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DEPARTMENT OF DEFENCE

DEFENCE SCIENCE AND TECHNOLOGY ORGANISATION

AERONAUTICAL RESEARCH LABORATORY

MELBOURNE, VICTORIA

Propulsion Technical Memorandum 460

MODIFICATION OF JINDIVIK AIR INTAKE DUCT WITH AN AUXILIARY INTAKE - STATIC AERODYNAMIC TESTS

by

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SUMMARY

Results are presented for an R & D program to improve the take-off performance of the Jindivik target aircraft. The engine air intake duct of Jindivik is aerodynamically optimised for altitude and high subsonic cruise, and scope for its modification, for improved performance at take-off, was limited to the incorporation of an auxiliary intake system which is only deployed during take-off and is closed in flight. The auxiliary intake concept was explored experimentally with a 1/4 model scale of Jindivik air intake duct, and involved both static testing and tests with forward speeds in the wind tunnel. This report covers the aerodynamic aspects of the static phase of the program, at which conditions substantial improvements in pressure recovery with acceptable levels of flow distortion at the engine face have been demonstrated for simple intake modifications.

DSTO ARL MELBOURNE

POSTAL ADDRESS: **Director, Aeronautical Research Laboratory**
506 Lorimer Street, Fishermens Bend 3207
Victoria Australia

CONTENTS

NOTATION

A	Auxiliary intake cross-sectional area [cm^2].
DC(60)	Distortion factor across all of the engine face
DC(cir)	Distortion factor around a circumferential probe ring in the engine face.
DC(rad)	Distortion factor along a radial probe rake in the engine face.
m	Engine air mass flow [kg/sec].
N	Engine rotational speed [RPM].
P_a	Atmospheric pressure. [kPa].
P_s	Air intake duct local static pressure [kPa]
P_t	Total pressure [kPa].
$(P_t/P_a)_{av}$	Pressure recovery (average of 30 separate P_t/P_a values at the engine face).
$P_{t,max}$	Maximum total pressure along a radial probe rake or a circumferential probe ring in the engine face.
$P_{t,min}$	Minimum total pressure along a radial probe rake or a circumferential probe ring in the engine face.
T_a	Atmospheric temperature [K].
V	Air velocity at the engine face [m/sec].
x	Axial length of the auxiliary intake [mm].
y	Lateral width of the auxiliary intake [mm].
ρ	Density of air at the engine face.

1. INTRODUCTION

Experience with the current Mark of Jindivik indicates that its aerodynamic performance is severely limited during take-off at high ambient temperature conditions due to flow separations at inlet lip and reduced engine air mass flow, with consequent exceedance of the design jet pipe temperature (JPT) limit if the design value of engine thrust or engine speed are demanded. As a consequence the aircraft can not safely undergo an aborted take-off at operational speeds within the length of the Jervis Bay airstrip, nor achieve its required payload performance. Upon request from RAN, an R & D program was undertaken by the Propulsion Branch at ARL to investigate means for alleviating this problem. The available options varied from modifying the engine air intake duct, to increasing the length of the runway at Jervis Bay air strip. The first option was investigated as a potentially cost - effective solution to the problem.

The air intake duct of Jindivik is known to have been aerodynamically optimised for altitude and high subsonic cruise, and with high engine speed at static and take-off conditions suffers total pressure losses which are mainly due to flow separations immediately downstream of the relatively sharp lipped intake. The adopted approach in this investigation, to minimise these losses, was to reduce the main intake flow by the incorporation of an auxiliary intake which would be deployed during the take-off phase. The auxiliary intake would more than compensate for the loss in main intake mass flow, as well as improving the pressure recovery at the engine face, hence allowing the engine to operate below the design JPT limits with design levels of engine thrust at take-off conditions.

This concept was explored experimentally with a 1/4 scale aerodynamic model of Jindivik air intake duct, and involved both static testing and tests at forward speed in the wind tunnel: only the results of the static phase of the experimental program are presented in this report.

The purpose of the static tests was to develop and optimise the auxiliary intake configuration in terms of position, aperture size, aspect ratio and lip profile to give maximum pressure recovery and minimum flow distortion at the engine inlet face. The wind tunnel test program, simulating take-off conditions and practical auxiliary intake geometries, was planned in consultation with ASTA Ltd. as the Jindivik design authority, and the results are reported in reference 1. The full investigation including the theoretical aspects of the intake performance is summarized in reference 2. Adoption of the auxiliary intake concept, which is the responsibility of ASTA Ltd., will involve full scale aircraft/engine ground tests followed by flight trials. The implementation of the intake modification will satisfy the RAN need to operate the existing Jindivik aircraft safely with increased take-off weights, and may feature on the Future Aerial Target System (FATS) aircraft.

