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PROPOSAL FOR FURTHER DEVELOPMENT OF THE AVROCAR

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1.0 INTRODUCTION

Recent studies reported in this document indicate the probability that a new vehicle, similar to the Avrocar, using what one might call a bona fide VTOL engine, can be designed; which we think has a very attractive performance potential and represents a satisfactory end product to the Avrocar research program.

Furthermore, the Avrocar is the only ground effect machine which can hover in the h/d range of 0.15 and up, and has demonstrated that use of the ground cushion in applications going beyond the skimmer role is quite practical.

For these reasons, we believe that the second Avrocar, which recently undertook limited terrain tests, represents an invaluable research tool which should be used both to further the development of a VTOL aircraft with a GEM role and to develop annular jet flying through the range of h/d and speed for which this device is contemplated.

This Proposal follows the successful completion of the Avrocar Continuation Test Program which was instituted in July 1960, and also the satisfactory completion of a parallel program funded by the Canadian Government. These two programs are reviewed in a report, "Summary Review of the Continuation Test Program for the Avrocar (including review of Allied Programs)" - 500/PERF/411, much of the material from which is reproduced here again for completeness.

Prior to these programs the situation was, that of the two aircraft previously built, one had just completed a series of wind tunnel tests at Ames Research Center, and the other was being used at Malton, Ontario for hovering trials.

Briefly, the wind tunnel tests were at that time unsatisfactory, showing that the focussing ring control was not suitable as a forward flight control, but the hovering trials had proceeded quite well and the focussing ring was, on the other hand, proving successful for this regime. Avro proposed first to improve the thrust toward the original figures and enable VTO. However, in view of the disappointing in-flight characteristics and particularly since the range and endurance capability for the Avrocar with the focussing ring control - even after thrust improvement - appeared to be minimal, the decision was taken to halt ground cushion development and introduce an in-flight control scheme to both aircraft. The first aircraft was then to be re-tested at Ames, and the second was to undergo a brief check out flight test at Malton after the alterations had been incorporated. A small extension to the program to cover limited terrain testing with the second aircraft was authorized last month.

The objectives of the program just completed were as follows:

(i) Static and Flight Test Program

To check the operation of the modified control system and to determine the aircraft behaviour in ground cushion had not deteriorated because of modifications that have been done.

This does not include any development testing to improve known ground cushion critical height problems, or extension of the speed range.

(ii) Model Test Program

To assess the effects of the proposed modifications and to assist in determining the aircraft tunnel test program.

(iii) Full Scale Wind Tunnel Test Program

(a) To define a forward flight performance envelope for the first Avrocar in its modified state, accepting the known thrust deficiency. To enable estimates of developed performance after thrust improvement to be made, and to assess the reasons for any deficiency between the latter and the performance originally specified (AVRO/SPG/TR 254).

(b) To establish the ability of the aircraft to accelerate in the ground cushion and if possible find a maximum ground cushion speed.

(c) To show that transition is feasible.

It will be appreciated that these objectives are limited and were not set up with the idea that a flight test program could follow immediately upon completion of this continuation test program.

At the same time the Canadian Government instituted a program in two parts. The first part was to study the design development of the Avrocar in its existing general form. The outcome of this part of the program was to be a proposal for a tip turbine driven fan type aircraft of circular planform employing an annular jet. The general characteristics of the aircraft were to be as follows:

(i) A speed capability of hovering to 300 knots.

(ii) Endurance to the maximum possible, and aimed at four hours.

(iii) Load capability for two men, and 1000 lb. of useful load at 10 lb/cu.ft.

The objective of the second part was to conduct a parametric design study of a GETOL subsonic aircraft to determine the merits of this concept. This study was to be made against a logistics supply mission involving the transportation of personnel, supplies and equipment from airhead to divisional area.

In this report a review will first be made of the in-flight control system modifications and the major significant test results from the wind tunnel program, with performance predictions for the present Avrocar, with and without thrust improvement. A brief review is then given of the Avrocar design development carried out under Part 1 of the Canadian Government Study Program.

Following this is an outline proposal which (now that the control and trim problems are largely resolved) re-introduces thrust improvement, in a program designed to remedy the other major deficiency and prove the lift efficiency out of ground effect, which is necessary to the successful realization of this concept. Transition to in-flight in free air then follows.

The recommended approach is not to commit seriously for the fairly extensive modifications required to achieve VTO before further assurance of their effect has been obtained from detail studies in local areas, using the second Avrocar and existing models for further tests.

2.0 SUMMARY REVIEW OF FULL SCALE TUNNEL RESULTS AND PERFORMANCE PREDICTIONS

Fig. 1 is a diagram which illustrates the jet flow in forward flight both for the first test series in which the focussed jet was attempted for forward speed as well as hovering, and after the new transition modifications in which a jet flap configuration with wing tip blowing was adopted for the in-flight configuration with internal transition from a focussed hovering condition.

This was achieved by the structural modifications illustrated in Fig. 2, which involved re-building the wing tip over about 2/3rds of the periphery so that the jet flow could exhaust directly through it, and fitting a series of transition doors which would direct the flow either through the focussing ring as before for hovering, or through the new passage through the wing tip for forward flight. A series of cascades was then fitted around the wing tip to direct the jet aft. An in-flight control was added around the rear 120° of jet exhausting from the wing tip in the form of in-flight pitch and roll control vanes. These were coupled to the focussing ring which was hung by modified hanger rods in order to allow a simple connection. The twelve transition doors were controlled by electric screwjacks, four jacks being driven by each of three electric motors. Finally, the yaw vanes were moved to a sector further forward and the collective control incorporated so that they would all be deflected backwards for in-flight and thus reflect the jet off the focussing ring in an aft direction. No change was made to the 90° sector at the front.

The effects of the new in-flight jet deployment on the aerodynamic characteristics were striking, as had been expected, and are shown up directly by measurements of lift, drag and moment at the same speed for the first and second series of wind tunnel tests, as plotted in Fig. 3.

From this Figure it will be seen that the lift curve slope has been enormously increased in fact, from a $\partial C_L/\partial \alpha$ of approximately 1.0 to a $\partial C_L/\partial \alpha$ of approximately 3.0. At the same time a considerable nose-down moment was created, so that for this control position the aircraft now has close to zero pitching moment at $\alpha = 0$ at this engine rpm. Now, if we consider the two cases at the angle of attack for which the pitching moment is zero, we see first that the usable lift has increased from about 2500 lb. to nearly 3000 lb., and second, that at the same time a drag of about 900 lb. has become a slight thrust. It will also be noticed from this Figure that although the lift curve slope has increased by a factor of 3, the moment curve slope is unchanged. The effect of this is to greatly increase the static in-flight stability, as is shown on Fig. 4, in which pitching moment coefficient is plotted against lift coefficient. The slope of this line indicates the proportion of the chord by which the neutral point, or aerodynamic center, is forward of the c.g. (0.5 chord), and it will be seen that this point has moved aft no less than 22% to a position 34% from the leading edge. Due to the jet deployment this position is now further aft than would be expected or has been obtained without the jet blowing. On the other hand the aerodynamic center of jet lift remains in the same chordwise position as indicated in the diagram to the right hand side of this Figure.

These favourable aerodynamic characteristics result from redeploying the wing tip jet from a focussed condition to a jet sheet. This is accomplished by means of the side transition doors which were operated in the Ames tunnel with the rest of the jet in the in-flight configuration, giving the results illustrated in Fig. 5. This Figure shows lift coefficient plotted against angle of attack, drag and pitching moment coefficients, for three selected transition door openings. The result again shows the improved lift slope, greater lift at the same angle of attack, more nose-down moment for the same lift, and much more thrust. For example, at zero pitching moment we move from $C_L = 0.47$ and $C_D = .055$ to $C_L = 0.8$ and $C_D = -.145$ (a thrust) by opening the side transition doors to in-flight.

The improved control characteristics are illustrated by the graph, Fig. 6, and now allow a modest flight range, even with the depressed thrust level available. Fig. 6 plots pitching moment due to control and lift due to control, giving a comparison between the first and second series of tests.

These in-flight results have been interpreted in terms of forward speed performance in Fig. 7. In this, thrust and drag are plotted against forward speed and a speed range of approximately 50 to 100 knots is shown for the second Avrocar as tested in the tunnel, with a small climb margin in the middle of this range. This marginal performance applies to a (by now) skimpy test weight of 4500 lb. and is due to the extraordinarily poor thrust which the powerplant is producing.

In fact the static thrust appears to be some 30% below the value it had during the previous tests (Fig. 8). In the hovering case this may be due in part to poor focussing, but the unexpectedly low value for the in-flight configuration indicates it is more likely nozzle loss. However, during the time that this tunnel program was going on, other tests were being conducted under the Canadian Government program in order to further investigate the losses in the ducted fan system. Three tests are of special importance to the performance; the first is the duct loss test, of Ref. 1, in which a segment of Avrocar duct with uniform entry profile, without simulated turbine exhaust, and with an improved final bend arrangement, was tested for pressure loss; and a loss coefficient in accordance with the original thrust estimates was obtained (Fig. 9). The second involved tests of a small model to establish the free air focussing efficiency. These tests are reported in Ref. 2, and show once more, a loss due to focussing commensurate with original assumptions (Fig. 10). We think, therefore, that the low static thrust level encountered in the full scale tests must be ascribed to high losses through the tip turbine (which are known to be present, tip clearances of as much as 25% of the turbine blade span having been observed), non-uniform duct entry profile and turbine exhaust flow mixing on the first bend in the flow beneath the fan (which is believed to cause the extremely uneven flow distribution in the duct), and a possibly very large corner loss for the final nozzle (which has inherited a narrow neck from the spoiler control, upstream of the last 180° of flow deflection, which involves taking this final corner at jet exhaust velocity).

The third test involved the measurement of intake pressure recovery in terms which include the effect of crossflow upon the efficiency of a flat fan-in-wing. In these tests it was found that the addition of a large cockpit bubble as a fairing in front of the intake reduced the pressure losses expressed in this way considerably; however, with this fairing the overall air intake pressure loss was greater than had been originally assumed in performance calculations (Fig. 11).

The developed performance now shown on Fig. 7 reflects the installation of modifications to re-institute the static thrust according to the original estimates and a variation of thrust with forward speed appropriate to the intake pressure loss measured with this canopy fairing. It will be seen that any speed between 0 and 250 knots is now possible with a large climb margin. The angle of attack and control position involved for trim at maximum engine speed with the present aircraft thrust level are shown in Fig. 12. During the test the pitch control vanes were found to be less effective in deflecting the trailing edge jet than had been hoped, and some modifications to improve the jet deflection were done. Lines for three configurations are therefore shown with a mean line drawn through representing the variations that would be achieved with a slightly modified control.

The objective of showing that transition is feasible was also achieved. This is illustrated in Fig. 13 which is a similar plot to Fig. 12, for various transition configurations at given weight. The transition procedure determined is illustrated diagrammatically on Fig. 14 which shows the freedom for transition control which was available. Either the rear transition doors could be opened, or, the port and starboard transition doors, or both could be opened together. All these three were tried but it appeared that the only satisfactory procedure for keeping the pitch control within bounds while at constant lift was to open the side doors completely first, and then the rear. The control actions required are illustrated by the dotted line, a, b, c, in this Figure. On Fig. 13 two lines are drawn illustrating the variation of angle of attack and pitch control position with speed for the following two cases:

(i) equilibrium (drag = thrust)

(ii) a constant accelerating force of 200 lb.

To further clarify the procedure the attitude and control actions are sketched in Fig. 33 for four speeds, hover, 30 knots, 50 knots and 97 knots (the maximum cushion speed on present thrust).

3.0 AVROCAR DESIGN DEVELOPMENT
(Canadian Government Part 1 Study)

It was realized that in order to extend the range and duration of the Avrocar type vehicle (as appeared to be essential to increase its operational utility), two approaches were possible:

(i) To considerably increase the power, thus allowing a weight increase, and retaining VTOL capability with a considerably improved fuel load.

(ii) To reduce the power and improve the cruising propulsive efficiency.

Both these approaches were tried. The design studies resulting from the second, finished up with an elliptical planform aircraft with conventional tail, with reduced capability and without VTOL. The other resulted in greatly improved capability and is illustrated here in two versions, Figs. 15 and 16. In this aircraft, the three J69 engines are replaced by two General Electric J85 engines in a different layout, and these provide approximately twice the power for no increase in powerplant weight at all. At the same time they provide a considerable improvement in specific fuel consumption. Reference to Fig. 15 shows an aircraft exactly the same size as the Avrocar with a crew of two situated in the middle in front of the main turborotor, the cockpit providing an inlet fairing to the fan. The two engines on either side of the cockpit exhaust into tusks which cover about half of the fan circumference in a partial entry turbine arrangement, similar to that adopted by General Electric, but they blow upwards through the tip turbine and exhaust rearwardly over the top of the aircraft rather than down into the duct, which was found to be unsatisfactory on the Avrocar; this arrangement is made possible by the partial entry turbine.

To absorb the increased power most effectively, the size of fan is increased from five feet diameter to six feet diameter, but this still leaves ample space within the vehicle for the accommodation of a standard fuel capacity of 4200 lb., plus a standard cargo capacity of 100 cu.ft.

After suitable allowances, based on the recent Avrocar and model tests, have been made the two J85's provide sufficient power to allow VTOL at a gross weight of 9700 lb. at which weight standard fuel and 1000 lb. cargo can be carried. By sacrificing some cargo capacity a maximum fuel weight of 6500 lb. can be carried allowing an improved range performance with STOL. The Avrocar focussing type hovering control and stabilizer system is proposed, with the same jet flap pitch and roll control for in-flight as have been recently tested. A single fin and retractable landing pads complete the picture.

The feasibility of this aircraft has now been very largely substantiated by the Avrocar and other tests, with one considerable exception; this is that the automatic artificial stabilizer for forward flight is still completely unproven. In an endeavour to avoid the development problems which are bound to be associated with this novel proposal, an alternative version based on a more conventional approach, albeit with a somewhat reduced performance capability, is also proposed.

This is shown in Fig. 16 and is seen to be exactly the same basic aircraft with fixed wing extensions to the rear. In this case the flow through the wing tip in the forward flight configuration is ducted through the wing extensions and exhausts through a full span slot fitted with a similar control vane for pitch and roll control in forward flight. Due to the increased moment arm of these controls, they will be more effective than the presently designed control vanes on the Avrocar. The single fin in the center is replaced by a pair of fins and rudders at the wing tip. The possible saving in development effort represented by the provision of natural stability on this design is imponderable; however, a notable advantage it possesses is that control is retained after the failure of both engines and because of the low wing loading a dead-stick landing should be quite feasible. However, because of the extra weight of the wing extensions the performance capability is markedly below that of the circular wing version.

Both versions have a greatly extended capability by comparison with the Avrocar, however, as is shown by the Table, Fig. 17, which compares the performance of the circular wing version with that of the original Avrocar according to specification. The thrust minus drag margin provided by the two J85s is adequate for a rate of climb almost three times that of the original Avrocar, in spite of the increased take-off weight, and the maximum speed is improved to 405 knots. Both range and endurance are in the order of 5 to 8 times as much as was originally available and it will be seen that the objective of four hours duration has been easily surpassed in the ground cushion, with about 3.3 hours being possible in normal cruising flight.

The performance is further illustrated in the suggested mission profiles given in Figs. 18 and 19.

Fig. 18 shows a sea level VTOL mission for both versions in which a penetration, cruising at high speed at tree top level, is visualized, with an allowance at the outward end for one hour cruising at a typical height in the ground cushion (during this time of course the ability to clear any obstacle is assured because of the VTOL capability) and return with 10% fuel reserve. Radius of action is then shown plotted against cruising speed and the advantage of the circular wing version due to its extra 850 lb. of fuel is seen to be about 30%, whereas the advantage of cruising on one engine with the other shut down is about 50%.

On this basis the maximum penetration radius of action is about 200 nautical miles in a mission lasting 2.8 hours at a cruising speed of about 220 knots, or 180 n.m. in 2.1 hours at 320 knots.

The capability is further improved in the maximum fuel case in which the take-off weight is now greater than will allow VTO. However, it is only some 20% greater and thus the distance to 50 feet is extremely short, being 350 feet with the circular wing version and 200 feet with the version with wing extensions due to its lower induced drag in the take-off phase. The increased fuel load has been apportioned to allow 1500 lb. fuel for scouting at the outward end which gives 1.5 hours in the ground cushion, and at the same time the radius of action with the circular wing version is seen to have increased to about 320 n.m. for a mission lasting 3.8 hours, cruising at about 225 knots (Fig. 19).

Because of its performance improvements and particularly because of its projected high speed and low structural weight, (in comparative cost evaluations price has also been based on bare weight), the direct operating costs in cents/mile and cents/ton mile for these aircraft appear favourable, in comparison with helicopters and other light aircraft. The superior VTOL performance and competitive economy results from increased all up weight, disposable load, and fuel carried, and does not reflect a much improved fuel economy compared with the Avrocar, although there is in fact a small improvement because of the greater efficiency of the J85's compared with the J69's.

The fuel logistics problem remains. Nevertheless this aircraft can apparently offer vertical take-off in standard conditions with considerably more than half its weight as a disposable load. It should perhaps be noted that structure weights are based on Avrocar experience and have been increased to allow for anticipated changes and slightly increased load factors.

4.0 REVIEW OF PROGRAM HISTORY AND ACHIEVEMENTS

The Avrocar program was started in March 1958, and a definitive contract was concluded on June 2. Avro undertook to build and deliver one Avrocar within one year from the contract date, and this was in fact rolled out complete early in May 1959.

The contract included a mock-up, and a minimum testing program on aerodynamic models and turborotor. It was increased by a Supplemental Agreement in March 1959 to manufacture a second vehicle, additional turborotors, and do full scale tests in the Ames Research Center wind tunnel.

This contract and Supplemental Agreement were fixed price in the amounts of approximately $1.8m and $2.1m. The Supplemental Agreement called for the second aircraft to be delivered six months from date of contract, and it was in fact finished in mid-August. It can in fact be claimed that all contractual commitments with regard to delivery have been met on these programs, although of course, more optimistic internal schedules were always set up and not always achieved. In addition to the above mentioned funds, U.S. Air Force support for a 1/5th scale wind tunnel model and simulation study work was provided by re-direction of funds from System 606A, in the amount of approximately $0.3m.

Solid gains from the program so far, include the development of the first tip turbine rotor, and the demonstration of the annular jet ground cushion and ground cushion pitch and roll stability and control to $h/d = 0.17$, with moderate terrain capability, plus full scale test data on the spread jet sheet, effect of tip blowing and transition control (partial ground cushion).

However, performance realized has not been satisfactory, although no feature of the scheme has been uncovered which invalidates the original concept or reveals any drastic misconception or misassumption in the original performance estimates. The low thrust level is rather due to mistakes in the execution of the basic concepts; this was realized as soon as the test program was well underway, however it has so far not been possible at any stage to incorporate the necessary improvements. Demonstration of the concept's usefulness has, therefore, been severely limited. Large gains should be possible for quite moderate thrust improvement and this is particularly true in forward flight, where a given percentage gain in gross thrust represents a larger percentage gain in net thrust, since reduction of loss does not increase momentum drag. Such gains will be all around and affect not only the forward thrust but the control power, control angle to trim, etc.

Nevertheless, considerable progress has been made in the aircraft development, and the general structure and mechanical reliability have been amply demonstrated. The first aircraft first underwent a static rig test program of 32 hours of test time (engines on) followed by the first series of wind tunnel tests of 36 hours duration, and finally the second series of wind tunnel tests in which 54 hours of testing were accumulated in about three weeks; for a total aircraft utilization time of 122 hours.

The second aircraft has logged a total of just over 68 hours since starting hovering trials in September 1959.

It is our belief that nothing has been discovered that invalidates the developed performance of this concept, and we therefore recommend the program outlined in Section 5 which follows.

5.0 OUTLINE OF PROPOSALS FOR FURTHER AVROCAR DEVELOPMENT AND MODEL TEST SUPPORT

5.1 Aircraft Status

With regard to the status of the two Avrocar machines that have been built; the first aircraft has undergone 54 hours of largely trouble-free running in the wind tunnel in a period of approximately four weeks, but has again suffered wide-spread minor damage. Without an extensive and costly repair program it could possibly be used for a short further test series, perhaps a brief investigation of the effect of wing extensions. A repair program of greater scope than that undertaken in the beginning of the last series would be necessary to restore it to its original condition and it should always be remembered that the aircraft has now been modified back to front because of the incompatibility of the tunnel mount with the aircraft undercarriage, and the cockpit therefore appears at the rear with respect to the transition controls, and faces aft.

The second aircraft is in good shape and is currently being used at Malton for preliminary terrain testing, hovering at heights up to three feet. With what has become fairly routine repair and maintenance, it can probably be used for a considerable further program. It has had fewer hours of use and has been more steadily maintained since from considerations of pilot safety it cannot be allowed to deteriorate far.

5.2 Scope

In whatever areas further development is postulated it becomes fairly clear that the program will be hamstrung unless some measure of thrust improvement is attempted. As mentioned in the introduction Avro had previously come in with a proposal for this, which was not adopted because of the more urgent in-flight control problems: so that there has been no development of thrust since the end of the static rig program. It is difficult to see any reason why a static thrust in the order of that originally estimated should not still be achieved, however it is also difficult to ascribe losses which can account for the deficiencies to particular areas in which no detail studies have been made. A brief initial program to establish the movements possible in these areas is therefore first suggested, followed by thrust mods and ground cushion and VTOL tests.

5.3 Objectives

In view of the foregoing the following detailed proposals are made with these objectives:

(i) To prove that the hovering thrust efficiency which is required for annular jet VTOL can be achieved, as appears to be indicated by model tests.

(ii) To carry out a VTOL program and demonstrate satisfactory flight characteristics in hover using a focussing control system and artificial rate damping by means of the mechanical stabilizer.

(iii) To make a transition to forward flight out of ground effect. To develop annular jet ground cushion flight through the range of h/d to free air, out of ground effect.

(iv) To establish the aerodynamic characteristics of the proposed positive stability margin version with wing extensions.

(v) To extend the ground cushion speed to a practical maximum and develop aerodynamic lift in the ground cushion in the h/d range up to 0.3.

(vi) To investigate flight over more difficult terrain than hitherto.

(vii) To investigate variations of the annular jet,(using the Avrocar as a test bed), in the h/d range up to 0.3.

All the items proposed are now described in the order in which they would be undertaken.

5.4 Initial Test Program

This is visualized as comprising three items and would be complete in ten weeks:

(i) Tests on the first aircraft in the static test rig. To make sure that the aircraft is out of ground effect the static rig (Fig. 20) must be raised about 3 ft. Tests would then be carried out in the rig as far as possible to prove the thrust increments available. One sector of the rig between two main ribs would be modified to represent an improved nozzle system for which the design improvement visualized is shown in Fig. 21, and also to incorporate the new stators and simulate the exhaust boxes planned, which are shown in Fig. 22. The effects of these modifications would be established by pressure traverse and flow measurements.

(ii) Existing sector model. With the concurrence of the Canadian Government a further program on this model would be carried out by Orenda Engines Limited in which the supposed bad features of the Avrocar duct would be represented in order to reproduce the high losses necessary to account for the observed thrust losses. These modifications would include the introduction of a turbine exhaust representation using cold air, and the present Avrocar duct and nozzle shape. Flow distortions at the entry to this model which represents the station beneath the fan would also be introduced.

This model is illustrated in Fig. 23. Immediately this information has been obtained the modifications which can be incorporated in the Avrocar would be incorporated and checked on the model. From the model we should then have three sets of results:

(a) the fairly ideal duct and flow already tested

(b) the Avrocar duct, as is

(c) the improved Avrocar duct

(iii) Lift efficiency model. A simple lift efficiency model would be made with the single objective of measuring the lift per lb. mass flow for given pressure at the fan station. The technique is illustrated in Fig. 24. Such a model would eliminate doubt with regard to lift efficiency measurement depending on pressure traverse and by incorporating representative internal flow passages would include the internal losses from fan station to nozzle. It would incorporate the proposed new central jet and means for testing several degrees of focussing and lift augmentation curves with ground height would be measured. Because of scale effect it is presumed that such a model will give a conservative answer and will thus demonstrate minimum thrust efficiency which need be considered.

