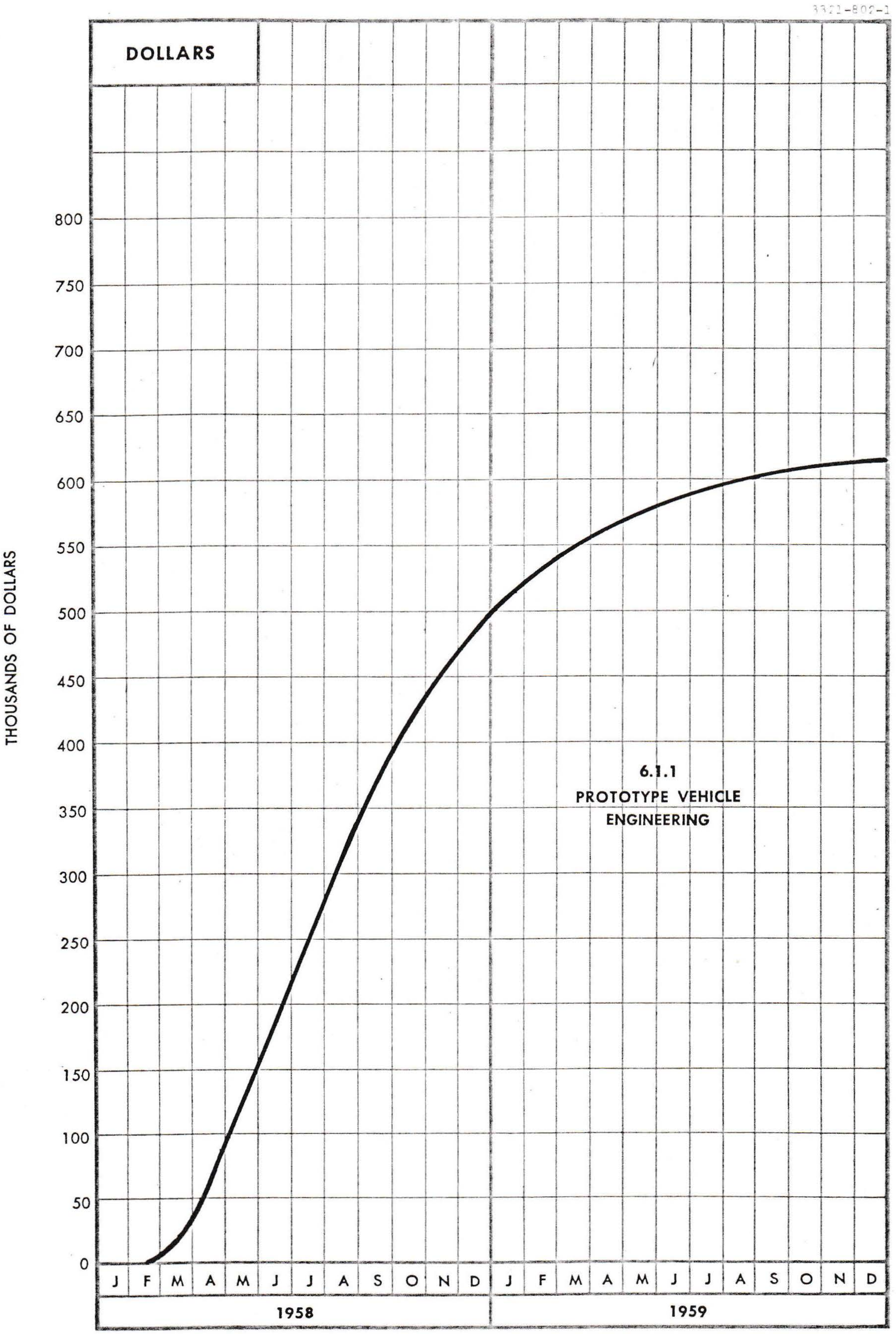

FIG. 26 PROTOTYPE VEHICLE ENGINEERING - DOLLARS - CUMULATIVE

3207-802-2

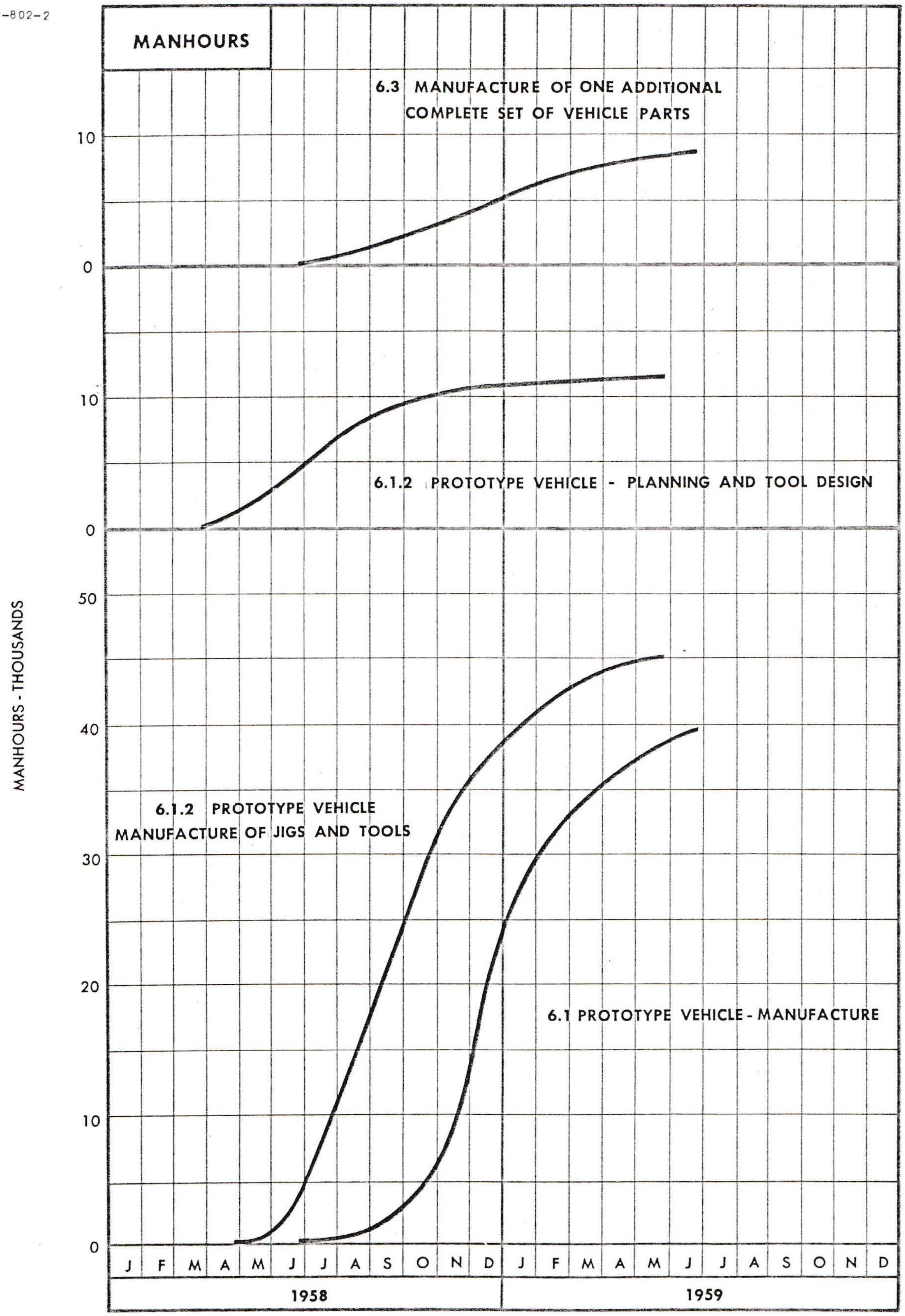

FIG. 27 PRODUCTION MANUFACTURING - MANHOURS - CUMULATIVE

3208-802-2

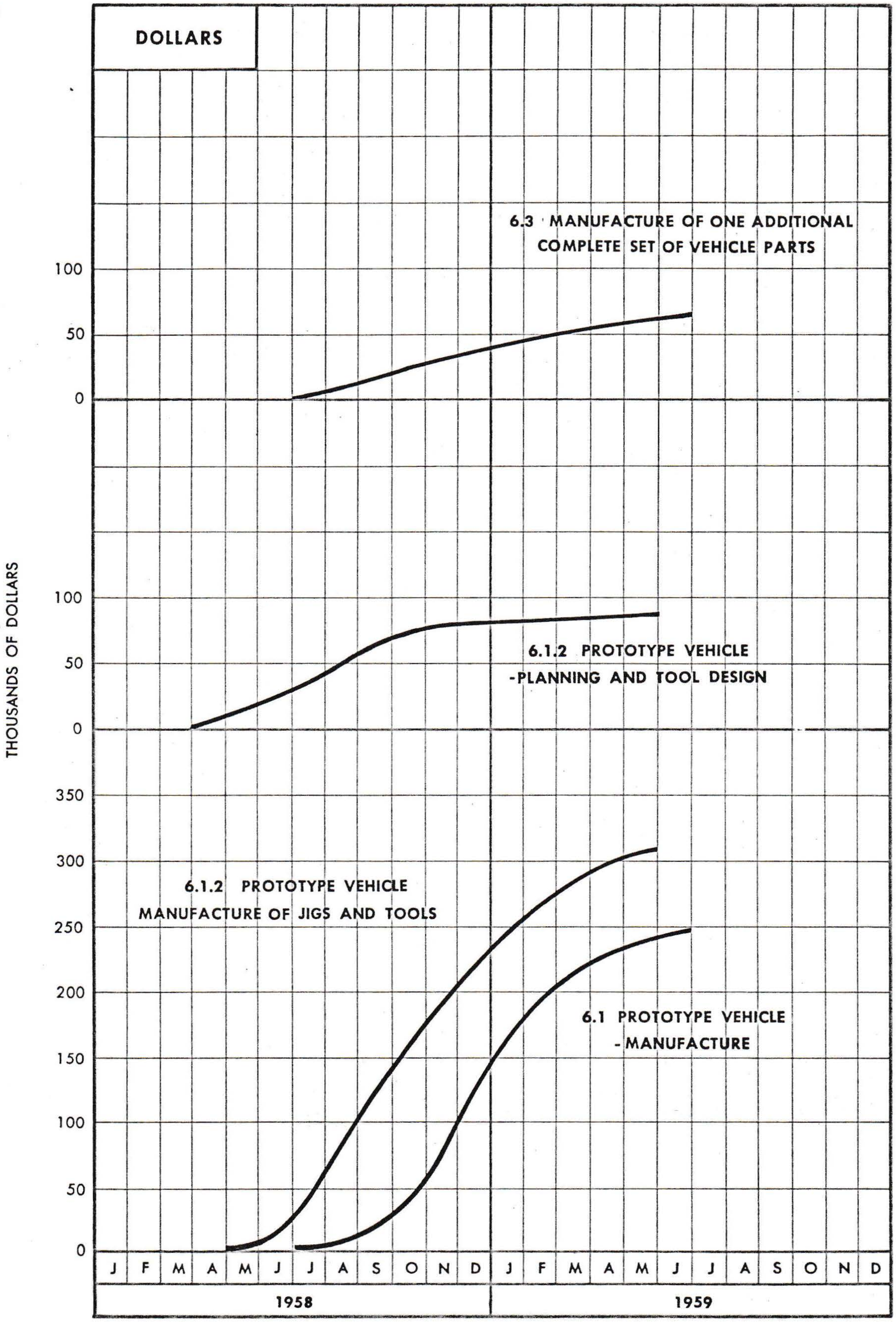

FIG. 28 PRODUCTION MANUFACTURING - DOLLARS - CUMULATIVE

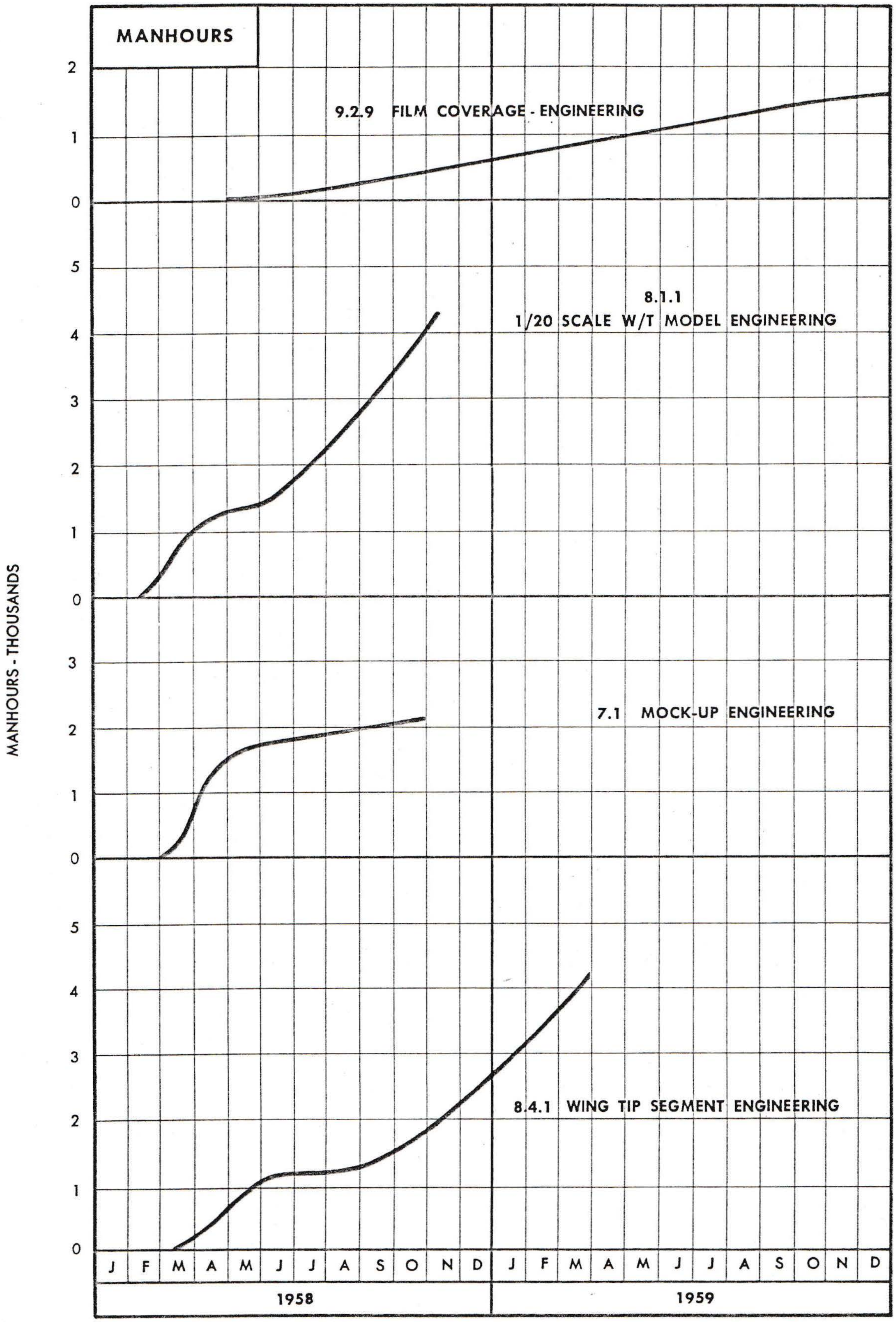

FIG. 29 MISCELLANEOUS ENGINEERING - MANHOURS - CUMULATIVE

3210-802-2

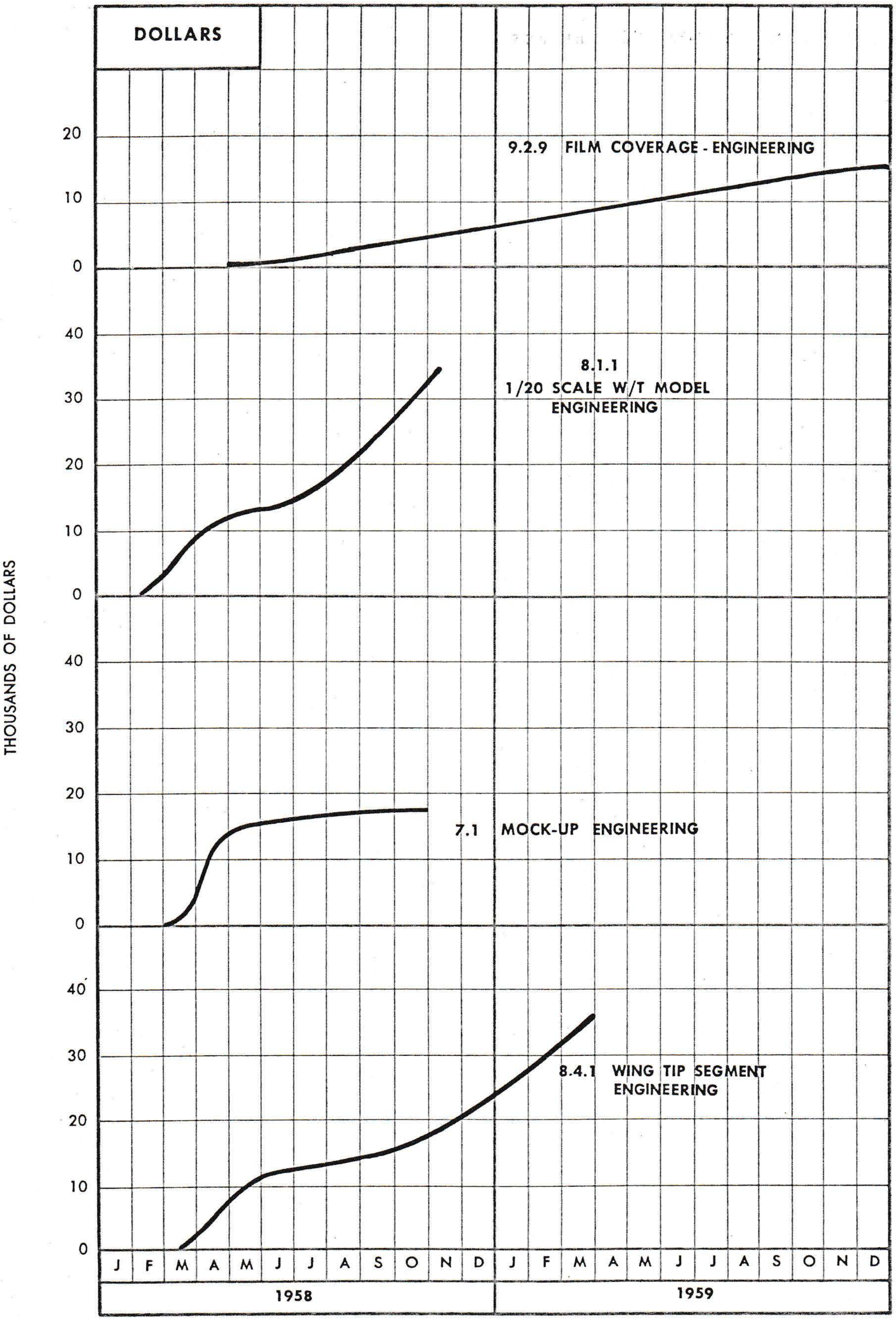

FIG. 30 MISCELLANEOUS ENGINEERING - DOLLARS - CUMULATIVE

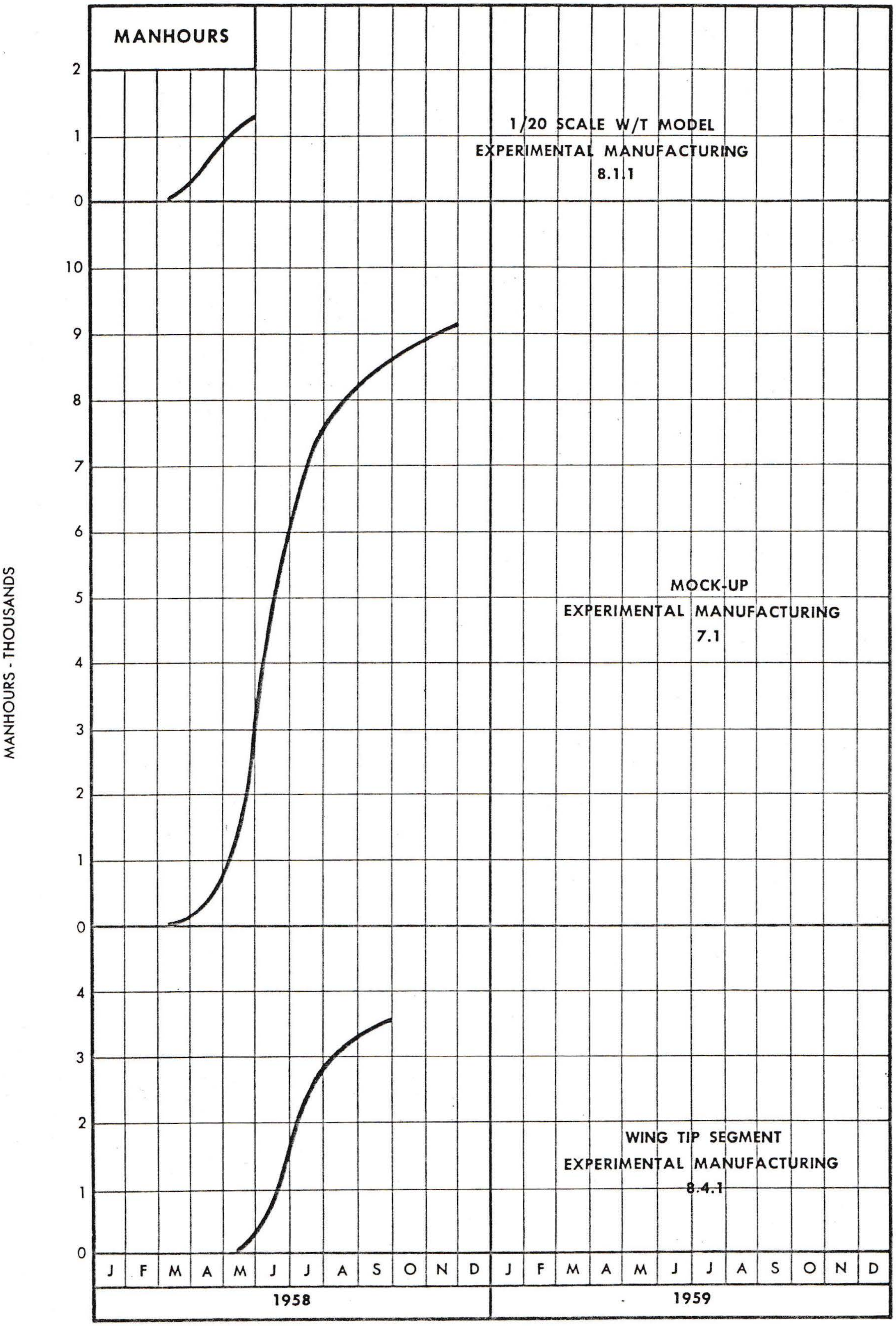

FIG. 31 EXPERIMENTAL MANUFACTURING - MANHOURS - CUMULATIVE