2. TEST MODEL, RIG AND INSTRUMENTATION

A photograph of the 1/4 scale model of Jindivik air intake system is shown in figure 1. The model consisted of the basic air intake duct with the nose and canopy; details are given in figure 2-a. A schematic diagram of the model installed in the static test rig is shown in figure 3.

Within the constraints of the aircraft structure, the choice of the auxiliary intake shape and location in the air intake duct is limited by the curvature of the canopy and duct surfaces. At the location (A-A) shown in figure 2-a, the axial and lateral curvatures of both the external and internal surfaces are at their minimum, and there is also a local expansion in the duct cross sectional area. This location was therefore considered to be the best, not only from the view of practical engineering considerations of manufacturing, incorporation and operation of the auxiliary intake door, but also in terms of potential aerodynamic performance. Since the optimising procedure of the auxiliary intake configuration would require testing of several aperture geometries, a number of removable plugs with internal and external surfaces matching those of the duct and canopy respectively were incorporated in the model design. Details of this are shown in figure 2-b.

Total pressure measurements at the engine face were made with a 30 probe rake, details of which are shown in figure 2-c. The rake was comprised of six strakes equally spaced about the engine face in the annulus and each having five total pressure probes. The probes were radially disposed in five circumferential rings located at the centres of equal areas in the engine face annulus. Internal static pressure was measured with tapping points at 15 locations along the length of the air intake duct, and at 6 tapping points equally spaced around the engine face location in the duct. The pressure tubes were connected to two SCANCO 48 D scani valves, and pressures were measured with strain gauge transducers and recorded on an X - Y plotter.

The engine air flow was simulated with a remote duplex blower. Air mass flow was measured with a Venturi meter with the appropriate lengths of upstream and downstream ducting to ensure as uniform flow as possible at the meter tappings. The Venturi pressures were recorded with inclined water manometers. Air temperature upstream of the Venturi was measured with a mercury in glass thermometer while measurement of ambient pressure in the test cell was made with a digital manometer.

3. RESULTS AND DISCUSSION

Tests at static conditions or zero forward speed were carried out with the basic unmodified model and with the model modified with a range of auxiliary intakes. Description of test configurations and discussion of results obtained for each are presented below.

3.1 Basic Unmodified AIR Intake Duct.

The characteristics of engine face pressure recovery $(P_t/P_a)_{av.}$, as a function of engine air mass flow parameter $m.\sqrt{Ta}/P_a$ measured for the basic unmodified model with and without the intake splitter**, are shown in figure 4. These results are compared with the only available full scale data, obtained from reference 3. Notwithstanding the different test conditions and instrumentation used, the difference between the two characteristics is thought most likely to have been due to differences in lip profiles of the ARL model and that used in reference 3. The former profile was determined from a full scale canopy provided to ARL by ASTA. The sensitivity of intake pressure recovery to lip profile was investigated by slightly extending and sharpening the model main intake lip, as shown in the inset of figure 4. The results with the two lip profiles are given in figure 4, and indicate that for a given mass flow parameter the average pressure recovery decreases markedly as the lip radius decreases. As the radius of the full lip used in reference 3 could not be substantiated, the imposed sharpness of the model lip was removed and the rest of the test program was conducted with the original model main intake lip.

Figure 4 shows the relationship between $(P_t/P_a)_{av.}$ and $m.\sqrt{Ta}/P_a$ for the fixed engine rotational speeds of N = 13800 RPM and N = 12000 RPM. The first of these represents the engine maximum design speed, while the second, N = 12000 RPM, is the maximum speed achievable on hot days (T > 25° C) with the unmodified intake before the maximum limit on jet pipe temperature (JPT) is exceeded.