5.5 Thrust Improvement Modifications

During the short initial test program as outlined above, feasible thrust improvement modifications will be studied and estimates of the performance improvement refined as far as possible. A preliminary re-estimate has already been made on the basis of a re-estimated duct loss factor of 0.38 q_{fan} (cf Fig. 9) and previously measured fan characteristics. This estimate is illustrated by Figs. 25, 26 and 27. Fig. 25 shows fan flow and rotor speed measured in the static rig on the first aircraft, and indicates the required extrapolation to 100% rpm, at which point the fan rpm appears to hit the design maximum speed of 2780 rpm. There are no test points beyond about 2400 fan rpm due to the hot intake conditions prevailing at the time, and since at max. fan rpm the fan flow and pressure are apparently such as will absorb the full power of the engines, it is believed that the full rpm will not in fact be achieved unless the turbine tip clearance is controlled. On the assumption that good turbine efficiency is maintained, the measured fan flow and rpm is then transferred to the fan characteristic as found from the Orenda test rig, and the presumable fan pressure ratio determined. Application of appropriate losses as indicated in Fig. 27 then produces the lift-rpm plot shown in this figure, in which a VTO weight estimate is also given and illustrates a small margin for VTO in standard conditions. At this stage the following thrust improvements are proposed:

5.5.1 Modified Wing Tip Nozzle

As explained earlier the present nozzle arrangement has inherited a narrow neck from the original spoiler control; this neck is upstream of the last 180° of flow deflection and therefore involves taking the final bend at jet exhaust velocity; any pressure loss coefficient experienced, based on the flow velocity at the entry to this final bend, thus represents an equivalent loss in thrust. This loss applies both to the hovering and the in-flight configurations.

Since it is usual to lose a coefficient of 0.15 for a well designed 90° bend, it is quite probable that 30% of the available nozzle momentum is destroyed in the nozzle. On the other hand, Orenda tests referred to above, and illustrated in Fig. 9, have shown that the overall loss can be quite small. It is therefore proposed to modify the wing tip nozzle as shown in Fig. 21 which will provide a nozzle contraction ratio of about 1.2 to 1: even presuming the same loss coefficient to obtain the thrust loss might be reduced by a large factor. In the estimate of Fig. 27 an increase of .017 has been assumed to allow for the developed final bend being of lower standard than the duct bend tested.

5.5.2 <u>Turbine Tip Clearance Modification</u>

The excessive turbine tip clearance which has been observed is alluded to in Section 2.0, and a fix for this problem has already been designed and proposed, on a previous occasion. This is illustrated in Fig. 22: the problem was found to be due to the expansion of the nozzle guide vane support ring which had been built in one piece; the temperature of this ring being considerably greater than had been anticipated and as a result of its expansion the turbine tip clearance opened out as much as 3/8 of an inch. It is therefore proposed to cut this continuous ring into segments and tie these segments back to the rotor hub so that circumferential expansion can take place without radial growth. At the same time it is proposed to introduce stainless steel honeycomb as a bedding material for the turbine blade tips, allowing them to rub in as the rotor speeds up. Finally, suitable insulating gaskets are proposed to reduce the temperature of the nozzle guide vane support ring.

5.5.3 <u>Exhaust Box Modification</u>

Modification to the present exhaust boxes was also submitted in a previous proposal, and again is illustrated in Fig. 28. The idea of this modification is to carry the turbine exhaust completely around the bend and so prevent the hot gas flow from distorting the fan profile; it is believed that the turbine exhaust separates on the inside of the bend. This modification has to be accompanied by the design of suitable seals to prevent the back pressure caused by the turbine exhaust boxes from spilling the turbine flow inboard underneath the fan. Design for such seals is also shown in Fig. 28. It is also accompanied by the installation of a suitable amount of insulation above the top skin of the duct to prevent remaining parts of the structure becoming overheated by the contained hot exhaust.

5.5.4 <u>Additional Stators</u>

The Avrocar stator design was always considered marginal, and somewhat imponderable, due to the fact that the trailing edge of the stator blended in to the shear web of the main rib. In this regard comparison with the General Electric fan (which is very similar in design point) shows a very striking difference and it is believed that the excessive gap between the stators is responsible in large measure for the distorted flow existing in the duct. It is therefore proposed to add two additional stators between each main rib, as shown in Fig. 22.

5.5.5 Turborotor Qualification

The above mentioned turbine tip clearance modifications require that the turborotor requalify, and for this purpose an additional preliminary flight rating test of a turborotor in the existing test rig (Fig. 36) is proposed. At the same time it is suggested that the performance of the modified turborotor, stator, and exhaust boxes be checked in this rig by means of suitable pressure instrumentation.

5.6 Development Design Tests

It is recommended that, concurrently with the aircraft test program, the development design outlined in Section 3 be carried a little further: to the point where satisfactory definition of a wind tunnel model can be made, and so that the results of such model tests can be used for a final definition of performance.

An engine air intake design will also be developed using electrolytic or electronic analogy methods to show how the ingestion of dust, grass, and other low density material can be minimized.

The recommended model for the wind tunnel tests is illustrated in Fig. 30, the primary objective being to demonstrate the stability, with wing tip extensions; and the secondary objective being to determine control power and performance. It will be seen that a half-plane model without intake but with jet blowing is recommended, and it is visualized that this could be most economically tested in the NAE low speed tunnel at Ottawa, using the jet blowing techniques recently employed there in other Avro tests. This model would not incorporate the jet hovering system and for this reason a final test on the effect of the wing extensions upon the hovering performance, particularly in the ground cushion, is an essential insurance; however, such a test can be very easily performed on an existing 1/20th scale Avrocar model which is fitted with the focussing ring control. Tests should include operation of the control at forward speed, and can thus fill in a considerable gap which exists in our present knowledge of control characteristics which has, at full scale, been limited to three ground cushion heights.

5.7 Hovering Stability and Control Modifications

Before this program can be started, three additional modifications to improve control and lift out of ground effect are required; it is anticipated that these three modifications will be installed at the same time as the thrust improvement modifications outlined earlier.

5.7.1 Control Actuation System Improvement

Although the travel of the focussing ring control was doubled, this being convenient in the course of the required wing tip modifications for the Continuation Program, no improvement to the actuation system could be contemplated and thus the Avrocar has been operating in hovering in a fairly marginal condition where the pilot can only use little more than half of the movement which is provided, and this only by means of devices such as removing the non-return valve required between the engine and the air main to the control system to provide a little more pneumatic pressure for actuation, and jumping to 90% rpm at take-off for the same reason. A new actuating system is therefore proposed, as illustrated in Fig. 29, in which the existing pneumatic bellows jacks are replaced by hydraulic units. (This Figure summarizes all the proposed modifications).

5.7.2 Modified Central Jet

It is clear that the existing central jet arrangement which was incorporated into the second Avrocar in the simplest, most expedient manner to provide fairly optimum stability characteristics in the ground cushion, is not compatible with the free air thrust efficiency tests illustrated in Fig. 10. However, these tests also indicated that a single central jet should provide adequate stability through the ground cushion height range as shown on Fig. 35, and it is therefore proposed to install the central jet modification shown in Fig. 29 at an early stage and verify that hovering characteristics are still satisfactory. It is believed that hovering lift in the ground cushion will also be improved, see Fig. 10.

5.7.3 Improved Rudder Control

The only unsatisfactory reaction of the newly incorporated in-flight control scheme on the hovering behaviour, has been the introduction of a pitch and yaw interaction; this is believed to be due to moving the rudder vanes forward on both sides of the aircraft (they used to be approximately opposite on port and starboard sides) so that the slight lift loss they are presumed to produce now results in a pitching moment. Also the rudder is not powerful enough. A new modification is therefore required equivalent to replacing the vane sectors to a symmetrical position and increasing the number fitted.

5.8 Variable Focussing Control

Additionally to these improvements a modified focussing control is recommended; which will incorporate a variable focussing feature. A proposal for this modification, which consists of a series of simple flexible flaps, is shown in Fig. 32. Its principal advantage is seen as the ability for the pilot to trim the focussing for best behaviour in the critical height region, and again for best lift out of ground effect. Other very important advantages to be sought are the elimination of the present large radial leak between the floating focussing ring and the bottom of the wing tip, and the ability to fair off the rear nozzle in forward flight, to thus avoid the high drag believed to be caused by the present focussing ring. It is possible that the elimination of the radial leak may be shown up as a necessary thrust improvement for VTOL. This will be determined in the initial test program.

5.9 Static Rig Performance Check

The next step is to check the lift of the modified second aircraft with the thrust improvement modifications in the static rig out of ground effect, and determine that VTO is possible. Following this check it is proposed that a ground cushion development program be carried out, including increasing static hovering height until the VTOL point is reached.

5.10 Ground Cushion Development Tests

After the static rig lift check, a ground cushion development program is proposed having as its principal objective, control and stability through the h/d range to hovering out of ground effect. It cannot be assumed that further control and stability problems will not arise at higher h/d but it is believed that the improved stabilizer performance and the new central jet and variable focussing control will go far towards making the critical height region at least negotiable. During the program, however, as in any similar program, minor development modifications to improve behaviour will no doubt be possible. These are accounted for in the cost of development flying.

Secondary objectives of this program are seen as increase of speed in the ground cushion and development of aerodynamic lift; and terrain tests over more difficult country than has hitherto been negotiated. For the latter to be successful it will be necessary to incorporate measures to control the ingestion of grass and other low density material into the engine and flight control systems.

A program such as would be involved in trying to prevent the engine intakes from swallowing the material (as in the design study, Section 5.5) is not intended.

The final objective is seen as the use of the aircraft as a ground cushion test bed for study of variations on the annular jet. The following particular research areas are considered, providing:

(i) Variable focussing tests, with different central jet combinations. Defocussing the annular jet will extend the h/d at which respectable augmentation occurs so that with quite moderate thrust improvement extension of the cushion ceiling to five or six feet is possible.

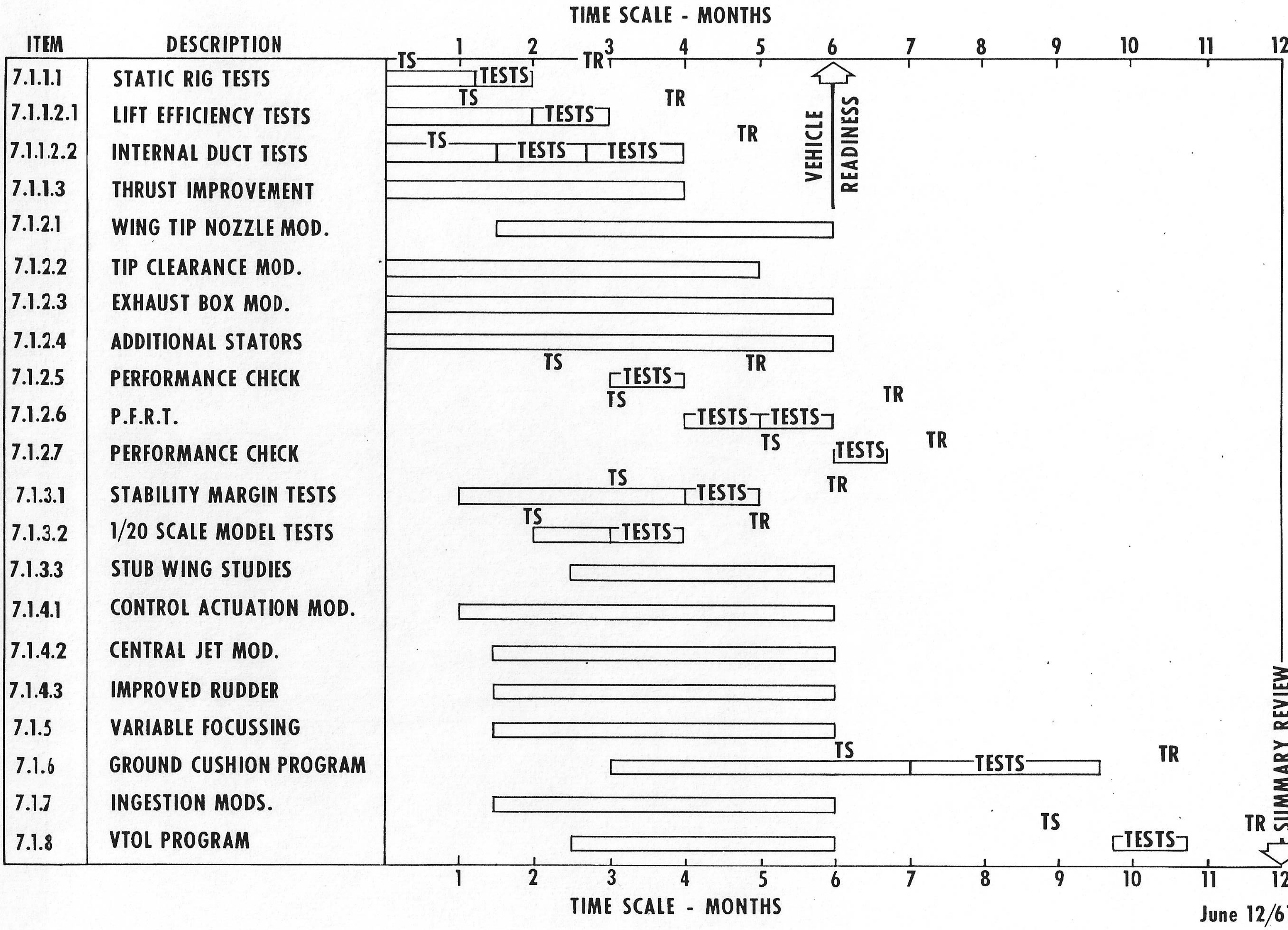
(ii) Skirt tests. It is proposed to apply a flexible skirt to the focussing ring and in this alternative way obtain increased ground clearance. Propulsion will be obtained by means of the transition doors.

5.11 VTOL Program

It has always been maintained by Avro that transition out of ground effect is simpler and therefore initially safer than GETOL. Despite the fact that trim conditions have been demonstrated and GETOL therefore proved feasible, it is recommended that transition in free air be attempted first, particularly since in-flight dependence on the stabilizer will be high. A short VTOL program, say nominally a maximum of ten hours, is therefore proposed in which the hovering behaviour out of ground cushion would first be assessed with slow speed translation up to 30 knots in the hovering condition: followed by cautious operation of transition doors and endeavour to reach the in-flight configuration. For this program an ejection seat would be fitted. This has been considered previously but not engineered.

6.0 PHASING OF WORK ITEMS

The phasing of the recommended work is given in the following chart.



AVROCAR FURTHER DEVELOPMENT PROGRAM SCHEDULE

7.0 STATEMENT OF WORK

The following summarizes the objectives and defines the tasks which shall be undertaken by the contractor:

7.1 Work Items

7.1.1 Initial Test Program

The contractor shall undertake an initial test program to establish thrust improvement increments possible in the known high loss areas as follows:

7.1.1.1 Thrust Investigation Rig Tests on the Second Avrocar

The contractor shall alter the thrust test rig to ensure that the aircraft is out of ground effect, and shall carry out tests on the second Avrocar in the Avrocar static rig.

Instrumentation as necessary will be fitted to the aircraft to obtain lift, radial and circumferential pressure gradients at the peripheral nozzle in the duct and on the undersurface of the vehicle, as well as flow measurements both in the main stream from the fan and gas generators, and any leakage paths such as the horizontal duct doors and focussing ring.

Also, local modifications will be undertaken in one rib sector and the tests will include data to demonstrate the effect of duct improvements by pressure measurements.

7.1.1.2 Thrust Investigation Model Tests

7.1.1.2.1 Lift Efficiency Model

The contractor shall design, build and test a 1/15th scale lift efficiency model for static tests at the contractor's facility. The model shall incorporate representative internal passages and lift efficiency will be based on measured mass flow, and measured total pressure at the fan station. The model shall incorporate alternative degrees of focus, and the proposed central jet. Lift augmentation due to ground at zero angle of attack will be measured.

7.1.1.2.2 Internal Duct Model

The contractor shall sub-contract to Orenda Engines Limited for further testing of an existing internal flow model. This model represents a single segment of the Avrocar type duct. The model shall be modified to simulate the existing configuration and tests will be done with both uniform and distorted flow profiles at entry. Model tests will be analyzed and reconciled with full scale results. The model will then be modified to represent the thrust improvement which can be incorporated into the Avrocar, and re-tested.

7.1.1.3 Thrust Improvement Studies

In conjunction with the test program, the contractor shall study feasible thrust improvement modifications with a view to providing the Avrocar with VTO capability, and estimate the performance improvement possible.

7.1.2 Thrust Improvement Modifications

The contractor shall undertake, by sub-contract to Orenda Engines Limited, (where indicated below) the following modifications for thrust improvement, and allied tests.

7.1.2.1 Modified Wing Tip Nozzle

The contractor shall design, build and install a modified wing tip nozzle arrangement with an improved area variation and contraction ratio to the focussed nozzle, compatible with the existing diffuser duct and existing methods for hovering and in-flight control.

7.1.2.2 Turbine Tip Clearance Modification

The sub-contractor shall design and build, and the contractor shall install in the second Avrocar suitable modifications to avoid excessive turbine tip clearance and associated gas leakage.

7.1.2.3 Exhaust Box Modifications

The sub-contractor shall co-operate in the design and the contractor shall build and install in the second Avrocar, new turbine exhaust boxes to carry the turborotor tip turbine exhaust completely around the first bend. The contractor shall supply the sub-contractor with a second set of exhaust boxes for rig test. The sub-contractor shall design, build and install suitable seals between the air and gas flows. The contractor shall design and install suitable insulation.

7.1.2.4 Additional Stators

The sub-contractor shall advise, and the contractor shall design, build and install, suitable additional stators beneath the turborotor for improved duct flow distribution. The contractor shall supply the sub-contractor with a second set of stator vanes for rig test.

7.1.2.5 Performance Check

The sub-contractor shall check performance of the modified turbo-rotor, stator and exhaust boxes in the Orenda Test Rig by means of suitable pressure instrumentation.

7.1.2.6 P.F.R.T.

The sub-contractor shall carry out a 50-hour preliminary flight rating test (PFRT) to qualify the modified turborotor for use.

7.1.2.7 Performance Check on Second Aircraft

The contractor shall check the performance of the modified Avrocar, with thrust improvement according to the previous items of this Statement of Work, in the Avrocar static rig. The techniques specified for item 7.1.1 above shall be employed.

7.1.3 Development Aircraft Studies and Tests

The contractor shall undertake the following studies and tests to show the feasibility of the proposed development aircraft:

7.1.3.1 Positive Stability Margin Model

To determine stability margin of the Avrocar type vehicle with wing extensions, and the in-flight control power and thrust, the contractor shall design, build and test a suitable scale model of the Avrocar with alternative wing tip extensions. The model shall incorporate jet blowing in the in-flight configuration and forces and moments shall be measured and analyzed.

7.1.3.2 Further 1/20th Scale Model Tests

The contractor shall, at the Avro facility, design and manufacture modifications and shall re-test an existing 1/20th scale model of the Avrocar fitted with stub wings to investigate suck-on effect in the hovering configuration. Further tests of the focussing control in the ground cushion for a range of forward speeds shall also be made.

7.1.3.3 Stub Wing Aircraft Studies

The contractor shall analyze the stability and control, and performance, of the proposed aircraft as a result of the tests: and shall prepare an intake design study to demonstrate theoretically a satisfactory clean air performance.

7.1.4 Hovering Stability and Control Modifications

The contractor shall undertake the following hovering stability and control modifications:

7.1.4.1 Control Actuation System

To increase control power and response, the contractor shall design and install a modified actuation system for the focussing ring control (such as a hydraulic system) capable of moving the focussing ring its full travel at 100% engine rpm.

7.1.4.2 Modified Central Jet

The contractor shall design a modified central jet arrangement whose objective is to retain adequate hovering stability but be compatible with high free air thrust efficiency, and install it in the second Avrocar.

7.1.4.3 Improved Rudder

The contractor shall design an improved rudder control of greater power and incorporate measures to reduce pitching moment interaction.

7.1.5 Variable Focussing Control

The contractor shall design, build and install an improved focussing control to replace the existing focussing ring. This control shall be designed to reduce leakage and shall incorporate means for variable focussing as well as hovering pitch and roll control.

7.1.6 Ground Cushion Flight Development Program

The contractor shall repair and maintain the second Avrocar as required and carry out a 40-hour ground cushion flight development program as follows:

7.1.6.1 Tests with increased ground cushion height, and a variable amount of peripheral nozzle focussing.

7.1.6.2 Tests to increase speed in the ground cushion, and develop use of aerodynamic lift. Speeds of 50 to 75 knots shall be the aim.

7.1.6.3 Further terrain tests over more difficult country.

7.1.6.4 Tests with unfocussed jet configuration in combination with central jet arrangement. The object of these tests it to extend the ground cushion hovering height to five or six feet on limited power.

7.1.6.5 Tests with a fabric skirt of varying depth. The object of these tests is to check stability and control, also to determine the increased obstacle clearance possible at given power with this device.

7.1.7 Modifications to Ensure Clean Air to Control Systems

The contractor shall design, manufacture and install suitable modifications to control the ingestion of low density material into the engine and flight control systems.

7.1.8 VTOL Program

The contractor shall carry out a 10-hour program of vertical take-off and landing tests including slow maneuvers out of ground effect. Use of the transition controls shall be tried. An ejection seat shall be installed (assumed to be a Government supply item).

7.1.9 Spares Allowance

To support the tests in items 7.1.6 and 7.1.7, the contractor shall provide a suitable spares holding based on his previous experience of operating the Avrocar, and assuming the first aircraft is available for cannibalization.

7.2 Photography

The contractor shall provide the following photographic coverage of the program:

7.2.1 Two (2) color contact film masters with optical sound track, which chronologically summarize in documentary form, salient, visual features of test models, static test and flight test programs, shall be despatched to the contracting authority ten (10) weeks after completion of all tests.

7.2.2 35mm black and white film for and process exposed negatives from auto-observer cameras, as required.

7.2.3 Still photographs, taken as required, of all test models, instrumentation, installations, etc.

7.3 Reports and Reviews

7.3.1 Progress Reports

The contractor shall prepare and submit to the contracting authority twenty (20) copies of a Progress Report to be despatched on or before the 5th day of the month following that being reported. The first report shall be due in the month following that in which the contract is fully executed. The first section will summarize the work performed and the results obtained during the preceding month. The second section will present the percentage of task accomplished in each area of work during the same period, also a graph of cumulative total hours and funds, and a tabulated summary of total hours and funds expended at the beginning of the reporting period.

7.3.2 Test Specifications

As a part of the work in the preceding paragraphs, the contractor shall prepare and submit to the contracting authority ten (10) copies of Test Specifications for the tests of items: 7.1.1, 7.1.2, 7.1.3, 7.1.6 and 7.1.8. These specifications shall be delivered in advance of test build.

7.3.3 Technical Reports

As a part of the work in the preceding paragraphs, the contractor/sub-contractor shall submit twenty (20) copies of Technical Reports covering the test results under items specified in para 7.3.2 above, and also the studies in 7.1.1.3, 7.1.2.5, 7.1.2.7 and 7.1.3.3.

7.3.4 Program Reviews

The contractor shall provide for two (2) Program Reviews to be held at a time and place mutually agreed between the contractor and the contracting authority, and shall submit thirty (30) copies of a Summary Technical Report at each review.

7.4 Delivery

Copies of the reports shall be delivered to the contracting authority on or before the dates specified in the attached work schedule.

LIST OF REFERENCES

Ref. No.