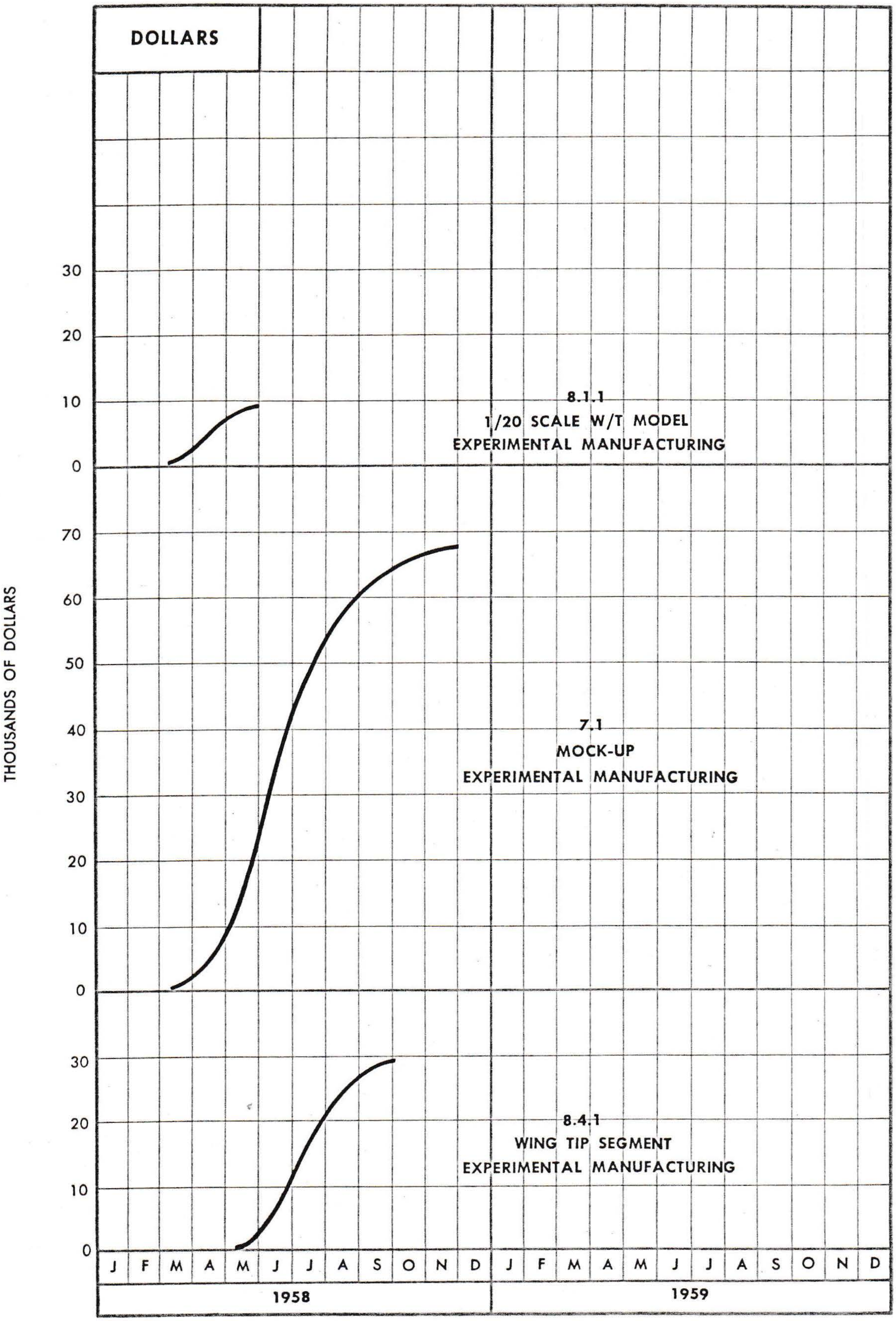

FIG. 32 EXPERIMENTAL MANUFACTURING - DOLLARS - CUMULATIVE

3213-802-2

3321-802-1

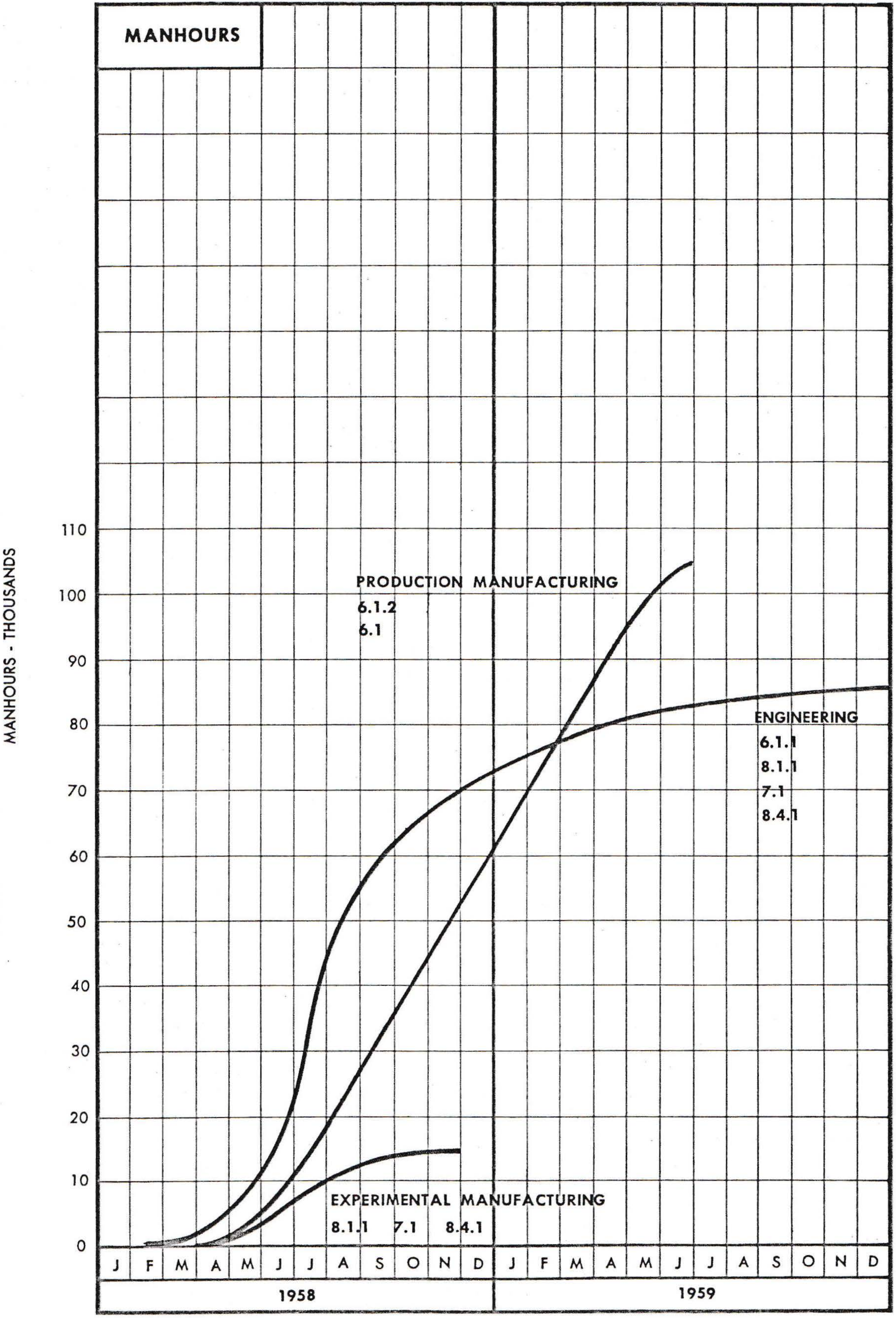

FIG. 33 SUMMARY OF ENGINEERING AND MANUFACTURING - MANHOURS - CUMULATIVE

3214-802-2

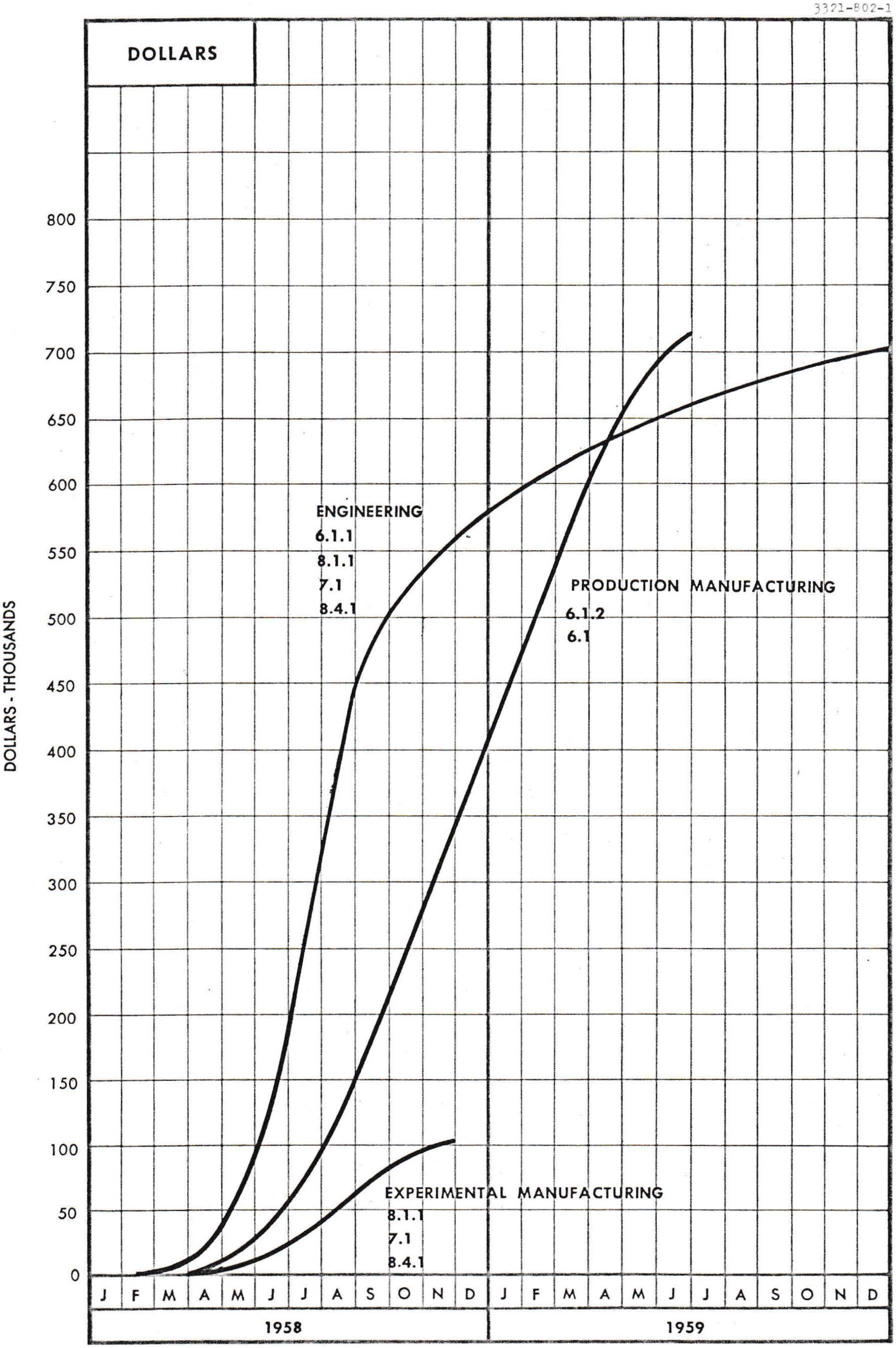

FIG. 34 SUMMARY OF ENGINEERING AND MANUFACTURING - DOLLARS - CUMULATIVE

3215-802-2

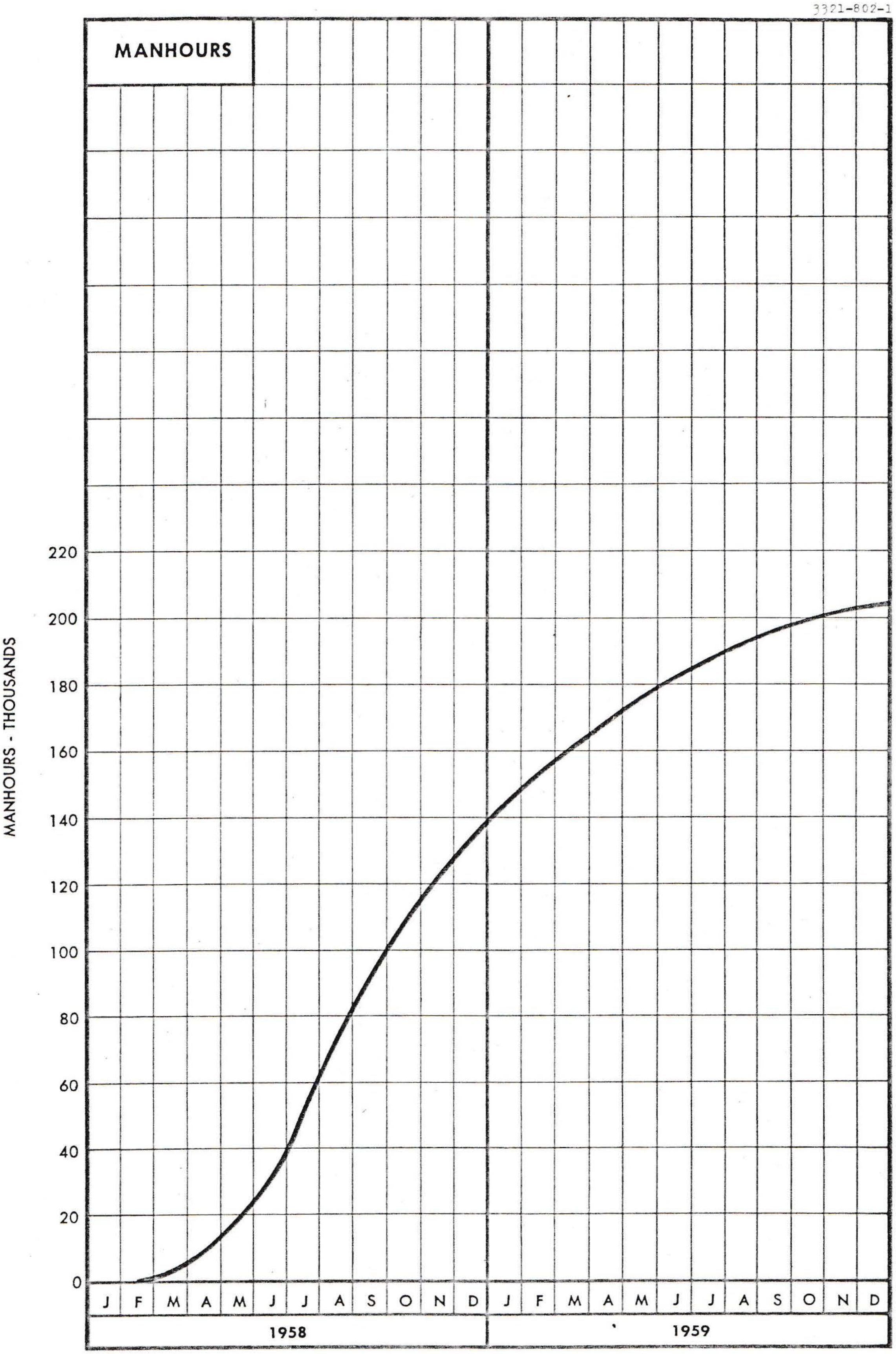

FIG. 35 AVRO TOTAL SUMMARY - MANHOURS - CUMULATIVE

70

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3321-802-1

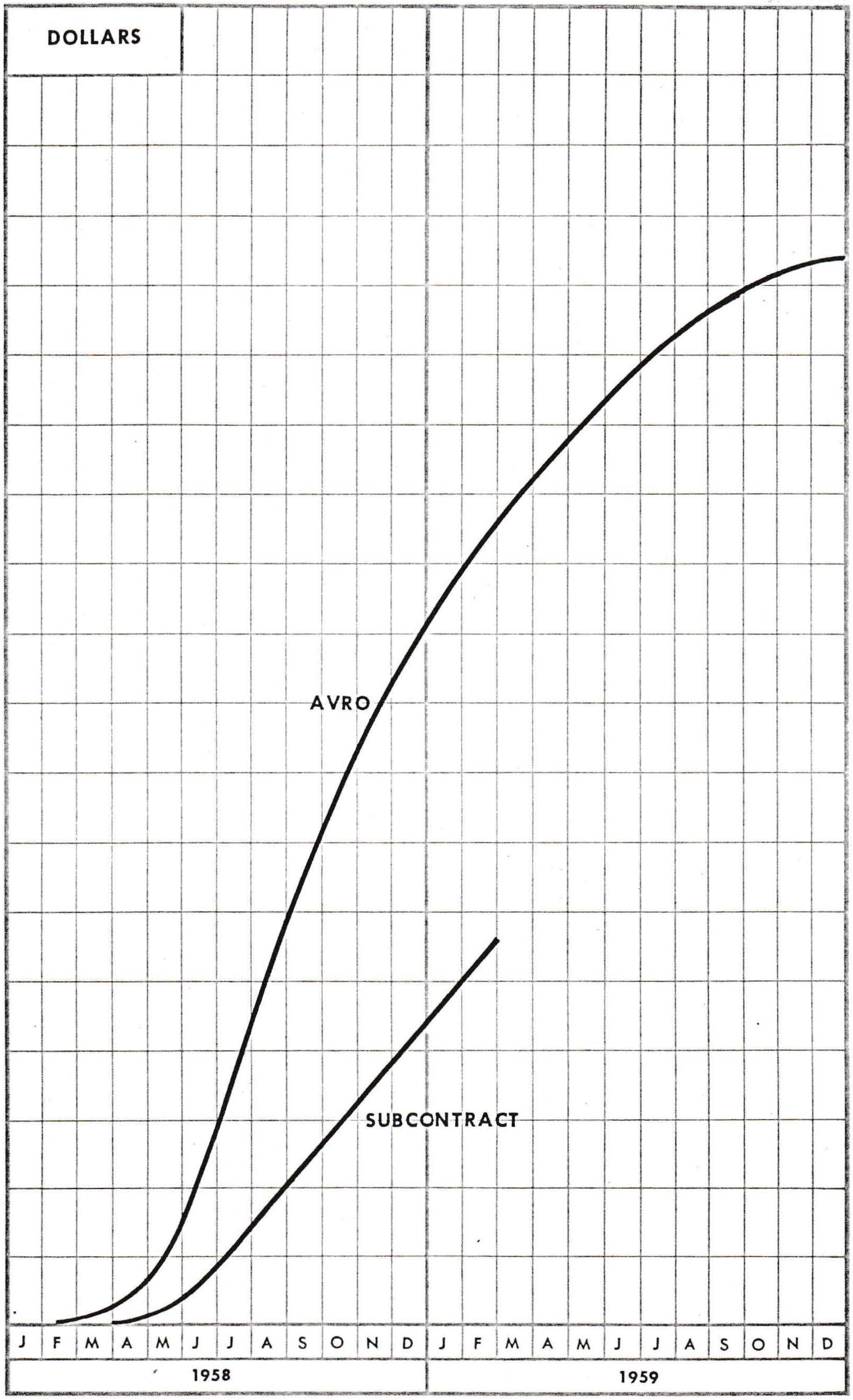


FIG. 36 AVRO AND SUBCONTRACT TOTAL SUMMARIES - DOLLARS - CUMULATIVE

