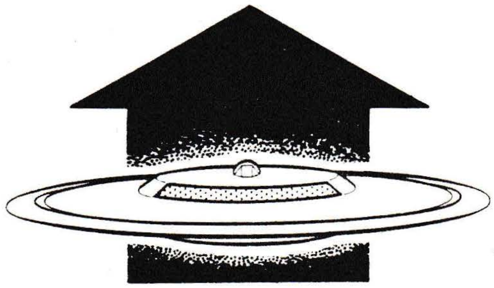
PROJECT Y2

BROCHURE NUMBER ONE

A. V. ROE CANADA LIMITED



PROJECT Y2

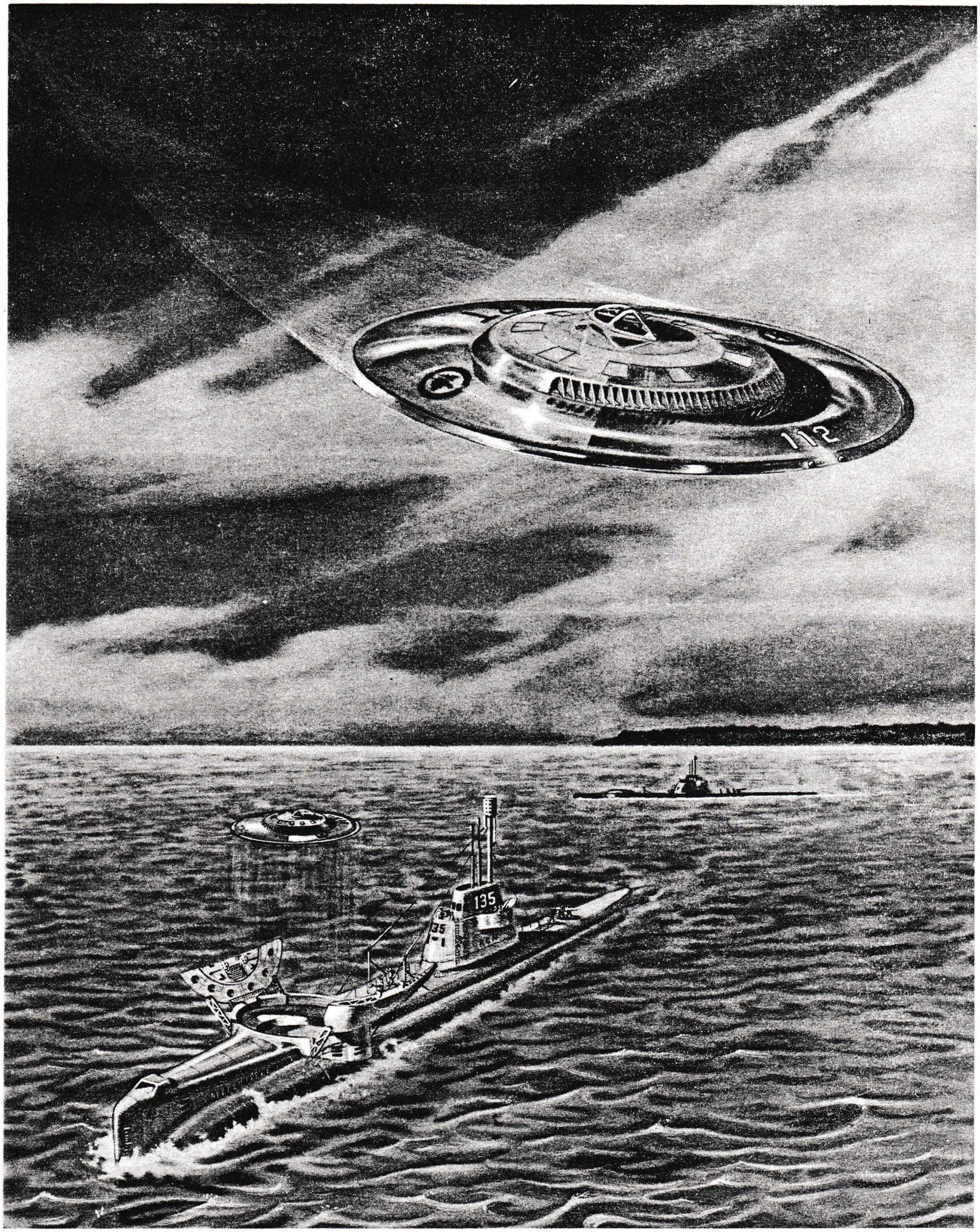
FLAT VERTICAL TAKE-OFF SUPERSONIC GYROPLANE

JUNE 1954

A. V. ROE CANADA LIMITED
AIRCRAFT DIVISION

MALTON - ONTARIO

PROJECT Y-2 VERTICAL TAKE-OFF



PROJECT Y-2 SUBMARINE BASED

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

PART I

INTRODUCTION

1 Two versions of small research type Vertical Take-Off aircraft, identified as Project 'Y' and Project 'Y2' have now been designed.

2 Each project, is essentially a simple proposal for the construction of a very large radial flow gas turbine engine, suitably shaped and covered to form a flying wing which is said to be the minimum aircraft that can be designed around a turbo-jet engine.

3 The engines are designed to fly "edge-on" to the wind instead of axially, as in the case of the more conventional types. Each engine is basically a large diameter airborne rotor disc, supported by an air bearing which employs compressor bleed air as its only form of lubrication. Polar inertia in the case of either engine, will be approximately one quarter of that of the complete aircraft. Stability and control, will be dominated by the gyroscopic reactions of the rotor.

4 The fundamental advantages seen for these particular types of aircraft are:-

(a) The manufacturing simplicity that results.

(b) The much greater than one thrust/weight ratio.

(c) The very high thrust/frontal area ratio.

(d) The ability to operate without prepared fields, the most important consequence of (b).

(e) Gyroscopic stability.

5 The Project 'Y' version, which was originally described in our July 1952 brochure and later in Reference 1, was designed to take-off and land "edge-on" to the ground. The latter version, Project 'Y2', which is covered within this volume, is designed for vertical take-off and landing "flat" from the ground. Unlike its counterpart, this aircraft rests horizontal with the ground and has no landing gear or surface controls.

6 The "flat take-off" technique, in the Project 'Y2' version, has a further fundamental advantage of great significance in that the peripheral jet produces a powerful ground cushion effect which eliminates the possibility of severe impact on landing.

The importance of this ground effect can hardly be over-emphasized, and it is obvious that the radial flow engine is particularly suited for this technique. Tests have shown that the jet lift is increased several times over for a flat disc near the ground. Further advantages for this technique are as follows:-

(a) It is safer and more acceptable to pilots.

(b) The gyroscopic plane is parallel with the ground.

(c) Visualization of the use of this type of aircraft in the transport category.

PART 2

DESIGN CONSIDERATIONS

1 The following considerations are overriding factors in the design of the aircraft.

(a) The jet exhaust must be directed downwards and be evenly distributed around the periphery of the aircraft for take-off and landing, and must be smoothly converted to a substantially aft flow for forward propulsion.

(b) A unified control system must be devised, so that movement of the pilot's controls will produce the same response on the aircraft irrespective of whether it is hovering or in forward flight. Thrust forces must be used for control during hovering.

(c) The air intake must be on the top of the aircraft for take-off and landing to avoid the swallowing of engine exhaust. Air must also be distributed between the top and bottom surfaces for forward flight to avoid excessive pitching moments. For supersonic speeds, it is essential to have forward facing air intakes.

2 In the proposed design, the considerations outlined in paragraph 1 (c) are achieved without recourse to a multiplicity of ducts and valves. The effects of paragraph 1 (b), are achieved by using direct or indirect thrust forces for control at all times. With the scheme proposed, the surface pressure on the aircraft will provide much larger moments than the jet thrust forces concerned. The conditions of paragraph 1 (c) are achieved by the opening and closing of intake doors, so arranged as to avoid hinge moment.

PART 3

DESCRIPTION

General

1 The proposed research aircraft, see Figures 1 and 2, consists of a very large radial flow gas turbine engine disposed between two concentric rings. It is estimated that the engine will produce nearly 50,000 lb. Sea Level Static Thrust.

2 Depending on the final design and balance, the circular plan form may need to be modified to accommodate trim flaps. The air intakes are also circular in plan, the skins extending across the central part of the plane.

3 The pilot, fuel and disposable loads are contained in the central compartment which is well insulated against aerodynamic heating by the fuel.

4 The aircraft is shown in the take-off configuration with both air intakes closed and relieving doors on the top intake open all the way round. This arrangement, permits the air to sink in and over into the intake annulus, then radially outwards to the jet exhausts which are normal to the surface around the whole periphery; about 15 in. from the edge.

5 Typical streamlines of the airflow through the aircraft are shown in Figure 3 which represents any section through the circular form of the aircraft.

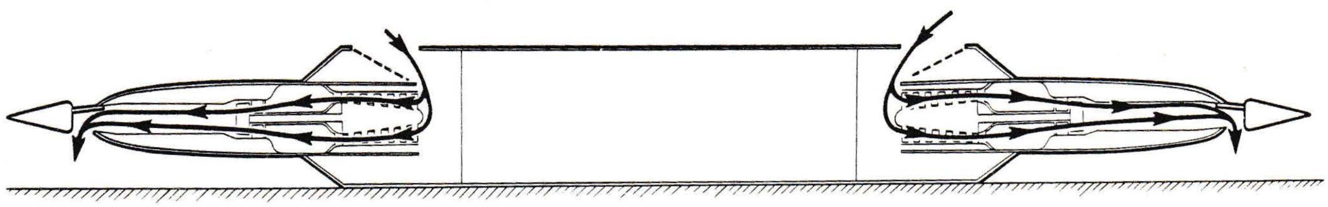


FIG. 3 SECTION OF AIRFLOW PATTERN FOR TAKE-OFF

Details of Radial Flow Engine

6 Aerodynamically, the double-sided radial engine, which is illustrated in Figure 4, is more or less a conventional gas turbine, not at present designed for reheat, although the implications of reheat have been considered.

7 Intake air is ducted to the first rotor stage (1) (no inlet guide vane is necessary) and is compressed radially outwards through rotors and stators, the stators being mounted on the aircraft structure and the rotors on the single disc. There are six stages giving a nominal pressure ratio of 3:1 SLS.

8 The design permits a clean symmetrical entry (2) to the combustion system, which is fixed in the body. The flame tubes are mounted between the sixty radially disposed structural ribs of the aircraft.

9 The engine pressure is contained between the outer skin of the aircraft and the flat sandwich type bearing plates above and below the rotor.

10 At the exit from the combustion annulus (3), the nozzle guide vanes make the final connection between the outer pressure wall and the bearing plates, ejecting the gases onto impulse turbine blades mounted on the rim of the disc and driving the rotor.

11 Since the air enters the intake and leaves the aircraft parallel to the line of flight with no swirl, there is no residual torque except during rotor acceleration. This latter condition will be compensated for by the off balance force produced by the differential movement of the rudder jets.

Starting the Engine

12 Starting is envisaged by high speed jets applied to the turbine blades from a ground supply system.

Structural Details

13 Due to the radial flow, the compressor and turbine blades are untwisted. They are parallel sided and can, therefore, be manufactured in strip by hot rolling to profile. This represents a very great manufacturing advantage. All the blades are shrouded and incorporate an aerodynamic seal on top of the shrouds to allow large tolerances with small leaks. This shroud seal is being developed by rig tests,

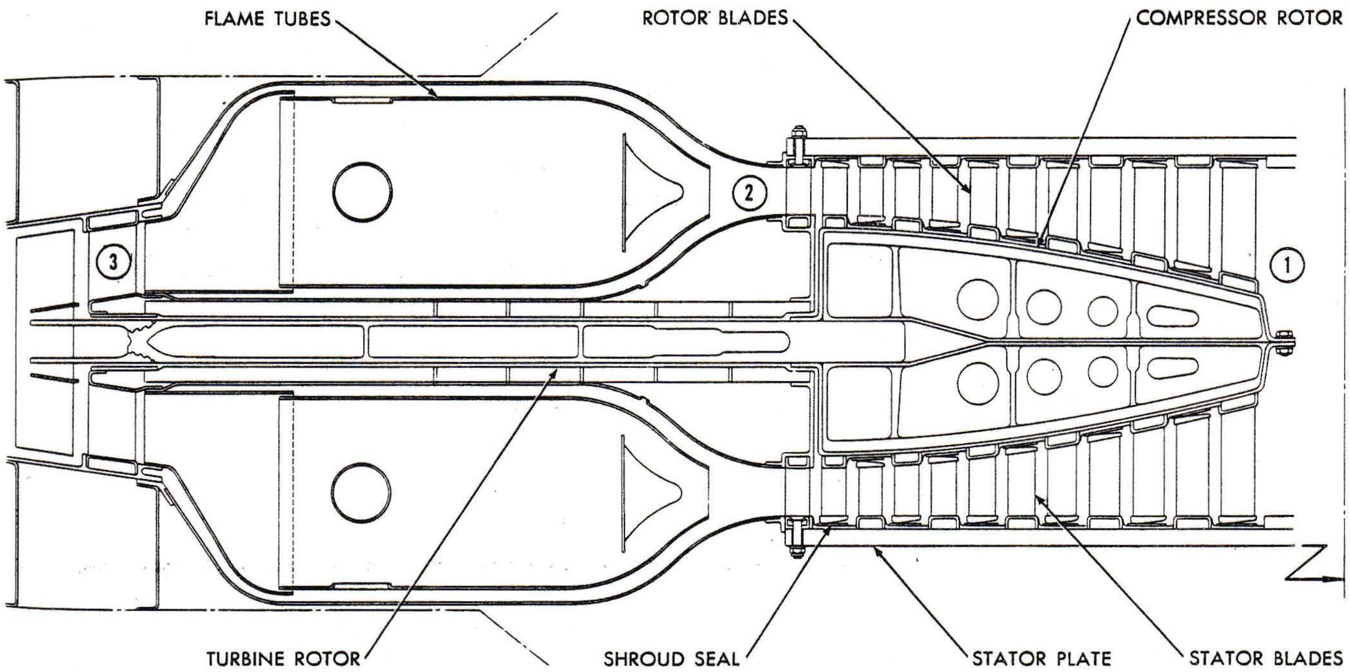


FIG. 4 TYPICAL CROSS-SECTION THROUGH ENGINE

Rotor Air Bearing

14 Application of this type of air bearing undercuts many problems previously imposed by mechanical bearings. The design configuration also lends itself to this application because of the following characteristics:-

(a) The large area of bearing surface (approximately 100 sq. ft., on both sides) which is available to support the 5,000 lb. (approx.) weight of the rotor.

(b) The high speed of rotation (approximately 500 to 700 ft./sec.) which increases the bearing capacity due to the large so called "hydro-dynamic wedge effect".

15 Figure 5 illustrates the support of the rotor on engine air. The double sided rotor bearing has a total area of 200 sq. ft. and for all practical purposes may be considered as being in two parts, as follows:-

(a) A flat double sided bearing which takes all normal loads.

(b) A vertical bearing for line of flight loads.

Combined, the two form a "T" section as shown in Figure 5.

16 The path of the bleed air, Figure 5, is shown in colour. The supply for the flat bearing is from secondary air in the combustion region, while the supply for the vertical bearing comes from the rear of the last stage compressor rotor. Exhaust is by controlled bleed to a low pressure annulus, reached through the hollow nozzle guide vanes, and also into the main exhaustor for cooling the turbine blade roots. The low pressure annulus will be vented in the rear.

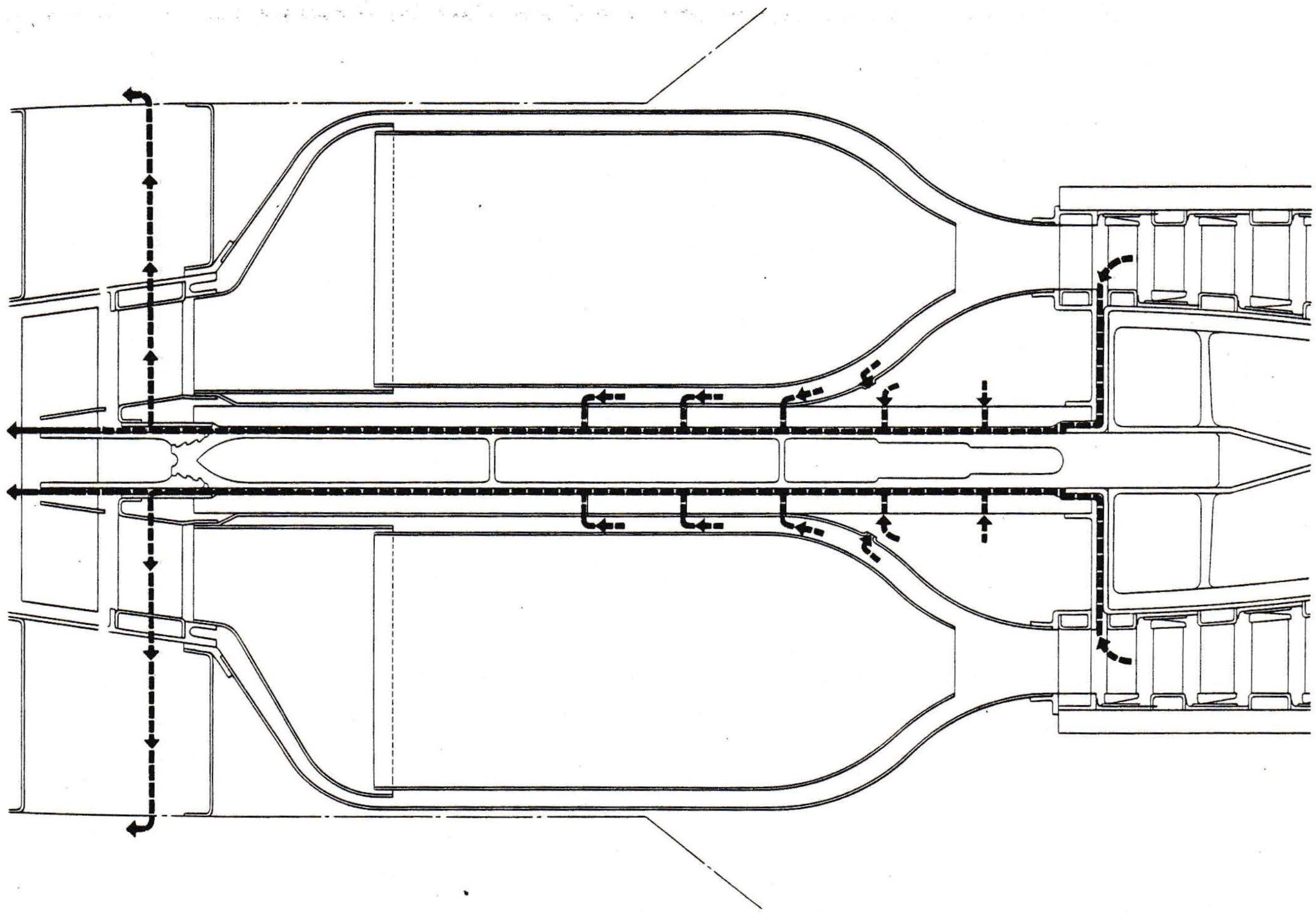


FIG. 5 CROSS-SECTION SHOWING BEARING AIRFLOW

17 Although the path of bearing air appears radial in Figure 5, the streamlines, because of engine rotation, will actually be volute shaped as shown in Figure 6.