1 Orenda Report CR-301 Volume III. Investigation into Exhaust Duct Pressure Losses April 1961.

2 Analysis of Tests of the 1/20 Scale Avrocar Development Model by M.B.P. Watson. Avro Report 500/AERO TEST/420.

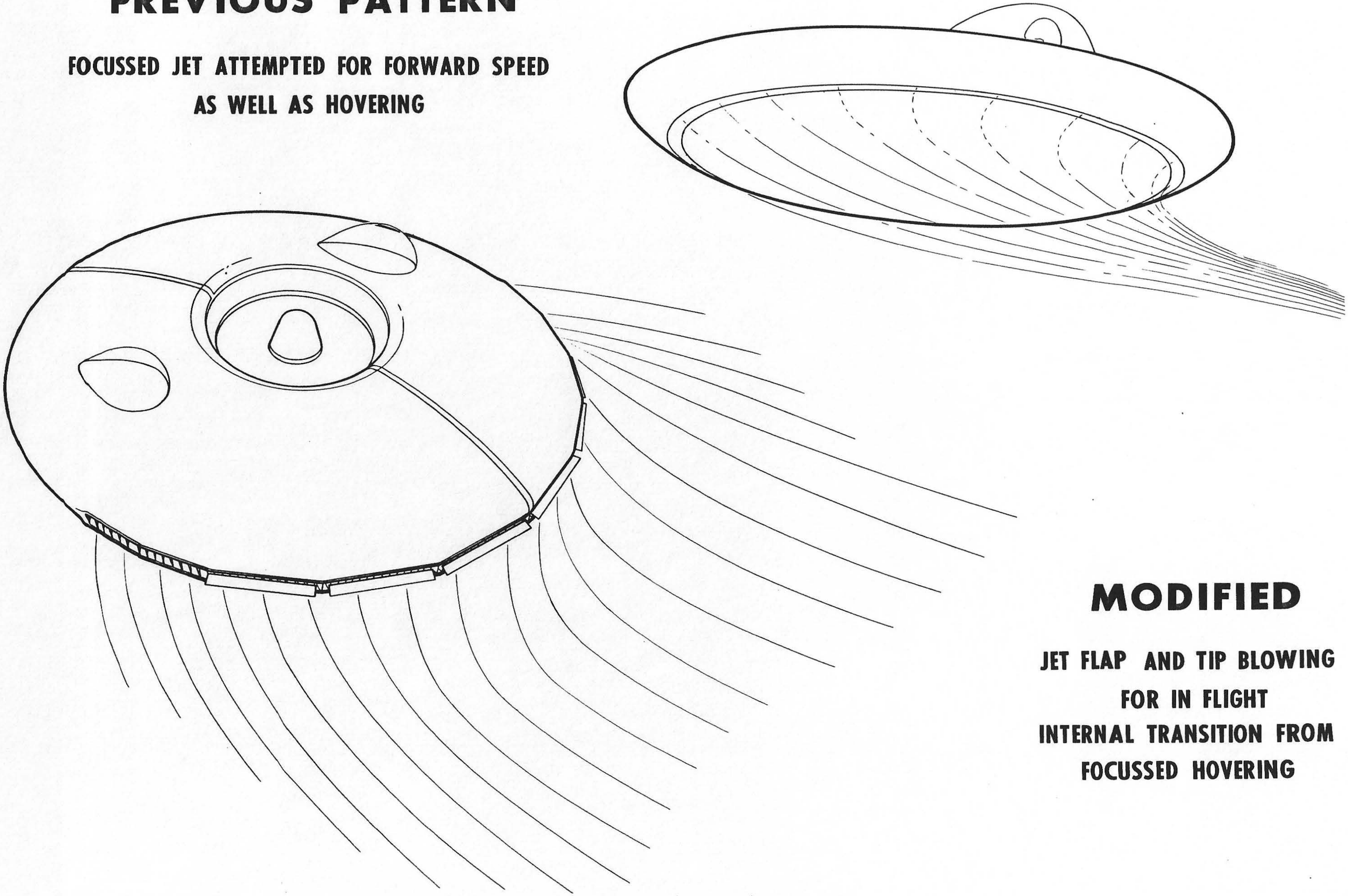


FIG 1 AVROCAR JET DEPLOYMENT

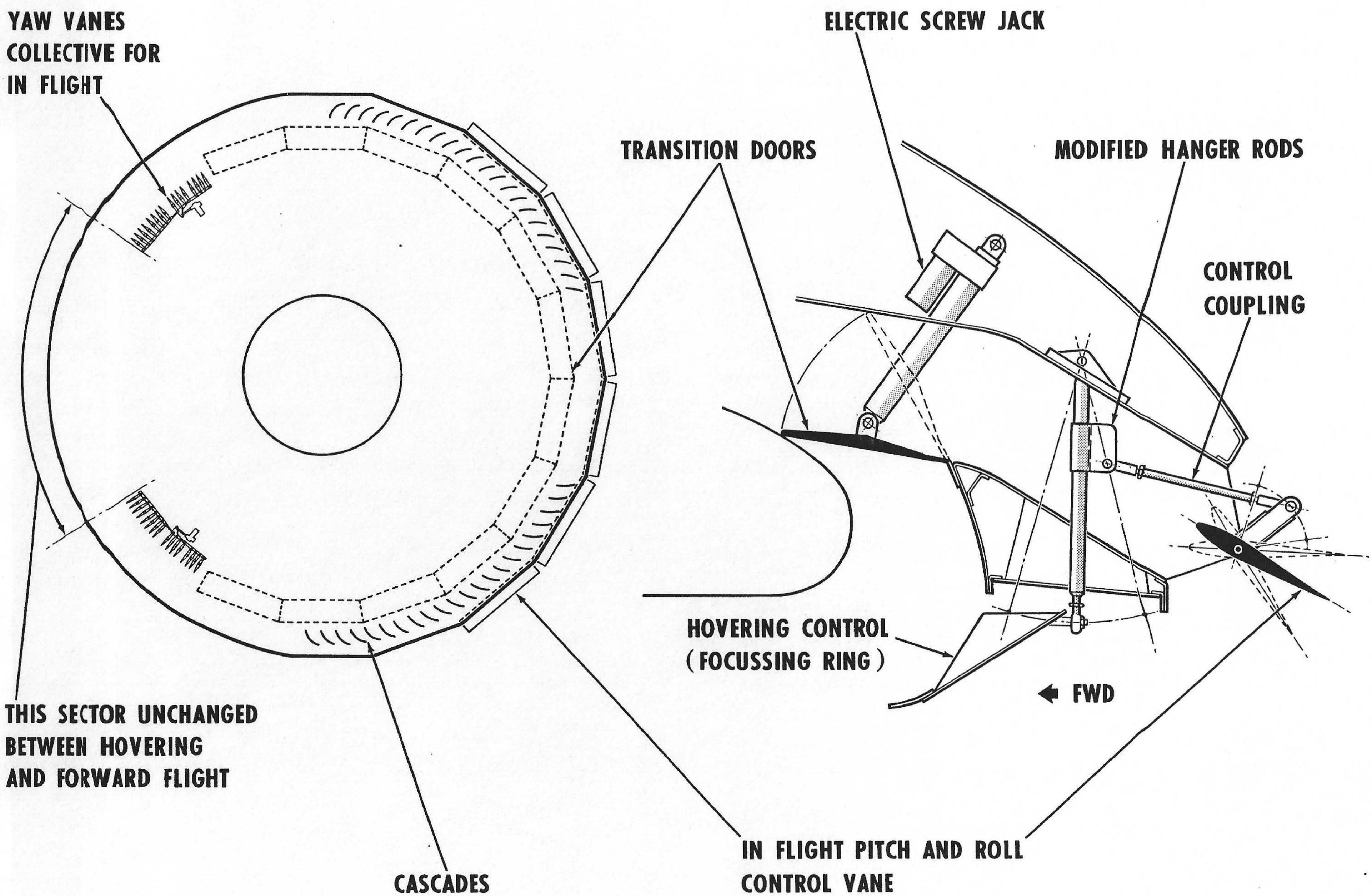


FIG 2 AVROCAR CONTROL AND PROPULSION DEVELOPMENT

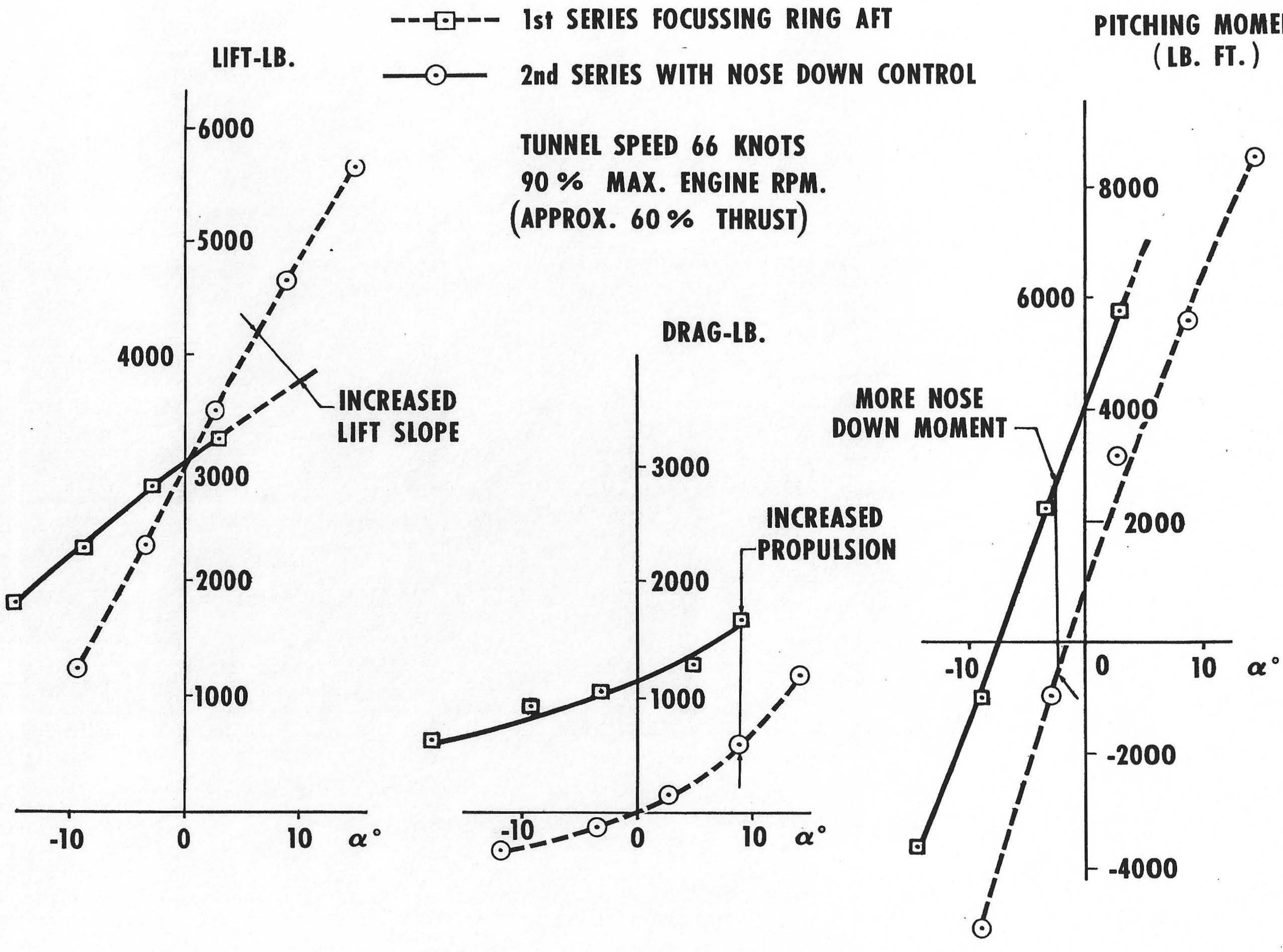


FIG. 3 LIFT, DRAG AND PITCHING MOMENT VERSUS ANGLE OF ATTACK COMPARISON

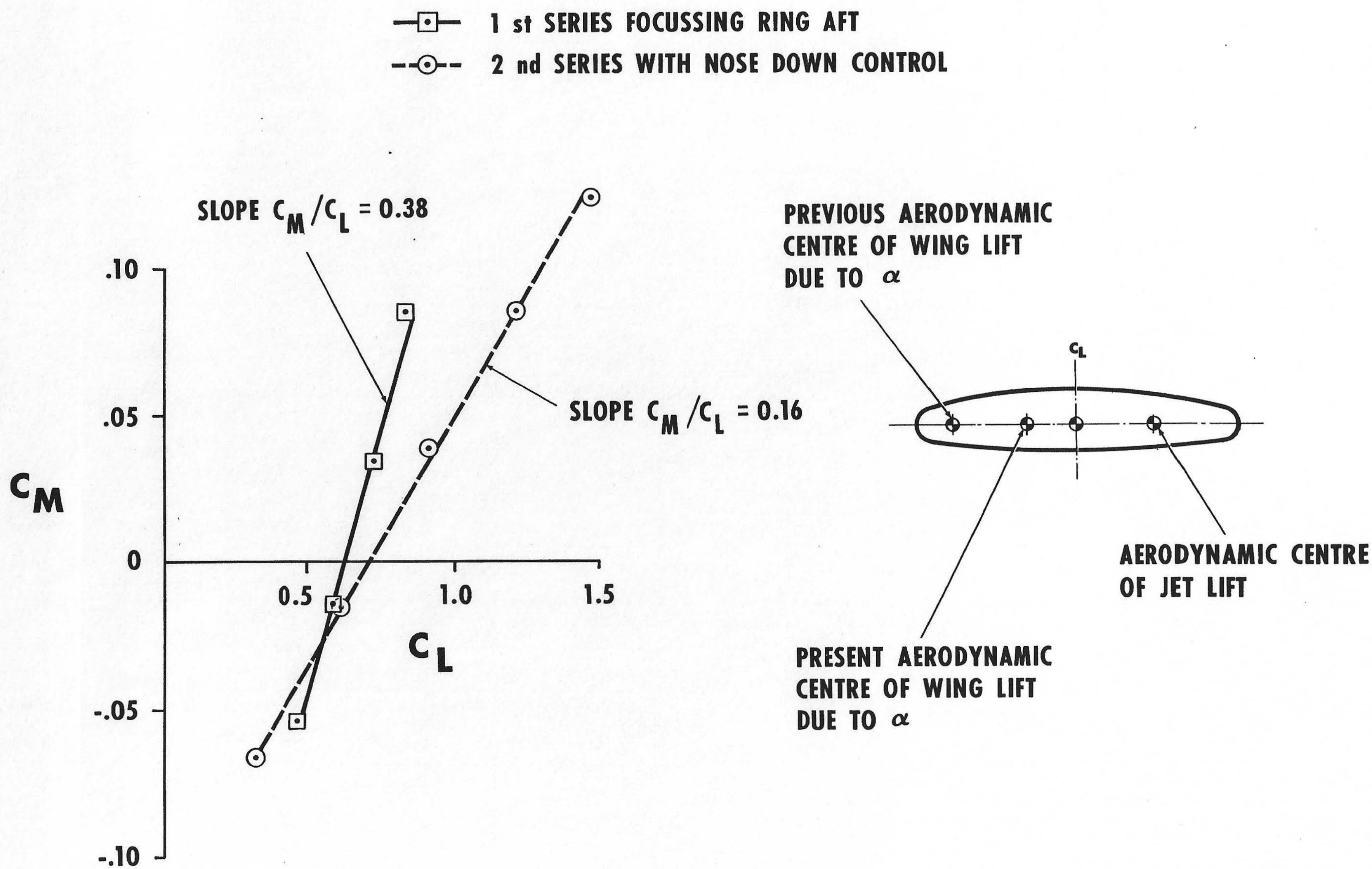


FIG. 4 STABILITY SLOPE COMPARISON

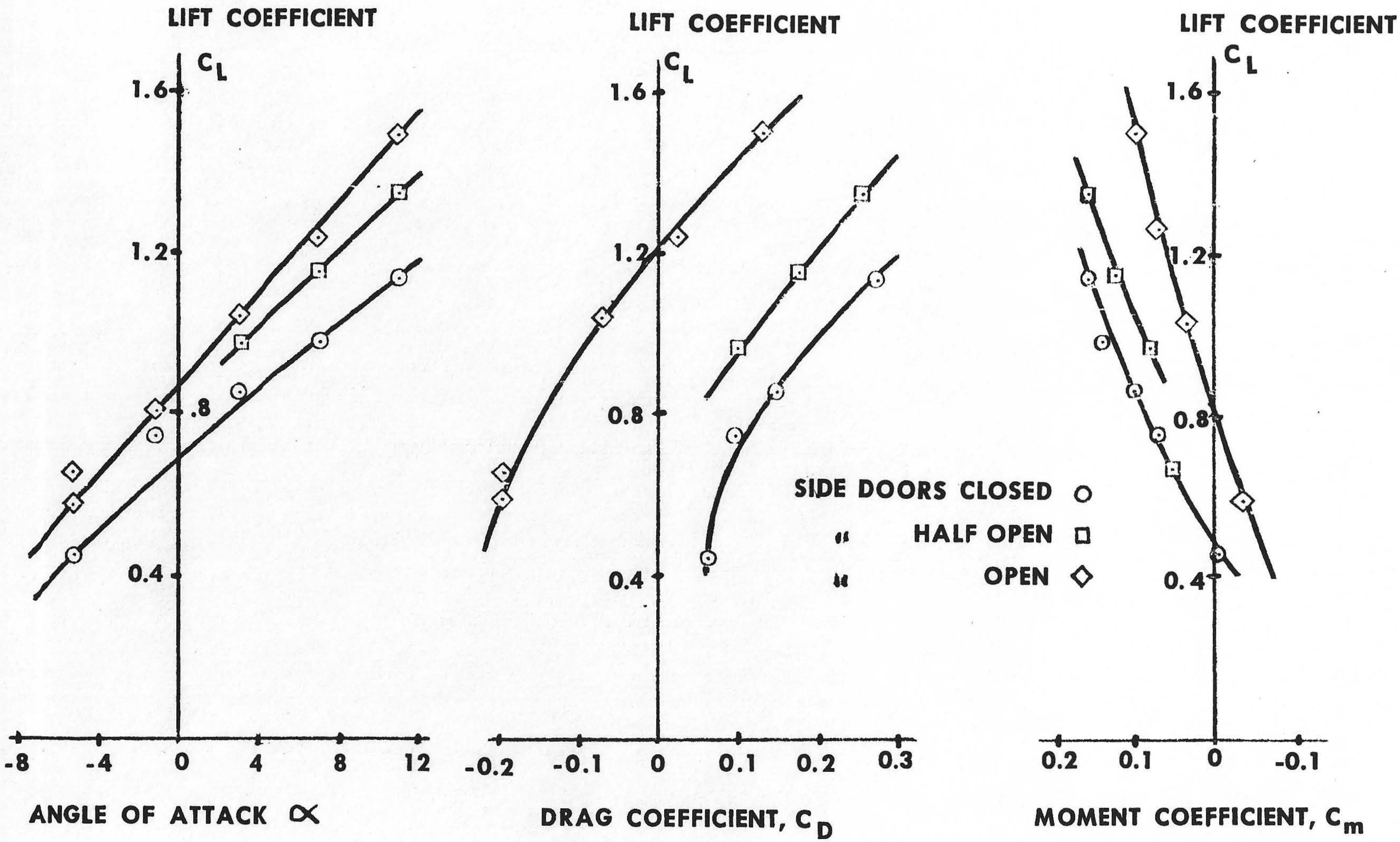