3322-802-2

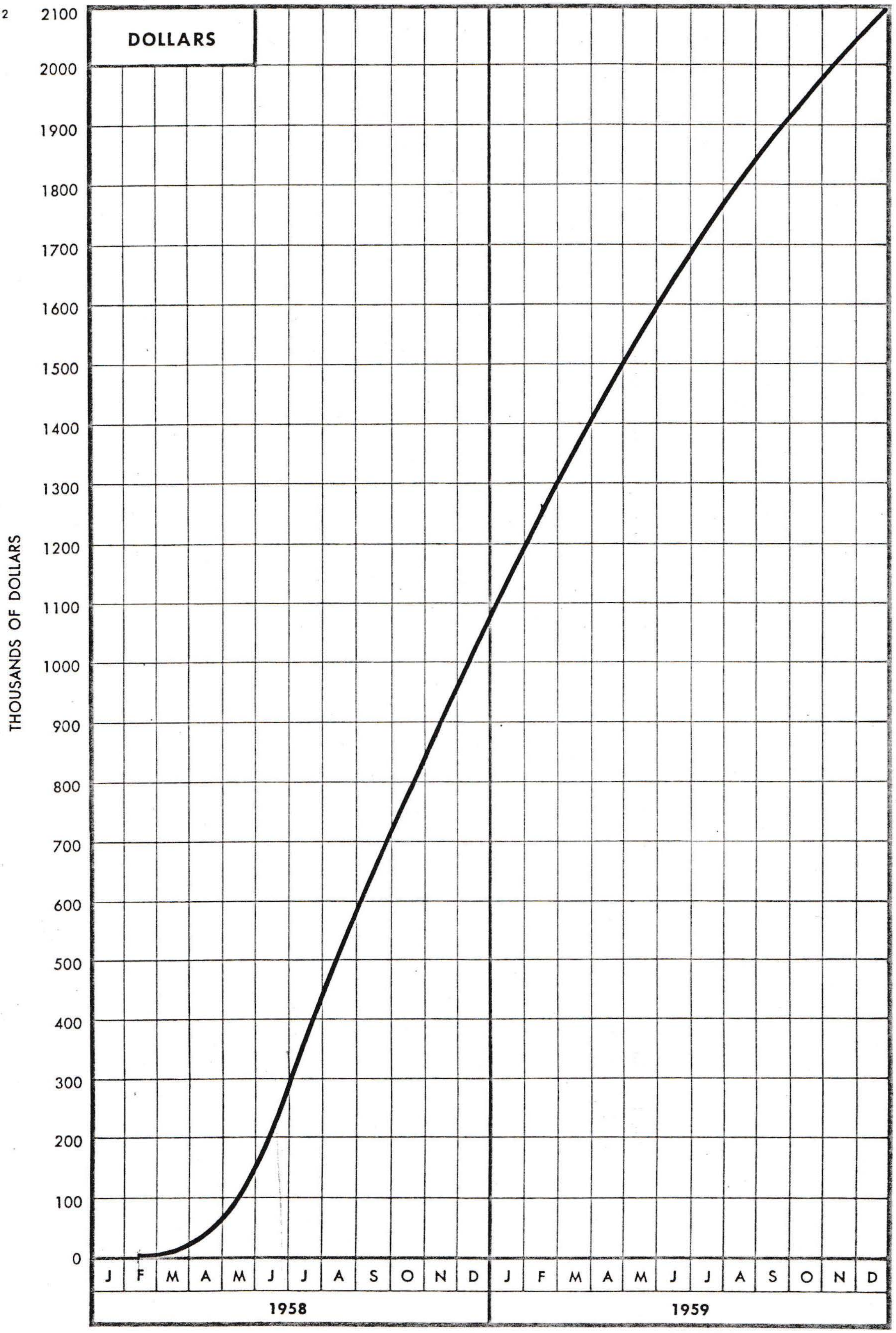


FIG. 37 TOTAL CONTRACT - DOLLARS - CUMULATIVE

7.0 COMPANY STATEMENTS

Management

The program of work specified in this proposal will be managed in all phases of Engineering, Administration and Manufacturing by the management personnel of Avro Aircraft Limited as shown in the Company and Special Projects Group organization charts on pages 75 and 77.

The Company however, reserves the right to effect changes of key personnel or their responsibilities at any time during the period of the contract.

Facilities