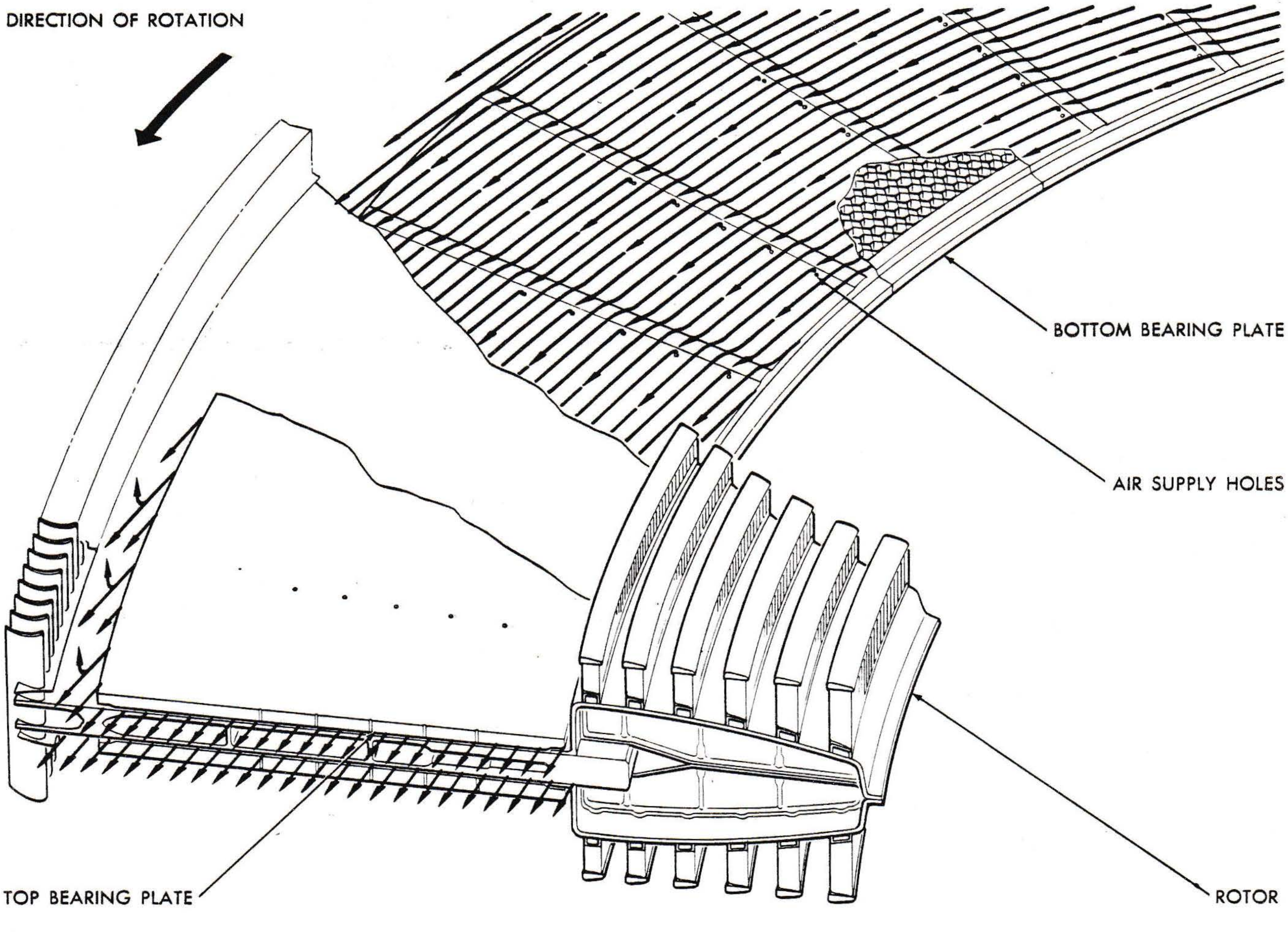


FIG. 6 PERSPECTIVE VIEW SHOWING TRUE PATH OF BEARING AIR

18 Bearing air will actually be supplied just downstream (in the direction of rotation) of the slightly raised self-lubricating pads which are fixed in the bearing plates at each structural rib.

19 In the high load case where clearances are small, the air, which is drawn across the pad by the viscous shear force due to rotation, is compressed to several times the supply value providing a considerable improvement in bearing efficiency. At the same time, the upper surface of the rotor experiences a large reduction of pressure due to the increased speed of flow.

NOTE

The rotor bearing has been tested at one-tenth scale. Results have been so far very satisfactory, but tests have not yet been completed.

20 Starting is envisaged from a ground supply of compressed air applied to points on the rotor bearing surface.

21 Stopping of the engine will be comparatively simple due to the low idling speeds. The rotor will ground on the self-lubricating bearing pads and slow rapidly to a stop.

NOTE

The proposed cast iron or carbon pads provide good dry bearing surfaces on steel and are not expected to suffer excessive wear or provide undue stopping torque. Compressed air may also be used for stopping purposes if found to be necessary.

Aircraft Structure

22 The basic structure of the aircraft, see Figure 2, consists of four typical regions. These are:-

(a) The central fuel tank - comprises a continuous ring of rectangular cross section, and a horizontal floor which divides the tank into upper and lower sections. A series of radially arranged baffles are also included. The inner ring of the tank forms the cylindrical cockpit wall. The tank structure, in general, carries all fuel inertia loads, plus pressure, and because of its fully enclosed cross section, provides an exceptionally strong and rugged base for the outer structure.

(b) The air intake zone - is a frame type structure, consisting of 120 ribs which are rigidly attached to the outer cylindrical wall of the fuel tank. These ribs, support the outer skins of the air intake along their top and bottom edges, and mate with the outer portion of the structure containing the main air bearing. the structural members are faired, to reduce drag inside the air intake.

(c) The upper and lower outboard shell rings - which bridge the rotor and contain the engine pressure, are joined together by bolts, arranged circumferentially, inboard of the compressor and outboard of the turbine. Each assembly consists of an outer skin supported by 120 ribs.

(d) The outer jet exhaustor duct - consists of self contained peripheral segments which are bolted to the outboard shell rings. This arrangement

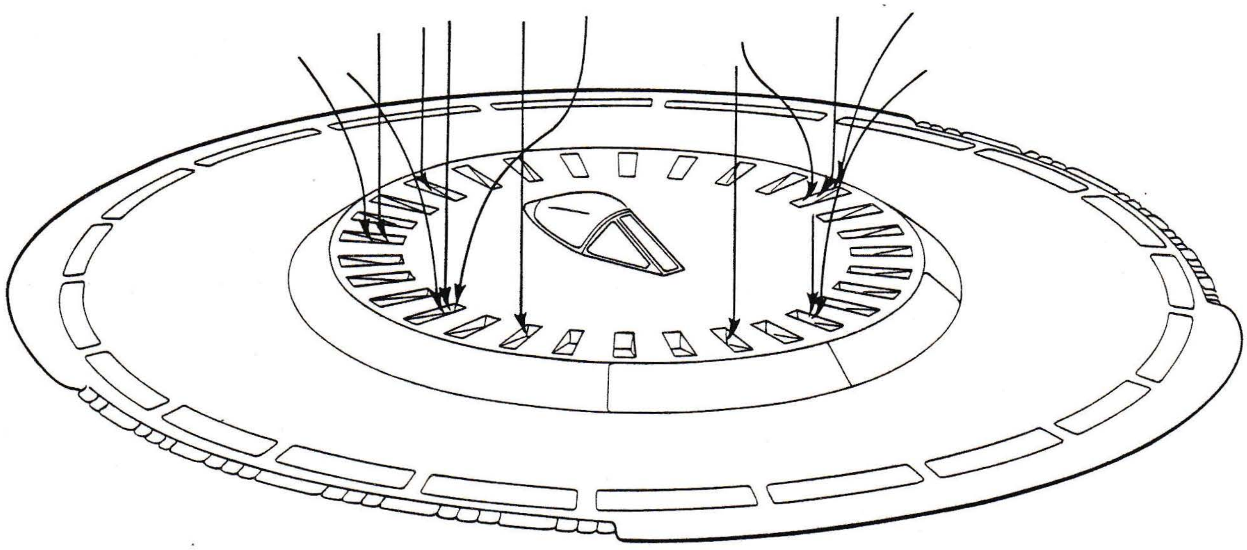


FIG. 7 AIRFLOW INTO INTAKE DURING TAKE-OFF AND LANDING

produces an exceptionally stiff structure, which is capable of carrying all air loads induced through combustion, flight and control.

23 The duct segments, which consist of upper and lower shells, are joined together by a system of posts and diagonals. These, like the air intake ribs, are faired to ease the duct flow in the forward flight condition.

24 All four structural components, as described in Paragraph 22, are fabricated in steel, with the exception of the cockpit walls and fuel tank baffles. These are of light alloy construction, the external walls of the fuel tank being insulated to provide protection against aerodynamic heat in forward flight, and ground heat during take-off and landing.

Air Intake

25 Above a Mach Number of approximately 1.4, the major portion of compression in the engine cycle should be derived from the air intake. At very high speeds, the intake compression ratio may be four or five times the mechanical compression ratio which it multiplies. The performance, in common with other supersonic designs, depends critically on the pressure recovery efficiency into the intake. Futhermore, the problem of avoiding spillage drag looms larger on this aircraft, since the same flight Mach Numbers can be obtained at much lower cycle temperatures (i.e. without reheat) due to the mass flow being proportionately larger.

26 In addition to the problems discussed in the preceding paragraph, as well as those of the overriding factors given in Part 2, we should also consider the problems

of balancing the pressures recovered into the top and bottom intakes (which may be substantially different at supersonic speed with the aircraft at a cruising incidence of approximately 5 degrees), and of ensuring a good radial distribution, to the compressor face with tolerable internal duct loss.

27 It is clear from the foregoing, that the intake poses the most difficult problems for compromise.

28 In the solution now proposed, the intake, see Figures 7 and 8, as viewed from the outside, resembles two very shallow truncated cones centrally disposed on the top and bottom surfaces of the aircraft. As previously described in Part I, the aircraft rests on the bottom intake when on the ground and "take-off" air is supplied through the 30 sq. ft. of relieving door area on the top intake.

29 The estimated area required for the intake in the SLS condition is 21 sq. ft. to give a Mach Number of 0.55 in the entry. The scheme proposed will provide:

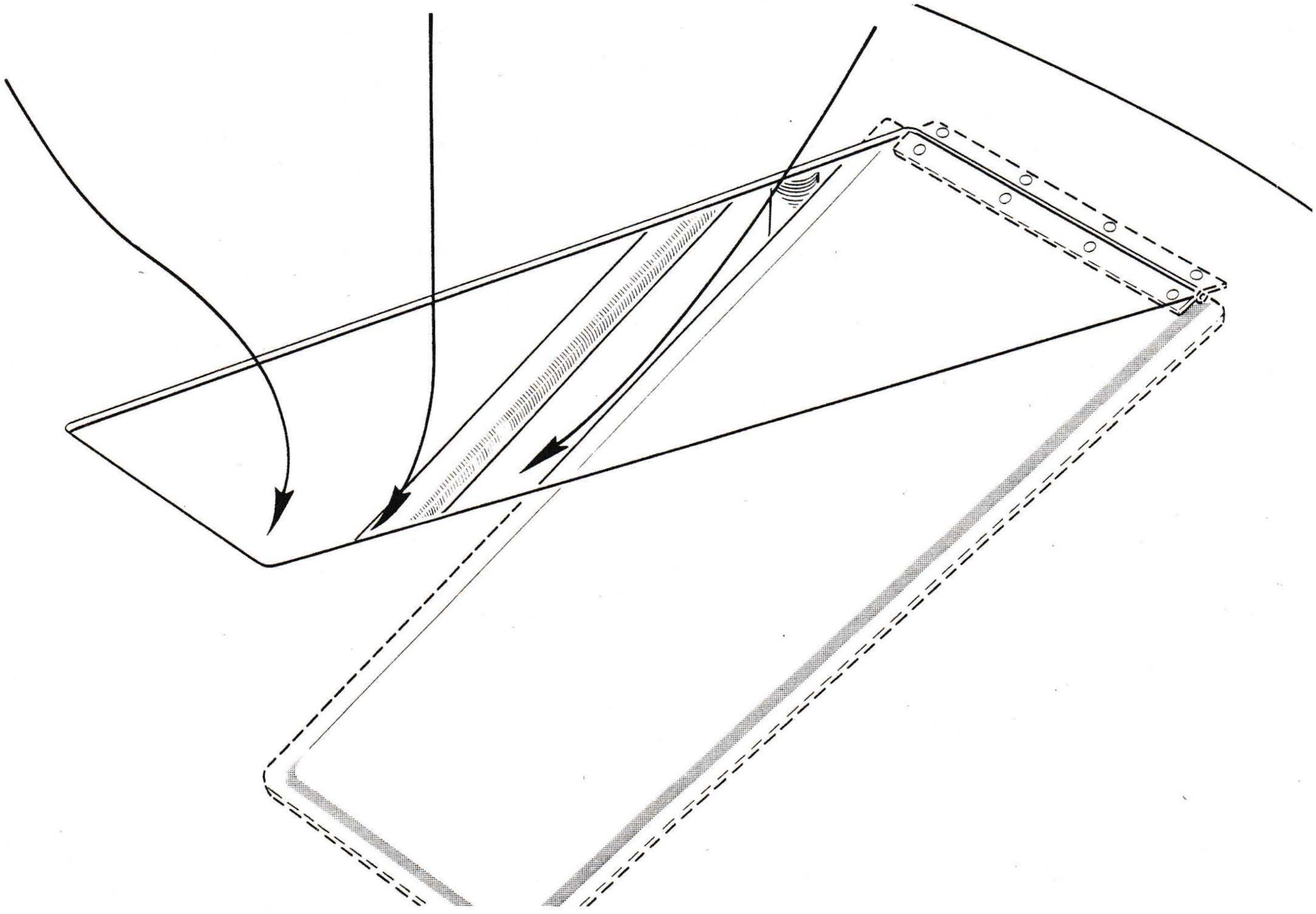


FIG. 8 DETAIL OF AIRFLOW INTO TAKE-OFF DUCT

(a) An entry Mach Number of 0.34.

(b) Optimum distribution through the radial arrangement of the internal structure.

(c) A minimum internal flow path.

(d) A large internal flow area with cascaded corners and a rapid contraction to the compressor face.

(e) An entry which is as far as possible from the exhaust to minimize the re-circulation danger.

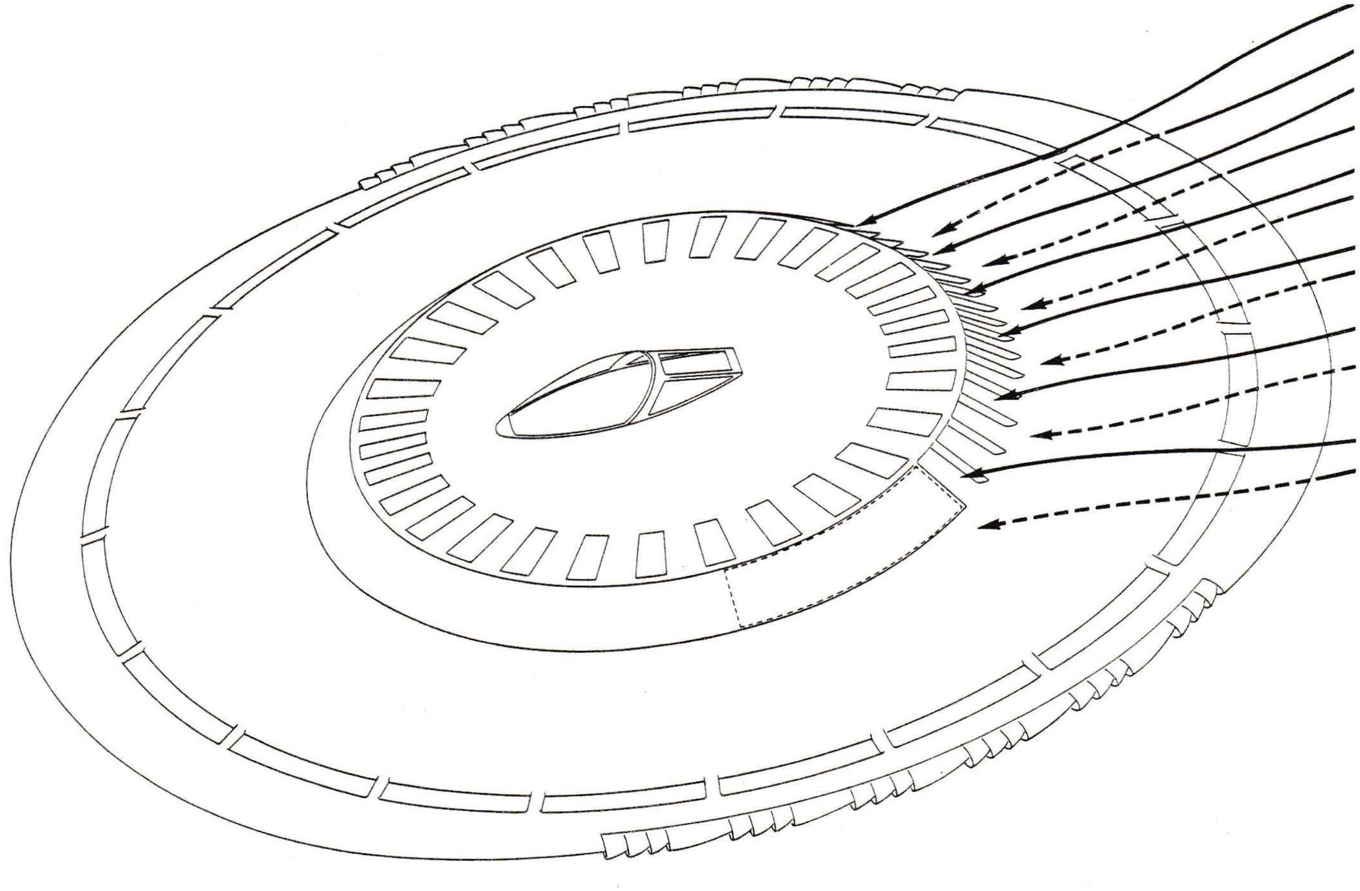


FIG. 9 AIRFLOW INTO INTAKE DURING FORWARD FLIGHT

30 After transition to forward flight, the forward facing doors (which may be pressure balanced) are opened to their fullest extent, see Figures 9 and 10, and the intake pressure will automatically close the relieving doors.

31 The following will form the basis for converting the axial flow to radial internal flow:-

(a) A slow diffusion from Mach 0. 55 at entry (21 sq. ft.) to Mach 0. 4.

(b) Acceleration on the outward side of the flow passage to pass the air to the rear.

(c) Plenum conditions in the rear segment.

(d) Streamlining of intake structural struts in the required direction.