3.2 Auxiliary Intake Modification

Optimisation of the auxiliary intake configuration in the static phase of the test program involved conducting tests with a large number of different aperture geometries. These are grouped in terms of aperture lip shape as follows:

3.2.1 Rectangular Lipped Auxiliary Intake

Using an auxiliary intake with a rectangular lip profile as is shown in figure 5-a, a series of tests was carried out to examine the effect of aperture area on performance. With a fixed aperture centre, and with a fixed lateral width of y = 80 mm, which is approximately the maximum before getting into the curved portion of the canopy surface, the aperture area was varied by varying the axial length in increments of 20 mm, between 40 and 100 mm. The results in terms of pressure recovery $(P_t/P_a)_{av.}$, as a function of engine air mass flow parameter, and as a function of aperture length for a fixed engine speed of 12000 RPM, are shown in figures 6-a and 6-b respectively. The latter figure clearly shows, as might be expected, that the intake performance improved with increasing aperture area until a maximum pressure recovery was reached. Beyond this

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****The intake splitter** is a thin plate installed in the air intake duct to support the roof and prevent it from collapsing when high suction pressures are encountered in the unmodified duct during take-off. The splitter was removed from the model when auxiliary intakes were incorporated.

limit, performance appeared to stabilise, and no benefit could be achieved from larger aperture areas.

3.2.2 Sharp Lipped Auxiliary Intake

Some preliminary flow visualisation, with hand held tufts, showed that gross flow separations occurred especially at the downstream corners and along the downstream lateral edge of the above rectangular lipped apertures. These flow separations would be expected to reduce the pressure recovery gain which could be achieved with an auxiliary intake. To reduce the influence of these flow separations, the upstream and downstream lateral edges of the aperture were modified to triangular sharp lip profiles as shown in figure 5-b. Visual observations of the flow at these sharp lips indicated significant improvements in the nature of the flow along the lateral edges, and to a lesser extent at the downstream corners of the aperture where flow separations were still evident. These separations appeared in the form of helical vortices, emanating from each corner.

a. **Tests with Variable x for a Fixed y**

With the same fixed lateral width y = 80 mm, and similar aperture cross sectional areas to those of test 3.2.1, the above series of tests was repeated with sharp lipped apertures. The axial length of the auxiliary intake aperture in this case was measured as indicated in figure 5-b. The $(P_t / P_a)_{av.}$ versus $m.\sqrt{Ta}/P_a$ characteristics obtained with this series of tests are included in figures 6-a and 6-b. The sharp lip pressure mass flow characteristics appear to collapse almost onto a single line. The improvement in pressure recovery obtained with this geometry, almost twice that achieved with rectangular lipped apertures, may be attributed to the reductions in flow separation at the aperture edges. Figure 6-b shows that the reduced separation permitted the maximum pressure recovery to be achieved with smaller aperture area than was the case with the rectangular lip, with no further benefit to be gained by increasing this area.

b. **Tests with Variable y for a Fixed x**

To examine the effect of the aperture lateral width on performance, a series of tests was carried out with a fixed axial length of x = 40 mm but with three different lateral widths; namely y = 80, 100 and 120 mm. The results obtained are presented in figures 7-a and 7-b. Again, the pressure recovery increased with increasing aperture width, appearing to reach a maximum at about y = 120 mm.

c. **Tests with Variable Aspect Ratio y/x for a Fixed Aperture Area**

With a fixed aperture area A = 32 cm^2 and sharp lip profile, a series of tests was carried out to determine the effect of aperture aspect ratio on performance. The results are shown in figure 8. For air mass flow corresponding to N = 12000 RPM, the measured engine face pressure recoveries improved continuously with aperture aspect ratio until a maximum was reached about y/x = 3.8. At this value the aperture appeared to be, more or less, a lateral slot. Increasing y/x beyond this limit appeared to be detrimental to performance, as is evident in figure 8-b.

The flow patterns at the auxiliary intake aperture were observed with the aid of a smoke generator and hand held wool tufts. With a fixed aperture area and lip profile, the observed patterns which are not presented in this report, showed the aperture in each case as a sink, but with streamwise vortices shed from each side of the aperture. These appeared to strengthen and grow in size in the downstream direction, such that with a relatively small aspect ratio aperture, this vortical flow appeared to occupy most of the lateral width of the aperture at its downstream edge. In this case, most of the auxiliary flow thus appeared to be engulfed in vortices. Increasing the aperture aspect ratio therefore permitted an increasing proportion of the ingested auxiliary flow to remain free of the immediate influence of the two streamwise vortices, at least in the vicinity of the intake aperture, and relatively free of the losses associated with downstream mixing and dissipation of the vortices. This, it is suggested, resulted in the improvement in pressure recovery generally observed with increasing aperture aspect ratio. Here may be observed a loose analogy to effect of increased wing aspect ratio on induced drag.