FIG. 5 EFFECT OF WING TIP BLOWING

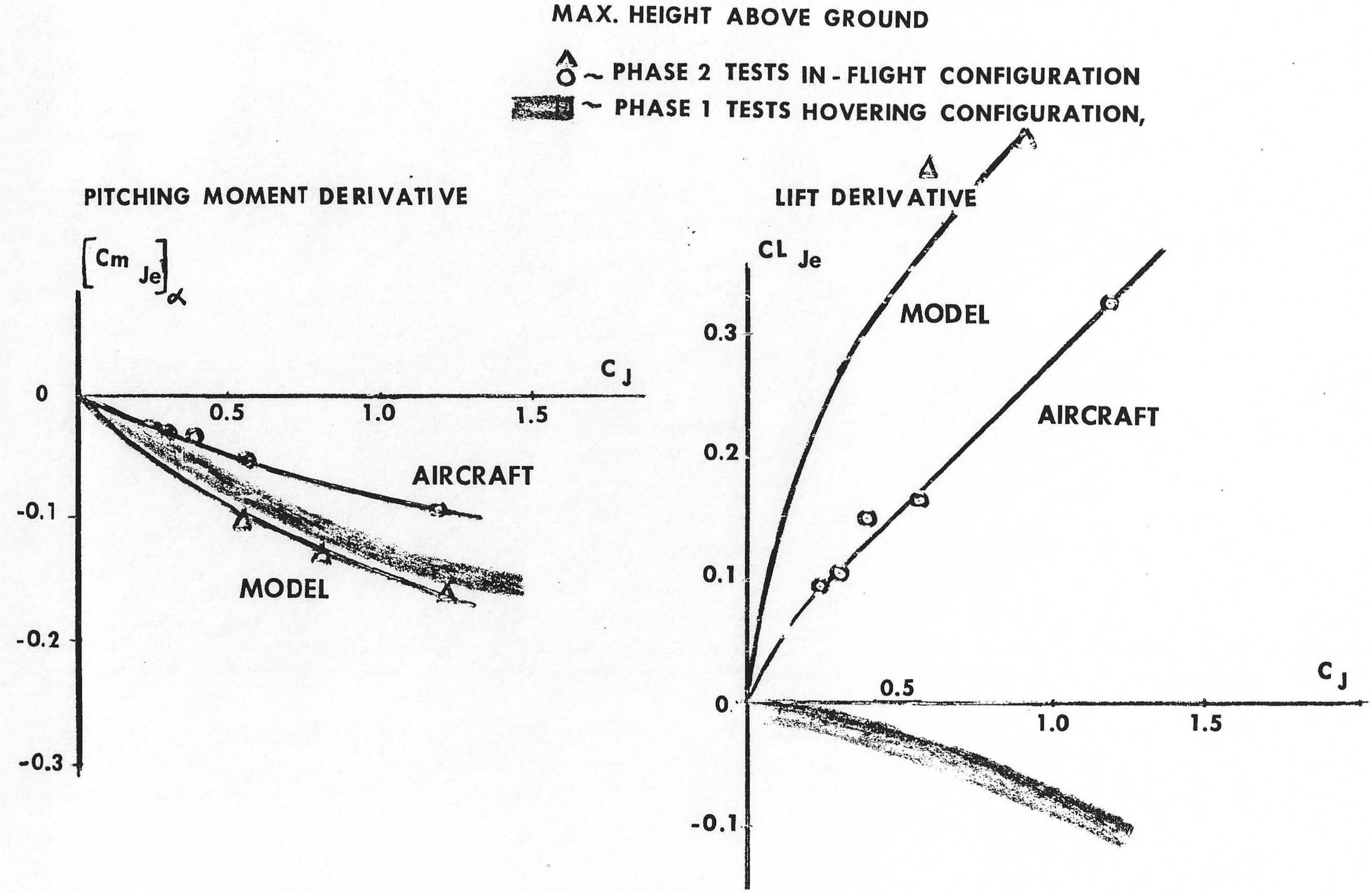


FIG. 6 LIFT AND MOMENT DUE TO CONTROL ACTION

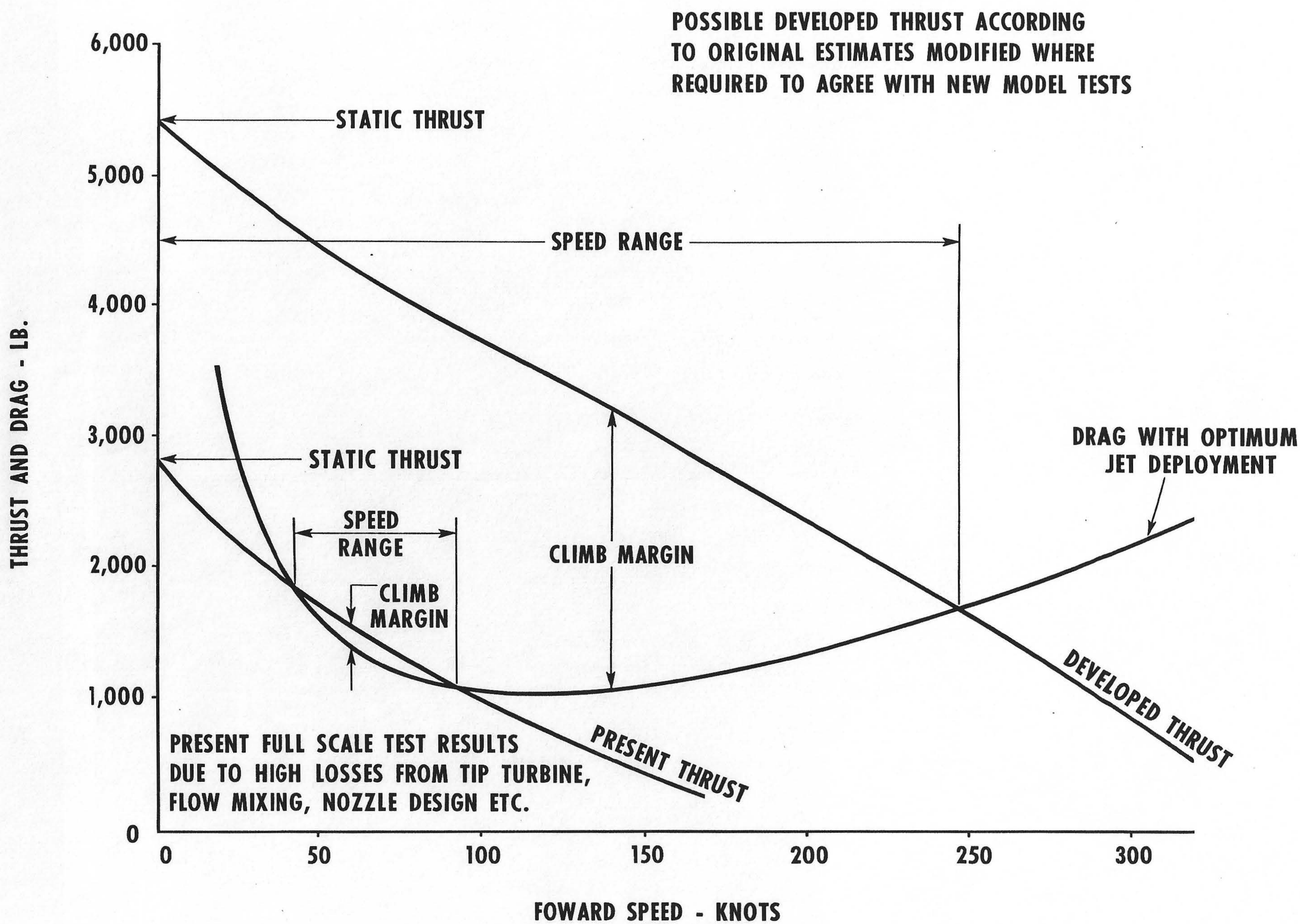


FIG. 7 FORWARD FLIGHT PERFORMANCE

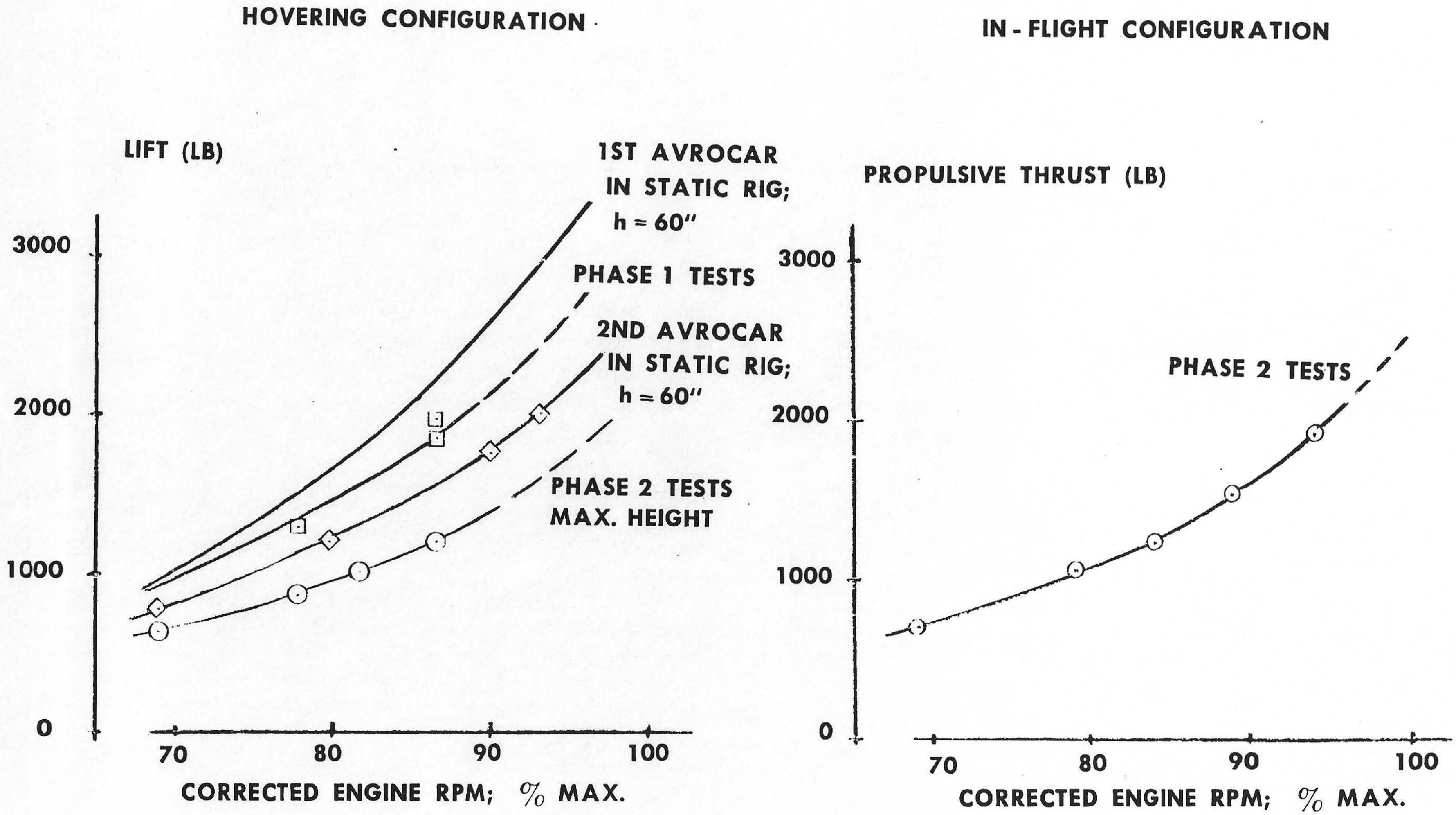


FIG. 8 FREE AIR STATIC LIFT PERFORMANCE

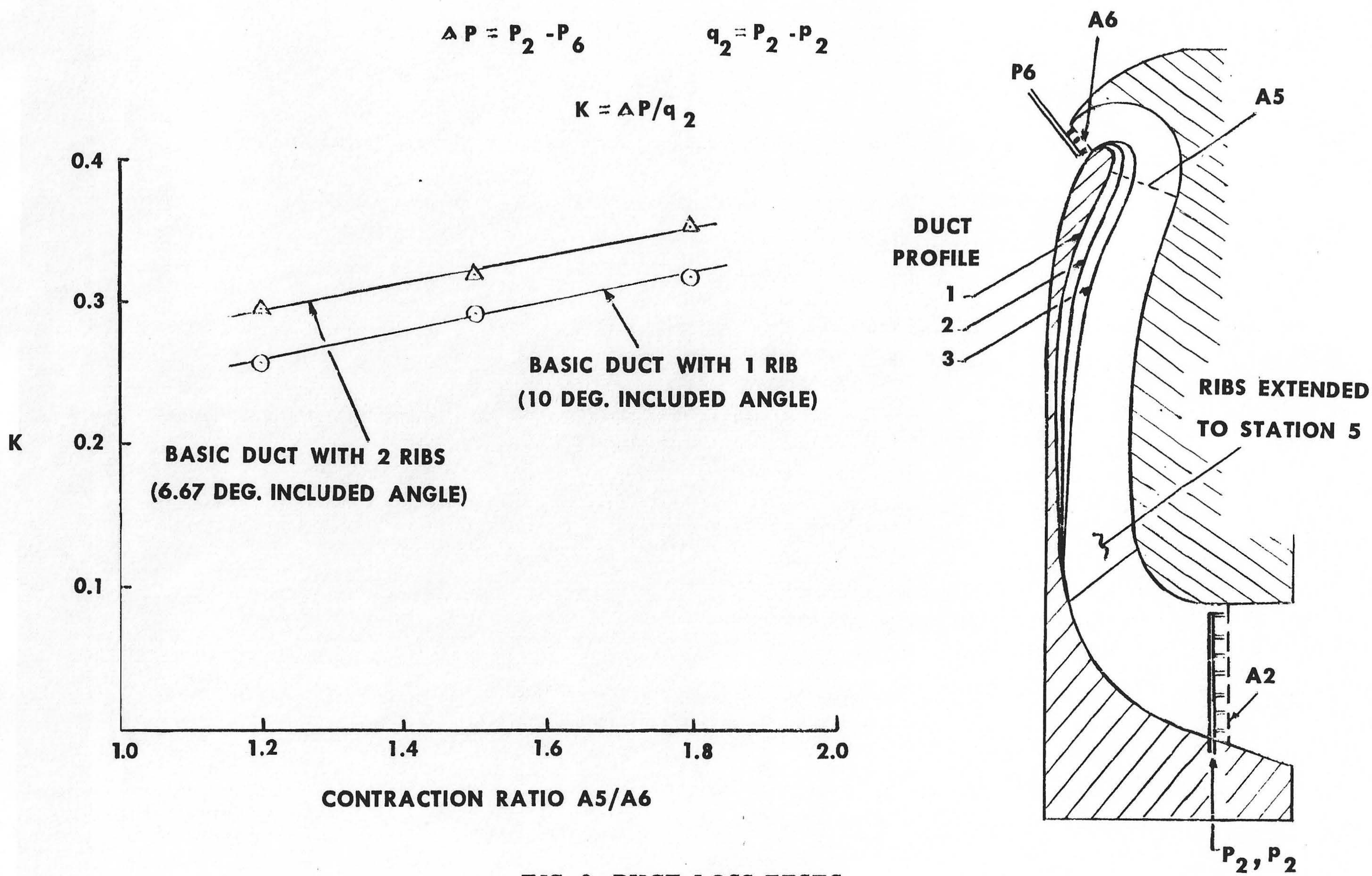


FIG. 9 DUCT LOSS TESTS

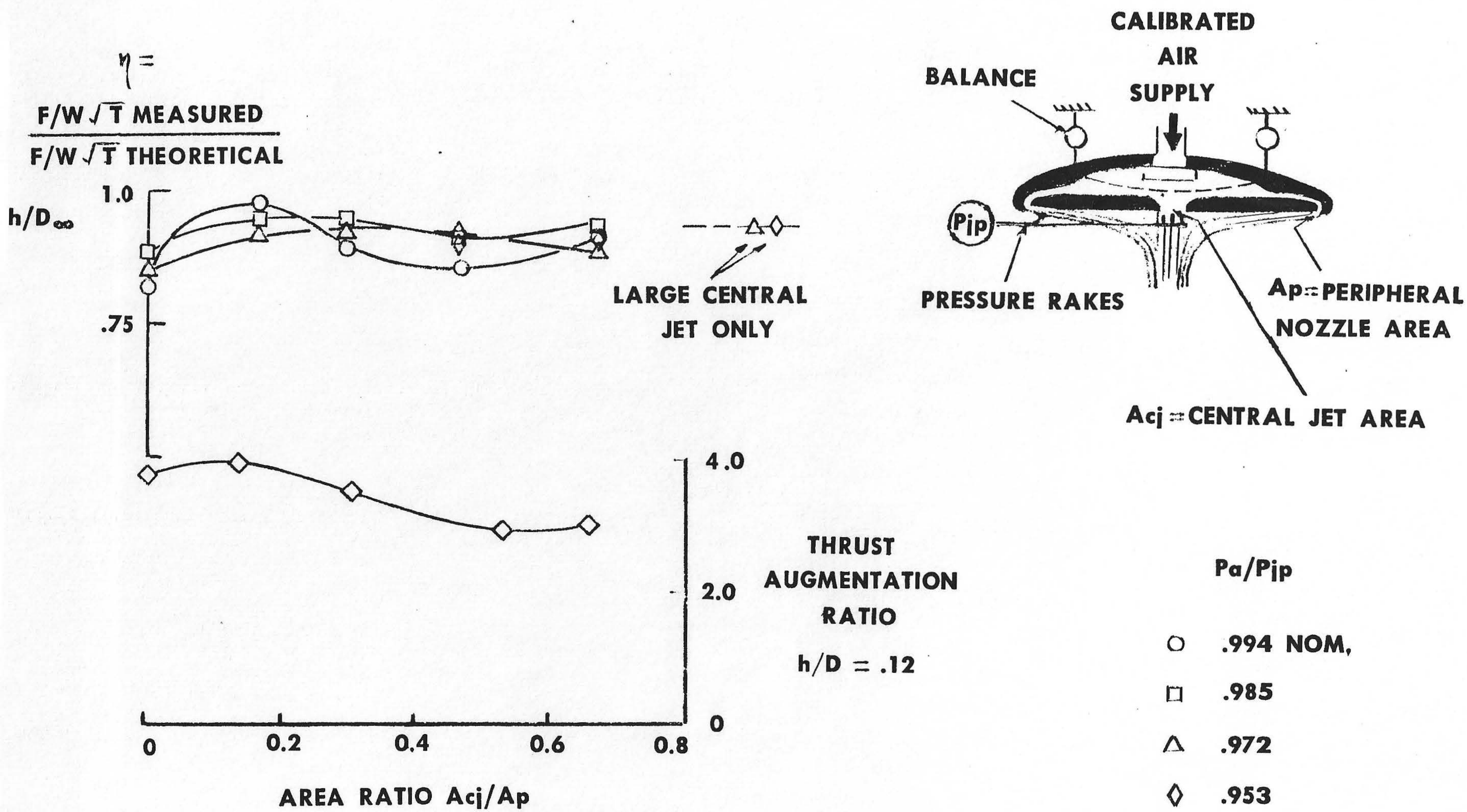


FIG. 10 EFFECT OF CENTRAL JET ON THE THRUST EFFICIENCY

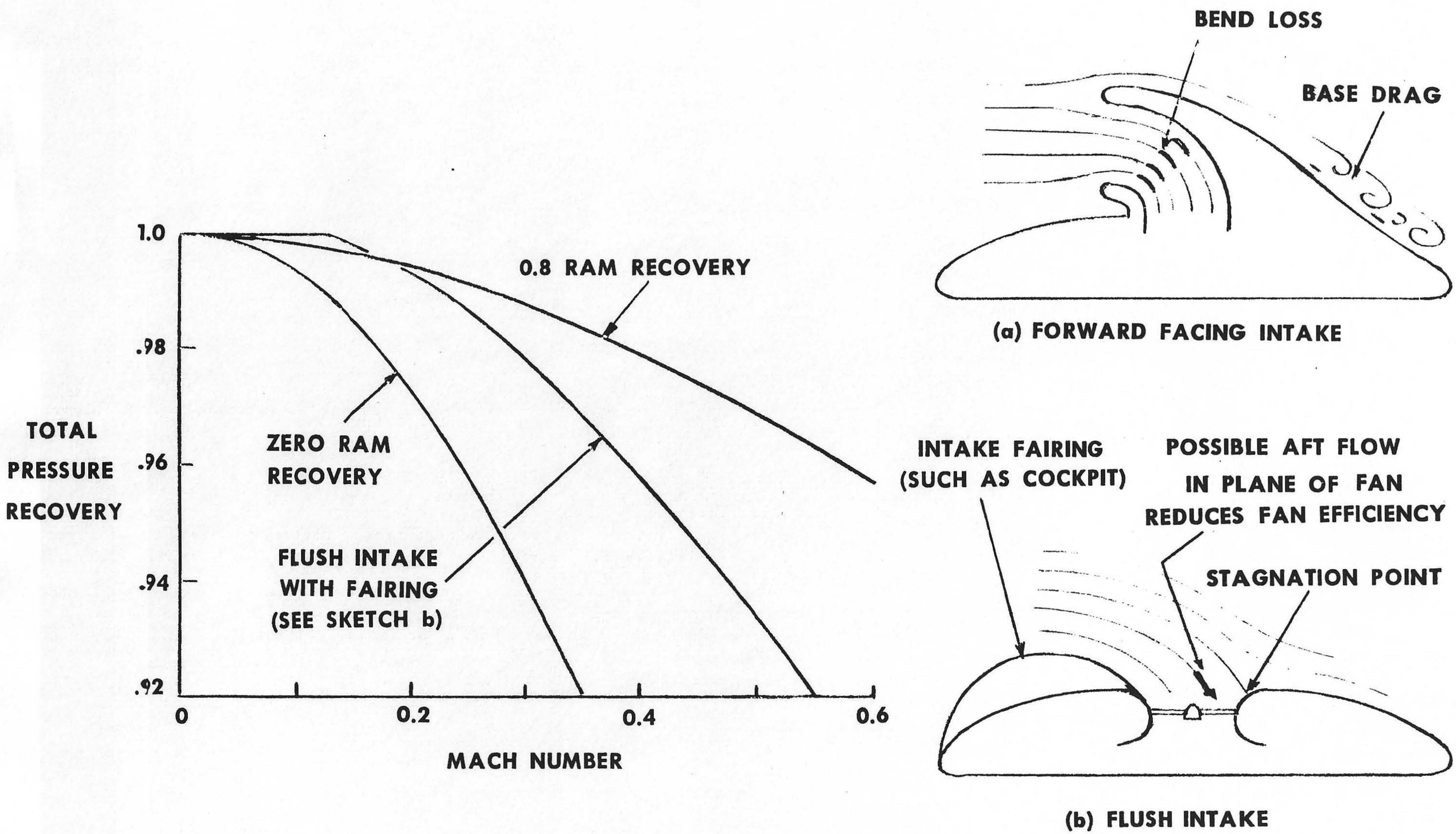


FIG. 11 INTAKE PRESSURE LOSS TESTS

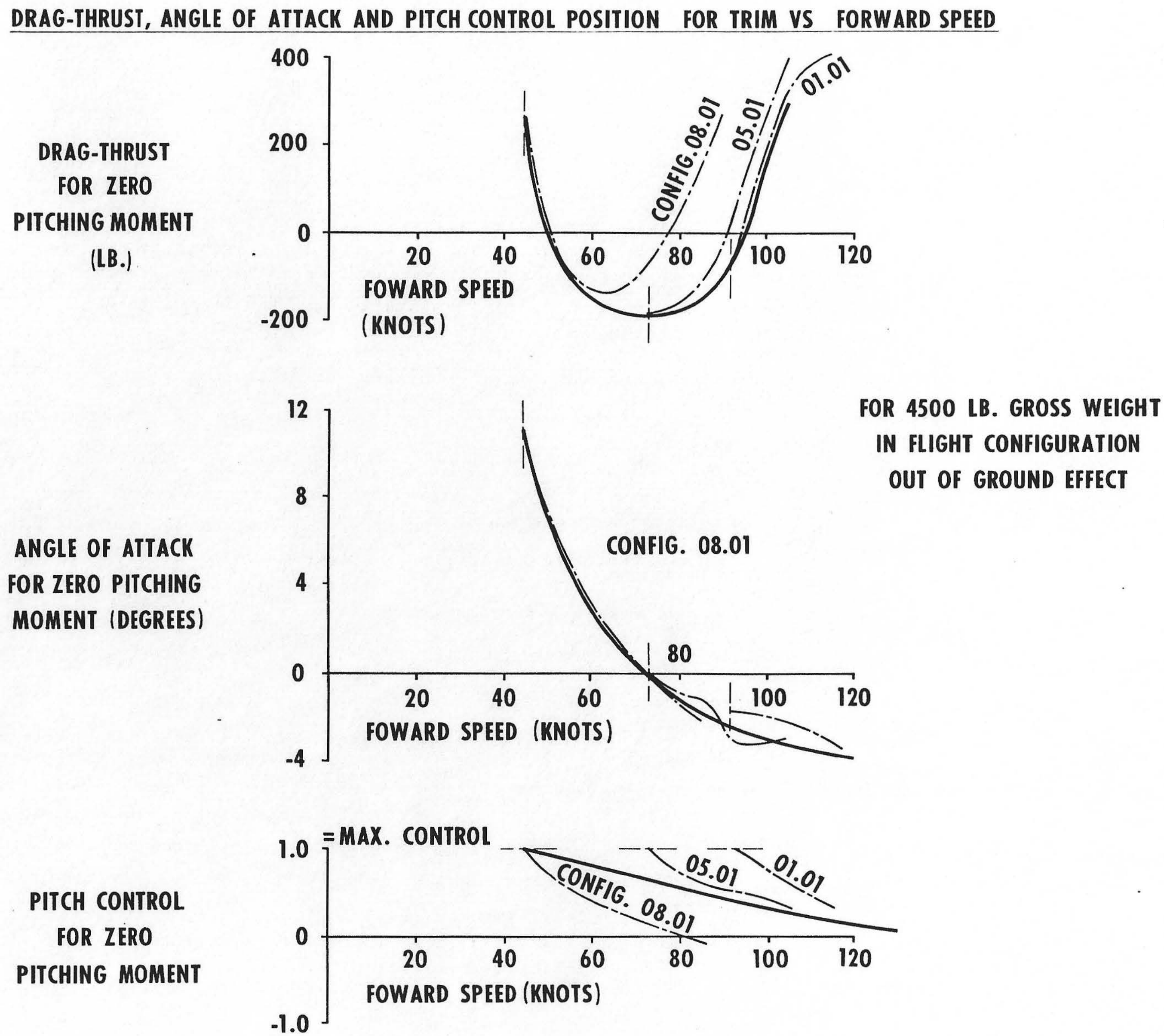
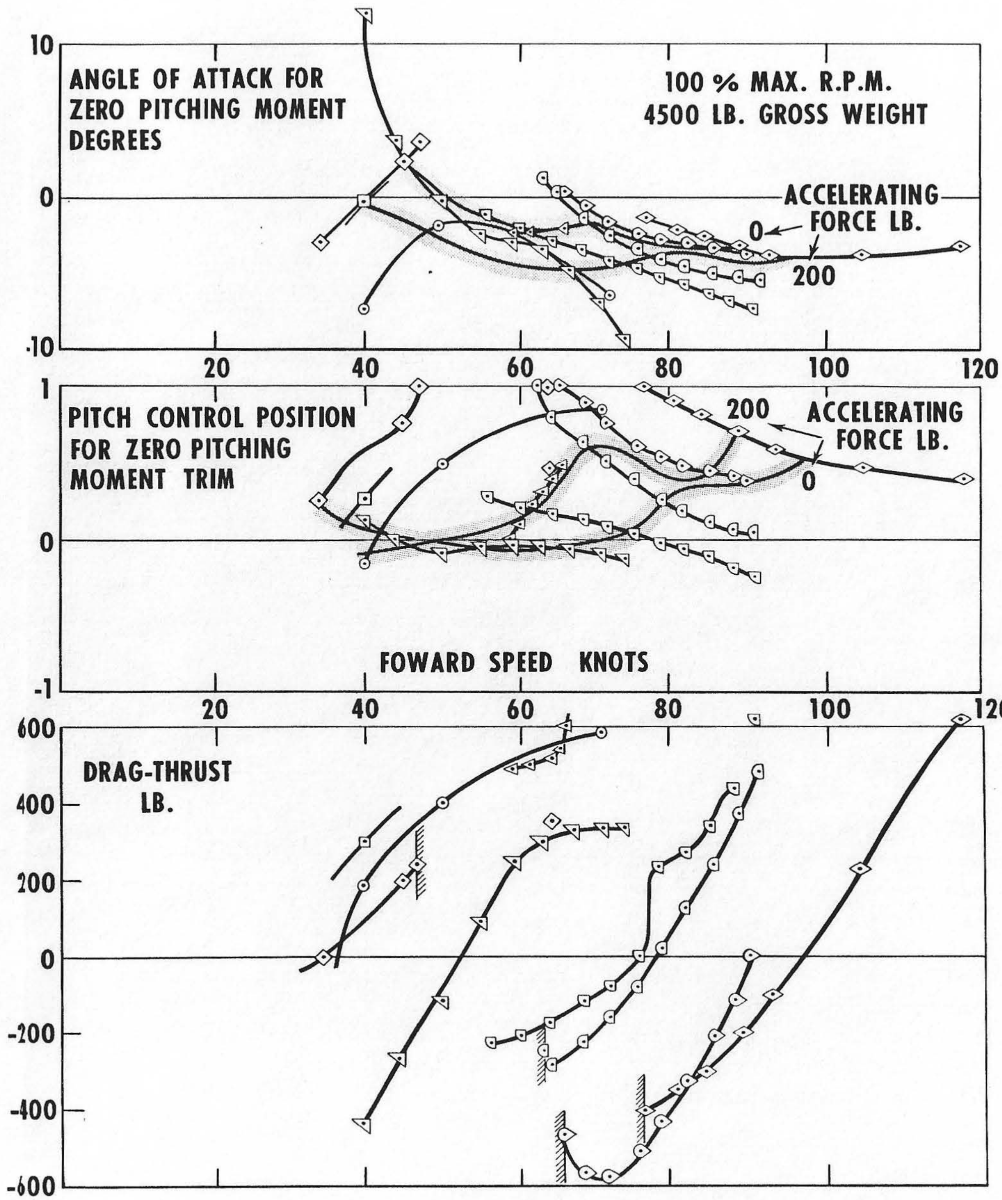