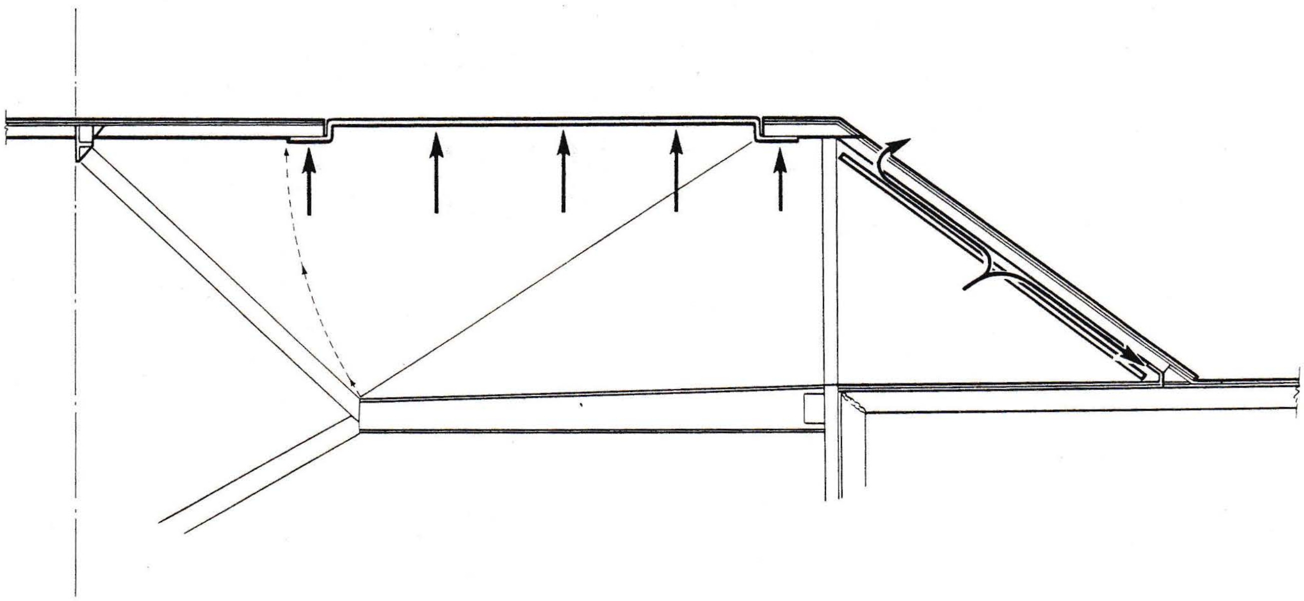


FIG. 10 AUTOMATIC CLOSING OF TAKE-OFF AIR INTAKE DOOR

32 With reference to Figure 11, some tests with satisfactory results have been obtained. Aerated water was used for flow visualization, the measuring of the total head distribution, and the entry and exit with air.

33 At supersonic speeds, the intake doors may be closed until the appropriate area is provided. When they are closed to this position, the resultant flow deflection

round the doors will be small because of the rake on the intake sides. With regard to pressure recovery, it may be generally specified that up to Mach 1.5 normal shock recovery is adequate, and that above Mach 2.0, some improvement above normal shock is essential to avoid intolerable wastage of available energy.

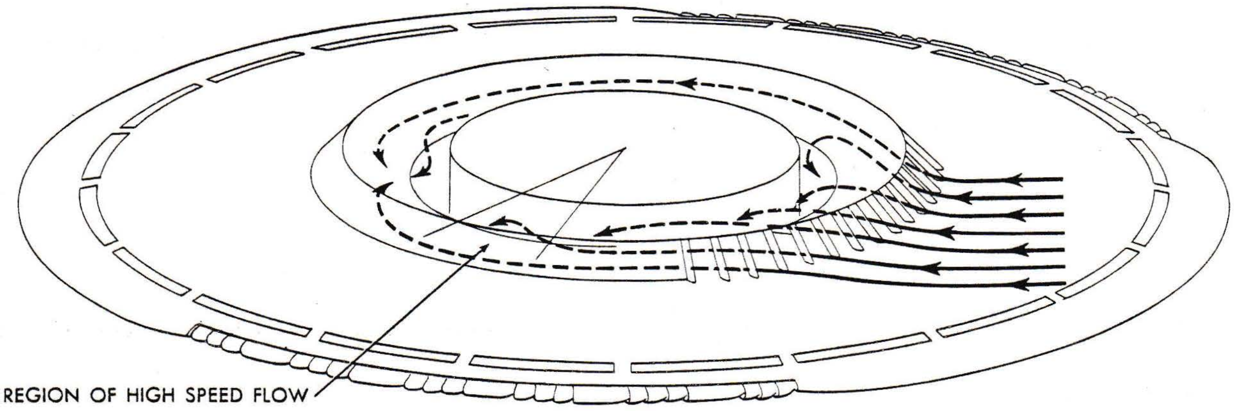


FIG. 11 INTERNAL INTAKE AIRFLOW IN FORWARD FLIGHT

34 It is proposed to obtain an optimum double shock pressure recovery either by means of a fixed wedge, designed for operation at one selected set of conditions, or by means of the system shown in Figure 12 which illustrates a nearly two-dimensional wedge type intake with the wedge provided by a "spoiler-generator".

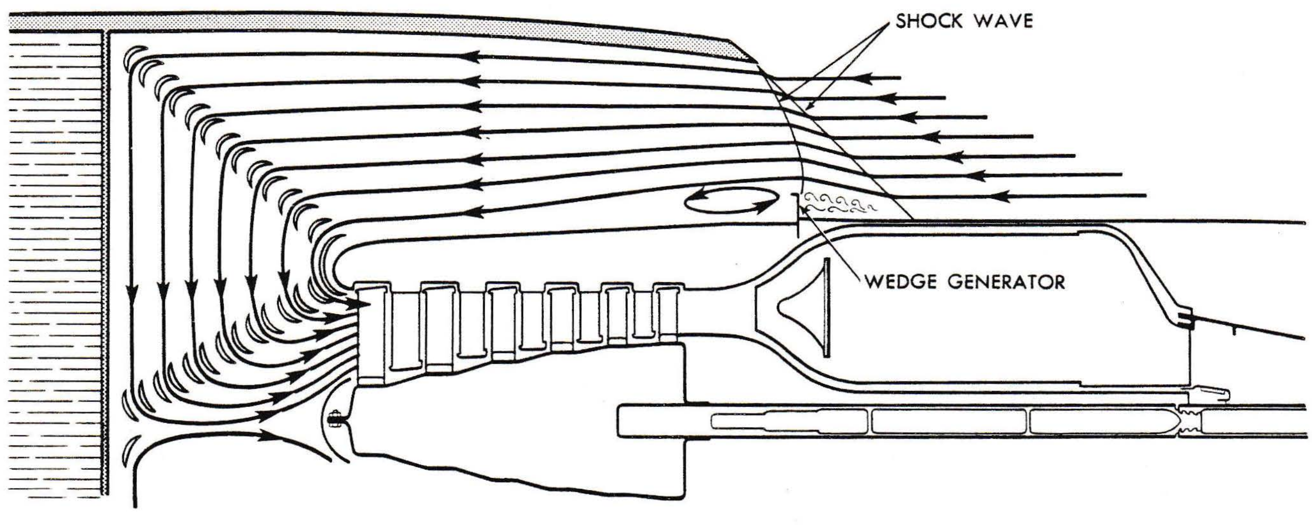


FIG. 12 FORWARD SECTION OF AIRFLOW INTO ENGINE SHOWING PRESSURE RECOVERY SCHEME

35 Breakaway is expected forward of the generator with the formation of an air wedge taking the place of a mechanical wedge. A fixed boundary layer bleed (which is an annulus, vented to the rear) will be necessary forward of the air wedge due to

the large surface area of wing in front of the intake. Advantages for this arrangement are as follows:-

(a) The spoiler operating loads have only to overcome friction and do not operate against the wedge pressure.

(b) The variable doors, make possible the focussing of the oblique shock just forward of the intake tip for any Mach Number or engine condition.

Exhaust and Nozzle System

36 Figure 13, shows a detailed section through the exhaust system at any station with the shutters in the take-off position. The duct, in a radial direction, is approximately three feet in length and the nozzle which is a double annulus around the aircraft, may be partially or completely closed on either the top or bottom surfaces by sliding shutters.

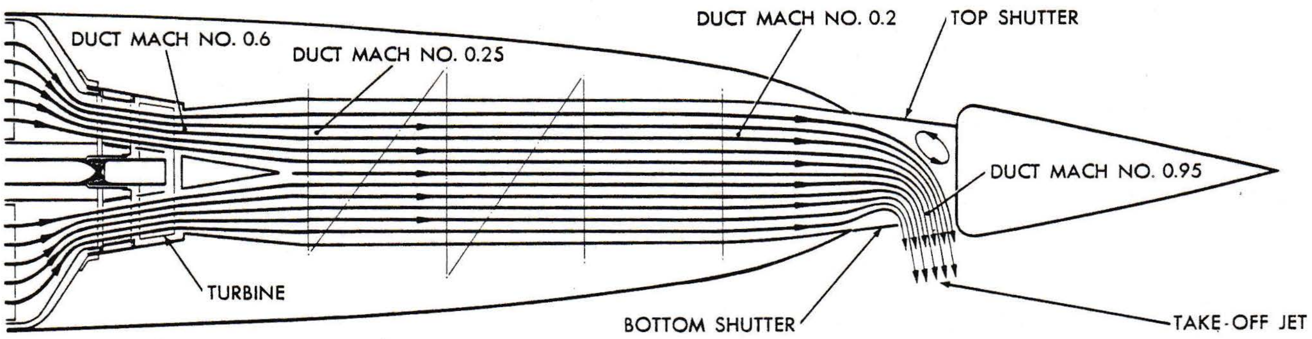


FIG. 13 TYPICAL SECTION OF EXHAUSTOR DUCT SHOWING TAKE-OFF GAS FLOW

37 For the take-off condition, the desirable factors for the low pipe and turning loss, are to have a slow diffusion to the maximum area possible, followed by a rapid acceleration where the large change of direction occurs.

38 Diffusion is provided by the tailpieces behind the turbine and the parallel sided ducts. Slow diffusion through the latter, is due to the increase in duct radius.

39 The Mach Number is rapidly increased from .25 at the end of the duct, to approximately .95 at the orifice. (The exhaust nozzle is not choked in the SLS condition, due to the low engine pressure ratio).

40 The estimated duct Mach Numbers, in the SLS maximum thrust design case, are shown at three stations in Figure 13. The size of the duct (which adds 270 sq. ft. of wing area, although the frontal area remains the same as for Project 'Y') is dictated by the amount of flow required for forward flight.

41 The change from take-off to forward flight, is governed by:-

(a) A generally forward movement of all shutters.

(b) A partial closing of the bottom and an opening up of the top shutters.

(c) Opening of the rudder nozzles.

42 The flow in the duct, between turbine and exit nozzle, corresponds to that shown in Figure 15, where the flow pattern is constructed by dividing the turbine exit and final nozzle areas into equal sections, while allowing for the flow out of the rudder nozzles.

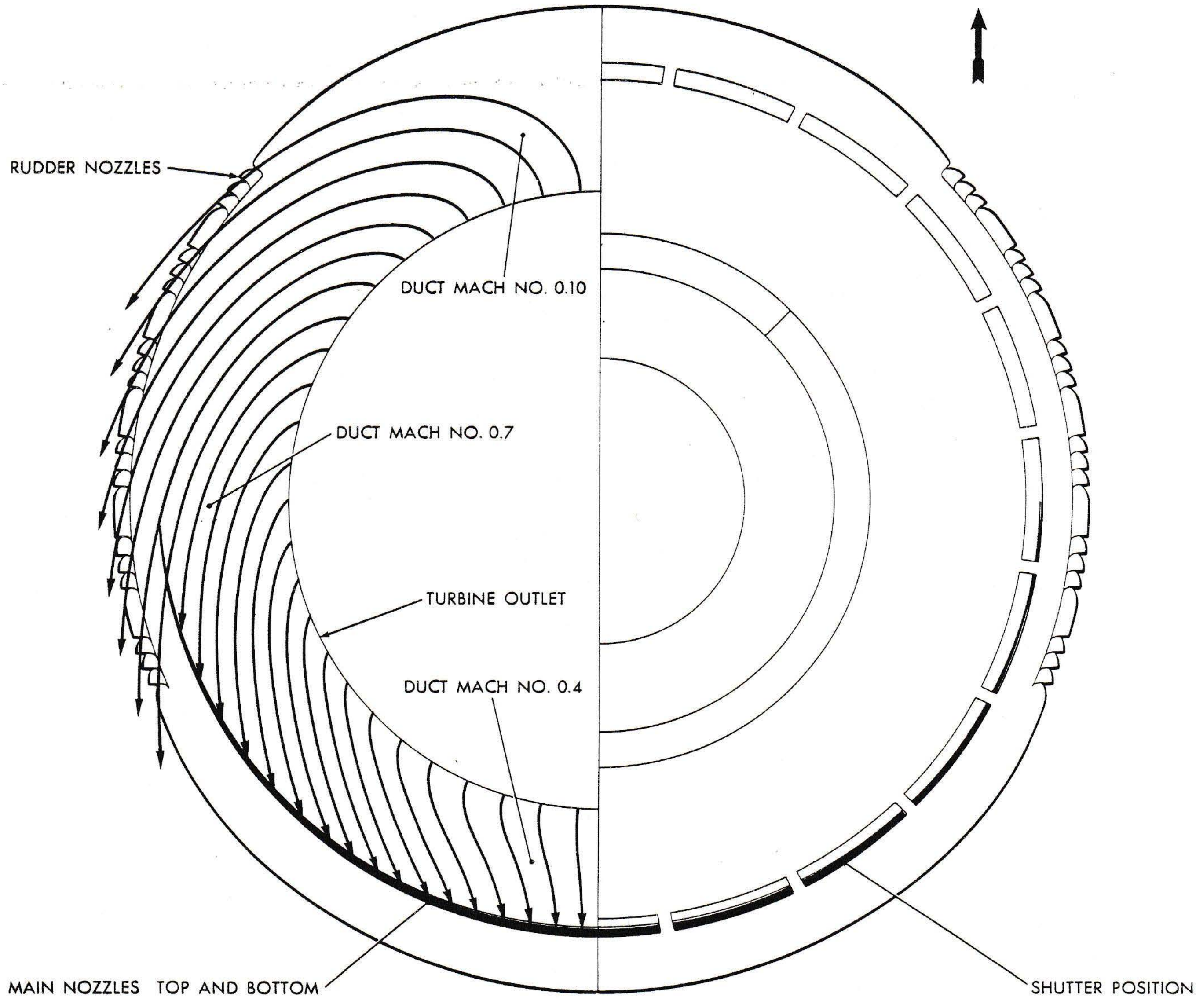


FIG. 14 INTERNAL EXHAUST DUCT FLOW DIAGRAM IN FORWARD FLIGHT

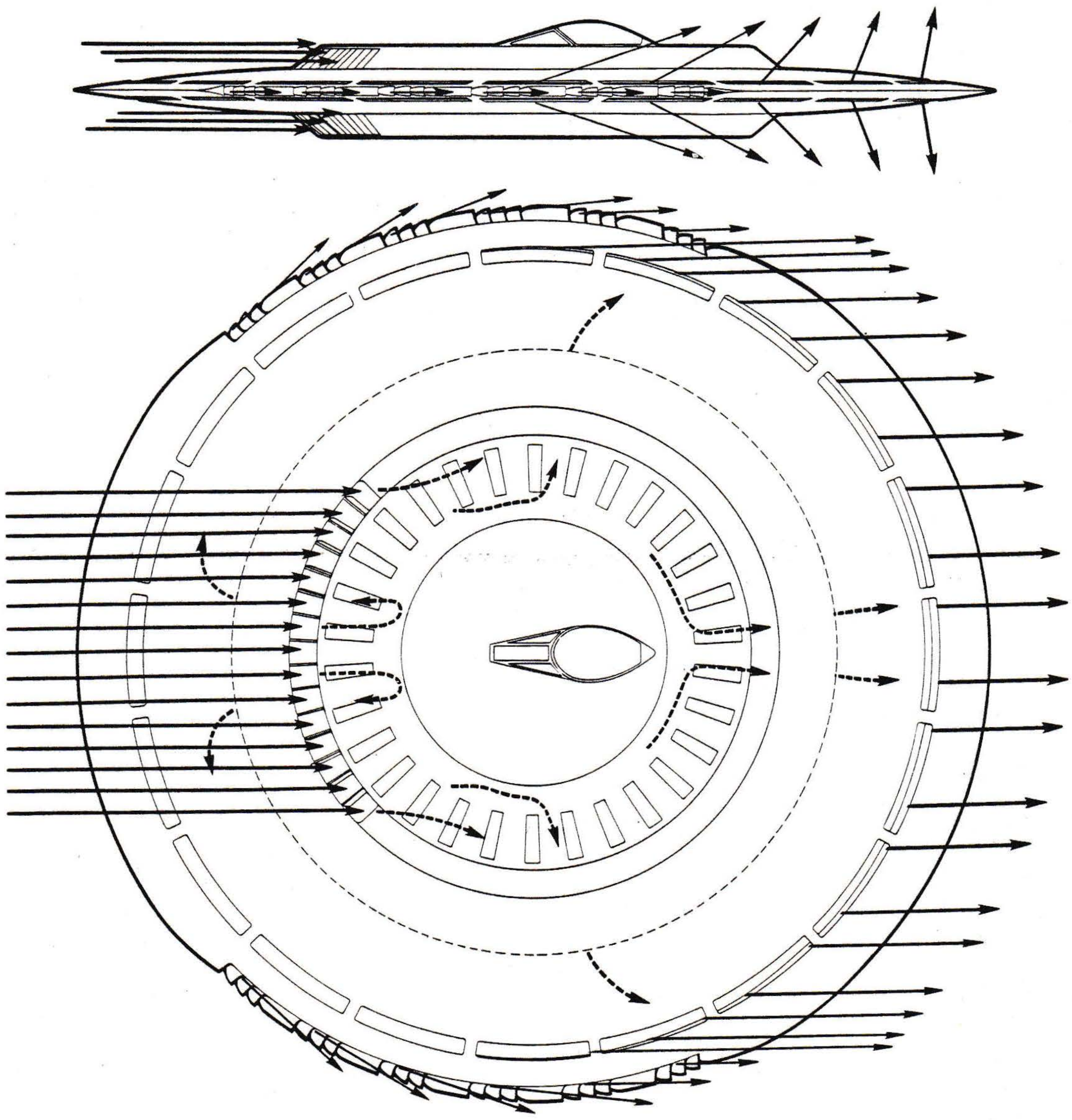


FIG. 15 THROUGH FLOW AT LOW FORWARD SPEED

43 With reference to Figure 14, the following points may be noted:–

(a) There is no exhaust in the forward half of the aircraft.

(b) 20% of the thrust is through the rudder nozzles.

(c) A region of high speedflow exists in the sides of the duct. The structural struts in this region will be faired for flow in the required direction.

(d) The streamline struts are only 5% of the total jet pipe wetted area. The total wetted area is only 50% more per lb. design air mass flow, than the tailcone, with no jet pipe of typical conventional engine.

(e) 70% of the flow exhausts in the rear 90° segment.

(f) At the extreme rear of the aircraft, the exhaust is normal to the surface, but progressively towards the sides the jet will lean further, in still air. This is illustrated in Figures 15 and 16.