The Company will provide all the facilities necessary to accomplish their portion of the program specified in this proposal with the exception of wind tunnel facilities which are to be furnished by the United States Government free of charge.

Facilities for the development of the Turborotor will be provided by Orenda Engines Limited.

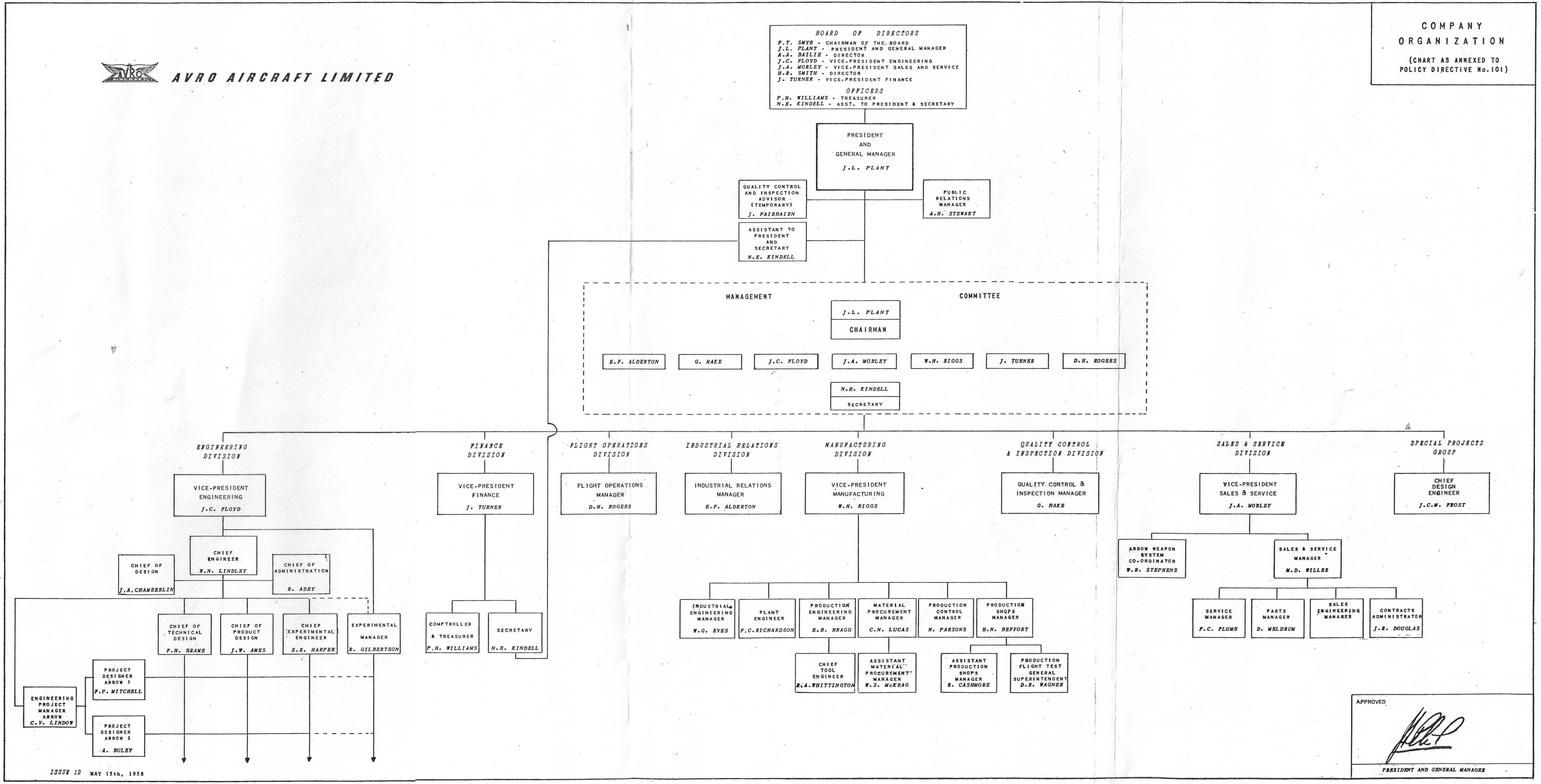
Personnel

The Company and Orenda Engines Limited undertake to provide professional, skilled, semi-skilled and other classifications of labour in sufficient numbers to support the program in accordance with the requirements of the time schedules included elsewhere in this report.