FIG. 12 THRUST - DRAG, ATTITUDE AND PITCH CONTROL IN FORWARD FLIGHT



TRANSITION PERFORMANCE AT 32 INCHES ABOVE GROUND

SYMBOL	J_{T1}	J_{T2}
○	0	0
□	0	.25
◇	0	.50
◁	0	.75
◹	0	1.0
◡ (flagged square)	.25	1.0
◖ (flagged square)	.50	1.0
⊳ (flagged circle)	.75	1.0
◇ (flagged diamond)	1.0	1.0

FIG. 13 THRUST - DRAG, ATTITUDE AND PITCH CONTROL IN GROUND CUSHION TRANSITION

DIAGRAM OF CONTROL MOVEMENTS DURING TRANSITION

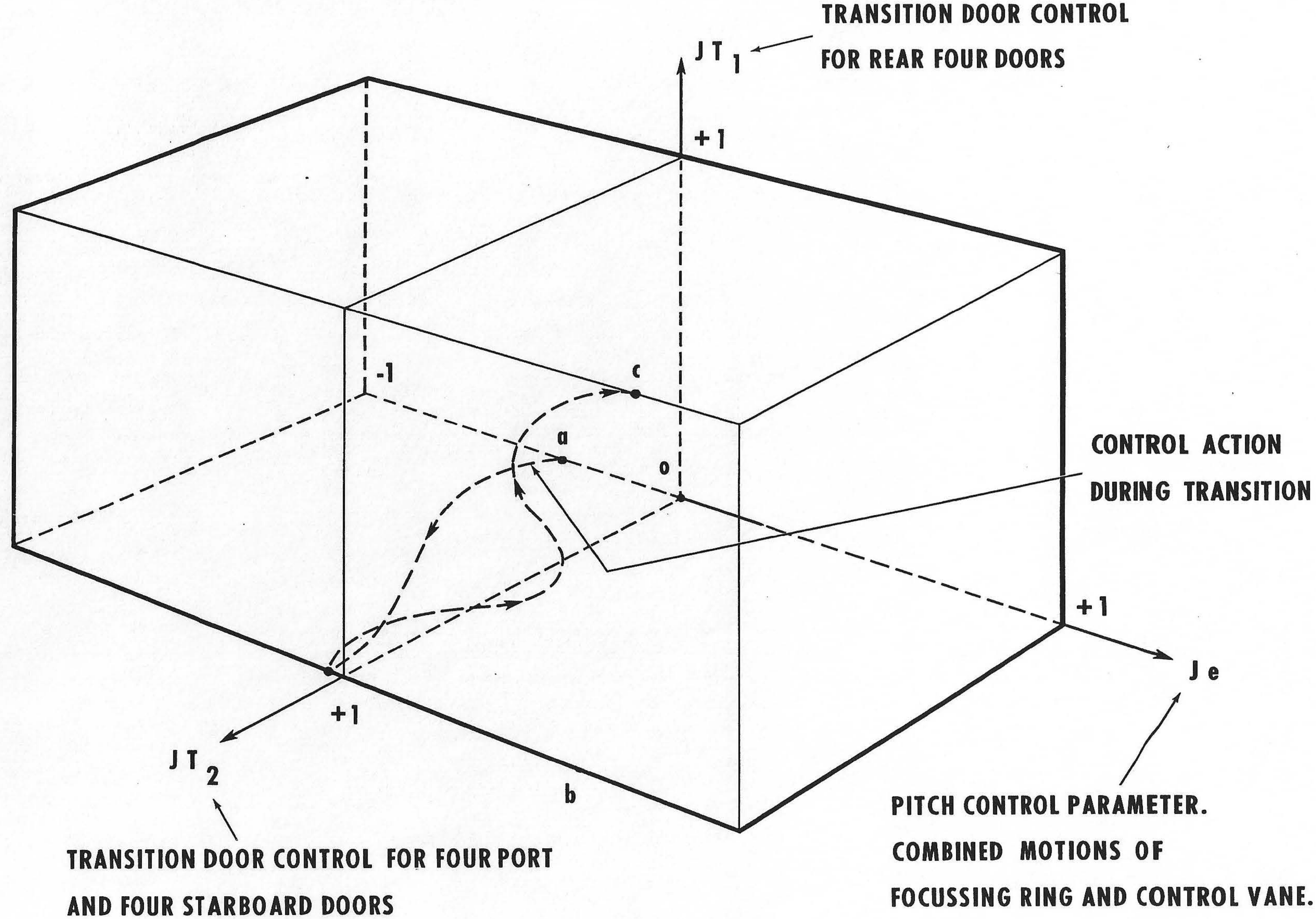


FIG. 14 DIAGRAM OF CONTROL MOVEMENTS DURING TRANSITION

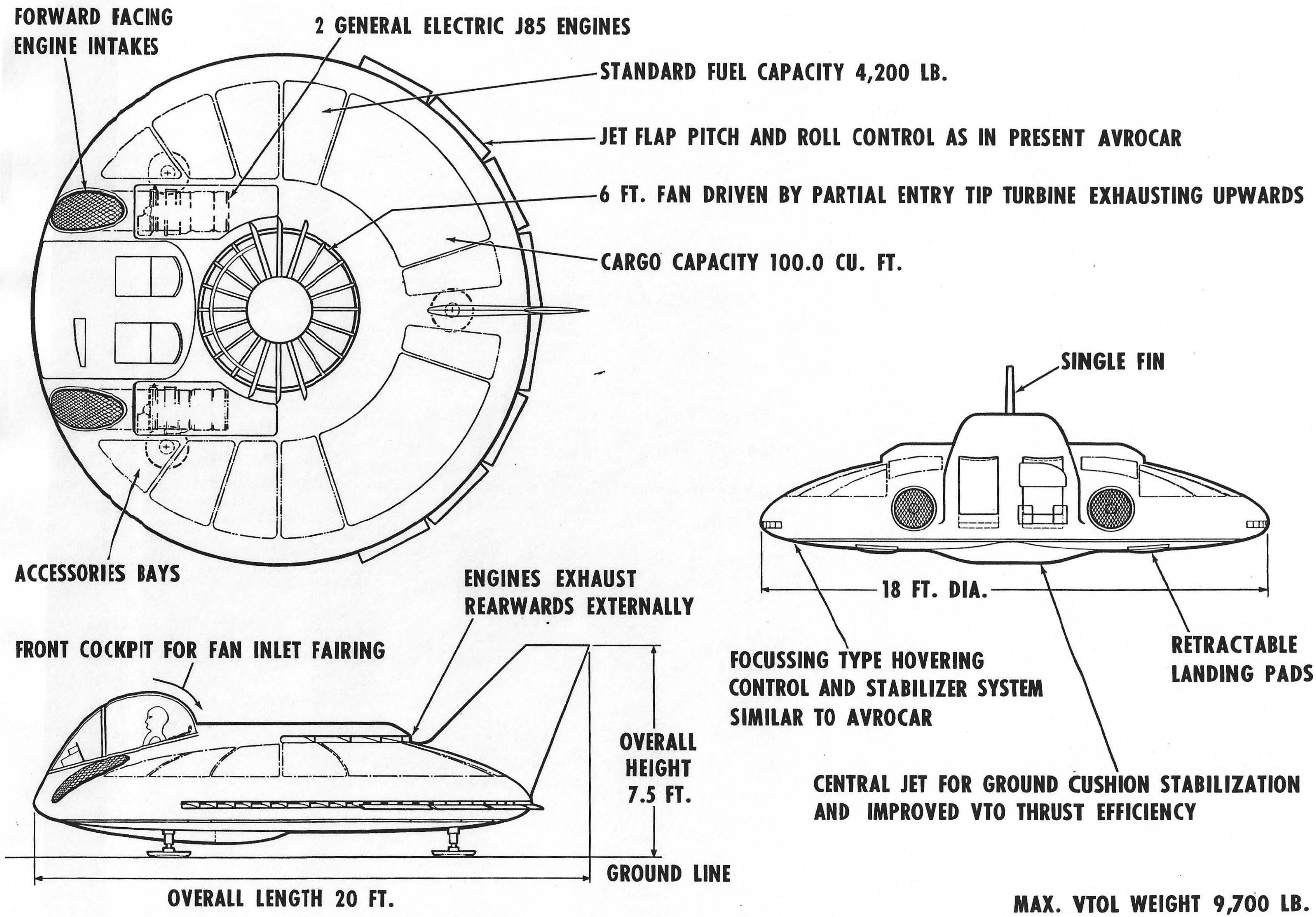


FIG. 15 AVROCAR DEVELOPMENT - CIRCULAR WING VERSION

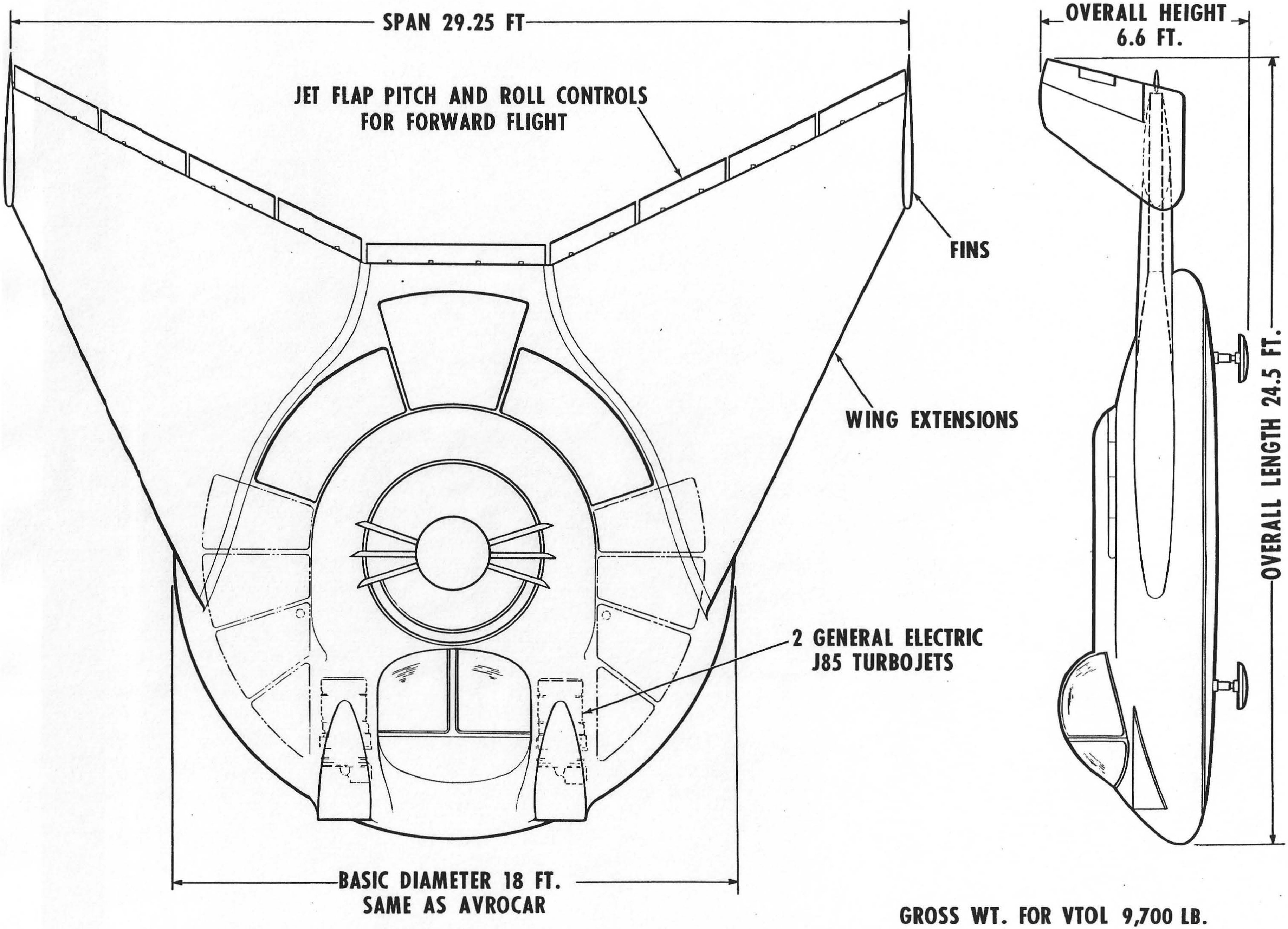


FIG. 16 AVROCAR DEVELOPMENT - VERSION WITH WING EXTENSIONS

	DEVELOPED AVROCAR VERSION CIRCULAR PLANFORM WING	ORIGINAL AVROCAR
REFERENCE	500/PERF/427	AVRO/SPG/TR 254
ENGINES	2 X J85 @ 2,700 LB.	3 X J69 @ 920 LB.
TAKE-OFF		Empty (5250)
MAX. VTO WEIGHT	9,700 LB.	5,650 LB.
FUEL + PAYLOAD & CREW	5,600 LB.	2,400 LB.
FUEL FLOW	4,800 LB. / HR.	3,120 LB. / HR.
INITIAL RATE OF CLIMB	11,000 FT. / MIN.	4,300 FT. / MIN.
SEA LEVEL - ALL ENGINES		
MAX. RANGE SPEED	210 KNOTS	235 KNOTS
NAMPP	.104	.097
MAX. SPEED	405 KNOTS	305 KNOTS
MAX. RANGE - NAUTICAL MILES	437 N. M.	79 N.M.
WITH NORMAL TANKAGE OF	4,200 LB.	810 LB.
AND PAYLOAD + CREW OF	1,400 LB.	1,590 LB.
MAX. DURATION IN-FLIGHT WITH NORMAL TANKAGE	2.5 HOURS	.42 HOURS
MAX. DURATION IN GROUND CUSHION AT 2 FT.	3.5 HOURS	.5 HOURS
SEA LEVEL - ONE ENGINE SHUT DOWN		
MAX. RANGE	613 N.M.	104 N.M.
MAX. ENDURANCE	3.3 HOURS	.52 HOURS
MAX. ENDURANCE AT 2 FT.	5.1 HOURS	.60 HOURS