44 Approximately 50% thrust will be available for acceleration at low forward speed. This sacrifice in possible acceleration potential, is not considered a serious handicap. At high speeds, in forward flight, however, a loss of only 10% of the total thrust is serious as it signifies a much larger percentage of loss of net propulsive thrust. (Total thrust minus internal engine drag). The proposed scheme will only be tolerable if most of the thrust from the rear jets is recovered in forward flight. This is believed to be possible through a jet bending mechanism which exists to deflect the thrust so that it leaves the aircraft in an "axial" direction.

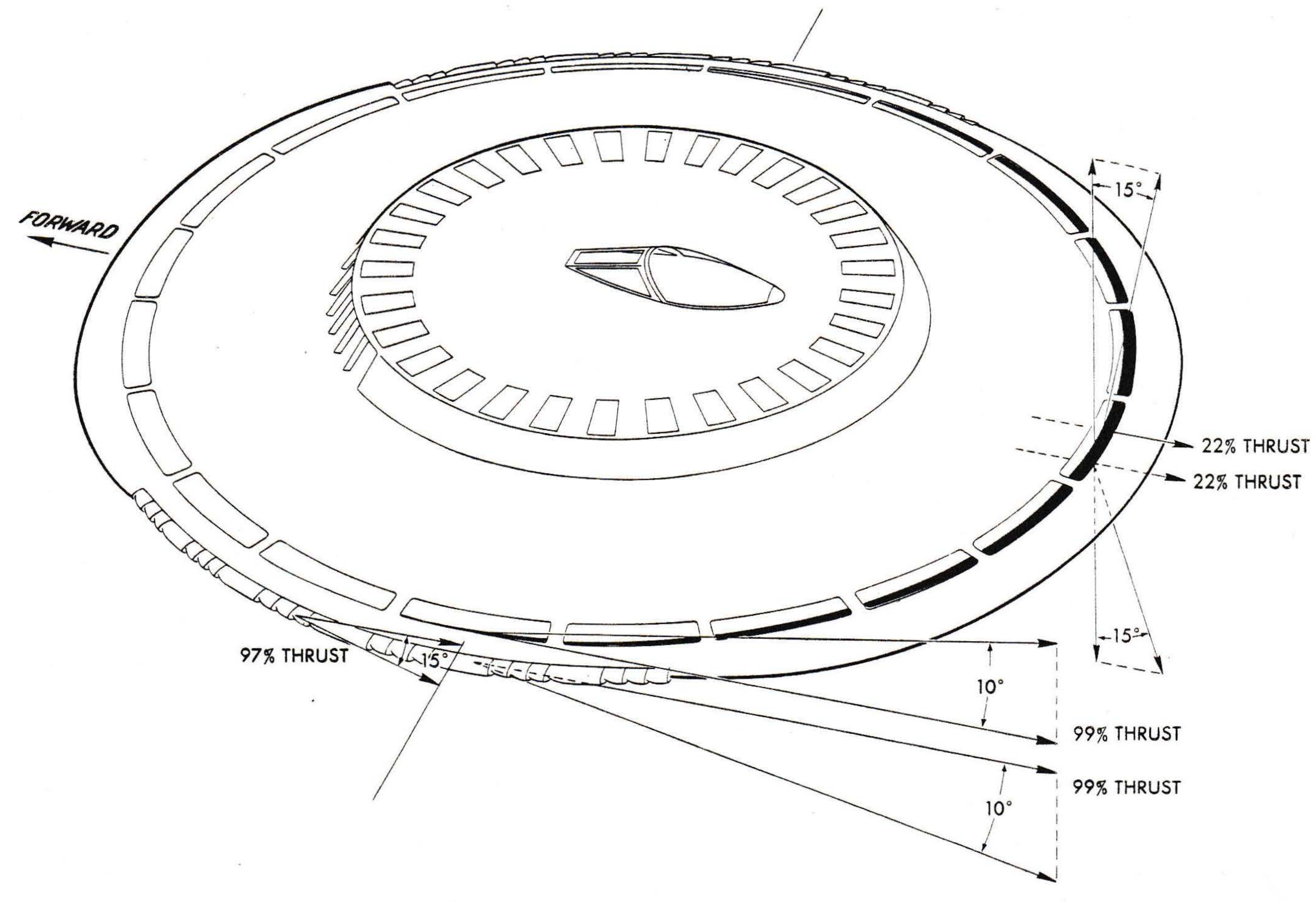


FIG. 16 EXHAUST JET ANGLES AT LOW FORWARD SPEED

45 Figure 17 illustrates the so called "Coanda Effect" where a jet, in the form of a slot, is deflected through large angles by placing a curved surface in contact with its edge, on one side.

46 A preliminary investigation into the mechanism (not published) indicated that statically, the critical value of the ratio of jet width to radius of curved surface, is approximately 0.5 (i.e. if the gap 'd', in Figure 17, is increased, the jet would break away and follow the boundary CE).

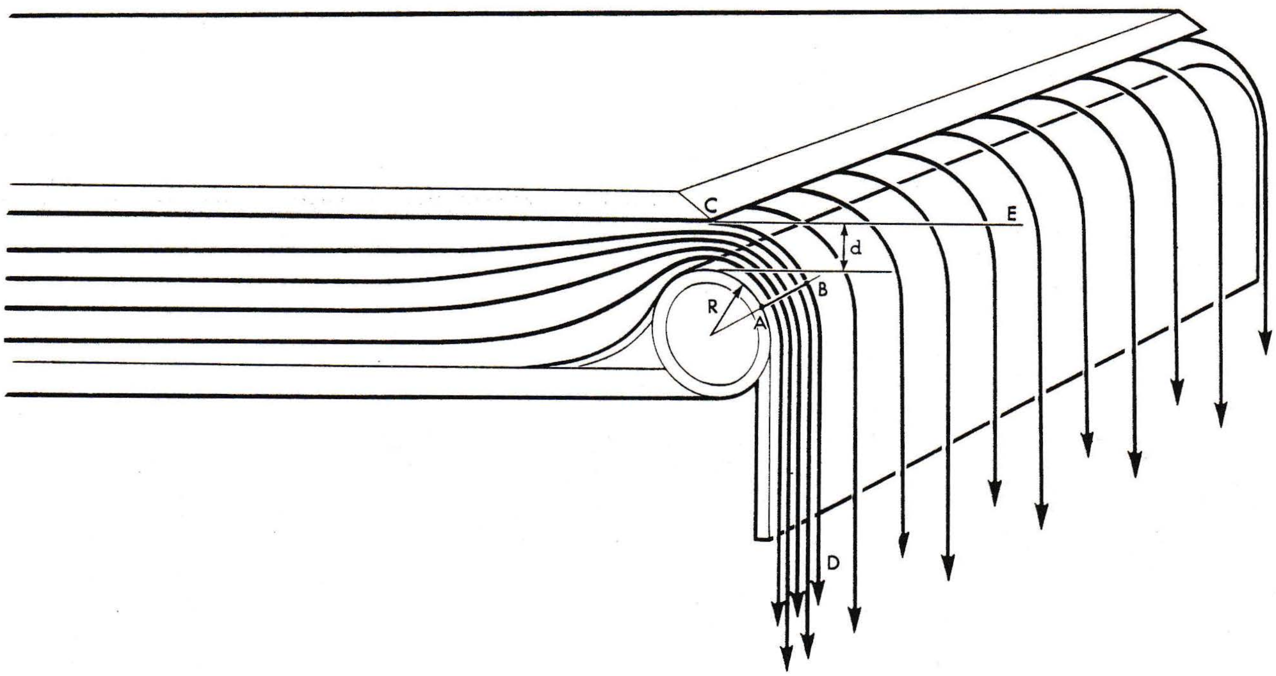


FIG. 17 COANDA EFFECT: HIGH ASPECT RATIO JET BENDING

47 Due to the bending of the flow with this mechanism, there is a pressure gradient across the jet at any section, e.g. Line AB of Figure 17, which balances the centrifugal force. This pressure gradient can obviously not exceed one atmosphere statically, since the pressure at the free boundary CBD is atmospheric.

48 Because of the radius required, this attractive method of bending the jet cannot be used for take-off purposes. In forward flight, however, the pressure on the free boundary will be greatly increased by the dynamic head of the oncoming air so that a much larger gap/radius ratio can be used.

49 In the proposed nozzle, the ratio reaches 2.0 at the extreme rear, and increases rapidly towards the sides. Figure 18, is a section through the extreme rear of the aircraft which illustrates the thrust recovery mechanism and expected shock pattern at supersonic speed.

50 Preliminary tests, indicate that this nozzle mechanism is adequately efficient. It should be noted that in any system involving jet bending, a very high aspect ratio jet for turning a corner with minimum loss, is at a premium.

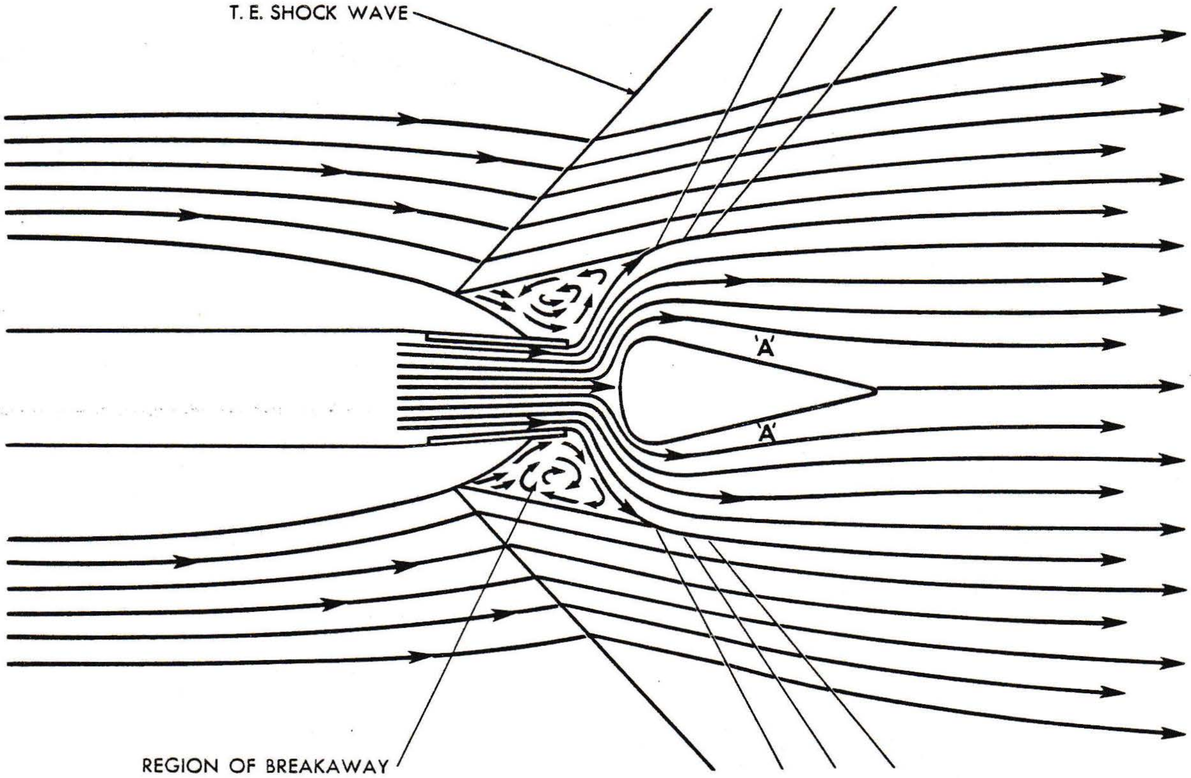


FIG. 18 SECTION THROUGH REAR OF AIRCRAFT AT SUPERSONIC SPEED

Control System

51 Aircraft controls are generally a compromise between what is possible aerodynamically and structurally, and what is tolerable dynamically. The ideal control system, should be capable of producing yawing, pitching and rolling moments together with longitudinal force change. Separately, each of these forces should have no influence on any other force or moment.

52 In the proposed aircraft, thrust forces are used for control at all times for the following reasons:-

(a) In the hovering case, it is mandatory to use thrust forces since no aerodynamic forces are available.

(b) Other types of control which will avoid a double system for hovering and forward flight appear to be considerably more elaborate.

(c) By using thrust forces to influence the surface pressure, the proposed scheme provides large forces with no hinge moments.

(d) In any supersonic aircraft, where indicated speeds of perhaps 700 to 800 knots, or dynamic pressure of over 2000 lb./sq. ft. have to be considered, a prima facia case exists for departure from the use of conventional flap type controls. The proposed control is not subject to flutter and applies a distributed load directly on to the wing.

53 The top and bottom control shutters may be considered as two rings, see Figure 19, which for take-off, hovering and landing purposes, are concentric with the annular nozzles. In operation, they contract or expand to open and close the top or bottom nozzles.

54 Rotation of the small centre rings will accomplish the desired movement, whereas, differential translation in azimuth, by exhausting more on the top and less on the bottom on one side, and more on the bottom and less on the top on the other side, will produce a rolling moment. Similarly, fore and aft movement of the rings will produce a pure pitching moment as illustrated in Figure 20.

55 A small gap, representing the amount of control available without change of jet-lift or side force component, is left open at the top for the hovering case. However, in view of the ground cushion, the secondary effects may not be important, and in this case, the top shutters would be closed.

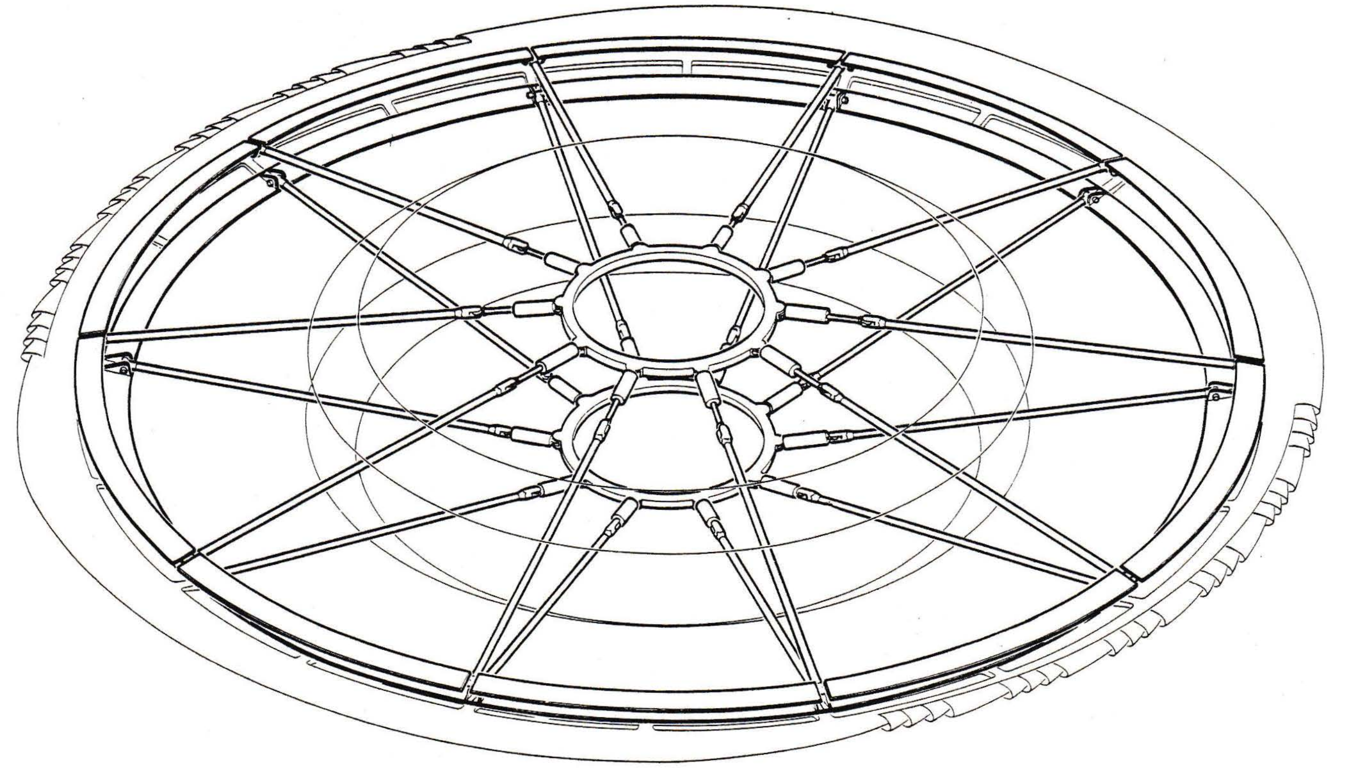


FIG. 19 SHUTTER CONTROL DIAGRAM

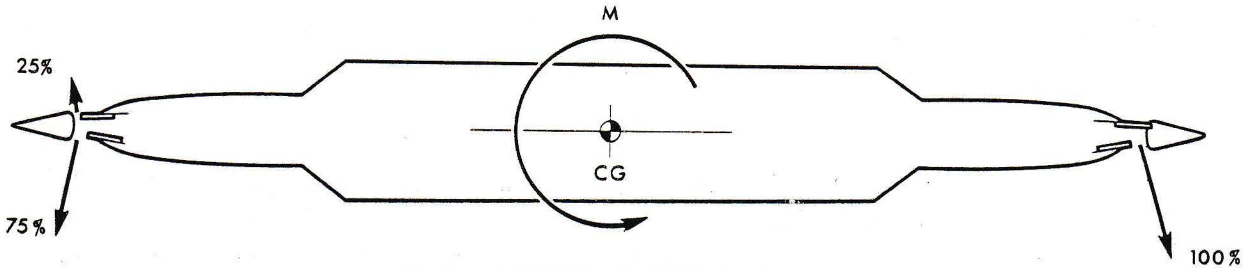


FIG. 20 CONTROL MOMENT DIAGRAM

56 For forward flight, both the top and bottom shutter rings are moved forward collectively, and the top shutter ring is contracted to open the upper nozzle, whereas the bottom shutter ring is expanded to compensate and provide the correct nozzle area.

57 In addition to the main shutter movements, described in Paragraph 53, the rudder nozzles are opened in forward flight. These provide 19.5% direct forward thrust (without correction for expansion on the nozzles) and the exhaust area is again compensated by a reduction of the top and bottom annular nozzle areas.

58 This produces the duct flow already illustrated in Figure 14, and the thrusting system at low forward speeds is illustrated in Figure 16. As speed increases, the thrust efficiency improves as described in Paragraphs 45 to 50 inclusive.

59 Rudder control in forward flight, is brought about by a partial closing of the rudder nozzles on one side of the aircraft.

60 The routine envisaged for the transition from hovering to forward flight, is described in Part 6.

Related Systems and Controls

61 The following, is a brief description of the related systems, controls and equipment, envisaged for the radial engined aircraft.

Fuel System -

(a) The fuel system, see Figure 2, consists of an integral tank with four air turbine operated high pressure fuel booster pumps, two flow control units and a duplicated piping arrangement.

(1) Piping comprises two harness assemblies which terminate at the injection nozzles of the combustion chambers on the top and bottom surfaces of the engine.

(2) Power for operation of the four fuel pumps is supplied by bleed air taken from the last stage of the engine compressor. Provision is made for one

of the pumps to be driven by a 24 volt d-c electric motor, so that an initial supply of fuel may be fed to the engine for starting purposes.

(3) The all metal tank, which is designed as a complete annulus, is pressurized to approximately 10 psi. Pressurization is necessary to prevent a high loss of fuel at altitude due to boiling. Tank baffles are incorporated to reduce surge, and the bottom surface and the inner wall of the tank (which is adjacent to the air intake) is well insulated to protect the fuel against aerodynamic heating.