AVRO AIRCRAFT LIMITED

COMPANY ORGANIZATION

(CHART AS ANNEXED TO POLICY DIRECTIVE No.101)



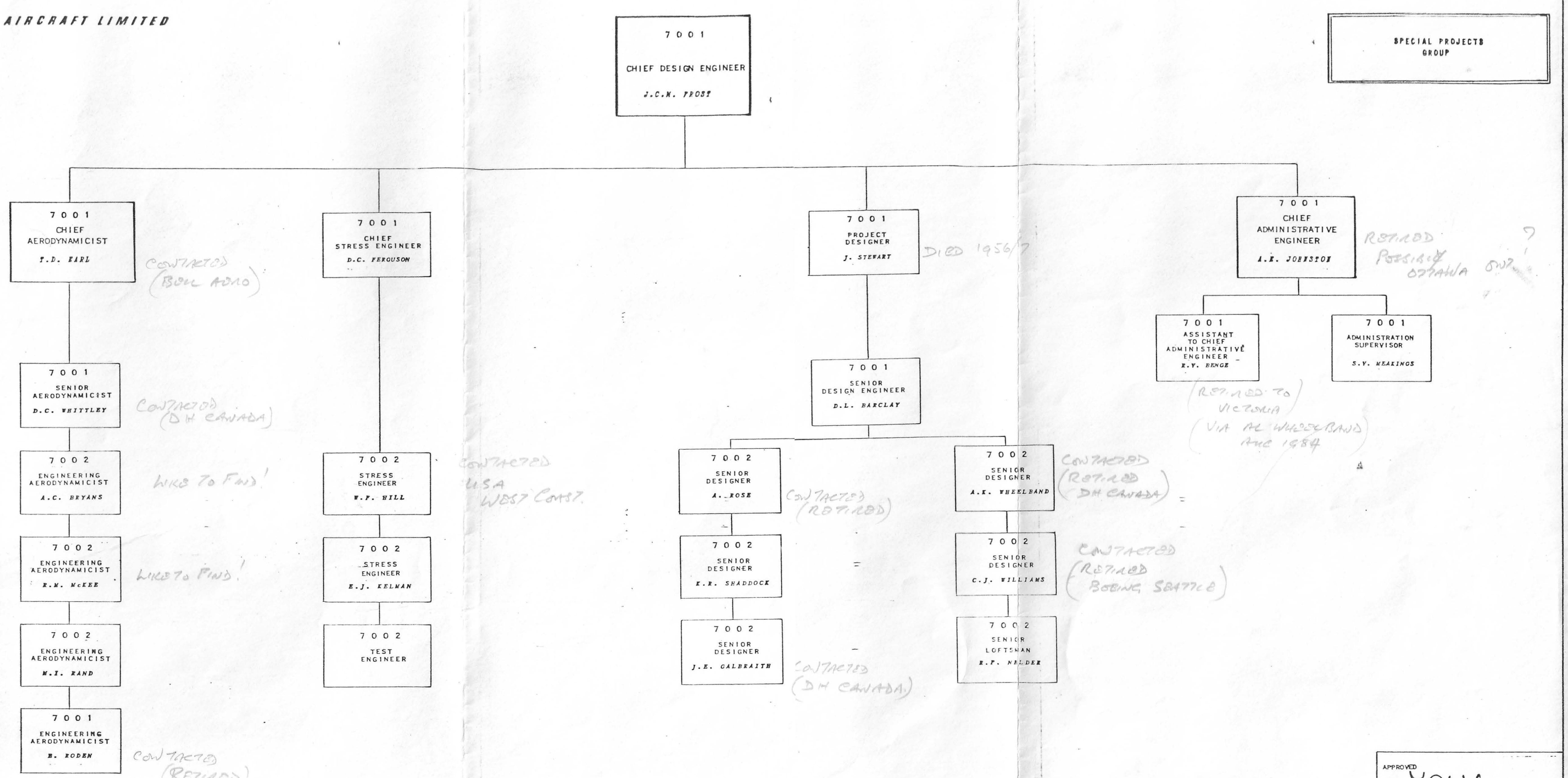
ISSUE 12 MAY 15th, 1958

APPROVED

PRESIDENT AND GENERAL MANAGER

MASTER. COPY

AVRO AIRCRAFT LIMITED



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(RETIRED TO VICTORIA) (VIA AL WHEELBAND AUG 1984)

JAN/58

ISSUE 5 JANUARY 15th, 1958

APPROVED J.C.M. Frost

CHIEF DESIGN ENGINEER

APPROVED

EXECUTIVE VICE-PRESIDENT & GENERAL MANAGER

APPENDIX I

AVROCAR TURBOROTOR PROJECT PROGRAM PLANNING REPORT - (Phase 1)

APPROVAL

Brochure B12-58-1 being a program planning report on the Avrocar Turborotor project is hereby approved.

S. L. Britton
Chief Administrative Engineer

June 1958.

CONTENTS

<u>NOTE</u>: Each part of this brochure is a self-contained unit with respect to page and illustration numbering. A detailed 'Contents' page is included for each part.

INTRODUCTION

This brochure presents the program to be carried out by Orenda Engines Limited to complete Phase 1 of the Avrocar Turborotor project.

It has been prepared in three parts to show:

(1) Specification and general description.

(2) Planning program.

(3) Program schedule and cost and manhour summary.

Phase 1 of this project covers the design of the turborotor assembly, limited manufacture, the design and manufacture of suitable test facilities and equipment, the necessary component testing, 250 hours of assembly development test running and the delivery, to Avro Aircraft Limited, of two complete turborotor assemblies.

It is understood that, in the fall of 1958, the necessary authority will be given to proceed with Phase 2 of the project. This will call for an additional test and development program of 250 hours running to attain a standard equivalent to the 50-hour preliminary flight test requirements of Specification MIL-E-5156B and for the delivery, to Avro Aircraft Limited, of three additional turborotor assemblies.

PART 1

SPECIFICATION AND GENERAL DESCRIPTION

CONTENTS

ILLUSTRATIONS

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PART 1

SPECIFICATION AND GENERAL DESCRIPTION

Statement of Work
Sub-parts

1. 1 DESIGN SPECIFICATION

9. 2. 5

1. 1. 1 General

The design specification hereunder is based on the requirements contained in Avro Aircraft Limited brochure AVRO/SPG/TR126 titled 'Design Specification for Avrocar Turborotor, (Issue 3)' and dated April 1958.

1. 1. 2 Scope

This specification is for the design of a small tip-driven turborotor for installation into a vehicle of circular planform called the Avrocar to be manufactured by Avro Aircraft Limited.

The VTOL-STOL performance potential of the vehicle depends on augmenting the static thrust of three gas turbine engines by using them as gas generators to drive the turborotor and also on ducting the flow radially to the wing tip. Thus the maximum possible mass flow consistent with ducting the flow through the vehicle to the periphery is required.

Upon the duct flow assumptions made (see 1. 1. 5) optimum thrust is obtained with a mass flow of approximately 550 lb/sec and this has therefore been selected as the design figure.

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The objective of the design is to obtain the highest possible pressure ratio for this mass flow for minimum possible weight.

1.1.3 Inclusions and Exclusions

For the purposes of this specification the following items are included as being the responsibility of Orenda Engines Limited.

Outer main shaft, and inner main shaft
Bearings and housings
Rotors, including compressor blades, rings,
turbine blades, etc
Oil system including pump, filter and motor if used
Turbine outer shroud and nozzle guide vanes
Tachometer drive or equivalent.

The following items are excluded, these being the responsibility of Avro Aircraft Limited.

Inner control shaft and upper and lower flexures
Centre structure, complete with lower shaft support
Spinner and oil filter
Engine exhaust diffuser
Turbine exhaust straighteners and exhaust boxes.

1.1.4 Materials and Weight

A target weight of 235 pounds has been set for the turborotor design to include all Orenda Engines Limited supplied items.

As economy of manufacture is also a most important feature, expensive materials and manufacturing processes will be avoided.

95

1.1.5 Gas Dynamic Design Basis

The following table lists the parameters which affect the turborotor design giving the estimated losses and loss factors, also a preliminary design point calculation of static thrust. The Orenda Engines Limited design is based on this information.

Engines	Continental J-69-T9
Design air mass flow (total air)	550 lb/sec
(Note - Engines breathe from end of radial diffuser duct)	
Loss to main compressor face	negligible
For first bend	$\Delta p/q_{inlet} = 0.10$
For radial diffuser duct	$\Delta p/q_{inlet} = 0.144$
For engine inlet to compressor eye	$\Delta p/q_{inlet} = 0.213$
For engine outlet diffuser duct loss up to nozzle guide vane (additional to normal jet pipe loss)	$\Delta P/P = 0.05$
For power turbine outlet duct loss	$\Delta P/P = 0.01$
Compressor temperature rise	$T_3 - T_2 = 9.0$ deg C
Compressor work done = turbine work done	= 1188 Chu/sec
Compressor efficiency	$\eta c = 0.88$
Compressor pressure ratio	$P_3 - P_2 = 1.09965$
First bend pressure recovery	$P_4 - P_3 = 0.9898$

Central nozzle pressure ratio	$P_a/P_4 = 0.91877$
Central nozzle area	$Ae4 = 576 \text{ in}^2$
Central nozzle airflow	$Q_C = 119.2$ lb/sec
Central nozzle thrust	$X_{GC} = 1452$ lb

Radial duct pressure recovery	$P_5/P_4 = 0.99$
Engine inlet pressure recovery	$P_6'/P_5 = 0.99$
Engine overall pressure ratio	$P_7'/P_6' = 1.646$
Engine outlet temperature	$T_7' = 954$ deg K
Engine outlet duct recovery	$P_8'/P_7' = 0.95$
Power turbine pressure ratio	$P_8'/P_9' = 1.5337$
Power turbine efficiency	$\eta t = 0.825$

Power turbine temperature drop	$H_S = 78.66$ deg C
Power turbine gas flow	$Q_E = 54.72$
Peripheral nozzle gas flow	$Q_P = 430$ lb/sec
Peripheral nozzle pressure recovery	$P_6/P_5 = 0.9865$
Peripheral nozzle pressure ratio	$p_a/P_6 = 0.94075$
* Peripheral nozzle outlet temperature	$T_6 = 380$ deg K
Peripheral nozzle thrust	$X_{GP} = 5048$
Peripheral nozzle area	$Ae6 = 2784$ in^2

Total thrust	$X_{TOT} = 6500$ lb
Total nozzle area	$Ae = 3360$ in^2

* <u>NOTE</u>

(1) The primary and secondary flows mix in the diffuser duct, however the gas generator inlet duct breathes unvitiated air since deflector ducting carries the turbine exhaust to the adjacent peripheral exhaust ducts.

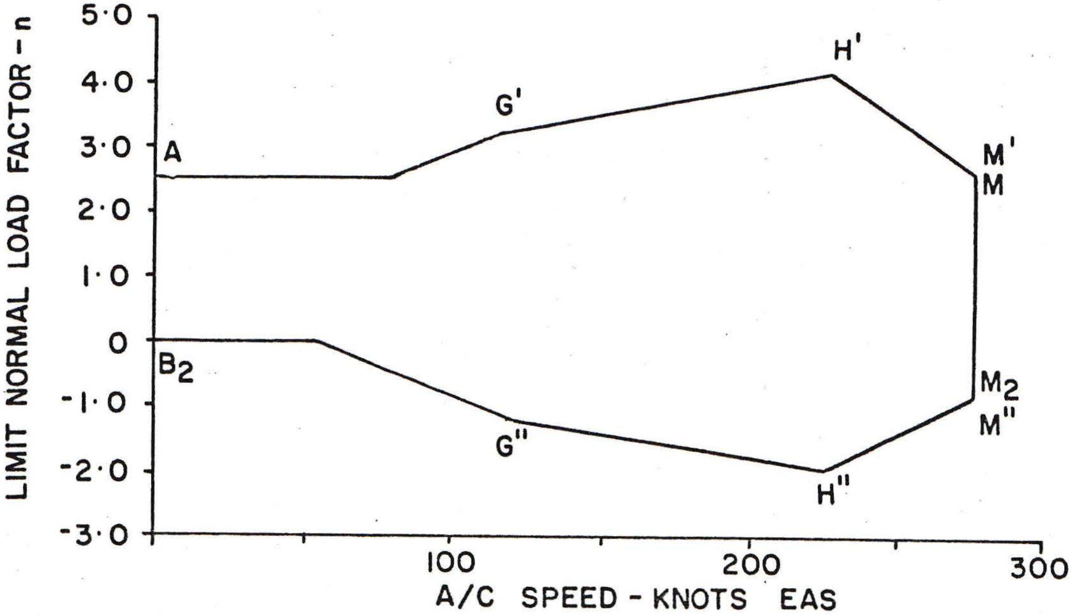
(2) A proportion (12.5 percent) of the total airflow is exhausted from a central annular nozzle arrangement in order to stabilize the aircraft while hovering in the ground cushion. This reduces the radial duct Mach numbers for the remainder of the flow.

1.1.6 Structural Design Criteria

1.1.6.1 Maximum Conditions

The rotor design will show a reserve factor $\geqslant$ 1.5 under all conditions encountered within the aircraft flight envelope shown in diagram below. In particular, the following conditions will apply at maximum rpm.

Limit normal load factor	=	4.02	-2.02	4.0	-2.0
Corresponding rate of roll or pitch	=	0	0	2.0 rad/sec	2.0 rad/sec



1.1.6.2 <u>Sustained Conditions</u>

The rotor shall be designed for continuous operation at the speed obtained with the engines operating at military rpm under the following loading conditions:

Limit normal load factor = 1.25
Rate of roll or pitch = 0.25 rad/sec.

1.2 GENERAL DESCRIPTION

6.2

1.2.1 General

A general arrangement of the assembly is shown in Figure 1. The design is a single rotor fan, with a tip diameter of 60 inches, driven by a turbine fixed to the tips of the fan rotor blades.

Because of the difficult sealing problem between the turbine and fan air passages at the large diameter of 60 inches, an impulse turbine design is used so that the pressure differential across the seal is as small as possible. This approach has been successful in reducing the pressure drop to zero at the design point. The static pressure in the turbine annulus and at the tip of the fan blades is 13.0 psia.

The single rotor fan is quite conservative as far as the normal design parameters are concerned except for the hub/tip ratio of 0.333. The tip diameter of 60 inches results in a fan blade tip speed of 728 feet per second at the design speed of 2780 rpm. The hub and tip air deflections are 37.4 degrees and 5.0 degrees respectively and the tip inlet Mach number is 0.78. Thirty-one blades are used, each blade having a constant chord of 4.1 inches. The thickness/chord ratio varies from 13.0 percent at the hub to 8.0 percent at the tip.