FIG. 17 VTOL PERFORMANCE COMPARISON

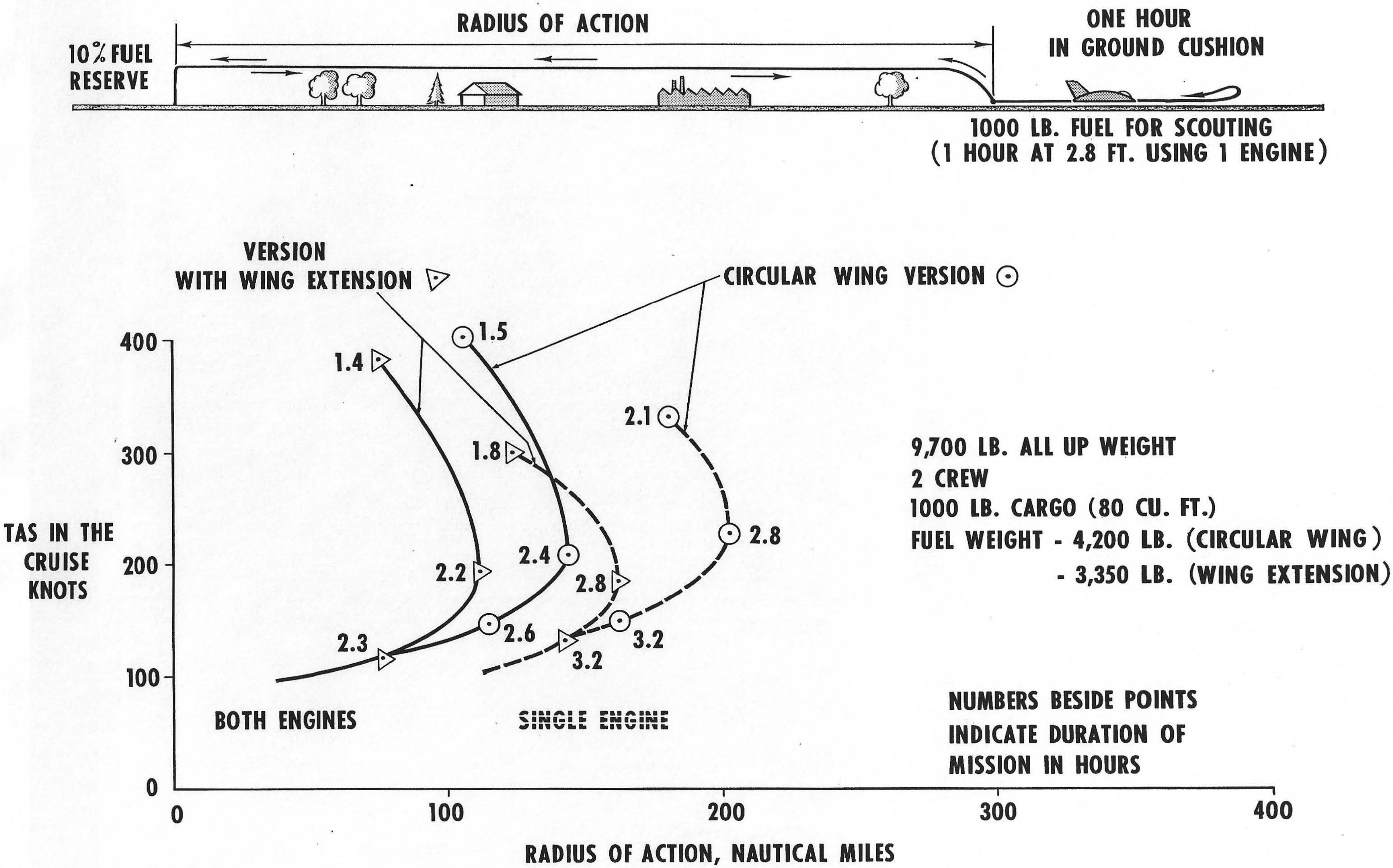


FIG. 18 AVROCAR DEVELOPMENT - SEA LEVEL VTOL MISSIONS

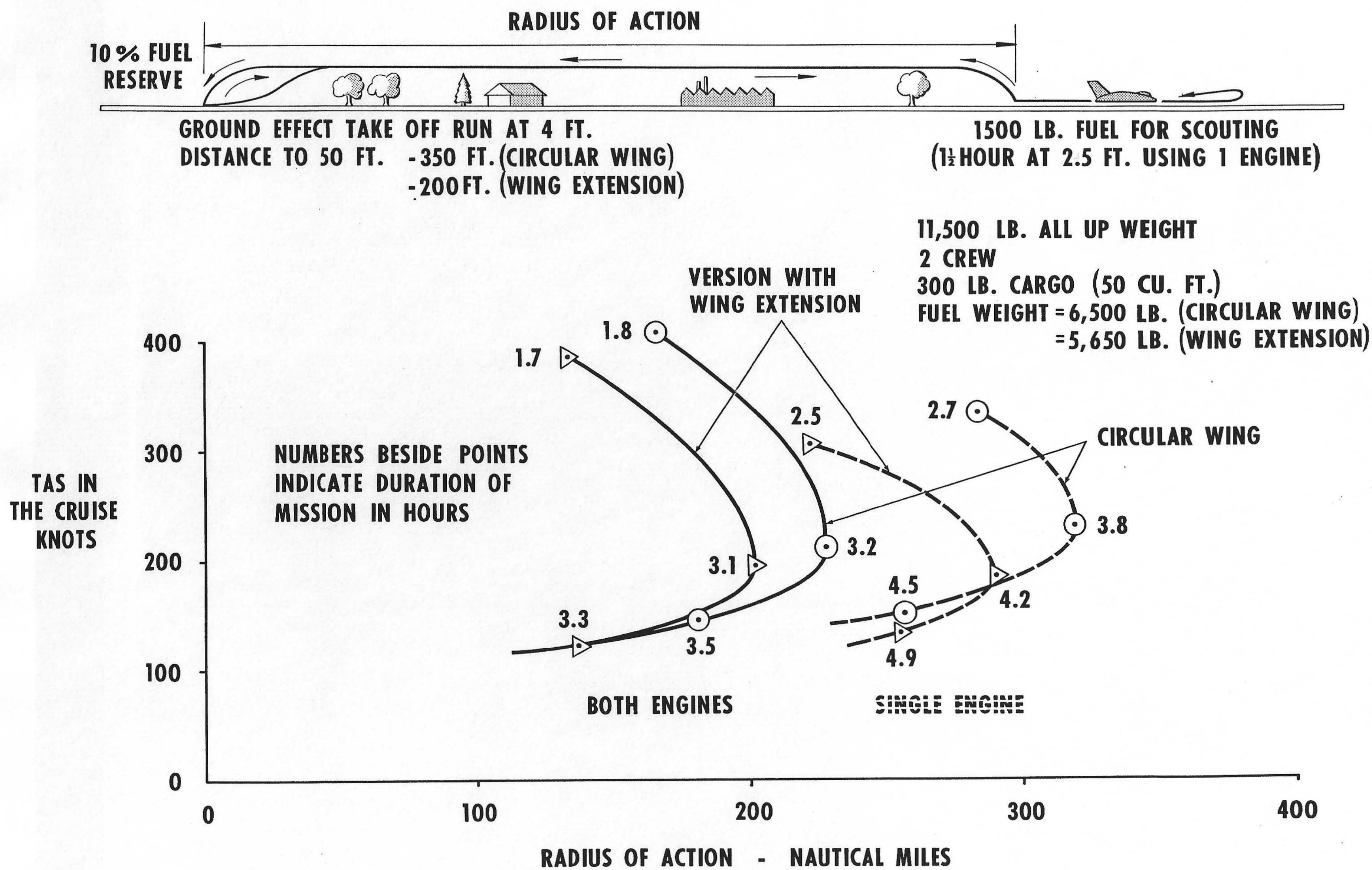


FIG. 19 AVROCAR DEVELOPMENT - SEA LEVEL STOL MISSIONS

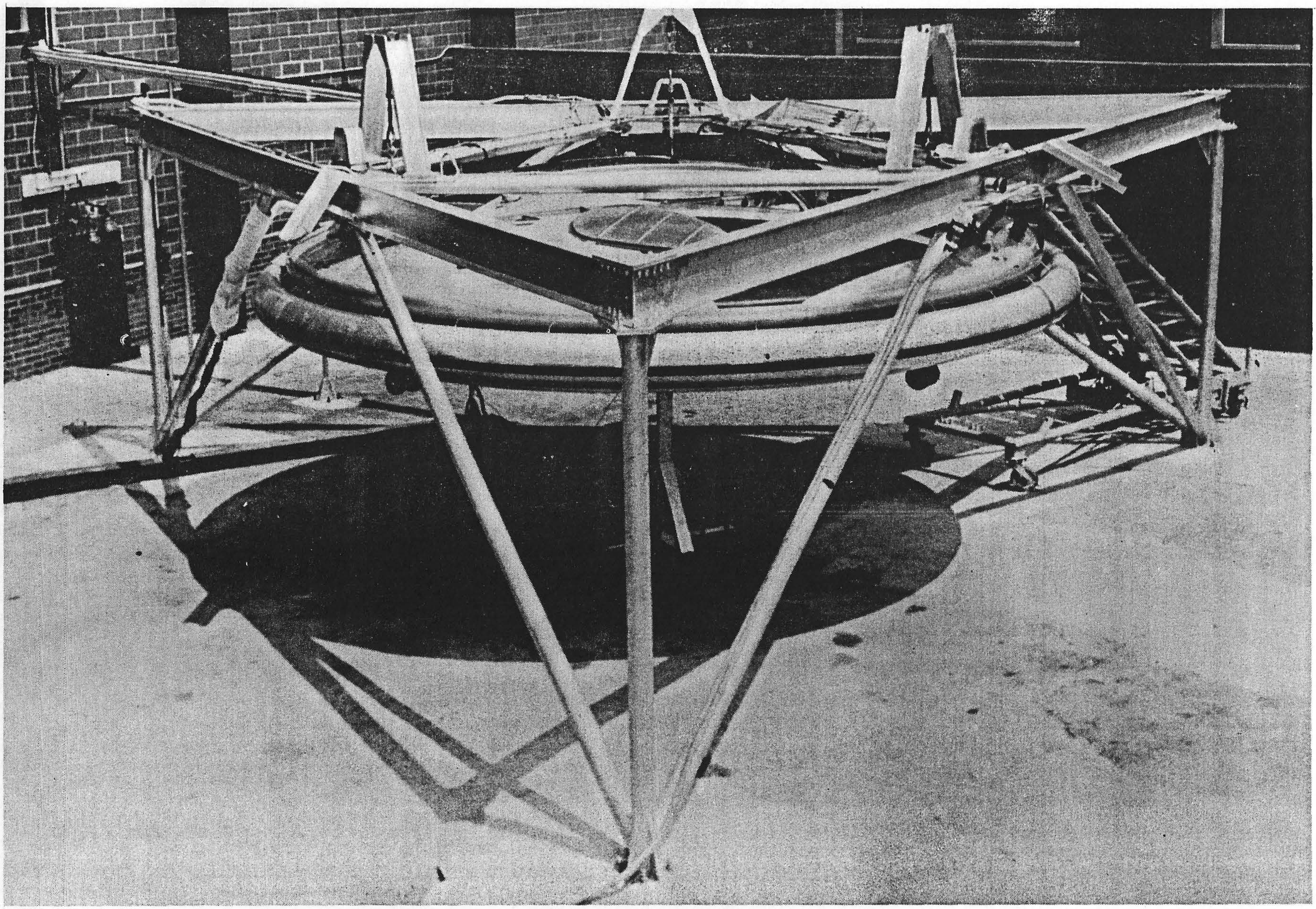


FIG. 20 THE AVROCAR IN THE STATIC RIG

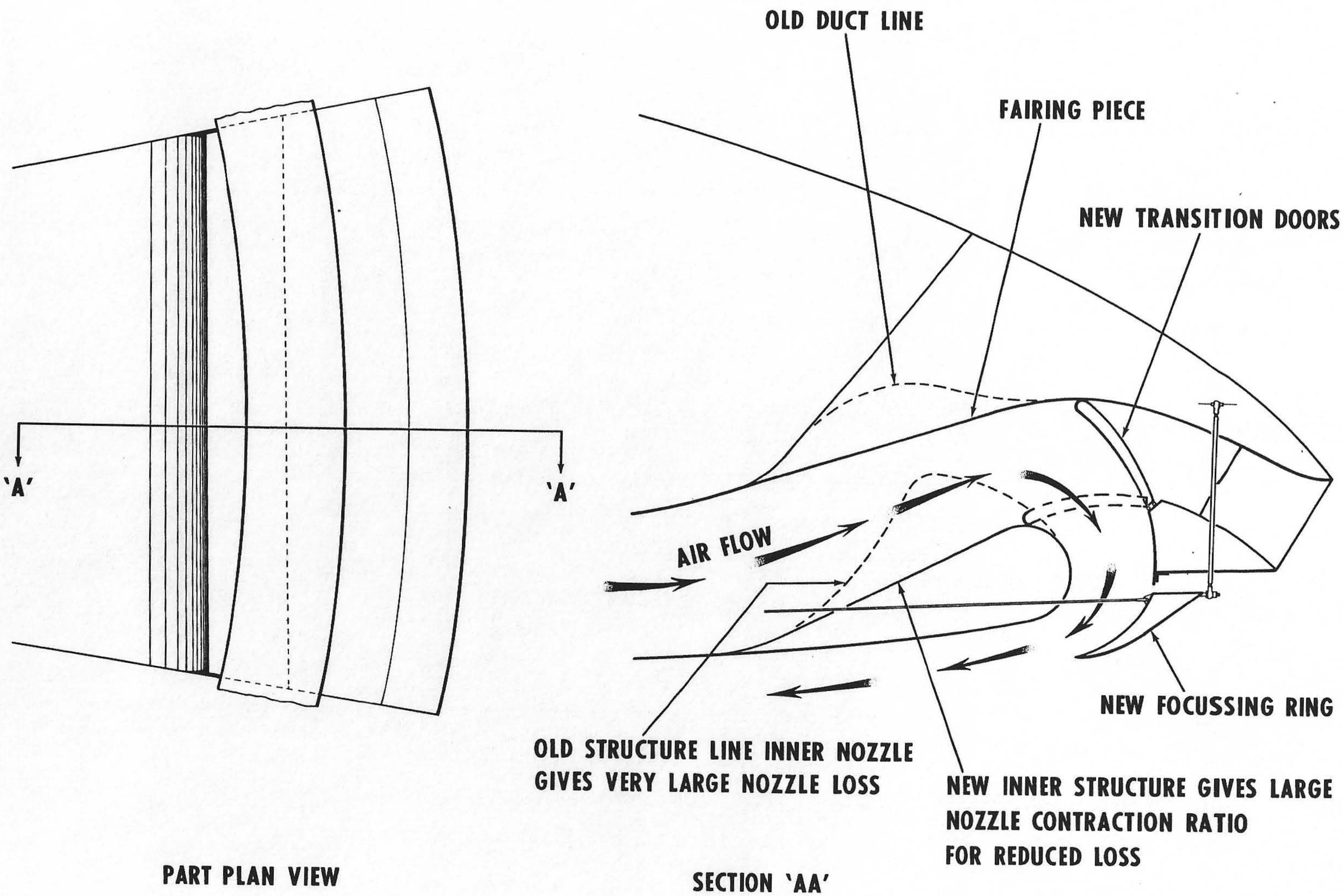


FIG. 21 MODIFIED WING TIP NOZZLE

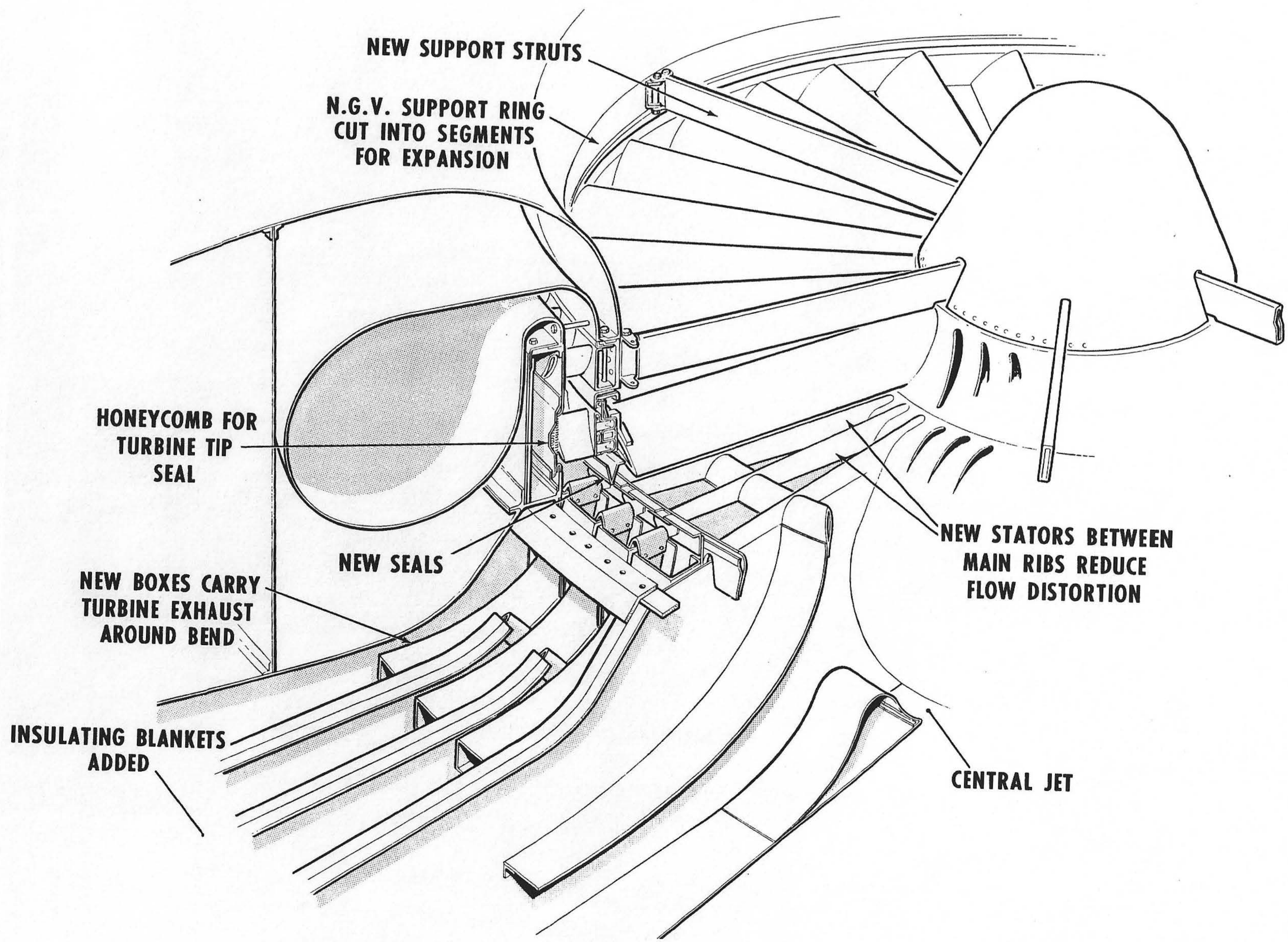


FIG. 22 · TURBOROTOR THRUST IMPROVEMENT MODS

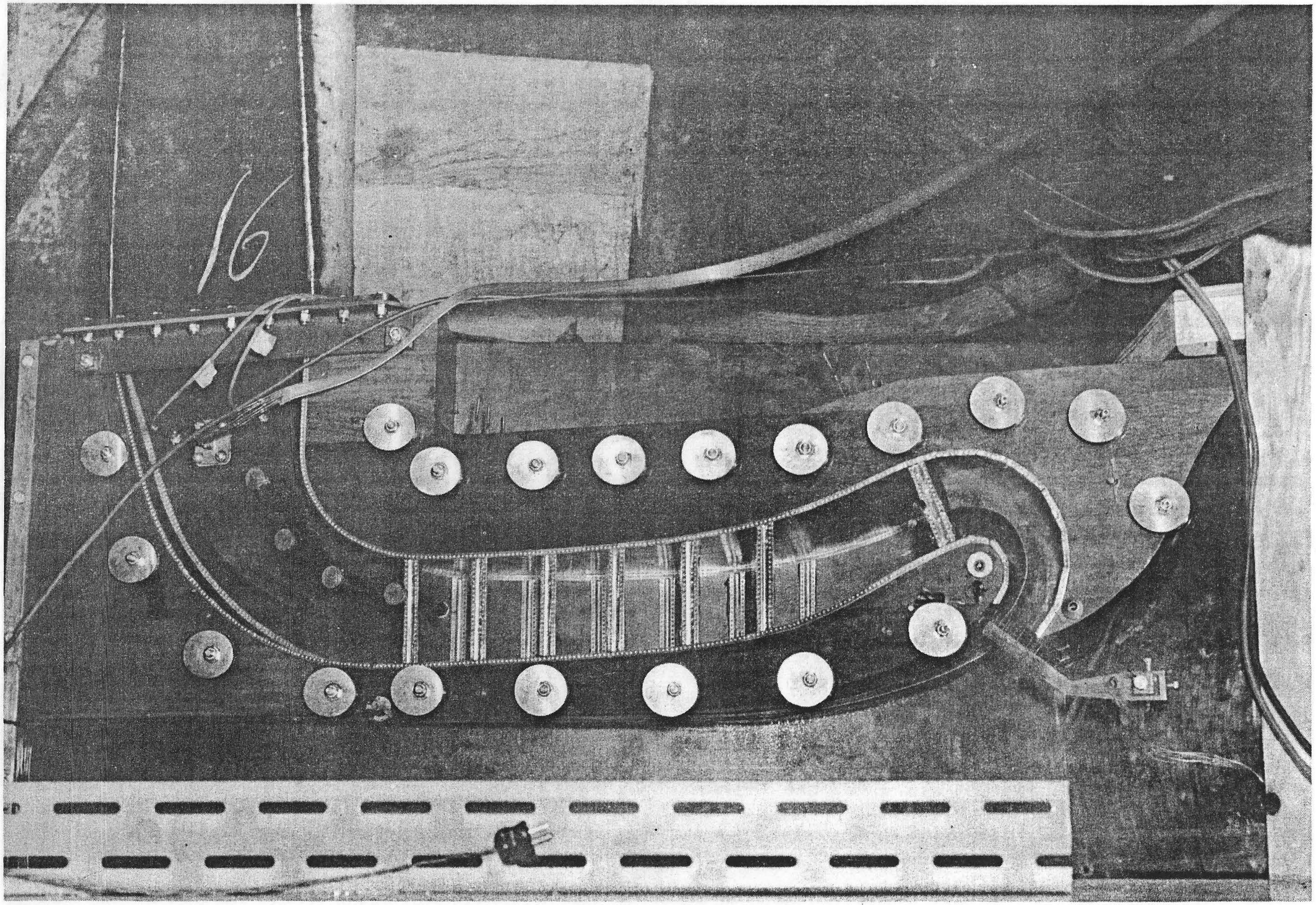


FIG. 23 DUCT LOSS MODEL

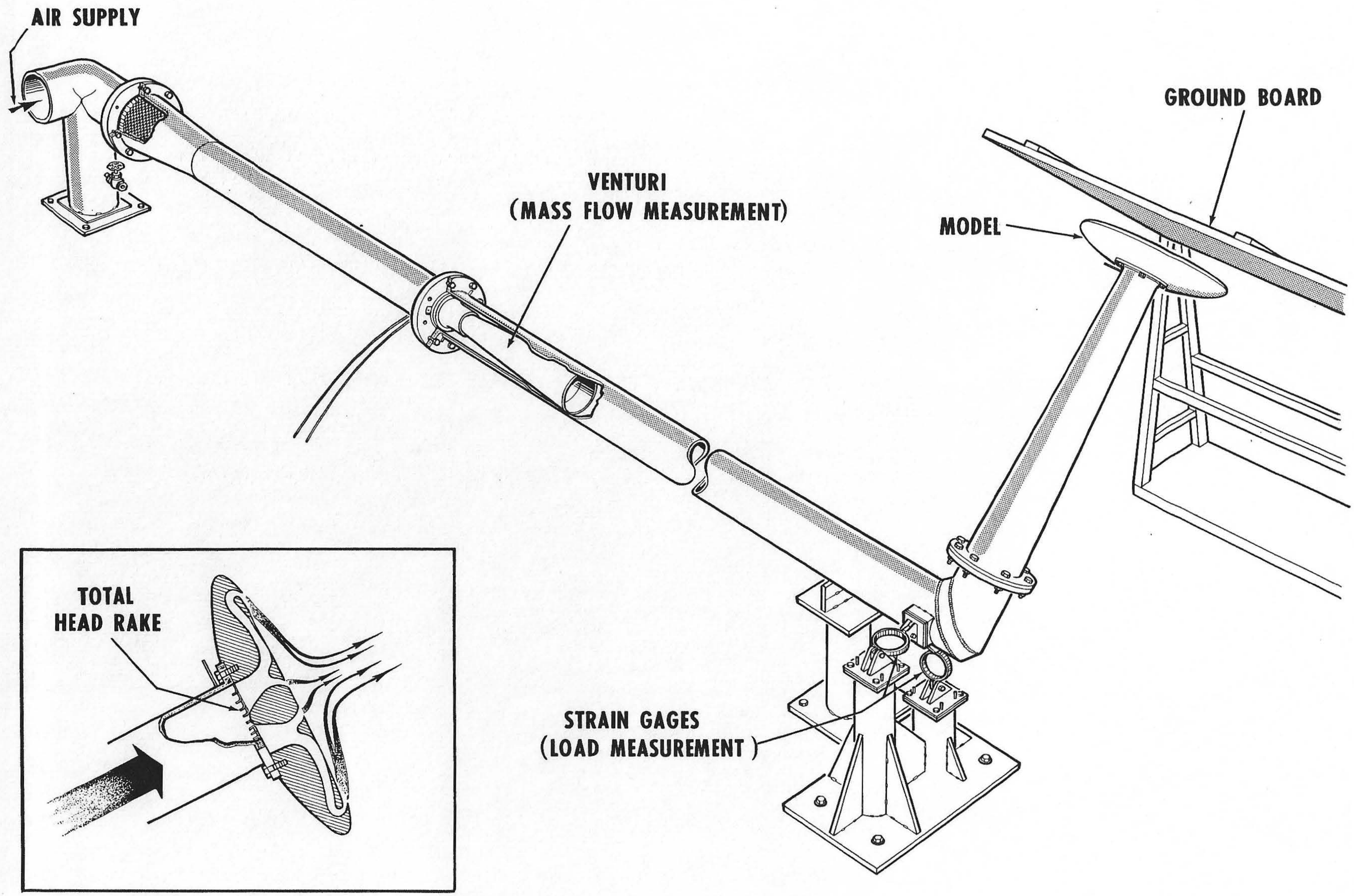


FIG. 24 LIFT EFFICIENCY MODEL

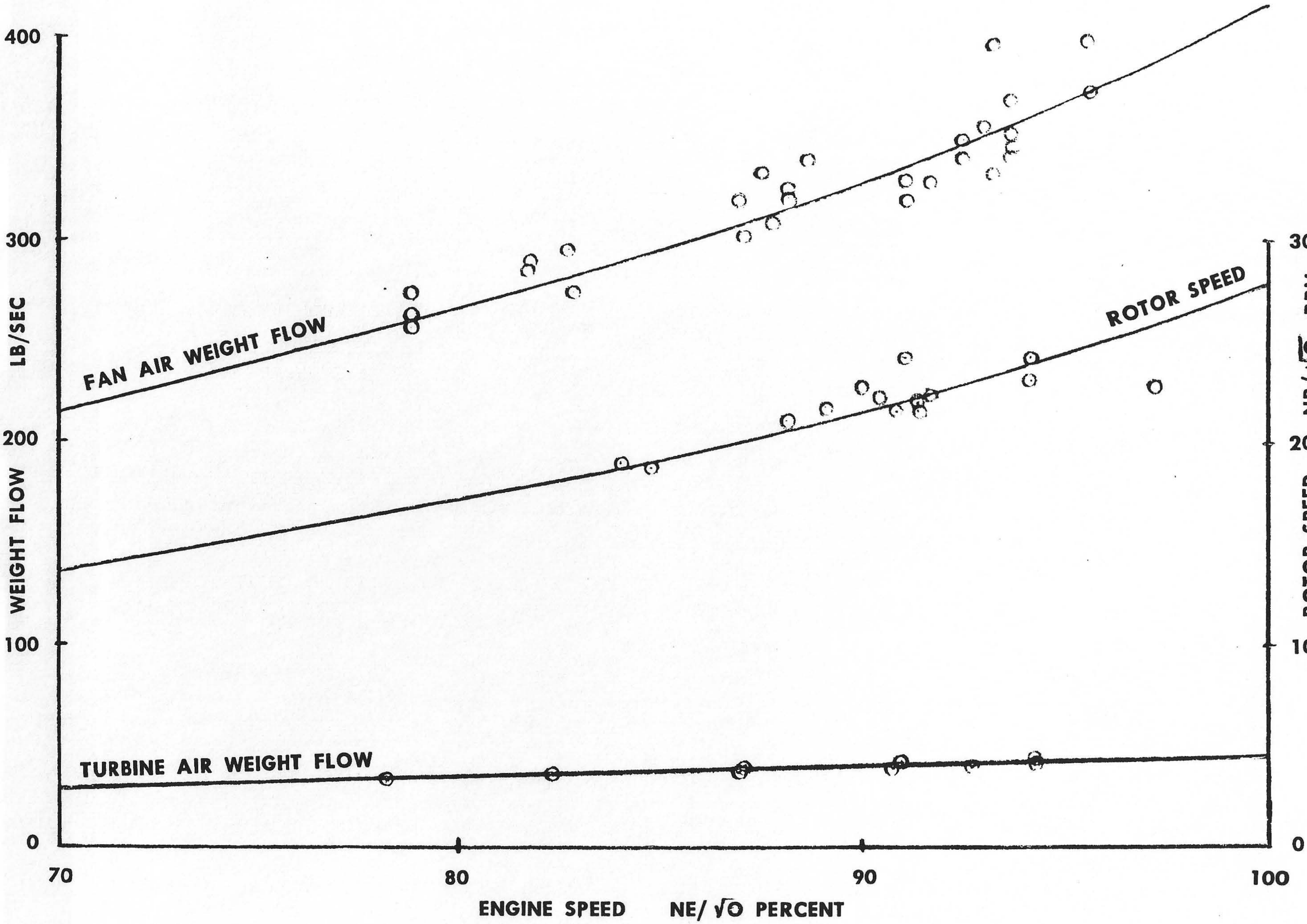


FIG. 25 MEASURED TURBOROTOR RPM AND MASS FLOW

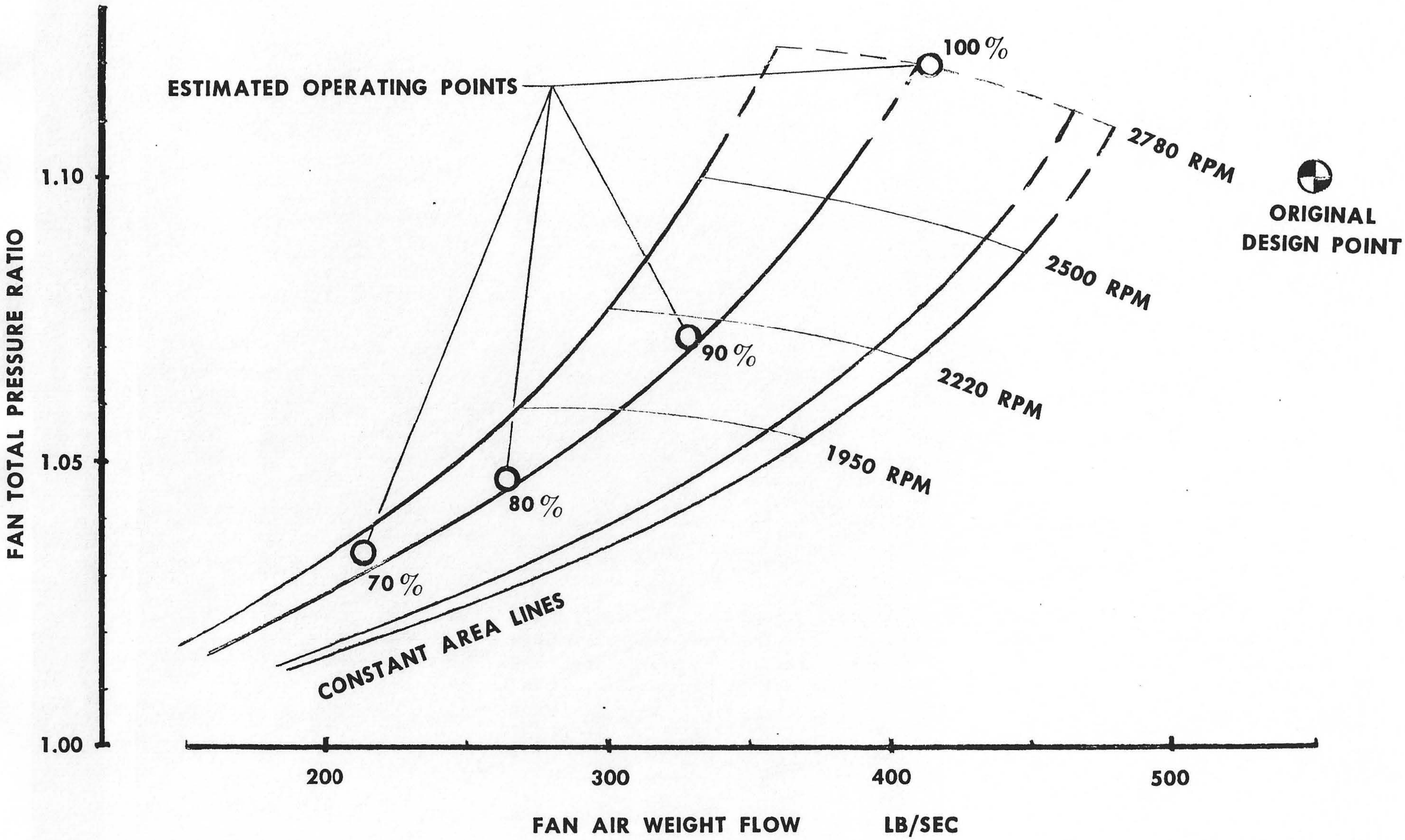


FIG. 26 MEASURED TURBOROTOR CHARACTERISTICS

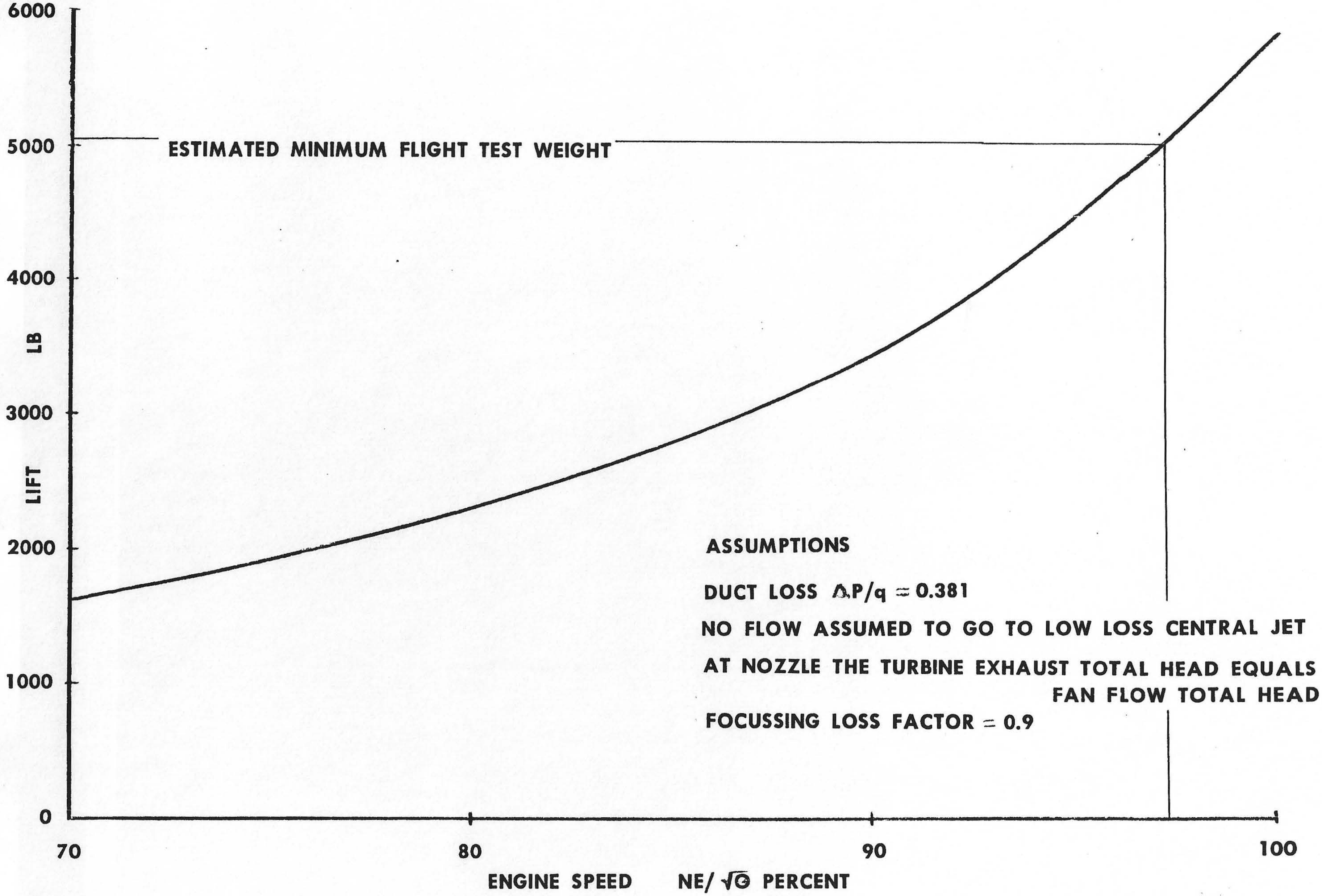


FIG. 27 ESTIMATED LIFT IN FREE AIR

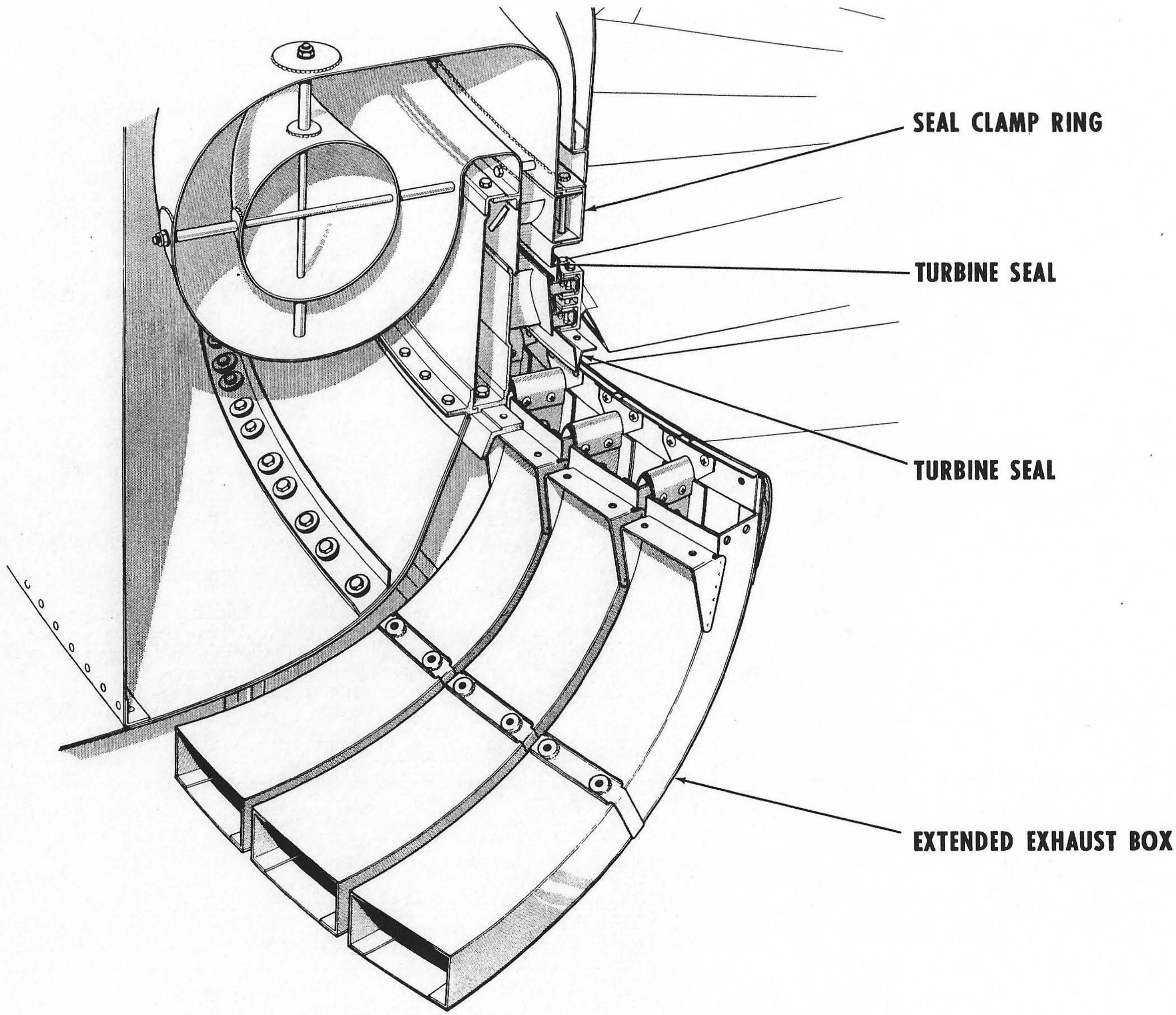


FIG. 28 DESIGN SCHEME FOR NEW EXHAUST BOXES

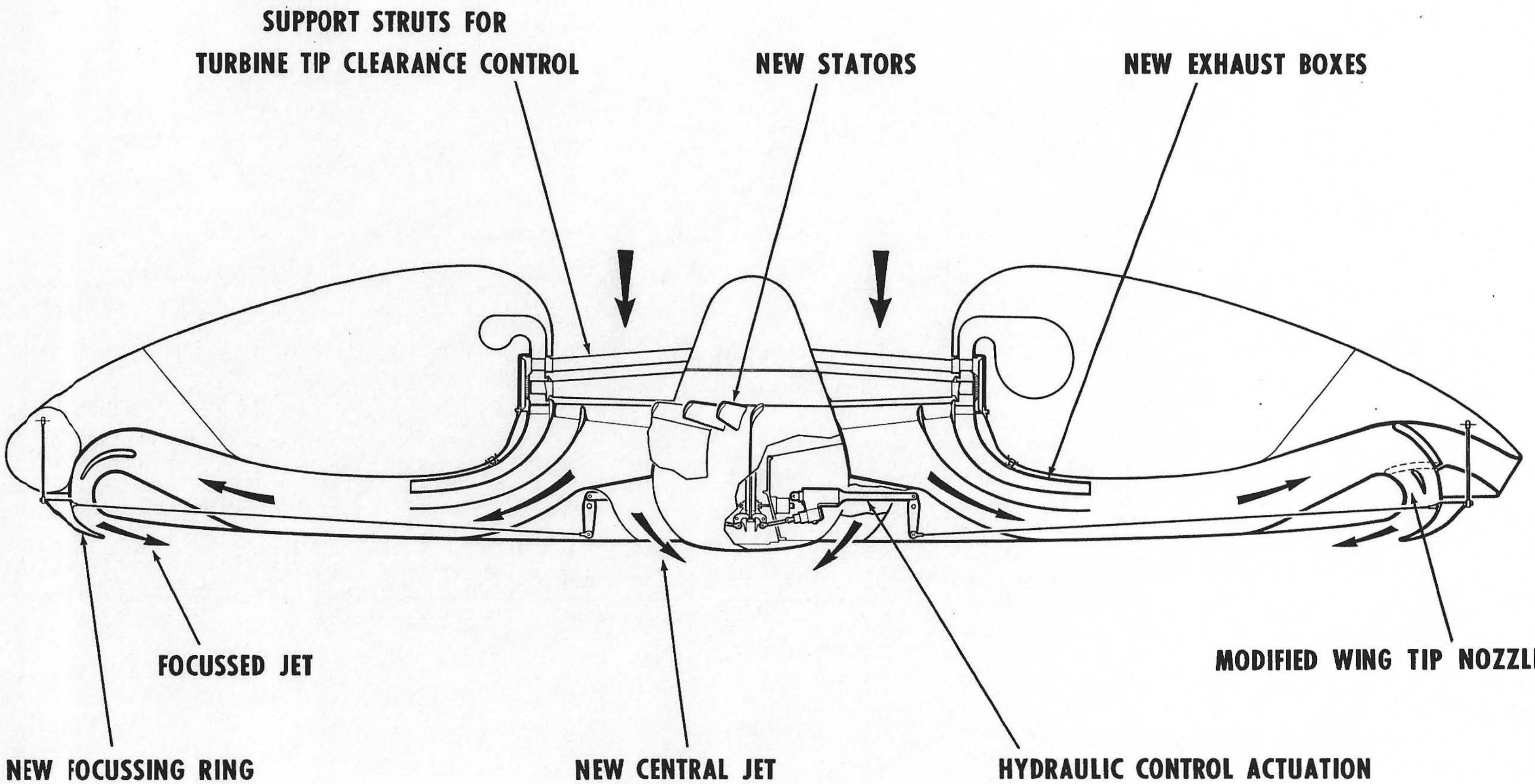


FIG. 29 PROPOSED MODIFICATIONS

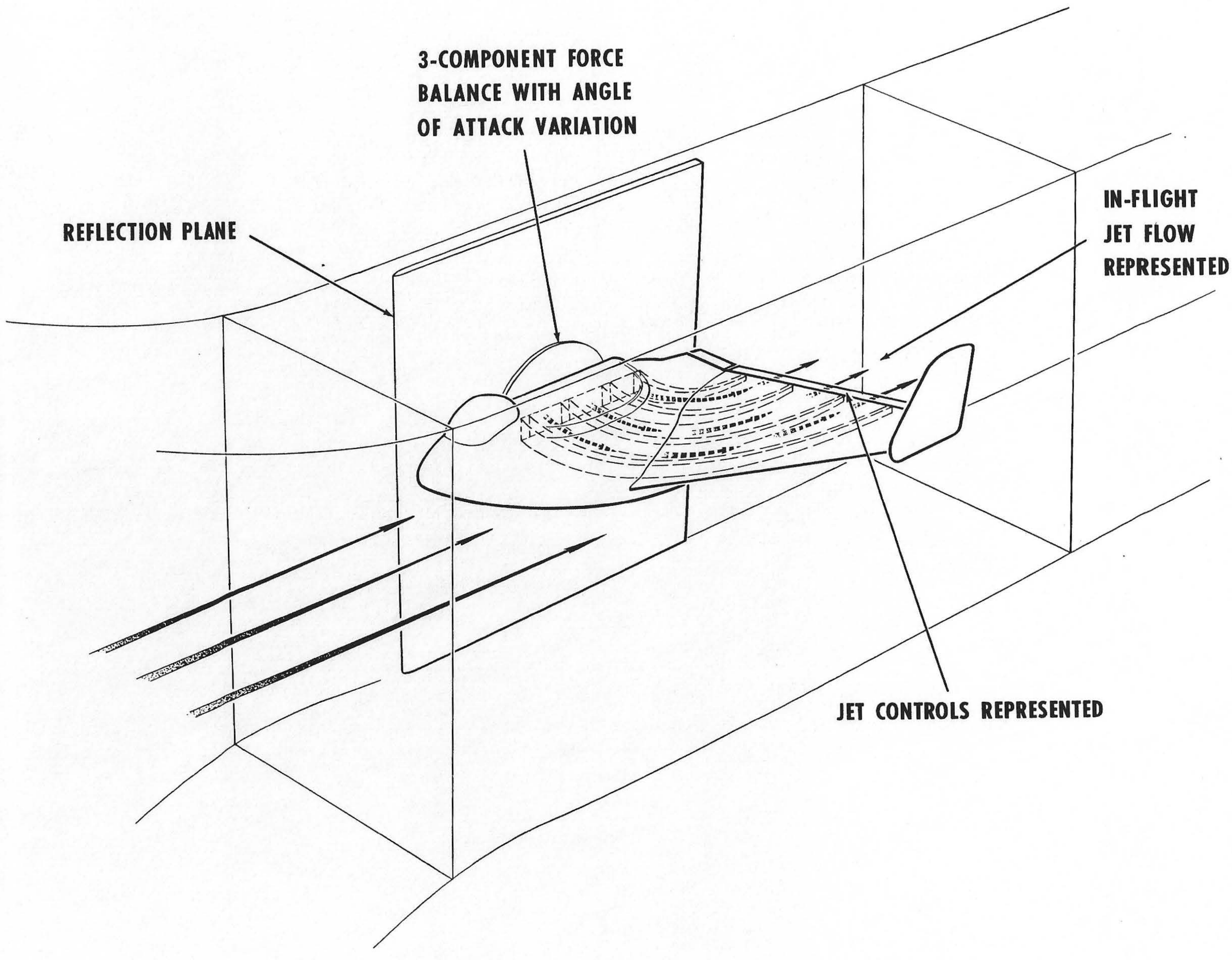


FIG. 30 MODEL OF VERSION WITH WING EXTENSIONS

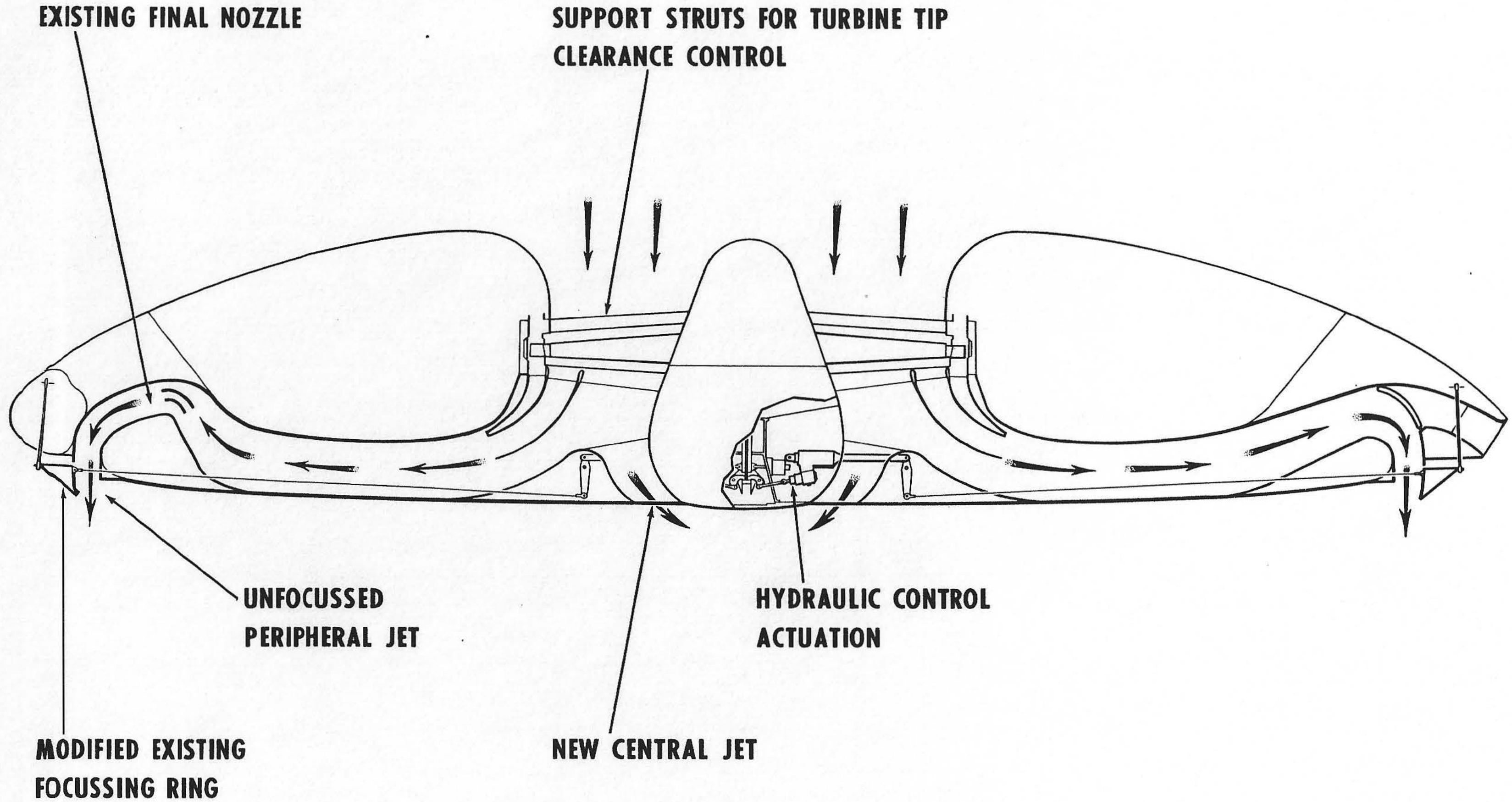


FIG. 31 GROUND CUSHION DEVELOPMENT MODIFICATIONS

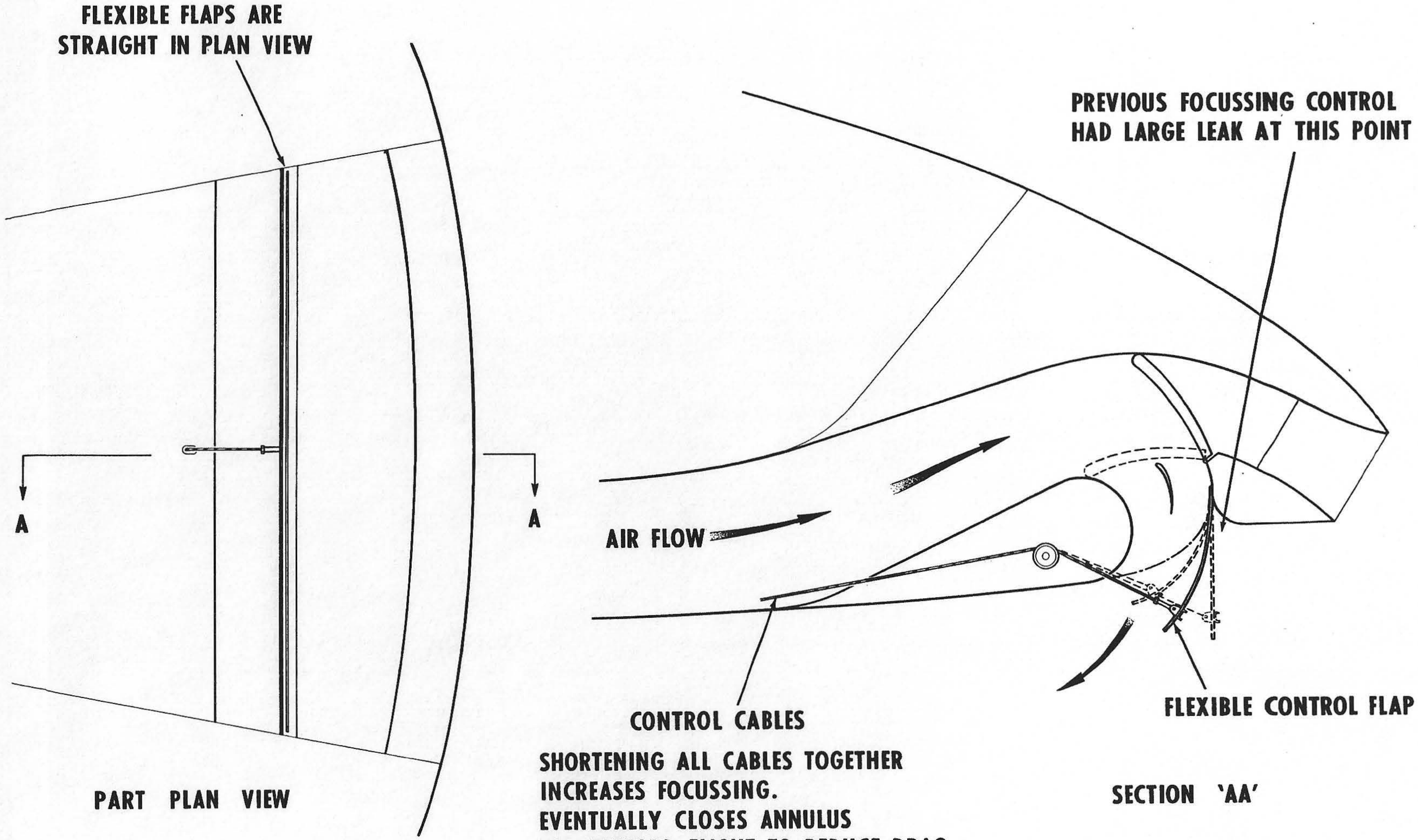


FIG. 32 VARIABLE FOCUSSING CONTROL SCHEME

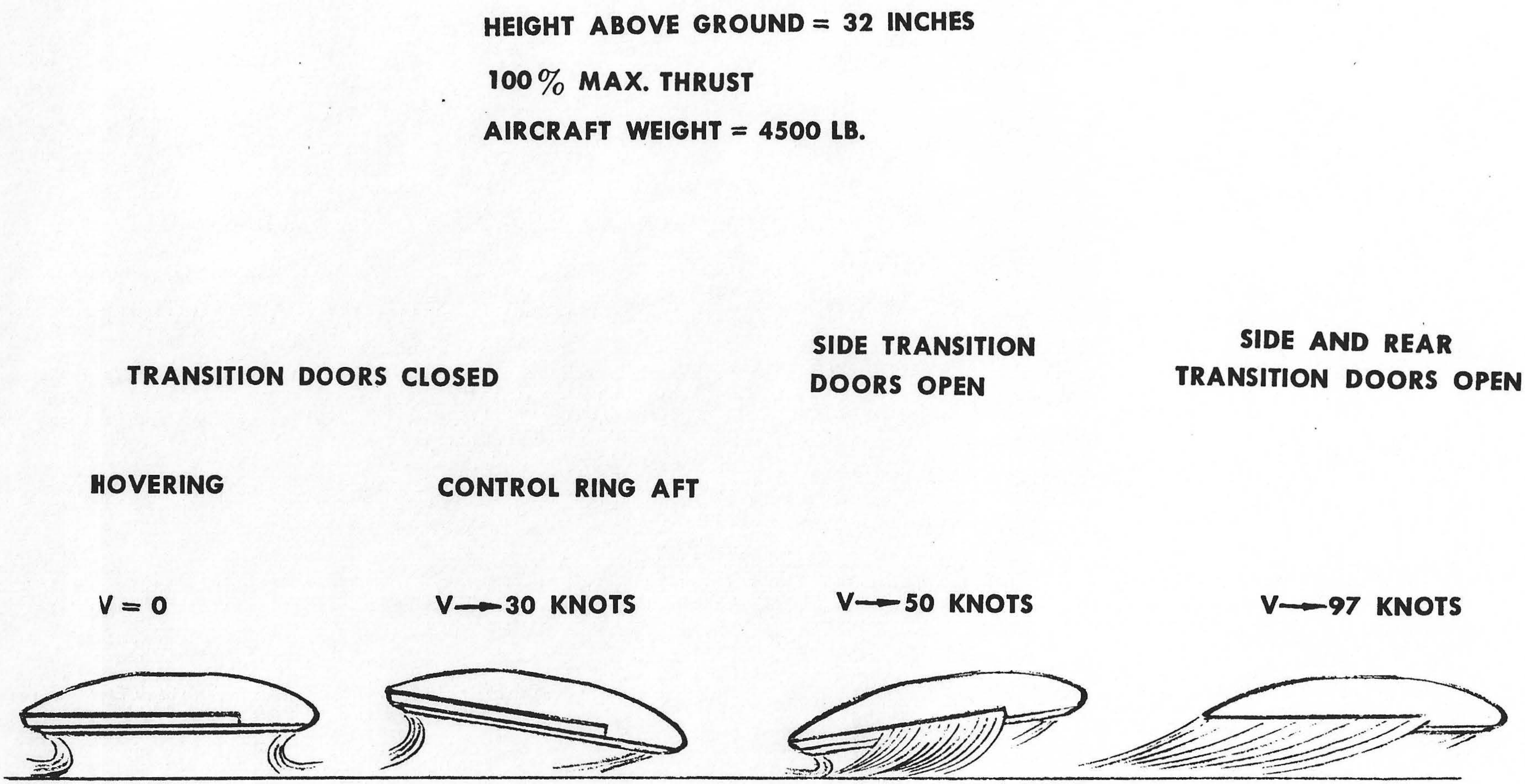


FIG. 33 TRANSITION SKETCH

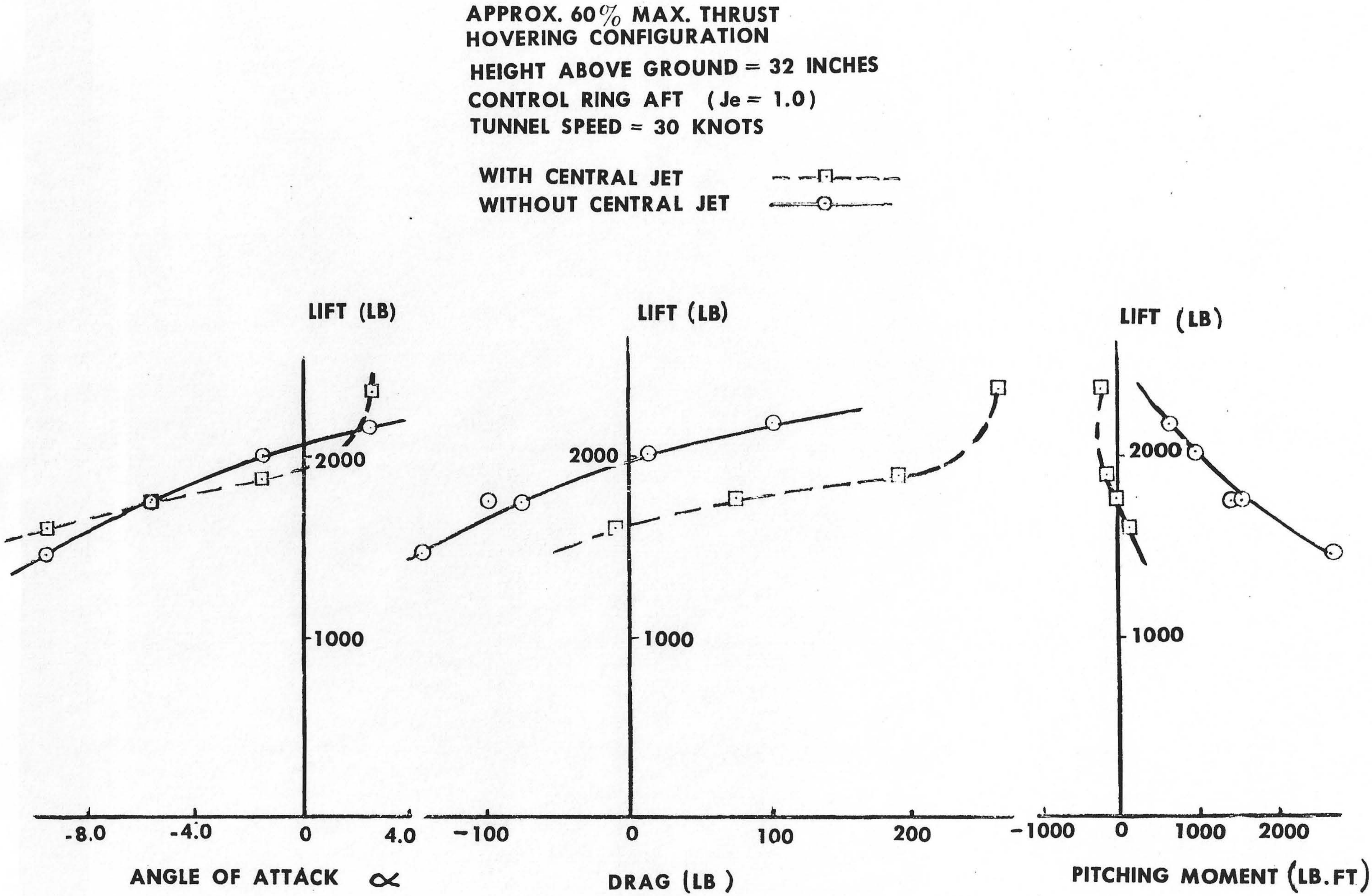


FIG. 34 EFFECT OF CENTRAL JET

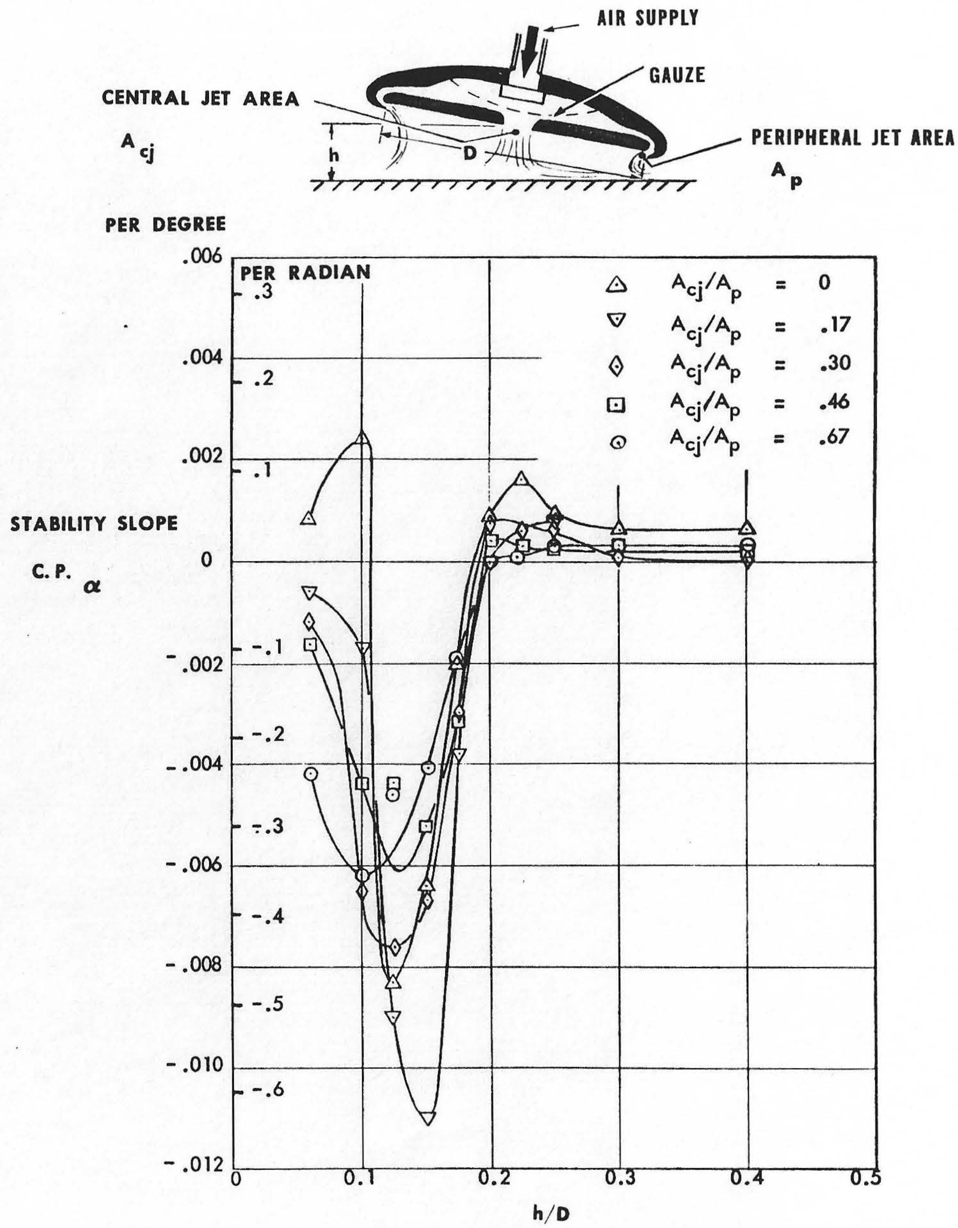


FIG. 35 VARIATION OF STABILITY SLOPE AND HEIGHT ABOVE GROUND WITH CENTRAL JET STRENGTH

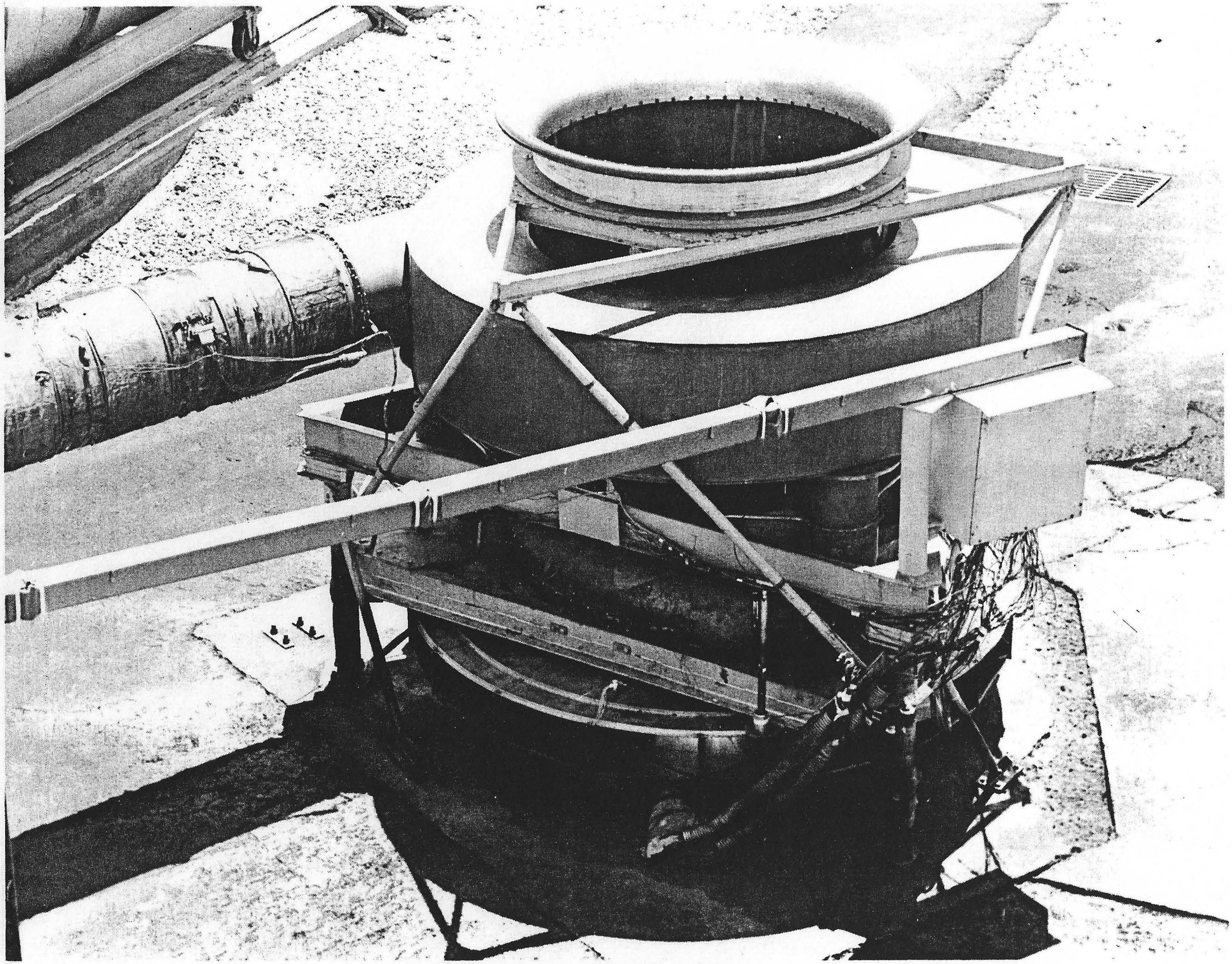


FIG. 36 TURBOROTOR TEST RIG

TABULATED COST SUMMARY FOR

PROPOSAL FOR FURTHER DEVELOPMENT OF THE AVROCAR

(ESTIMATE NO: C22-20-0/6 , DATED June 13, 1961)

WORK ORDER NO.	S.O.W. ITEM NO.	STATEMENT OF WORK DESCRIPTION	MANHOURS	LABOUR	LABOUR OVERHEAD 125 %	MATERIAL AND DIRECT CHARGES	SUB-TOTAL	ADMIN. OVERHEAD 15 %	SUB-TOTAL	PROFIT 7 %	TOTAL (CAN.$)	EXCHANGE PREMIUM 1.5% %	TOTAL (U.S.$)