Oil System -

(b) An oil system is not necessary since the engine is air lubricated.

Hydraulic System -

(c) A hydraulic system is not required, as there is no retractable undercarriage or hydraulically operated controls fitted to this aircraft. The limited number of remote controls employed are mechanically operated.

Electrical System -

(d) The 24 volt a-c and d-c power is supplied by an air turbine driven alternator and a selenium rectifier. The system provides power for operation of instruments, radio and other auxiliary services. A conventional battery installation provides d-c power for the engine torch igniters.

Cockpit Equipment and Instruments -

(e) Cockpit equipment consists of conventional flying controls, to which are added a trim wheel for setting the aircraft to forward flight, and two trim buttons, for adjusting the nozzle area of the top and bottom shutters.

(1) The rudder pedals, which act in a conventional manner, control the operation of the rudder nozzle shutters. A trimmer for adjusting the rudder nozzle settings is also installed.

(2) A single throttle lever, controls the engine rpm, and a shut-off button operates the fuel shut-off cock.

(3) Instruments consist of the normal blind flying panel, an rpm indicator, a jet pipe temperature indicator, a fuel contents gauge, fire warning indicators, and a gyro compass. DF, air to ground RT, and other navigational aids are located on the right and left consoles.

(4) A simplified form of ejector seat is fitted, as high ejection velocities are not considered necessary for this tailless aircraft.

PART 4

AERODYNAMIC DESIGN AND PERFORMANCE OF RADIAL ENGINE

General

1 Reference 2 is a detail study of the aerodynamic design and performance prediction of the engine for Project 'Y'. The basic design is conservative and corresponds aerodynamically to a conventional engine of about 1947.

Basic Data and Assumptions

2 Compressor - at SLS conditions a compression ratio of 3:1 with isentropic efficiency of 84% has been taken. The compressor has six stages and with 288^{o}K inlet total temperature, a rise of 126^{o}K is required.

3 Combustion Chamber - a loss of 5% of the total pressure at entry is assumed. An effective heat release of 10, 300 CHUs/lb. has been used to calculate fuel consumption. With a wide range fuel of 10, 500 CHUs/lb. , this allows for 2% combustion losses.

4 Turbine - inlet temperature 1100^{o}K. Isentropic efficiency 85%.

5 Exhaust System - expansion efficiency 96%.

6 Design Mass Flow - with the data assumed above, the specific thrust is 52. 9 lb. /lb. /sec. The unit is designed for 823 lb. /sec. SLS mass flow giving a basic thrust of 43, 500 lb.

Development

7 The engine of Project 'Y2' is identical to that of Project 'Y'. However, a number of detail developments have taken place since the publication of data on the latter. These are as follows:-

(a) The air bearing has been incorporated and the disc redesigned to suit.

(b) The rotor has been effectually split into a compressor rotor and a turbine rotor, to allow independent expansion and to obtain a better overall stress distribution in the disc. The turbine rotor, see Figure 4, is sandwiched into the compressor rotor, the drive being through shear bolts.

(c) The design of the shroud seal has been modified in accordance with the results of tests.

(d) The combustion chambers, which were designed by Messrs. Joseph Lucas, have been shortened and the entry has been improved. The following data is applicable to the present scheme.

Area combustion intensity CHU/hr./ft.^{2}/atm.	5.21
Mean velocity ft./sec.	70.7
Pressure loss factor	46.5

(e) The compressor has been lengthened (the overall length of the rotor remaining the same) and the root blade chords have been increased with the object of increasing the blade Reynolds number through the compressor, see Reference 2. First stage blades are now 1.35 in. chord instead of 0.8 in., progressively reducing to 0.8 in. at the last stage.

(f) The fixing of the turbine blade has been improved.

8 In a supplement to Reference 2, the effect of up-designing the engine in two ways is considered as follows:-

(a) Increasing the turbine temperature from 1100°K to 1200°K by means of turbine blade cooling. This is clearly an attractive line of development for this engine, where cooling air may be led through the inside of the hollow turbine rotor and through the blades to exhaust at their tips.

(b) Allowing the Mach number on the first stage blading to increase from 0.72 to 0.85 thus increasing the throughput without altering the size of the engine.

Performance Potential

9 The net thrusts and specific fuel consumptions quoted in Figures 21 and 22 take into account:-

(a) The preceding limited developments.

(b) An improved supersonic pressure recovery, together with 90% isentropic efficiency for the flow between intake and compressor face. The pressure recovery factor is given in Figure 23.

(c) Plain nozzles and 100% 'thrust recovery' from the jet-bending at the rear nozzles.

10 With regard to net thrust, it should be appreciated that at high supersonic

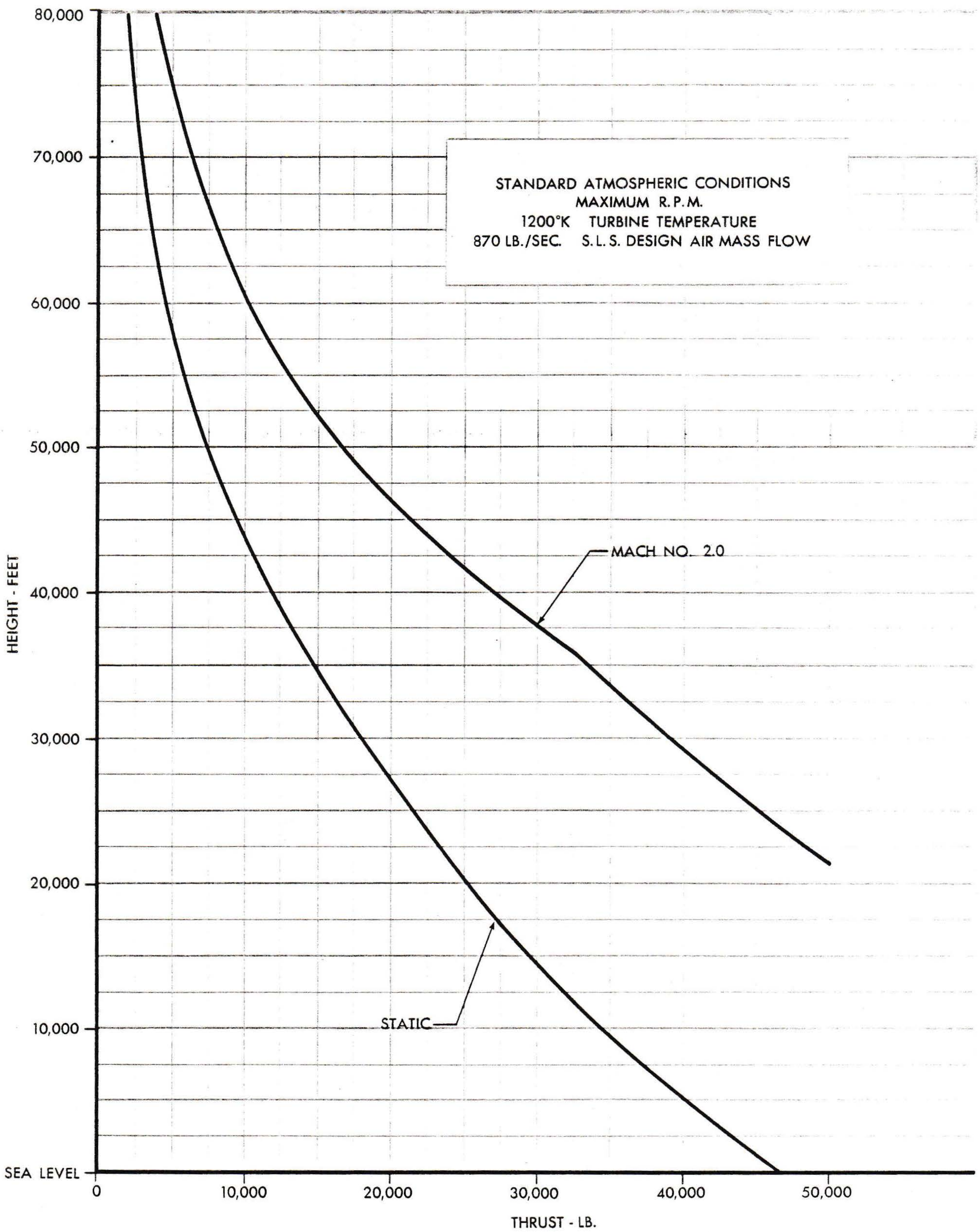


FIG. 21 THRUST VS. ALTITUDE

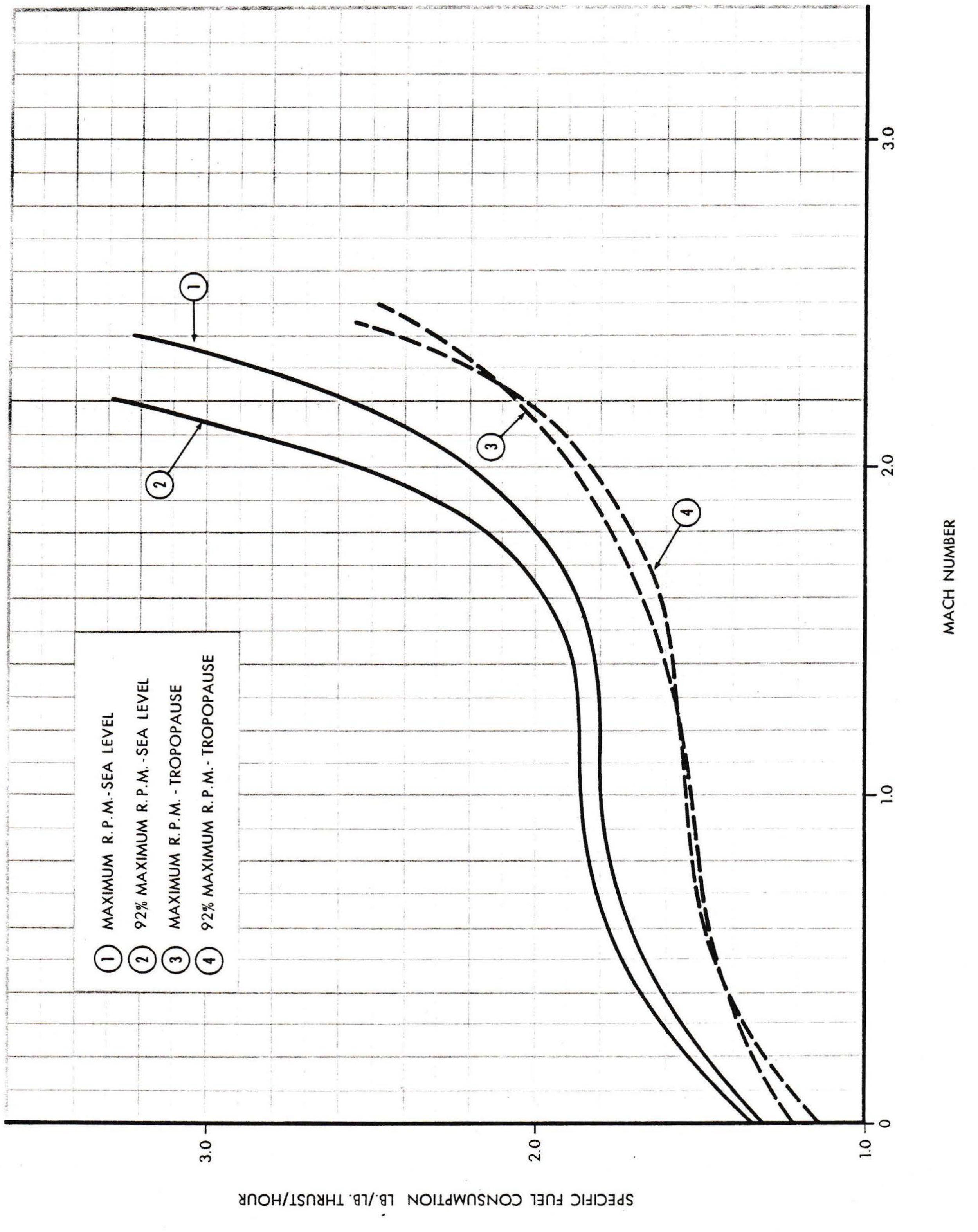


FIG. 22 SPECIFIC FUEL CONSUMPTION

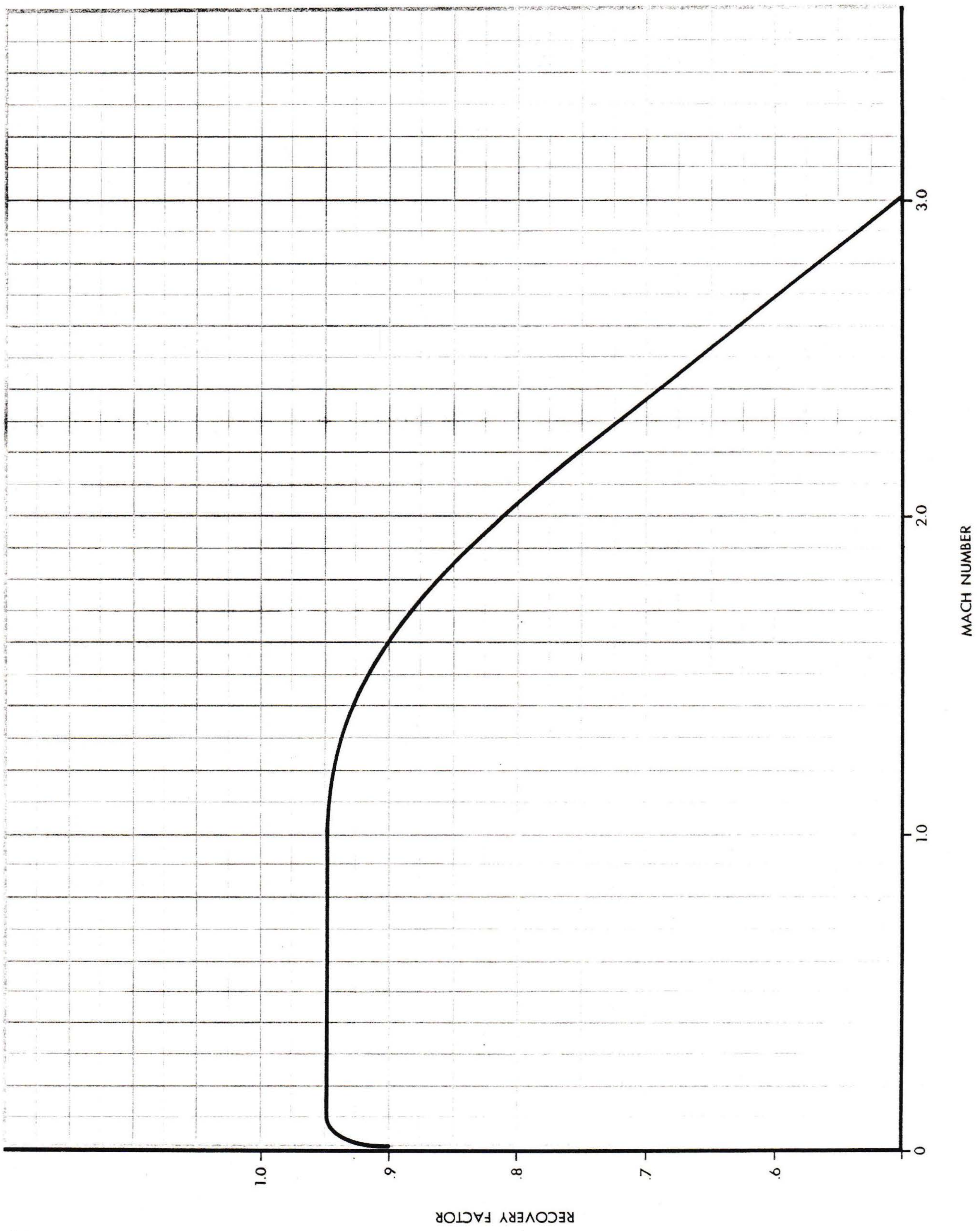


FIG. 23 PRESSURE RECOVERY ASSUMPTION

speeds the net thrust is the small difference between two large quantities, total thrust and integral engine or momentum drag. A small percentage change in total thrust makes a much larger change in net thrust. Two ways in which the total thrust will be affected are as follows:-

(a) Loss due to the jet-bending.

(b) Increase due to full expansion before the jet has left the system.

11 In the proposed aircraft, the rudder nozzles, which are not used during take-off, will be fixed convergent/divergent. In forward flight 20% of the thrust (suffering a 3% angle loss) exhausts from there. Also some expansion may be expected at the rear, e.g. in Figure 18, the pressure on the 'halo' at (A) may be greater than free stream.

12 For these reasons the simplifying assumption, given in Paragraph 9 (c), has been taken in advance of tunnel testing.

PART 5

PARTICULARS, WEIGHT AND PERFORMANCE DATA

1 The leading particulars are summarized in Table 1.

TABLE 1 - LEADING PARTICULARS

PARTICULARS	VALUES	
(a) Weight Dimensions etc.		
Aircraft gross take-off weight	lb.	29,000
Gross wing area	sq. ft.	670
Span (= diameter)	ft.	29.2
Height over canopy	ft.	3.75
Standard mean chord	ft.	23.0
Aspect ratio	-	1.27
Mean t/c ratio excluding intake	-	0.06
Intake base area	sq. ft.	20.0
Approximate jet base area in forward flight	sq. ft.	16.0
Wing loading at mean weight of 26,000 lb.	lb./sq. ft.	38.8
Maximum internal fuel	Imp. Gal.	950
	U.S. Gal.	1,140
(b) Take-off Thrust/Weight Ratio	-	1.73
SLS thrust/frontal area	lb./sq. ft.	900
(c) Approximate moments of inertia		
Polar moment of inertia of whole aircraft including rotor at gross weight	slug ft.^{2}	33,000
Polar moment of inertia of rotor	slug ft.^{2}	8,200
Aircraft moment of inertia in pitch or roll	slug ft.^{2}	20,000

2 Table 2 provides a detailed weight breakdown.

TABLE 2 - WEIGHT BREAKDOWN

PARTICULARS	lb.	lb.
(a) Aircraft Main Structure		
Cockpit well and fuel tank	696	
Intake structure	1,341	
Main structure	2,904	
Outer wing and exhaustor	2,990	
Halo	781	
Cockpit and canopy	165	
Control shutters	410	
Control system	245	9,532
(b) Power Plant		
Rotor assembly	5,750	
Stator blades, plates and attachments	2,120	
Combustion system	1,180	
Air bearing assembly	1,400	10,450
(c) Extra to Structure		
Cockpit equipment	118	
Radio and electrics	352	
Fuel system	264	
Air conditioning and oxygen	250	
Miscellaneous	84	1,068
AIRCRAFT EMPTY WEIGHT		21,050
(d) Disposable Load		
Crew	200	
Fuel	7,750	7,950
AIRCRAFT GROSS TAKE-OFF WEIGHT		29,000

3 The performance potential of the aircraft, as shown in Figures 24 to 27, is based on the net thrusts and consumption given in Figures 21 and 22 and the zero-lift/drag and efficiency factor given in Figures 28 and 29.