Immediately dowstream of the rotor, straightening vanes are fixed to the leading edges of the 18 diffuser splitter vanes. The object of the straightening vanes is to remove the rotor outlet swirl which varies from 37 degrees at the hub to 17 degrees at the tip.

Aerodynamically, the turbine is of the impulse type and consists of 144 nozzles and 124 rotor blades. Both the nozzles and the rotor blades are constant section with no change in stagger from hub to tip. The chord both of the rotor blades and the nozzles is 2.0 inches. The turbine blade tip diameter is constant at 65.000 inches but the hub is flared from a diameter of 62.148 inches at rotor blade inlet to a diameter of 61.734 inches at rotor outlet. The rotor blade inlet hub/tip ratio is 0.956. The turbine outlet Mach number is 0.56. The rotor outlet swirl is only 5.0 degrees in the direction of rotation and this means that no straightening vanes are required after the turbine. The turbine working fluid will be supplied by three J-69 gas producers.

The fan inlet should be supplied with generous fairings at the edges. If an inlet debris screen is required, it is preferable that it be of the honeycomb type in order that it can also serve as an inlet flow straightener. If high forward speeds of the order of 250-300 mph are to be catered for, some special intake configuration such as a honeycomb of vanes may have to be included but this might compromise the performance under hovering conditions due to the increased losses.

1.2.2 Rotor

The rotor is comprised of one stage of 31 hollow blades. Each blade is made of two sheet metal skins brazed at the leading and trailing edges, an internal stiffening baffle of corrugated section, an insert for attachment of the blade to the hub at the inner end, and an insert for carrying the turbine rotor segments at the outer end. The inserts and baffle are brazed to the skins.

The blade is attached to the hub at its inner end through the precision cast insert which has three lugs formed in a radial plane. There are four flanges on the outside of the hub to engage the lugs on the insert so that the lug carrying the greater portion of the load has a flange on each side and each outer lug has a flange adjacent to its outer face. Two holes are drilled through each flange with corresponding holes drilled through the lugs. Attachment is made by through bolts.

Registering on the inner diameter at each end of the hub is a short sleeve which acts as a bearing cartridge. Each sleeve has an external flange which abuts the end face of the hub, and an internal flange that axially locates the outer race of one main bearing.

Concentrically mounted on the bottom face of the hub is a cylindrical extension that is bolted in position. This forms part of the sealing arrangement for the oil tank and has a lobe machined on its outer periphery that provides a cam drive for the oil pump.

The rotor is carried by two heavy duty tapered roller bearings whose inner diameters fit on a sleeve which in turn is carried by a spherical bearing. This permits the rotor assembly to pivot about the bearing axis thereby allowing for gyroscopic torque compensation. The above components are mounted on a removable centre column thereby allowing the complete hub assembly, including the centre column which is bolted to the main structure, to be mounted as a unit to the main structure.

Lubrication for the main bearing is provided by a cam operated piston type pump which is mounted in the oil tank. The tank is a sheet metal container bolted to a flange on the bearing sleeve and located below the hub. Oil scavenge depends on gravity and centrifugal action.

Rotor speed will be recorded by a modified automotive electrical tachometer. In order to transmit the rotational speed, a number of magnets would be attached to a rotor flange and impluses from these transmitted via a coil pickup and switching mechanism to the tachometer.

Power is supplied to the rotor by a single stage impluse turbine consisting of 124 hollow steel blades made up into 31 segments. The segment has a stiffened box-shaped section to resist the high centrifugal bending stresses and is brazed up complete with the blades. They are pinned to a precision cast insert brazed to the end of each rotor blade. Each insert has two fixing holes and each segment is carried by two pins - one registering in a hole and the other in a slot thereby allowing for thermal growth in a tangential direction.

To offset the decreasing material properties due to temperature, the segments are provided with holes which allow cooling air from the main stream to flow through them.

A labyrinth seal is provided to separate the compressor airflow and the turbine gas stream. The rotating part of the seal is carried by the turbine rotor and the stationary portion by the turbine stator assembly.

1.2.3 Turbine Stator and Casing Assembly

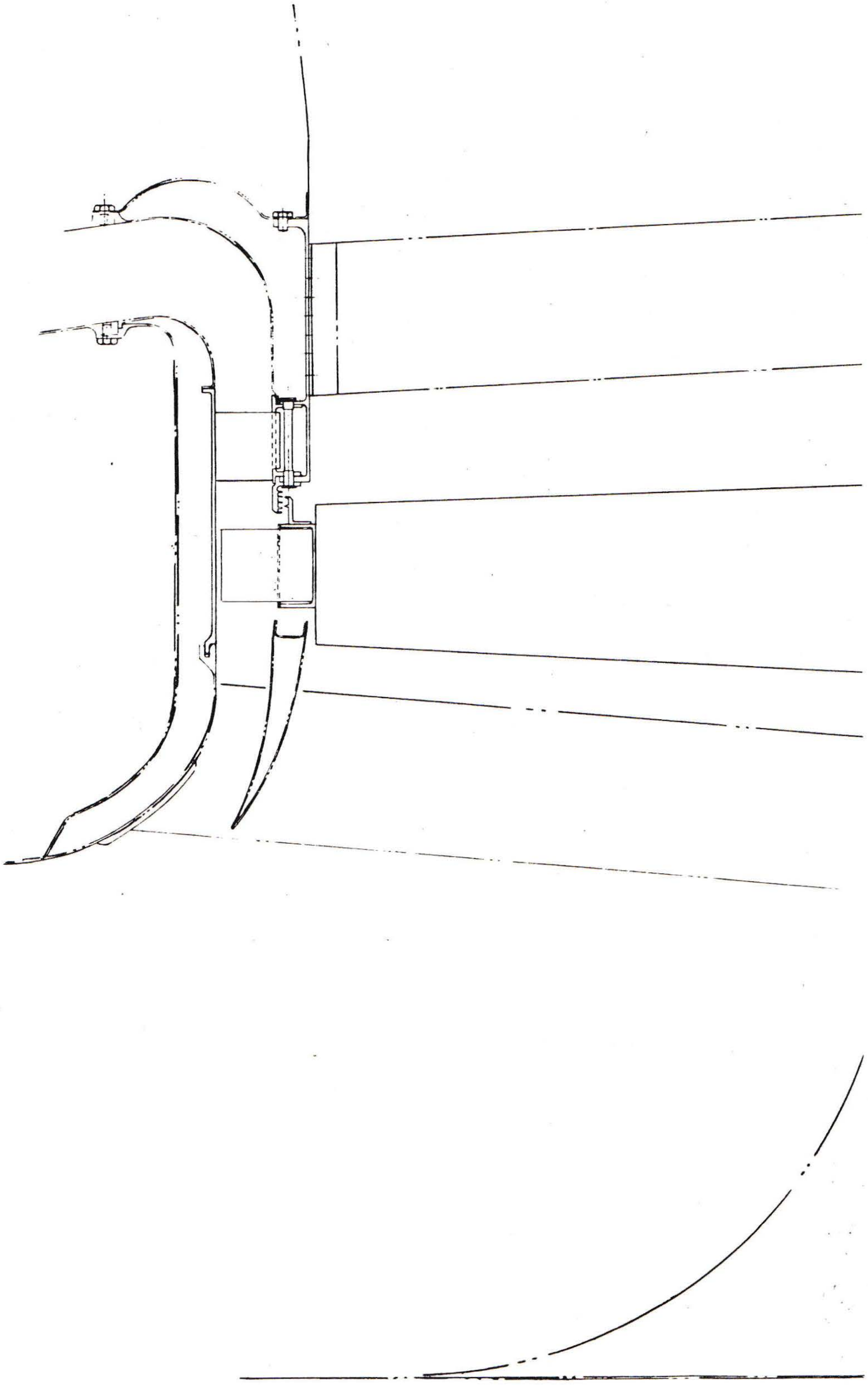
Basically the turbine stator consists of 18 segments each of which contains eight blades.

The stator assembly comprises a 'U' section ring together with 18 'U' section stator blade segments. Each of the segments is attached to the ring by two pins. One of these pins locates through a hole; the other passes through a slot to accommodate thermal expansion. The segments mate with the ring in such a way that when pinned together they form a box section.

The blades are hollow and have a chord dimension of two inches. They pass through slots in the stator segments and are brazed in position; the outer ends being butt-brazed to the 18 segments that form the upper part of the turbine casing. The lower part of the turbine casing consists of nine segments into which the upper segmented part of the casing locates. The complete assembly is positioned concentrically with the rotor assembly by slots which are machined in the bottom faces of the lower casing segments and which engage with a spigot formed on the main structure.

Clearance is allowed between segments to accommodate thermal expansion. The gaps are sealed to prevent gas leakage.

The annular gap between the turbine casing and the aircraft structure is insulated by a 0.5 inch blanket.



PART 2

PLANNING PROGRAM

CONTENTS

ILLUSTRATIONS

PART 2

PLANNING PROGRAM

Statement of Work
Sub-parts
6.2

2.1 SCOPE OF WORK

2.1.1 General

The work defined hereunder will be performed by Orenda Engines Limited to complete Phase 1 of the Avrocar Turborotor project.

(1) The design of a turborotor assembly to the requirements of the design specification contained in Part 1 of this brochure.

(2) The manufacture of components and assemblies to this design.

(3) The necessary individual component testing.

(4) The design, manufacture and erection of a rotor test stand.

(5) Initial assembly development testing - 250 hours.

(6) The delivery of two rotor assemblies to Avro Aircraft Limited.

A program schedule and a cost and manhour summary for this work are contained in Part 3 of this publication.

In the following paragraphs the broad scope of the required work is defined. The work areas are covered in a substantially chronological sequence.

2.1.2 Design

This area will cover the design of the turborotor assembly to the general requirements of the Orenda Engines Limited design specification contained in Part 1 of this publication.

Design work will include the preparation of layouts, detail design, assembly and systems design and the necessary re-design 'follow-up' required in the development of the project.

2.1.3 Manufacture

This work area will consist of:

(1) The design, procurement and/or manufacture of the necessary tooling.

(2) The material procurement, component manufacture, and assembly of the turborotors.

2.1.4 Facilities and Equipment 8.2

2.1.4.1 Component Test Rigs

A program of component development will be carried out in parallel with the turborotor assembly program. Where practical, existing Orenda Engines Limited facilities and equipment will be used. The adaption and necessary re-work of existing rigs will constitute this work area.

2.1.4.2 Rotor Test Stand

To carry out the development testing of the complete turborotor assemblies it will be necessary to prepare and erect a special test stand. This will be set-up on the existing silencer foundation behind the Orenda Engines Limited experimental test cells located on Avro Aircraft Limited property.

The exhaust from an Orenda engine will be fed to a pressure vessel and thence ducted to feed simultaneously three vertical take-offs to the inlets of the turbine manifold (see Figure 1). It should be noted that Figure 1 shows the initial proposal only. Modifications to this rig will be made as necessary as the project develops. Basic experimental test cell services will be used where practical.

The following equipment and parts will be purchased from Avro Aircraft Limited in support of this work:

Avro Reference	Description	Quantity
1A 558	Exhaust box	18
29N 532	Rib (shortened)	18
1N 531	Centre support	1
66A 532	Straightener vane	18
11A 530	Centre fairing	1
11N 532	Floor skins	18

Work required in this area will cover: the necessary design and drafting and the supporting laboratory and technician services: the manufacture of the foundation, basic stand and engine support: the procurement and/or manufacture of instrumentation (other than 'special'): the manufacture and set-up of expansion joints and controls: general assembly of the testing facility.

2.1.4.3 Special Instrumentation 8.3

Work in this area will be that necessary to design, procure and/or manufacture, install and service the special instrumentation required on the complete turborotor assembly during development testing to provide the mechanical and performance data required.

For this project 'special instrumentation' is considered mainly to be that concerned with strain gauging, slip ring adaption, speed measurement and performance evaluation.

2.1.5 Development 8.2

2.1.5.1 Component Testing

The component testing program will be used to investigate individually the mechanical reliability and performance of the key components of the arrangement to assure the integrity of the complete turborotor system. Work in this area will cover the drafting of test requirements, the preparation and set-up of specimens and the evaluation of test results.

2.1.5.2 Assembly Testing

This will cover the development testing of the complete turborotor assemblies in the rotor test stand. A development test time of 250 hours at static ground level conditions is programmed for this phase.

The work will include the preparation of test schedules, set-up and removal operations, test running and the evaluation of test results.