1		THRUST IMPROVEMENT [redacted] PROGRAM											
	1A	Thrust Investigation Rig Test on 2nd Avrocar	5,174	15,243	19,054	2,265	36,562	5,484	42,046	2,943	44,989	675	45,664
	1B	Lift Efficiency Model	3,844	11,552	14,440	1,584	27,576	4,136	31,712	2,220	33,932	509	34,441
	1C	Internal Duct Model	5	13	16	46,812	46,841	7,026	53,867	3,771	57,638	865	58,503
	1D	Thrust Improvement Studies	837	2,763	3,454	140	6,357	953	7,310	512	7,822	117	7,939
	1F	Modified Wing Tip Nozzle	5,872	16,432	20,539	3,452	40,423	6,064	46,487	3,254	49,741	746	50,487
	1G	Turbine Tip Clearance Mod.	872	2,473	3,091	181,167	186,731	28,010	214,741	15,032	229,773	3,446	233,219
	1H	Exhaust Box Modification	5,572	14,830	18,537	3,712	37,079	5,562	42,641	2,985	45,626	684	46,310
	1I	Additional Stators	2,397	6,906	8,632	1,274	16,812	2,522	19,334	1,353	20,687	310	20,997
	1M	Performance Check on 2nd Aircraft	1,688	4,804	6,005	491	11,300	1,695	12,995	910	13,905	208	14,113
			26,261	$ 75,016	93,768	240,897	409,681	61,452	471,133	32,980	504,113	7,560	511,673
2		DEVELOPMENT AIRCRAFT STUDIES AND TESTS											
	2A	Positive Stability Margin Model	5,141	15,918	19,898	14,510	50,326	7,549	57,875	4,052	61,927	928	62,855
	2B	Further 1/20 Scale Model Tests	1,467	4,756	5,945	242	10,943	1,642	12,585	881	13,466	202	13,668
	2C	Stub Wing Aircraft Studies	650	2,170	2,713	1,162	6,045	908	6,953	487	7,440	111	7,551
			7,258	$ 22,844	28,556	15,914	67,314	10,099	77,413	5,420	82,833	1,241	84,074
3		HOVERING STABILITY AND CONTROL MODS.											
	3A	Control Actuation System	2,647	7,738	9,672	5,102	22,512	3,377	25,889	1,812	27,701	415	28,116
	3B	Modified Central Jet	4,722	13,538	16,922	2,665	33,125	4,969	38,094	2,666	40,760	611	41,371
	3C	Improved Rudder	1,150	3,469	4,336	400	8,205	1,231	9,436	660	10,096	151	10,247
	3D	Variable Focussing Control	3,682	10,685	13,356	1,662	25,703	3,856	29,559	2,069	31,628	474	32,102