4 Table 3 is a summary of the main performance features.

TABLE 3 - PERFORMANCE

PARTICULARS		Without Reheat	With 1500°K Reheat
Maximum level speed	mph knots Mach No.	1,720 1,490 2.6	2,300 2,000 3.48
Ceiling (max. power at mean wt.)	ft.	71,600	80,600
Time to height from hovering start for 36,090 ft. 60,000 ft. 70,000 ft.	 min. min. min.	 1.76 2.66 4.2	 N.A. N.A. N.A.
Still air range with allowances for take-off, climb, cruise, descent and landing	miles	620	N.A.
Take-off and landing distances	-	Nil	Nil
Maximum hovering altitude from take-off	ft.	10,000	N.A.
Maximum hovering altitude at mean wt. 26,000 lb.	ft.	18,000	N.A.

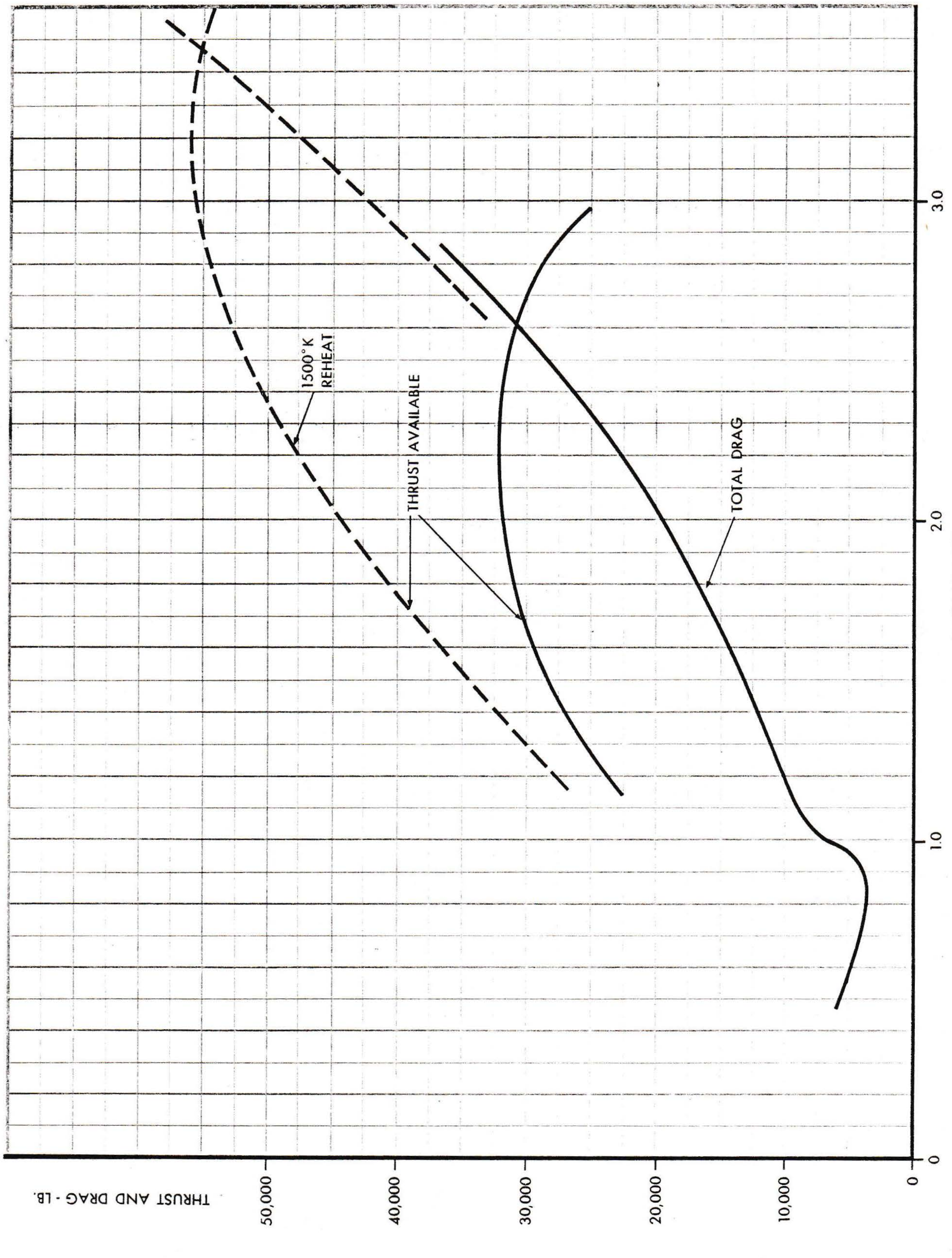


FIG. 24 TOP SPEED POTENTIAL (36,090 FT.)

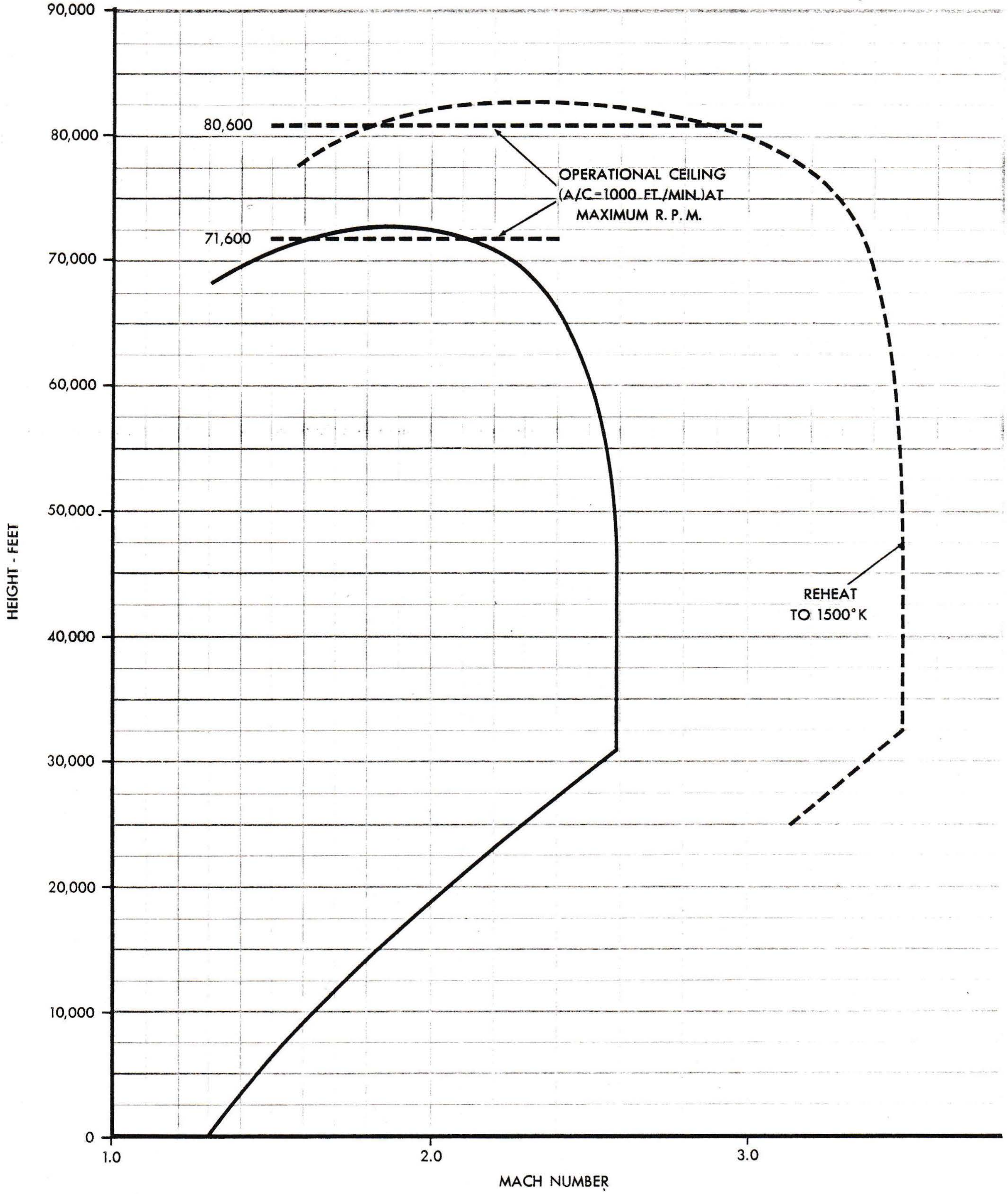


FIG. 25 MAXIMUM LEVEL SPEED AND CEILING
(ALL UP WEIGHT 26,000 LB)

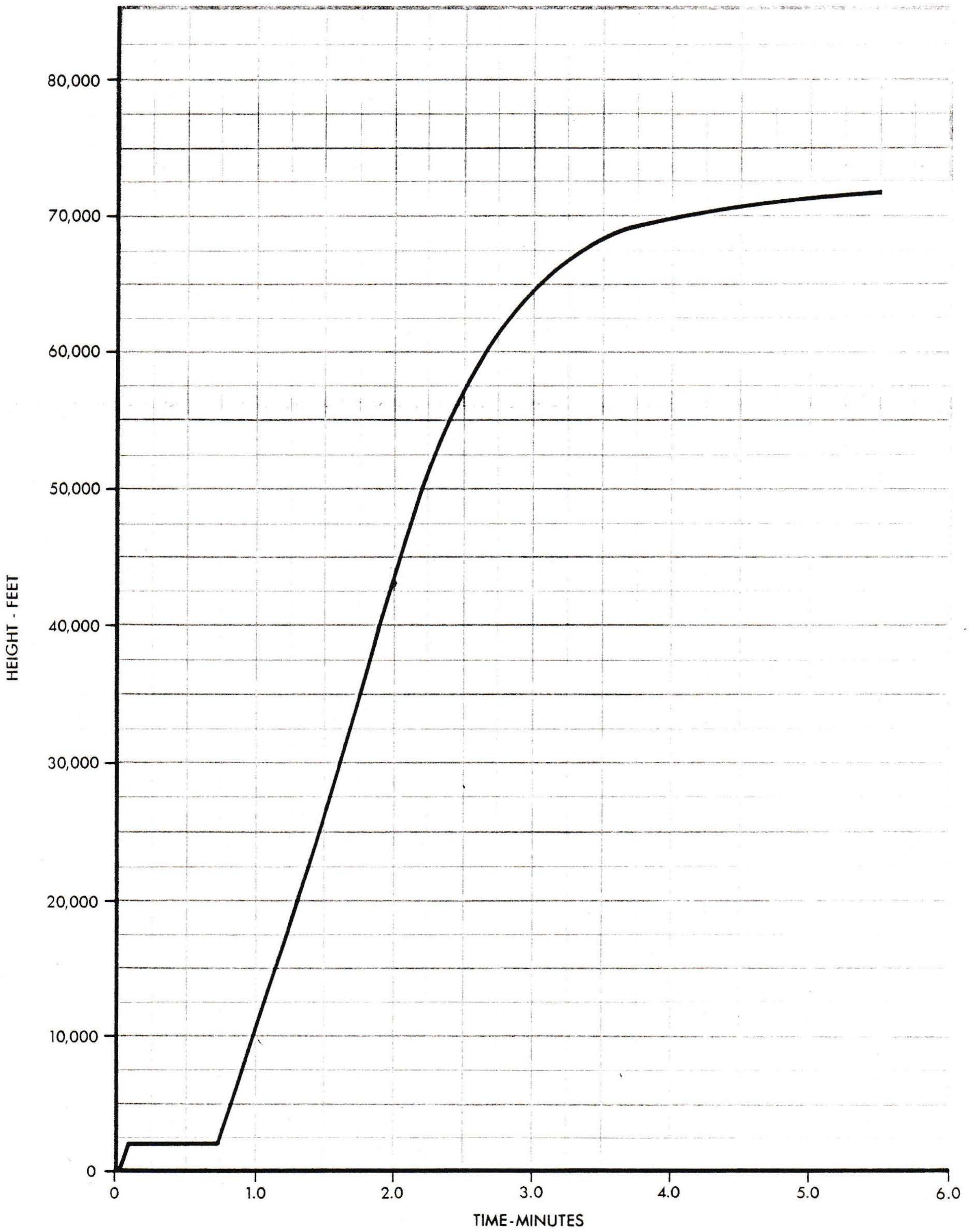


FIG. 26 TIME TO HEIGHT FROM HOVERING START

(GROSS TAKE-OFF WEIGHT = 29,000 LBS.)