2.2 SUBMISSION OF REPORTS 9.2

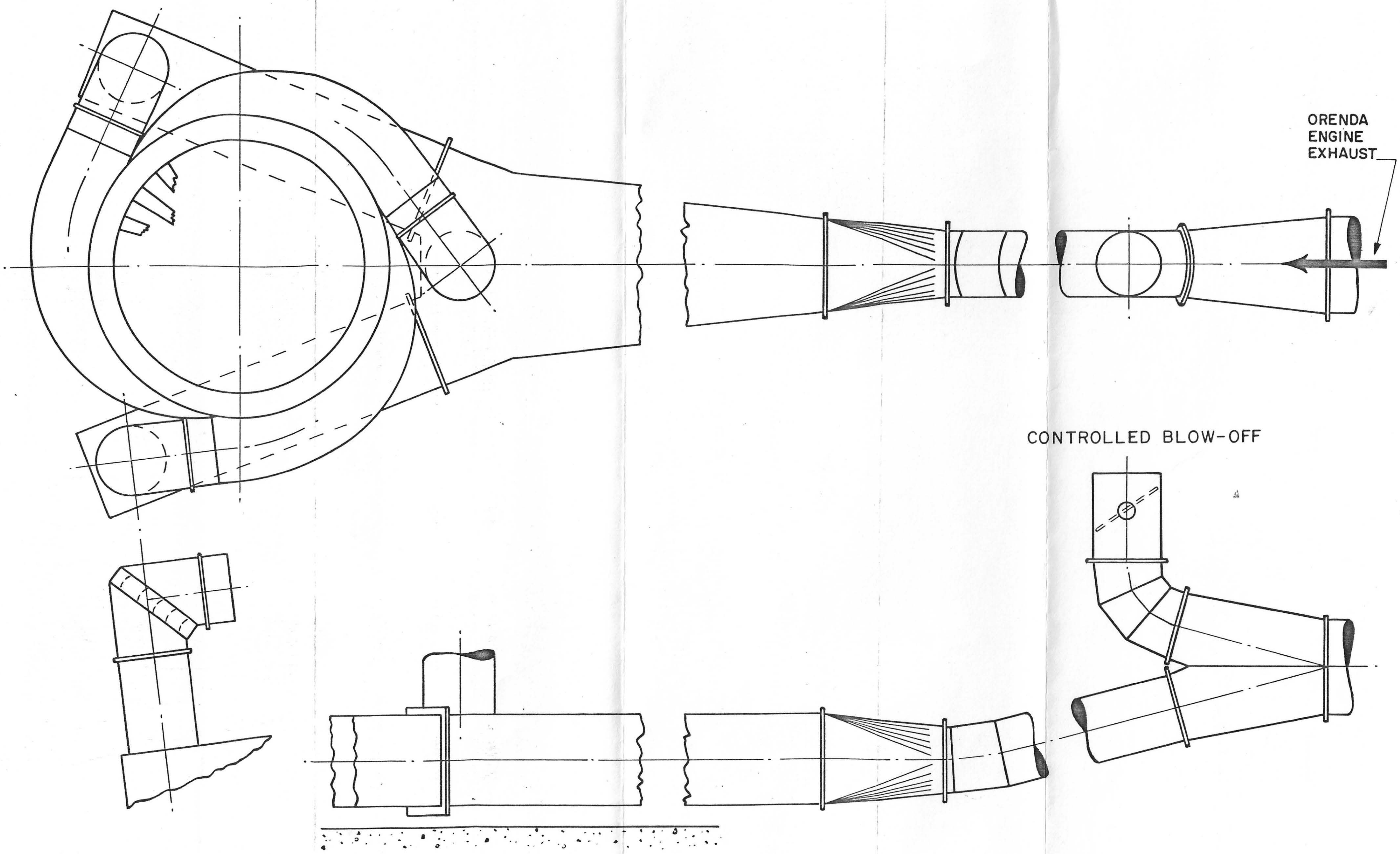
Orenda Engines Limited will prepare and submit to Avro Aircraft Limited the following reports and drawings relating to this phase of the project:

(1) Monthly progress reports: each will present a summary of work performed, percentage of task accomplished, results obtained, problems encountered, and the budgetary status of the program in relation to the program planning forecasts. Reports will be submitted on or before the fifteenth day of the month immediately following the end of the reporting period. Alternate reports will be in letter form. 9.2.3

(2) A summary report: this will be prepared at the end of the initial 250 hours development testing. The report will contain an introduction containing historical background and statement of objective, discussion of design concept, presentation of significant results, evaluation of these results, conclusions and recommendations. 9.2.7

(3) Financial reports: these will be submitted quarterly. The reports will be based on the program cost schedule contained in Part 3 of this brochure. 9.2.4

		Statement of Work Sub-parts
(4)	Test specifications: detail specifications of tests to be conducted on turborotor assemblies required by Item 8 of the Statement of Work will be submitted before August 31, 1958.	9.2.6
	Technical reports presenting the results of tests so conducted and other significant test work accomplished (not the subject of detailed test specifications) will be submitted as soon as possible after the conclusion of tests.	9.2.8
(5)	Definitive drawings: one complete set of detail drawings and data covering the turborotor assembly will be delivered at completion of the contract.	9.2.10



PROPOSED GAS SUPPLY SYSTEM TEST RIG

PART 3

PROGRAM SCHEDULE AND COST AND MANHOUR SUMMARY

CONTENTS

ILLUSTRATIONS

PART 3

PROGRAM SCHEDULE AND COST AND MANHOUR SUMMARY

3.1 GENERAL

This part of the brochure presents a program schedule for Phase 1 of the project, summarizes work area details, costs and manhours and includes, in curve form, the projected costs and manhour expenditures for the phase.

3.2 PROGRAM SCHEDULE

Figure 1 shows the detailed program schedule. The work area breakdown follows the pattern used in the program cost summary given below.

3.3 PROGRAM COST AND MANHOUR SUMMARY

3.3.1 Design

Layout
Detail drawings
Assemblies and systems
Development 'follow-up'

Cost $ 57,462 Manhours 5,515

3.3.2 Manufacture

3.3.2.1 Tools

Tool - design and drafting
Tool - materials
Tool - manufacture

Cost $ 64,550 Manhours 8,350

3.3.2.2 Turborotor

Rotor material
Rotor detail manufacture
Assembly

Cost $ 71,130 Manhours 9,200

3.3.3 Facilities and Equipment

3.3.3.1 Test Rigs

- Component Test Rigs
  - Design and drafting
  - Material procurement
  - Detail manufacture
  - Assembly

- Rotor Test Stand
  - Design and drafting
  - Laboratory and technician support
  - Material procurement
  - Manufacture and rework (includes sub-contract)
    - Foundation
    - Basic stand
    - Engine support
    - Instrumentation (other than 'special')
    - Controls
  - Assembly

Cost $ 27,565 Manhours 1,275

3.3.3.2 Special Instrumentation

Strain gauging (turbine and rotor blades)
  Design and drafting
  Material procurement
  Manufacture

Adaption of slip ring etc.
  Design and drafting
  Material procurement
  Manufacture and rework

Performance instrumentation
  Design
  Material procurement
  Manufacture

Cost $ 9,820 Manhours 997

3.3.4 Development

Component testing
  Individual components
  Lubrication system
  Bearings
  Vibration

Assembly testing(includes fuel costs)
  Main rotor test (250 hours)

Cost $155,600 Manhours 12,935

Total	Cost	$386,127	
Contingency		$ 38,613	
Fee		$ 31,855	
GRAND TOTAL		$456,595	Manhours 38,272

NOTE: -

(1) Costs have been modified to take into account duplication of strain gauging and associated work.

(2) A projected cost expenditure curve is shown in Figure 2.

(3) A projected manhour expenditure curve is shown in Figure 3.

3.4 LABOUR AND OVERHEAD RATES

The following rates of Labour and Overhead have been applied in the compilation of cost estimates for the program of work outlined in this proposal.

Labour Rates

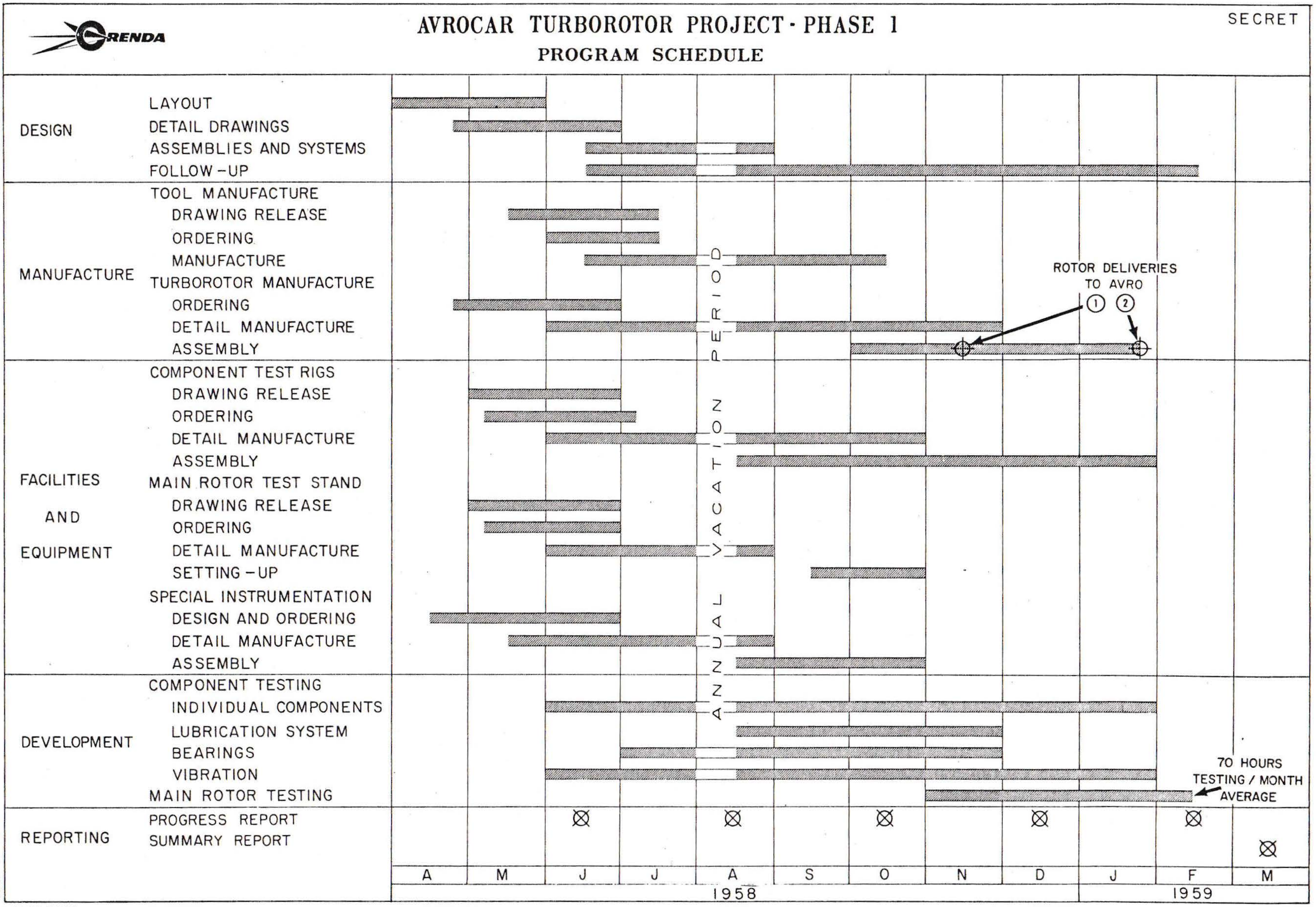
For Engineering	$ 2.75 hour
For Experimental Manufacture	2.24 hour

Overhead Rates

For Engineering	210 percent
For Experimental Manufacture	200 percent
For Administrative	9 percent

Application of Rates

Labour + Overhead + Material and Direct Charges + Administrative.