			12,201	$ 35,430	44,286	9,829	89,545	13,433	102,978	7,207	110,185	1,651	111,836
4		GROUND CUSHION FLIGHT DEVELOPMENT											
	4A	Cushion Flight Tests with Variable Focussing	2,110	6,061	7,577	1,327	14,965	2,245	17,210	1,204	18,414	276	18,690
	4B	Cushion Speed Tests	2,108	6,055	7,569	1,329	14,953	2,243	17,196	1,203	18,399	276	18,675
	4C	Terrain Tests	2,108	6,055	7,569	1,329	14,953	2,243	17,196	1,203	18,399	276	18,675
	4D	Cushion Height Tests with Unfocussed Peripheral Tests	2,078	5,975	7,469	1,319	14,763	2,214	16,977	1,188	18,165	273	18,438
	4E	Cushion Skirt Tests	2,078	5,975	7,469	1,319	14,763	2,214	16,977	1,188	18,165	273	18,438
	4F	Duct Ingestion Mods	1,132	3,310	4,138	532	7,980	1,196	9,176	642	9,818	147	9,965
			11,614	$ 33,431	41,791	7,155	82,377	12,355	94,732	6,628	101,360	1,521	102,881
		TOTAL CARRIED FORWARD		$									

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TABULATED COST SUMMARY FOR

PROPOSAL FOR FURTHER DEVELOPMENT OF THE AVROCAR

(ESTIMATE NO: C22-20-0/6 , DATED June 13. 1961)

WORK ORDER NO.	S.O.W. ITEM NO.	STATEMENT OF WORK DESCRIPTION	MANHOURS	LABOUR	LABOUR OVERHEAD 125 %	MATERIAL AND DIRECT CHARGES	SUB-TOTAL	ADMIN. OVERHEAD 15 %	SUB-TOTAL	PROFIT 7 %	TOTAL (CAN.$)	EXCHANGE PREMIUM 1.5 %	TOTAL (U.S.$)
5		V.T.O.L. PROGRAM	6,464	$ 18,859	23,574	3,286	45,719	6,863	52,582	3,681	56,263	844	57,107
7		MISCELLANEOUS REPAIRS AND MODIFICATIONS	1,480	3,805	4,756	937	9,498	1,425	10,923	765	11,688	175	11,863
8		PHOTOGRAPHY - DOCUMENTARY	620	1,662	2,078	15,590	19,330	2,900	22,230	1,556	23,786	357	24,143
9		PROJECT REPORTS & REVIEWS											
	9A	Progress Reports	191	569	712	40	1,321	198	1,519	106	1,625	24	1,649
	9B	Program Review	852	2,620	3,274	90	5,984	898	6,882	482	7,364	110	7,474
			1,043	$ 3,189	3,986	130	7,305	1,096	8,401	588	8,989	134	9,123
		GRAND TOTAL	66,941	$194,236	242,795	293,738	730,769	109,623	840,392	58,825	899,217	13,483	912,700
		TOTAL CARRIED FORWARD		$									