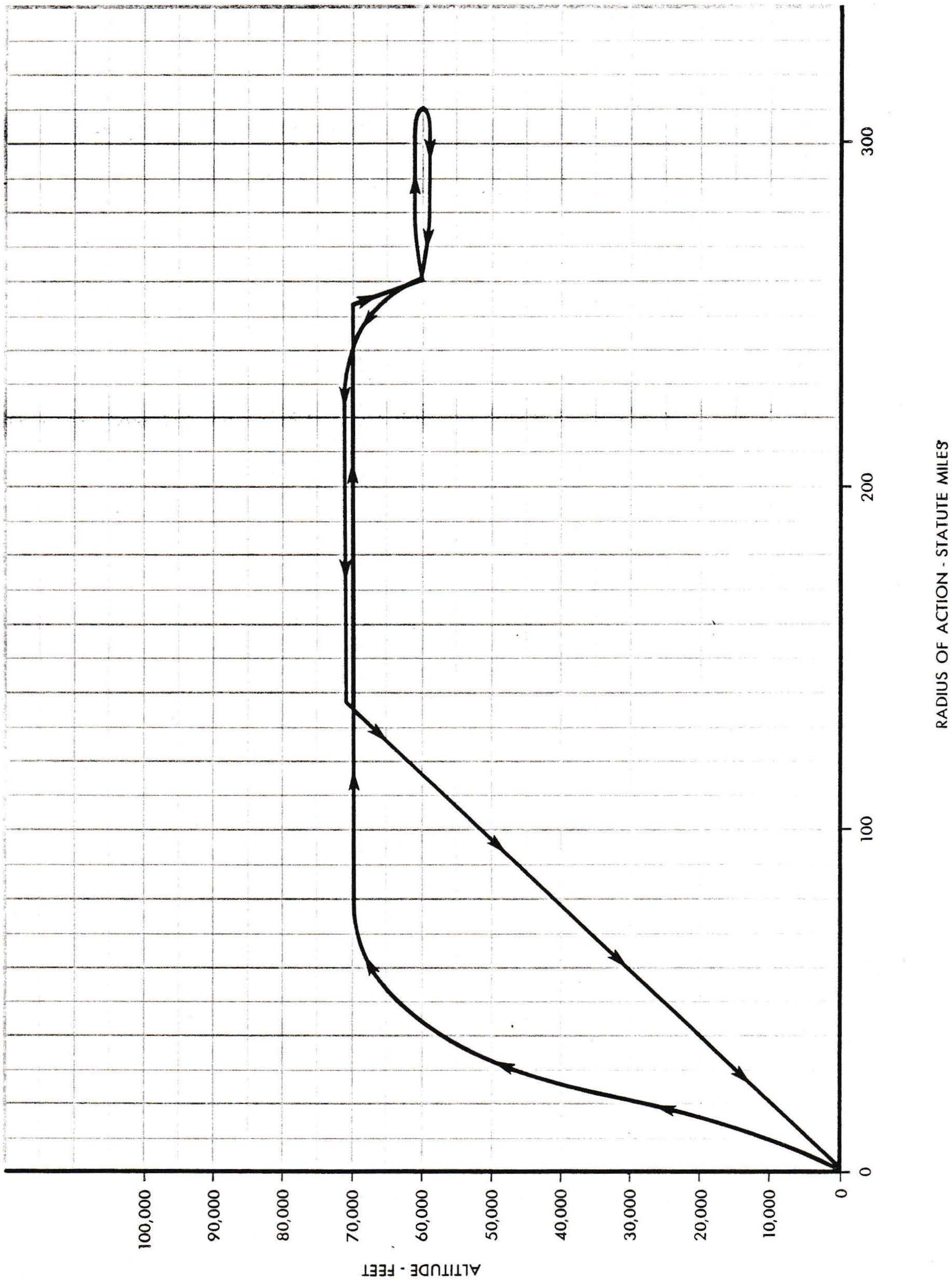


FIG. 27 COMBAT RADIUS OF ACTION

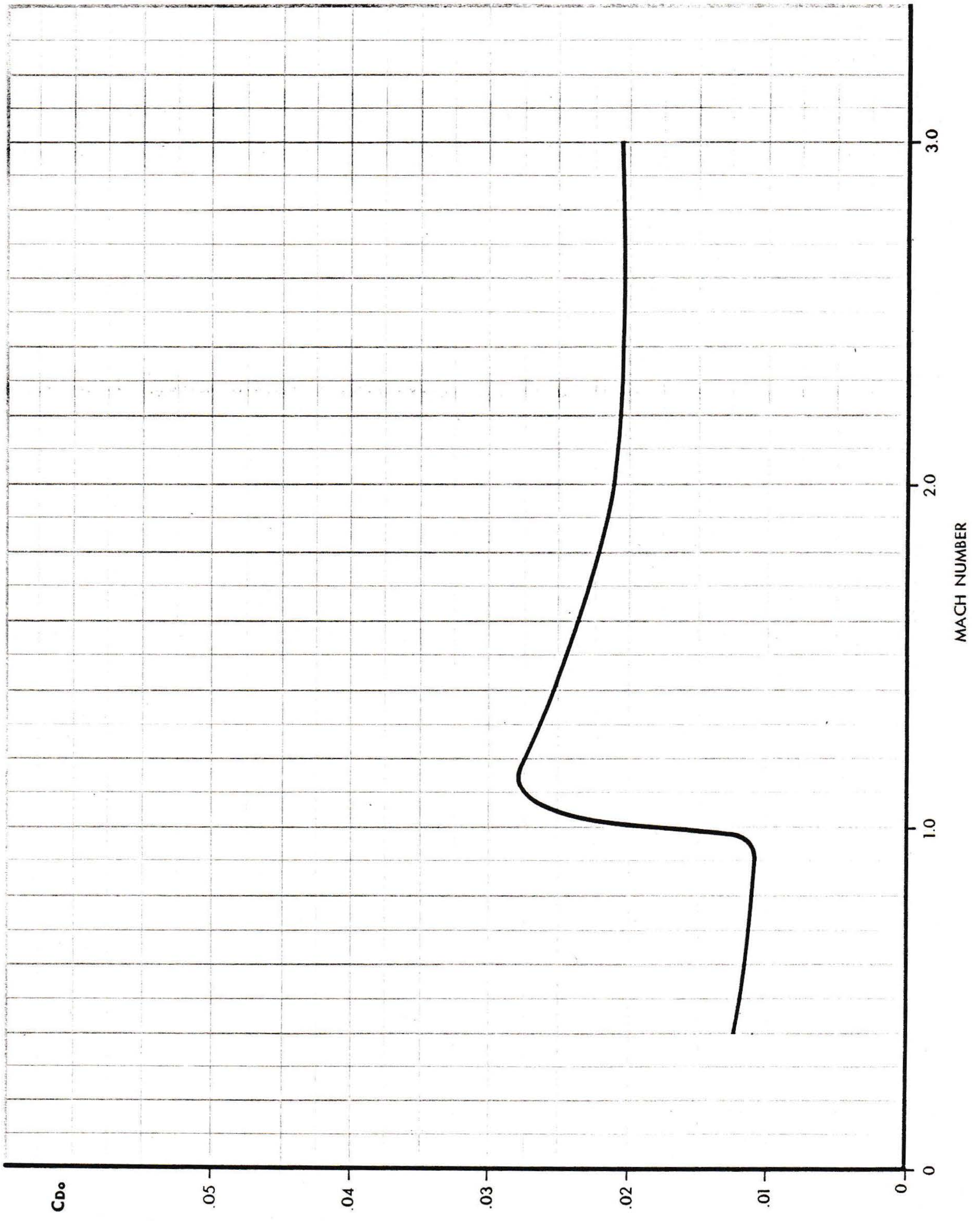


FIG. 28 ZERO - LIFT DRAG ASSUMPTION

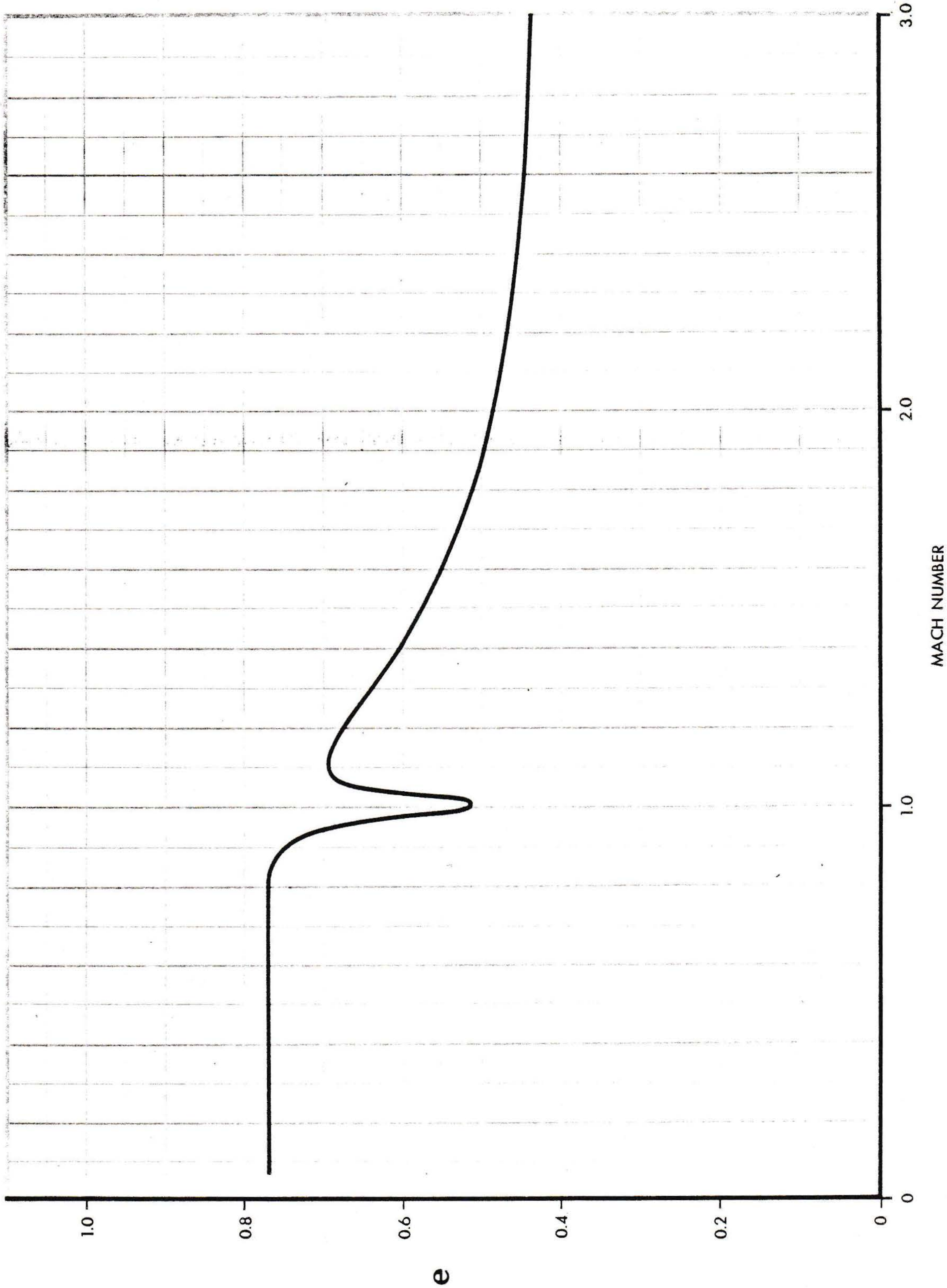


FIG. 29 EFFICIENCY FACTOR ASSUMPTION

PART 6

STABILITY AND CONTROL

General

1 The aircraft differs fundamentally from the conventional in that the gyro rotor (which rotates in the chord plane) couples the lateral and longitudinal behaviour. This type of coupling will occur on any aircraft with a rotating engine, but is normally relatively unimportant.

2 The coefficients of the stability polynomial can be separated into contributions which include gyroscopic effects, and those involving the normal aerodynamic quantities. On the present aircraft, the gyroscopic quantities are many times greater than the normal aerodynamic quantities. It is therefore obvious that the behaviour will be substantially different to that of the conventional aircraft.

3 The general stability and control problem is discussed in the following paragraphs under the headings of - Stability, Trim, Manoeuvrability, Control and Transition.

Stability

4 The equations of motion have been established (Reference 3) and solved (Reference 4) for the modes corresponding to small perturbations from rectilinear flight. The modes (the nature of which are examined in Reference 5) are as follows:-

(a) A high frequency nutational oscillation. The frequency of which is almost unaffected by the aerodynamics. It is damped primarily by the normal aerodynamic damping coefficients in pitch and roll (there being small contributions to these quantities from the internal gas flow of the engine). At low speed where the damping will be negligible, it is impossible to excite any appreciable amplitude (Reference 6).

(b) A snaking mode. This involves perturbations occurring almost exclusively in angle of yaw and sideslip velocity, the yawing being about an axis parallel to the gyro axis. This is a motion very similar to the snaking mode of many jet aircraft, except that no rolling occurs. The damping of this mode is however, somewhat greater than normal, due to the engine torque characteristics (Reference 7). It is to be anticipated, therefore, that in the absence of a yaw damper, this aircraft will have snaking characteristics somewhat superior to conventional aircraft.

(c) A fairly rapid subsidence, primarily in the vertical velocity component. This mode will normally be quite stable.

(d) Three very small roots, one or more of which may be positive or zero. These roots,when positive, represent such exceedingly slow divergencies as to be of no possible embarrassment to the pilot.

5 The important discovery has been made, that the above conclusions are valid with large negative static margins (e. g. 20%).

6 It has not been possible at this stage to estimate fin requirements for this aircraft, since the contribution of the wing and intake base and the intake lip reaction is unknown. The exhaust jet may also have a significant effect. Due to the symmetry of the aircraft, a relatively small positive directional stability may be acceptable, and it is possible that no fin will be necessary. However, the addition of fin area on the top surface, would appear to present little difficulty.

7 Stability is also required to be satisfactory under the hovering flight condition. It is apparent that the aircraft is gyroscopically stabilized in roll and pitch, and that in yaw, the aircraft is neutrally stable when the gyroscopic plane is parallel with the ground.

8 It seems likely that the modes are sufficiently slow for an experienced pilot to maintain the aircraft in this condition.

9 The conclusion has been reached, that with any likely changes in either aerodynamics or mass distribution, the stability will remain entirely satisfactory. The problems are therefore reduced to those of trim and manoeuvrability.

Trim Requirements

10 It is a fundamental necessity, that the pilot shall be able to trim the aircraft to steady rectilinear flight conditions, anywhere between hovering flight and design diving speed. In rectilinear flight the gyro will have no influence on the motion, and the fundamental problem involved is quite conventional.

11 The centre of gravity of the aircraft described, is obviously very close to the centre, although the addition of military load or armour will bring it forward. The centre of pressure position is however, difficult to estimate, as little data is available on any shape approximating to the design, and the effect of the exhaust and intakes may have a significant effect, particularly at low speeds. At supersonic speeds, the low aspect ratio is expected to result in a centre of pressure, positioned substantially forward of the 0. 50 chord. It is therefore probable, that a moderate negative margin, requiring a positive trimming moment, will be present. The necessary downward thrust deflection will contribute to the lift.

12 In subsonic flight the negative margin is expected to be larger, requiring a greater thrust deflection at the rear.

13 Since the trimming moments are provided by using the jet exhaust to deflect the flow over the aircraft, the pilot will not be free to throttle back completely and still maintain the aircraft in steady rectilinear flight. This may prove an embarrassment at subsonic speed at high altitude, and for deceleration from supersonic speed; therefore trim flaps may be required. It is not considered worthwhile to attempt to assess this requirement, until data on control effectiveness and centre of pressure position has been collected from tunnel tests.

Manoeuvrability

14 Manoeuvrability on this aircraft, both in respect of rolling performance and steady level turns, involves the precession of the engine rotor.

15 The steady rate of roll that can be achieved at supersonic speeds, has been examined for Project 'Y' in Reference 8. By contrast with conventional aircraft, rate available diminishes with altitude. This undesirable characteristic is fundamental to this type of aircraft, however, the rates that can be achieved supersonically, are quite adequate for many purposes (i. e. about 55^o and 22^o per second at 20,000 and 40,000 ft. respectively). The rates of roll on Project 'Y2', cannot be reliably estimated without tunnel test of the control effectiveness.

16 It is of significance that the rate of roll available, is a function of the aircraft's margin; increasing for negative margins and decreasing for positive margins. Therefore the subsonic rates should be reasonably good.

17 The steady level turns are in no way limited by gyro precession, as the rates of pitch involved are relatively small at the high speeds for which the aircraft is designed.

Control

18 When it is required to pitch or roll the aircraft, it is necessary to precess the gyro by applying either a rolling moment or pitching moment respectively. This suggests a 'crossed' control system, in which fore and aft movement of the stick causes differential lateral movement of the control shutters, causing a rolling moment to be applied. Under this arrangement, lateral movement of the stick would cause differential longitudinal movement of the control shutters, applying a pitching moment to the aircraft and causing it to roll. The situation is somewhat complicated however, if one considers the effect of the pilot demanding a pitching motion. His first action will be to move the stick backwards, this will cause differential lateral movement of the controls and introduce a rolling moment. The aircraft initially responds by pitching, but the pitching increases the incidence which in turn produces a pitching moment. The pitching moment thus induced, produces a rolling response, the sign of which depends on the sign of the aircraft's static stability.

19 This effect is not however unacceptable, as the immediate response of the aircraft is always in the right sense, and the pilot's instinctive corrective action to this undesired rolling motion will also be correct. It should also be noted, that at supersonic speed the aircraft will have a smaller margin, so that this secondary effect will be smaller. In hovering flight, the aerodynamic forces resulting from a change of attitude are so small as to leave the control response entirely satisfactory.

NOTE

On conventional aircraft, secondary control effects are often undesirable. For example, the application of a small amount of aileron initially causes rolling, but this induces sideslipping, which in its turn, produces yawing and the aircraft finishes in a spiral dive.

20 The yaw control in forward flight, is by differentially closing the rudder nozzles, instead of by flap movement, but is in other respects conventional. Under hovering conditions, the rudder nozzles are closed and yaw control is by differential opening. This will result in an out of balance force, giving the aircraft a translational velocity, which is considered acceptable, as the rotation will form the major part of the movement, and the amount of skid in the turn will be small.

Transition from Hovering

21 It is visualized that the normal take-off technique for this aircraft, (where the thrust/weight ratio is considerably greater than one) will be to take-off vertically and climb with the gyro plane parallel with the ground to a height of 1, 000 ft. or more and then commence transition to forward flight.

22 It is however more than probable that a satisfactory transition to forward flight can be made while hovering in the ground cushion.

NOTE

This means that aircraft with thrust/weight ratio less than one, which will necessarily be the case for large aircraft, may take-off vertically into the ground cushion to get away from confined spaces and unprepared fields.

23 In either case the transition routine envisaged is similar. From hovering at less than maximum throttle setting, the rudder nozzles are opened and the throttle is advanced at the same time, so that the aircraft will begin to pick up forward speed without loss of height.

NOTE

The trim control, which adjusts the position of the rudder nozzles, is mounted on the throttle lever.

24 As the wing begins to support the weight of the aircraft, the main nozzles are trimmed to the forward flight position; using the trim wheel to counteract the nose-up pitching moment which will develop due to aerodynamic lift on the wing.

25 As the aircraft gains height, the jet-lift system is transferred to a thrusting system by closing the lower annulus and opening the upper annulus. This will also cause a nose-up pitching moment which is again counteracted by completing the trim of the main nozzles to the forward flight position.

26 It is well known, that whereas stick force should not be maintained over any period of time, actual stick position is relatively unimportant in normal flying. As there is no feel to the controls, and since the stick position will give an indication of the amount of trim being used, trim of the stick position is not desirable.

27 The transition from forward flight back to the hovering condition, is similar to that described in the preceding paragraphs.

28 It is accomplished by closing the throttle and rudder nozzles, (the throttle being closed to the minimum required to maintain trim) and by raising the nose as the speed falls to increase drag (at very high incidence the drag is greatly increased by the de-stalling effect of the jet).

29 Thrust is then transferred to jet-lift by closing the top annulus and opening the lower annulus, and at the same time trimming the shutters back to the hovering position. From moderate speed, deceleration will be rapid with the aircraft at a high angle of attack and the jet-lift exerting a considerable backward component on the aircraft.

30 As aerodynamic lift falls, the throttle is advanced and incidence reduced until jet-lift is fully established. For landing, the throttle is closed until the thrust/weight ratio is reduced to slightly less than one, and the aircraft sinks to approximately 35 ft., when it enters the ground cushion and begins to decelerate.

Summary

31 The jet control scheme is an important aspect of this design, as it is obvious that thrust forces, in some form, must be used to control the aircraft in the hovering condition. This has led to the proposed scheme of jet control, which avoids the difficulties of hinged flap controls at high indicated speed. Advantages gained are:-

(a) The jet control is not subject to flutter.

(b) It has no hinge moment or heavy stick forces.

(c) It distributes the air loads directly onto the structure, avoiding concentrations at hinge points.

32 The control, it will be appreciated, has to replace the function of a flap in deflecting large masses of air flowing over the aircraft through small angles. This will not be achieved directly from the jet reactions at the nozzle except in hovering or at slow speed. Clearly adequate aerodynamic data must be assembled before the design can be thoroughly analysed and shown to be satisfactory and adequately effective at all required conditions and throttle settings. However, the achievement of a satisfactory system of jet control is regarded as an important secondary objective, and the results of initial testing in this direction appears to be most promising.

PART 7

GROUND EFFECT AND RADIAL FLOW

1 The strongest argument for radial flow, is the powerful ground cushion associated with a distributed jet. The radial flow power plant, which takes in air at the centre and distributes its jet outwards to the wing periphery, undoubtedly provides the best jet configuration for vertical take-off. Figure 30, shows effective thrust against distance from the ground, for three things:-

(a) A plain jet.

(b) A distributed jet around a wing.

(c) A plain jet in the centre of a wing.

2 Thrust is not affected by the distance from the ground, when an aircraft such as Project 'Y' taking off from its edge, employs the plain jet (a). Thrust for Flat Vertical Take-off aircraft, using methods (b) or (c), as exampled in Figure 31, is however greatly affected.

3 In consideration of the above, the alternative behaviour of two 30 ft. span jet-lift aircraft, in certain conditions, would be as follows:-

(a) Vertical Approach - from free air hovering - when the throttle is eased back to give a thrust/weight ratio of just less than 1.0, the aircraft (b) would sink to about 40 ft. and decelerate before settling into its ground cushion at 19 ft. See Figure 30. In the same conditions, the aircraft using configuration (c), would sink to about 25 ft. and then accelerate until it hit the ground.

(b) Take-off - for this condition, aircraft (b) would leave the ground at very low thrust and hover at a gradually increasing altitude as the throttle was advanced. On the other hand, aircraft (c) would have to be supported more than 3 ft. from the ground before it could produce any effective thrust. Supposing it to be supported approximately 6 ft. from the ground, it would not take-off until the thrust/weight ratio reached 1.75 when it would rise with uncontrolled acceleration.

4 Furthermore, the aircraft described in case (b) will doubtless be able to make a satisfactory transition from the ground cushion to forward flight. In addition, the convex undersurface employed in this particular configuration will tend to make the aircraft stable in the ground cushion, in which it is floating.

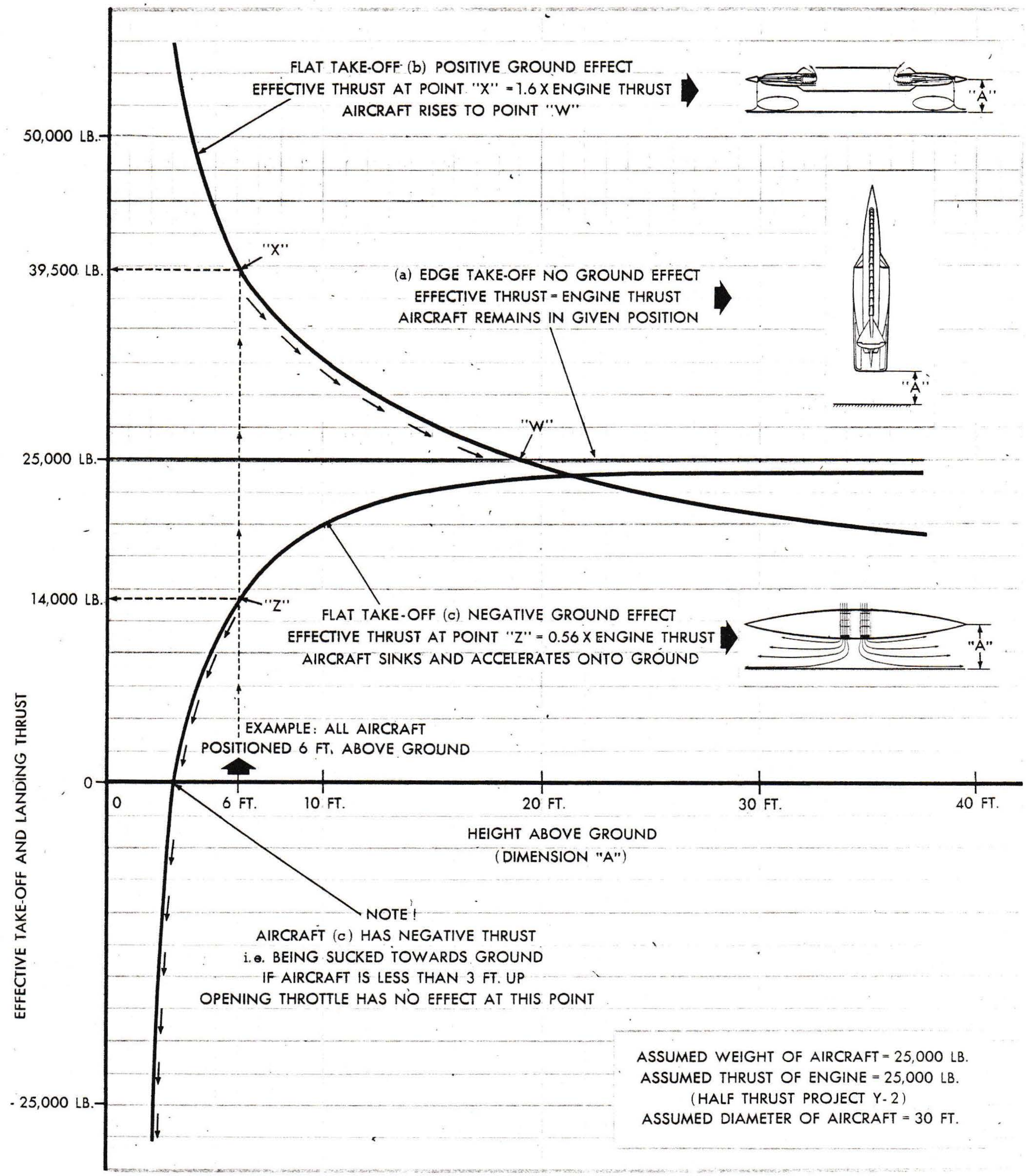


FIG. 30 COMPARISON OF GROUND EFFECTS, FOR FLAT TAKE-OFF AND EDGE TAKE-OFF AIRCRAFT

5 The use of the ground cushion is even more significant when considering a landing manoeuvre onto a difficult ground, such as a small ship or submarine.