SECRET

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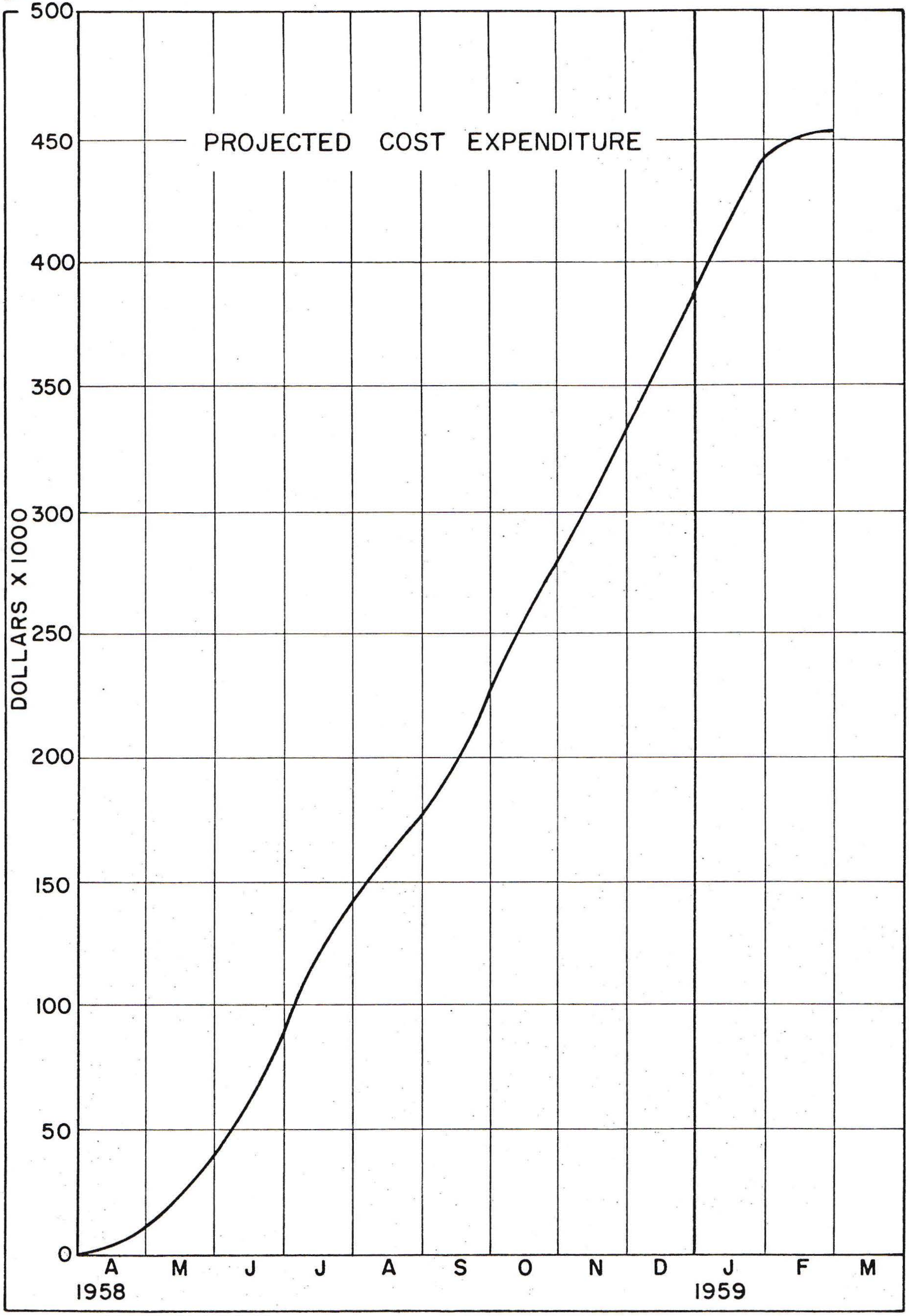
Part 3 Fig. 1


PROJECTED COST EXPENDITURE
DOLLARS X 1000
500
450
400
350
300
250
200
150
100
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0
A
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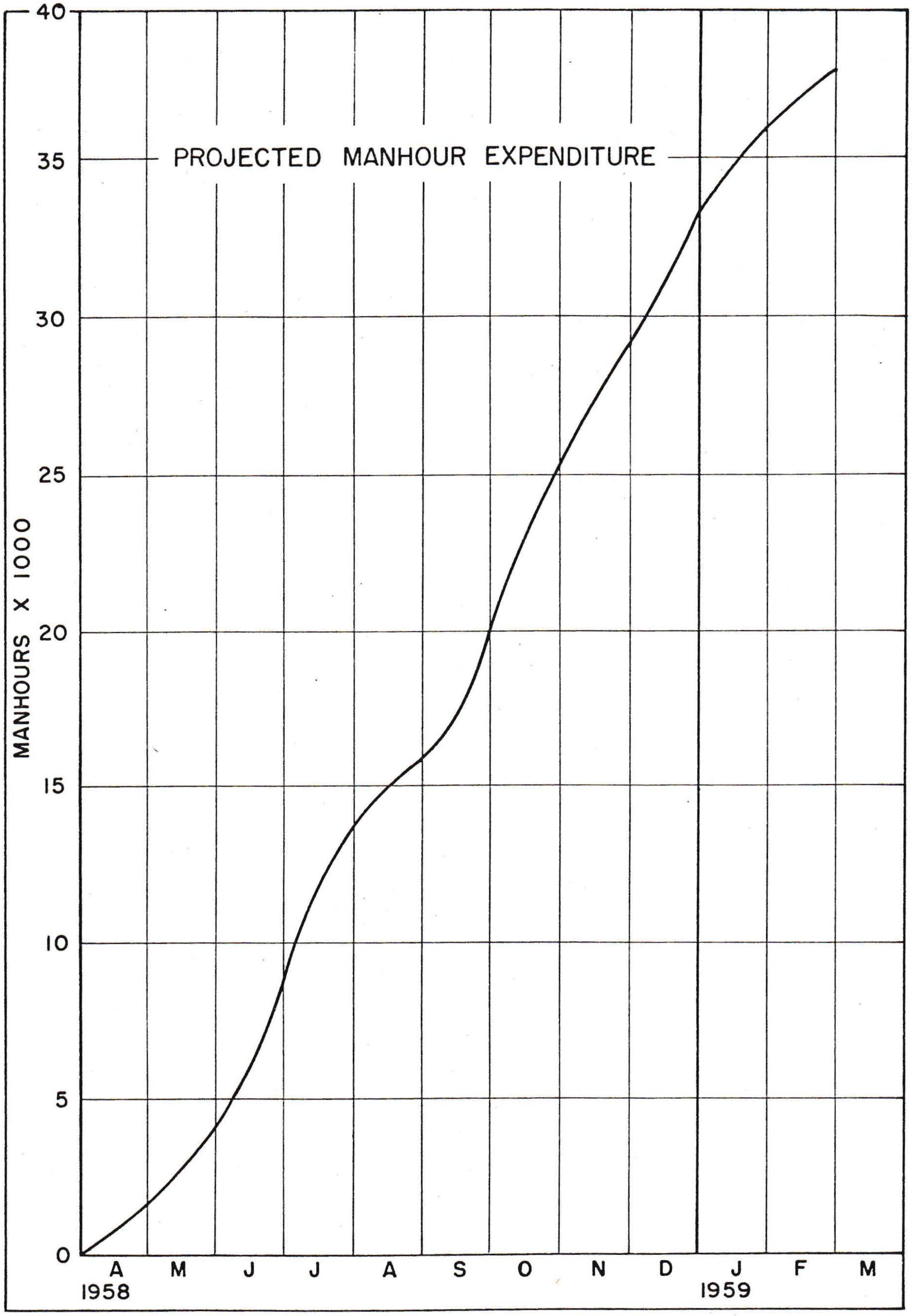
PROJECTED MANHOUR EXPENDITURE
MANHOURS X 1000
40
35
30
25
20
15
10
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0
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J
F
M
1958
1959

Part 3 Fig. 3

APPENDIX II

PRELIMINARY STATEMENT OF WORK

AVROCAR VEHICLE - 1 MAY 1958

I. D. No. 58RDZ-12743

1. PURPOSE

1.1 The purpose of this program is to develop, test and produce an experimental AVROCAR type vehicle by late 1959 to demonstrate basic feasibility of this type of aircraft.

2. MILITARY CAPABILITY REQUIREMENTS

2.1 This system is not required to have an operational capability.

3. PERFORMANCE REQUIREMENTS

3.1 The system shall meet the following minimum performance requirements.

3.1.1 Take off and hover out of ground cushion at sea level standard conditions.

3.1.2 Take off and hover at a minimum height above the ground of 6 ft., carrying 1,000 lb payload (including crew) for a minimum duration of 10 minutes at sea level standard conditions.

3.1.3 Take off carrying 1,000 lb payload (including crew) transition to forward flight, carry this load for a distance of 25 nautical miles and land with this payload at sea level standard conditions.

3.1.4 Attain a minimum forward airspeed of 25 knots in zero wind at sea level standard conditions.

4. SYSTEM DESIGN

4.1 The system design shall be accomplished in accordance with the approved Avro model specification identified as "Avro Aircraft Project AVROCAR I for US Army" dated 20th May 1958.

5. OTHER

5.1 Subsystem procurement: Other contractors may be used for subsystem procurement; however, subcontractor selected by the prime contractor will be subject to Air Force approval.

6. WORK REQUIRED

6.1 The contractor shall accomplish the manufacture of one (1), the first test vehicle in accordance with Avro model specification, dated 20 May 1958. The turborotor will be provided under para 6.2. This effort shall include:

6.1.1 Engineering and design of the vehicle.

6.1.2 Process planning, tool design, manufacture of jigs, tools, and fixtures sufficient to accomplish manufacture of prototype vehicles.

6.2 Manufacture two (2) sets of turborotors in accordance with the approved turborotor specification. This effort shall include:

6.2.1 Engineering and design of the turborotor propulsion system.

6.2.2 Process planning, tool design and manufacture of jigs, tools and fixtures sufficient to produce prototype turborotor systems.

6.3 Manufacture of one (1), additional complete set of aircraft parts.

7. MOCK-UP

7.1 The contractor shall construct a 1/2 portion of the AVROCAR in mock-up form as an aid to engineering. The mock-up shall be completed six (6) months from date of contract.

8. TESTING

8.1 Wind tunnel testing.

8.1.1 Design, manufacture, test and prepare reports on a 1/20 scale wind tunnel model of the AVROCAR described in the Model Specification. Tests are to be conducted at the Avro facility.

8.2 Turborotor Testing.

8.2.1 Conduct a test and development program on the two (2) turborotors (required by para. 6.2) for a period of 250 hours of operation under static ground level conditions and provide reports on results under this testing program. The contractor shall provide for:

8.2.1.1 Experimental test cell silencer foundation.

8.2.1.2 Orenda engines.

8.2.1.3 Basic experimental test cell services.

8.2.1.4 Instrumentation.

8.2.1.5 Labor and material.

8.3 Special Instrumentation.

8.3.1 The following special instrumentation shall be provided:

8.3.1.1 Strain gauging - Turbine and Compressor blades.

8.3.1.2 Adaptation of slip rings.

8.3.1.3 Performance instrumentation.

8.3.1.4 Labor and materials.

8.4 Control system tests.

8.4.1 Design, manufacture, test and prepare report on a full scale segment of approximately 1/12 of the outer wing tip section complete with controls.

9. DATA REQUIREMENTS

9.1 Project review. Three (3) project reviews of the program shall be given by the company at times and places as mutually established by the Contracting Officer and the contractor.

9.2 Reports:

9.2.1 Model specification. Twenty-five copies of the model specification shall be submitted forthwith upon execution of the contract. This specification shall be revised as necessary during the course of the contract.

9.2.2 Program planning report. The contractor shall prepare and submit for approval forthwith upon execution of the contract, fifteen (15) copies of a Program Planning Report for the work required herein. The Program Planning Report shall include a description of methodology, work definition, time scheduling, cost (expenditure and commitment) and manhour data by sub parts. The Program Planning Report shall list all reports to be submitted during the course of the program to include items such as progress reports, aerodynamics, stress analysis, control system design, propulsion system analysis, weight and balance, etc. These reports shall be listed in tabular form with delivery dates shown for periodic, preliminary or final reports as applicable.

9.2.3 Monthly Progress Report - The contractor shall furnish by the 30th of the month following the reported one (1) month period, twenty-five (25) copies of monthly progress reports presenting a summary of: Work performed, percentage of task accomplished, results obtained, problems encountered and the budgetary status of the program in relation to program planning report forecasts (expenditure and commitments). Alternate reports shall be in letter form.

9.2.4 Financial Report - The contractor shall furnish ten (10) copies of a Quarterly Financial Status Report of Contract (DD Form 1097) in accordance with the schedule of the approved Program Planning Report.

9.2.5 Turborotor System: The contractor shall furnish for approval six (6) copies of a design specification for the turborotor propulsion system in accordance with the schedule of the approved Program Planning Report.

9.2.6 Test Specifications. The contractor shall submit ten (10) copies for approval, of detailed specifications of the tests to be accomplished under Item 8. Test specifications will provide information on test objectives, facility requirements, model characteristics, test conditions, instrumentation requirements, data collection and reduction, etc. Test specifications will be furnished in accordance with the time schedule of the approved Program Planning Report.

9.2.7 Summary Report - The contractor shall submit twenty-five (25) copies of a summary report to contain: (1) an introduction which includes historical background and statement of purpose or objectives, (2) discussion of the design concept, (3) presentation of important results, (4) evaluation and interpretation of these results, (5) conclusions and (6) recommendations.

9.2.8 The contractor shall submit twenty (20) copies of Technical Reports presenting results of tests accomplished under Item 8 and to cover other work accomplished but not specifically referenced herein. These reports will be submitted in accordance with the time schedule of the approved Program Planning Report or forthwith as the tests are accomplished.

9.2.9 The contractor shall provide motion picture coverage of significant events such as mock-ups, engine test stand runs, wind tunnel tests, etc. One partially edited master of 16 mm color film, with a written description of subject matter, will be submitted quarterly. In addition a complete narrated color film will be delivered at the end of the contract.

9.2.10 One (1) complete set of detail drawings and data covering the AVROCAR vehicle shall be delivered at the completion of the contract.

10. DELIVERY

10.1 The contractor shall furnish the data required by para. 9 to:

Headquarters
Air Research and Development Command
ATTN: RDZSXA
Wright-Patterson Air Force Base, Ohio

10.2 The AVROCAR test vehicle, complete with turborotor shall be completed and delivered to the Government within twelve (12) months from date of contract.

10.3 The contractor shall distribute copies of data as directed by the Procuring Contracting Officer. For planning purposes, fifteen (15) copies of Monthly Progress Reports, Technical Reports and final Summary Report will be required by the department of the Army and six (6) copies of the Quarterly Financial Status Report will be required by the Commanding Officer, Air Transportation Research and Engineering Command, Fort Eustis, Virginia, Attention Comptroller. No distribution of the reports shall be made without the express approval of the Procuring Contracting Officer.