6 For example, Project 'Y' (which is an edge take-off aircraft employing hovering thrust for landing, instead of the ground cushion) would remain at a fixed height in the air, and if the ship was rising and falling in a heavy swell, a chance of a collision or a falling away of the ship from the aircraft as the throttle was closed for landing, is likely.

7 Project 'Y2' however, (which is supported in the ground cushion) would in similar conditions, rise and fall at approximately a constant height above the ship and land without difficulty when the throttle was closed.

8 The steepness of the curve in Figure 30 illustrates that the closer the Project 'Y2' aircraft is to the landing ground, the less height variation, or bounce, there would be at a given throttle setting.

ITEM B

ITEM C

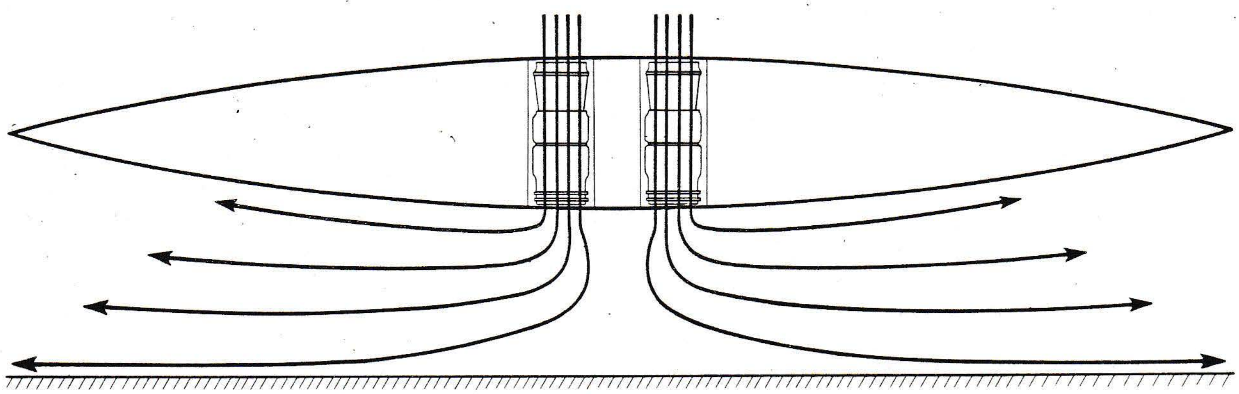


FIG. 31 ALTERNATIVE JET-LIFT INSTALLATIONS

9 Considered purely from the standpoint of maximum installed thrusting efficiency in forward flight, the radial flow installation is bound to be below the optimum represented by a straight through internal flow with the power plant mounted inside some hypothetical aircraft in line of flight. In order to obtain maximum overall efficiency however, a real aircraft plus engine combination must be considered as a whole, and in view of the thrust/frontal area figures which are achieved by this layout, it does not appear likely that a more efficient design will result from an aircraft based on a line of flight power plant installation.

10 In the first place, the internal losses associated with the radial flow installation are not expected to be large; tolerable internal efficiencies are likely to be achieved with steady development. Secondly, at supersonic speeds (where the aircraft is designed to fly) the internal losses are relatively unimportant, compared to the external intake and entry losses which depend so critically on the external design of the intake and nozzle, and for which (at least in the former case) high efficiency is so difficult to achieve.

11 A comparison of internal and external effects on thrust and consumption is given in Figures 32 and 33.

12 Figure 32 is a typical plot of the thrust variation of a gas turbine engine with Mach No., at the tropopause; in which the various curves were constructed by making various entry and outlet assumptions. The enormous spread in thrust potential supersonically as the speed increases will immediately be remarked; except for the intervals between curves (3) (4) (5) which show no spread supersonically, and may be distinguished as internal exhaust and intake losses rather than external.

13 The range of speeds of most interest for the type of aircraft under consideration is from Mach 1.7 to 2.7 since it will have a supersonic cruising speed of around 1.7 to 2.0 and top speed well in excess of this. Mach 2.0 is probably the limit cruising speed tolerable at the present time from the point of view of aerodynamic heating.

14 In Figure 33, attention is first drawn to curves (2) and (6). Curve (2) probably represents close to a practical upper thrust efficiency limit, having an optimum double shock intake, a full expansion nozzle and no internal intake or exhaust pipe losses: whereas curve (6), having a normal shock entry, a plain nozzle and large internal losses, is suggested as an arbitrary minimum below which a system ought not to fall. At Mach 2 the total loss between curves (2) and (6) is 42.5%, and when considering the assumed internal losses, curves (3) to (5), it is seen that they account for only 7%. At Mach 2.5 the same total loss is 58% and the internal losses only 5.5%.

15 These assumptions of internal loss are deliberately made quite severe for these purposes of comparison, and it is seen that statically they account for an 18% loss of thrust (which has fallen to 9% at Mach 2). The intake loss is 20% of the intake

velocity head and is considered somewhat pessimistic for a radial flow installation; the bending of air through angles up to 180° is not uncommon in gas turbine engines and need not be productive of large loss. The exhaust duct loss on the other hand is considered definitely severe and represents a total loss of the dynamic head in the duct for a duct Mach No. of 0.5; in spite of this the thrust loss is small. It is clear that the exhaustor duct problems are mechanical rather than gas-dynamic.

16 Curve (5a) shows the loss due to expelling the jet in the wrong direction and represents a 10% loss of gross thrust with no reduction of internal engine, or "momentum" drag. This may be called "cosine" loss and it is large, because at supersonic speed the net thrust tends to become the small difference between a large gross thrust and a large momentum drag. The "thrust recovery" scheme proposed is subject to this type of loss, but it should be noted that this simple scheme is not fundamental to the radial flow aircraft. A slightly more elaborate nozzle system will result if the thrust recovery proves inefficient.

17 Figure 33 shows the equivalent effects on fuel consumption. Out of 24.5% difference in specific fuel consumption between curves (2) and (6) at Mach 2, the severe internal loss accounts for 3%, which is not a heavy price to pay for the radial flow installation.

18 Other principal advantages resulting from the radial flow layout are:-

(a) The striking manufacturing simplicity, which results from a radial spoke structure in a body of revolution, is illustrated by Figure 2.

(b) The SLS thrust/gross take-off weight for this aircraft without reheat is about 1.75.

(c) Thrust/frontal area for the whole aircraft, without reheat, is 900 lb./sq. ft. The ability to achieve high thrust/sq. ft. frontal area, although the engine is not shielded by the air intake, is illustrated by first substituting small conventional engines, installed radially, in place of the single-disc engine, to find out how many can be installed, and by superimposing the front view of these engines on the front view of the aircraft, as shown in Figure 34. It is not then surprising, that thrust/frontal area for the air-

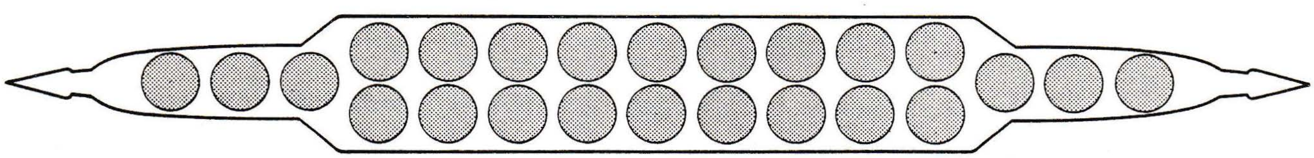


FIG. 34 FRONT VIEW OF AIRCRAFT WITH SPANWISE SUPERIMPOSED GAS TURBINE ENGINES

craft is 70% of the thrust/frontal area of the bare engines. Furthermore, it is most unlikely that they could be installed in line of flight (in a real aircraft) in an outline no larger than Project 'Y2'.

(d) The application of jet-lift to large aircraft can be foreseen if full use is made of the ground effect to support the aircraft during take-off and cushion it in a vertical landing. A small aircraft can today be designed with jet-thrust greater than its weight, so that it can rise vertically into the air. Now if everything in the aircraft is simply scaled up, so that its span is doubled, its area will be four times greater and its weight will be eight times greater (since it is also twice as thick). However its "jet-thrust", which depends on area, will also only be four times greater, so that its thrust/weight ratio will be halved, and it can no longer take-off vertically. Now to some extent this "square-cube law", which is forcing the thrust/weight ratio down as the aircraft increases in size, will no doubt be defeated for this type; as it has been in the past on conventional aircraft. However, that range payload capability will increase with size, in the same way as it has for conventional types through the years, cannot immediately be assumed; since the transport performance of present day large aircraft would be drastically reduced if they had to take-off in the same distances and operate at the same wing loadings as the smaller aircraft which preceded them.

19 Figure 35 illustrates the possibilities of ground cushion take-off for aircraft whose thrust is less than their weight (and which also have increased wing loadings). It assumes that scaling up Project 'Y2' will increase the weight to the 2.75 power instead of the cube, (making an arbitrary allowance for betterment of the "square-cube law") and the thrust as the square; with this assumption the variation of maximum hovering height above the ground at full throttle with aircraft weight is shown, and it appears that at weights above 50,000 lb. free-air hovering would not be possible. The actual distance from the ground is going down slowly with weight increase (because the aircraft is also getting larger) though the percent span is diminishing fast. This should be satisfactory since :-

(a) The typical obstacle for clearance stays the same height.

(b) The large aircraft's reaction to disturbances will be slower and therefore displacement angles smaller.

(c) It will be legitimate for larger aircraft to demand the somewhat larger open spaces necessary because of the lower thrust/weight ratio.

It is not possible to determine range payload capability without design study and this has not yet been carried out for a large aircraft.

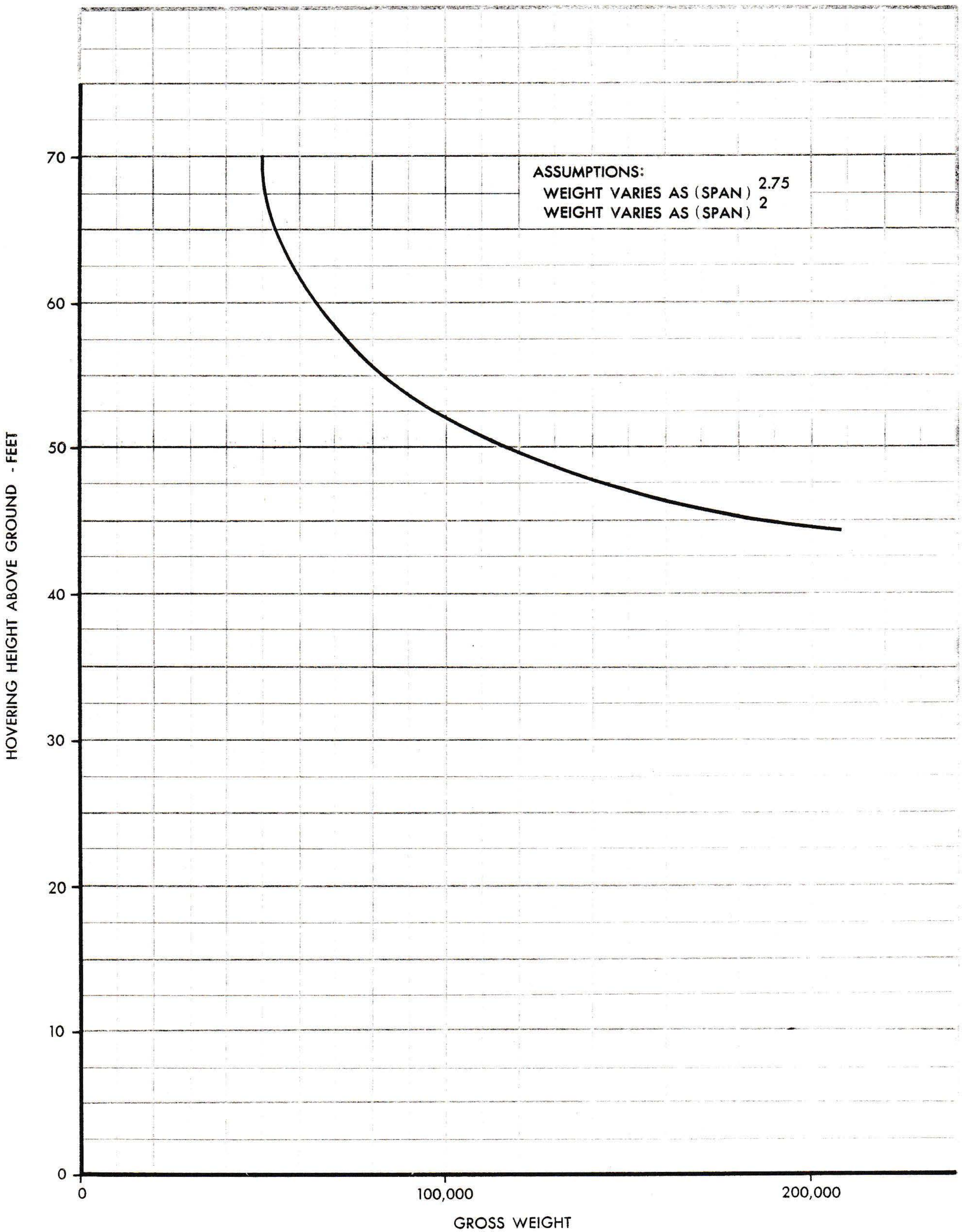


FIG. 35 EXTRAPOLATION OF TAKE-OFF CHARACTERISTIC TO LARGE AIRCRAFT

20 The advantages of gyroscopic stability, as provided by the single-disc engine, seem to outweigh the restriction it imposes on rate of manoeuvre:-

(a) It allows freedom of choice for C. G. position, limited only by trim force available - an entirely revolutionary state of affairs.

(b) It provides stabilization in the absence of aerodynamic forces.

(c) It can be expected to provide a steady flight régime and eliminate all sudden changes, especially in the transonic region.

PART 8

POSSIBLE AIRCRAFT ROLE, FUTURE DEVELOPMENT AND CONCLUSION

Role

1 From the military point of view, the type of aircraft described in the foregoing can be visualized as pursuit, reconnaissance, ground support, ambulance, bomber or transport. The artist's impression of a naval application, shown in one frontispiece, depicts a small aircraft in a practical role of particularly deadly utility, operating as a submarine based scout or bomber.

2 The installation of armament is not seen to present any special difficulty. Guns or rockets may be mounted in the nose, or to fire out of the intake. Similarly, radar may be installed in a nose pod or if the scan is considered adequate, inside the intake(s), where the drag penalty will be less (since the flow around the scanner would then be subsonic and much more nearly isentropic). Guided missiles may be carried externally.

3 A larger bomber version of the aircraft is visualized as having more available payload space in the central well.

4 The aircraft under study has an ample margin of thrust/weight to lift additional military load from the ground. Performance penalty will therefore only be felt at a somewhat reduced range and ceiling. Top speed is unlikely to be affected, since the drag due to lift is extremely small for this condition.

5 Larger aircraft may be expected to have longer range, but no detail figures are yet available.

Development

6 Engine development towards higher turbine temperatures is naturally attractive for this design where turbine blade cooling is mechanically simple.

7 Such development will, to some extent, obviate the advantages to be gained from reheat. Nevertheless it is considered, that the vehicle will only become fully efficient when the outer wing, as well as the centre wing, becomes a working part of the engine. With the development of reheat the whole wing becomes a propulsion unit.

8 The outer jet exhaustor duct appears to be most suitable for reheat, except for the necessity of spanning the duct with some simple arrangement of cross struts, for structural purposes. Faired sleeves around the struts, will carry a cooling

flow of air from the compressor which will exhaust into the duct. The shutters will also be cooled by the exhausting of their lubricating air into the annular nozzles. The benefit to be gained from a mild degree of reheat is illustrated in Part 4.

9 Part 7 Paragraph 18(b), shows it is possible to produce the radial gas flow required with a ring of conventional engines. These engines are housed in almost the same envelope which is used for the large single radial flow engine. In this way it is possible to develop an aircraft which may fly supersonically, and to separate the problems associated with the airframe and aerodynamics, from those associated with the large flat engine. This method will permit the design of a flying aircraft, with a ring of conventional engines, which will have all the characteristics of a large single radial flow engined aircraft, with the exception of gyro stability.

10 This possibility points the shortest route to the development of the flat take-off gyroplane described; since a test aircraft may be balanced to give a C. G. associated with conventional stability, and still take-off vertically flat with the ground, and explore the possibilities of jet control.

11 The parallel development of the radial flow engine, will provide an aircraft with an elegant solution to the stability problem posed by a design requirement to fly in still air, subsonically, transonically and supersonically; and at the same time provide an engine of unique simplicity.

12 However, there is also the possibility of development of operational radial flow aircraft with conventional engines, since an alternative solution to the subsonic stability problem exists, namely to rely on an artificial stabilizer. With regard to this alternative, there is little doubt that it is theoretically possible. How much advantage can be obtained in this way however, depends on what is mechanically practicable and systematically reliable.

13 Two advantages offered by the multi-engine design, must however be stated. These are:

(a) Multi-engine reliability.

(b) Improved manoeuvrability.

Therefore, the possibility of development on conventional power plant lines must not be neglected.

Conclusion

14 Aircraft with thrust/weight ratios of over one, making free-air hovering take-off and landing with jet-lift feasible, are today everywhere being studied.

15 There is every possibility that (taking advantage of the great increases in

engine efficiency possible at supersonic speed to offset the lower flight efficiency exampled by lower maximum lift/drag ratio) aircraft with economical supersonic cruise ability can be designed. It becomes clear that a large increase in thrust/weight ratio will lead not only to vertical take-off, faster climb and higher ceiling; but above all, by allowing higher cruising altitudes and speeds, will bring the supersonic cruise, with its vastly greater work capacity, into competition with the subsonic.

16 This aircraft is postulated not only as having a thrust/weight ratio of 1.75 without reheat, but also as employing for the first time the important and far reaching technique of take-off and landing from a jet-lift ground cushion.

APPENDIX 1

REFERENCES

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Ref. 3 - S. & C. 1 - THE EQUATIONS OF MOTION OF THE AVRO V.T.O. AIRCRAFT - by J. Dubbury

Ref. 4 - S. & C. 2 - DETERMINATION OF THE STABILITY MODES CORRESPONDING TO FOUR TYPICAL LEVEL FLIGHT CASES - by J. Dubbury

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