Similar series of tests with two more aperture areas were performed, namely A = 48 and 65 cm^2. The results are illustrated by the open symbols in figure 9, where they are compared with those obtained for A = 32 cm^2, again at a fixed engine speed of 12000 RPM. As was the case with the smaller aperture area, the $(P_t/P_a)_{av.}$ versus y/x characteristics reached a peak, the peaks occurring at y/x = 2.5 and y/x = 1.75 for A = 48 & 65 cm^2 respectively. It is obvious that the limiting y/x value decreases with aperture area. Notwithstanding this, the corresponding maximum $(P_t/P_a)_{av.}$ is clearly shown to be the same for the three areas tested. This maximum $(P_t/P_a)_{av.}$ = 0.951 defines a ceiling on pressure recovery which can be achieved with a sharp lipped rectangular auxiliary intake located at this particular aperture centre. Furthermore, the aperture width corresponding to this maximum $(P_t/P_a)_{av.}$ = 0.951 was found to be fixed at about y = 110 mm for the three values of x tested.

d. Tests with Variable Aperture Location

The aperture geometry x = 29.1 mm and y = 110 mm which produced the maximum pressure recovery for A = 32 cm^2, was used to examine the effect on performance of auxiliary intake axial location along the air intake duct. Tests were performed with the aperture centre shifted 40 mm (model scale) upstream and 40 mm downstream of its original location. The results of these two tests are compared in figure 10 with those previously obtained for the original location. The central location produced slightly better performance than either of the other two locations. However, the effect was very small and did not warrant further investigation.

e. Tests with Bellmouth on Aperture Lip

The extent of improvements which could be achieved with further reduction in auxiliary intake lip losses was examined using a bellmouth modification to the sharp lip. Bellmouth fairings were installed along the downstream lateral sharp edge and along the axial rectangular sides of the aperture as is shown in figure 11-a. This modification was applied to three geometries of different y/x with the aperture area fixed at A = 32 cm^2. The results of these tests are compared with the corresponding sharp lipped apertures, in terms of the open symbols in figure 12, for a fixed engine speed of 12000 RPM. As expected, significant improvement in performance was achieved with this modification at each value of y/x.

3.2.3 Profiled Lip Auxiliary Intake

Due to both external drag and practical engineering considerations, the bellmouth arrangement would not be acceptable in the full scale installation. The sharp lip was therefore profiled within the thickness of the canopy as is shown in figure 11-b. The previous three series of tests of fixed aperture areas A = 32, 48 and 65 cm^2, with varying aspect ratio y/x, were repeated with this arrangement. The measured pressure recoveries are represented by the closed symbols in figure 9, where they are compared with the performance of the equivalent sharp lipped apertures. In each case the benefit of increased aspect ratio was more pronounced than was the case with sharp lip profiles, to the extent that substantially higher maximum pressure recoveries were available. At low aspect ratio the two lip profiles resulted in similar levels of performance, presumably because most of the auxiliary flow would be engulfed in vortices minimising the role of lip profile at the downstream lateral edge in establishing the overall magnitude of the losses. The opposite appeared to be true in the higher range of y/x, where the influence of the profiled lip in reducing two dimensional separation losses at the downstream lateral edge benefited a higher proportion of the auxiliary flow. The profiled lip was thus always superior to the sharp lip at higher aspect ratios.

The curve for A = 32 cm^2 is reproduced in figure 12, where it can be compared with the result for the bellmouth configuration as well as the sharp lipped inlet. The trend of pressure recovery versus aspect ratio, whilst generally positive, is somewhat different between the bellmouth and profiled lip geometries. This is thought to be due to the fact that the bellmouth had more effective fairings on the streamwise edges of the aperture than did the profiled lip aperture.

The best pressure - mass flow characteristic obtained with a profiled lip auxiliary intake geometry, x*y = 37*130 mm, marked (*) in figure 9, is compared with that of the basic unmodified configuration in figure 13. Also included is a curve derived from results reported in reference 3, measured at full scale with a bellmouth (or "Horse Collar") fitted to the main intake lip. This device is currently used only in static ground runs to permit the engine to be run at full RPM for test purposes. It is clear that worthwhile improvements in pressure recovery are available from the use of the auxiliary intake, especially in the relatively high range of engine mass flow which corresponds to the take-off range of engine speeds. These improvements appeared to be marginally better than those obtained with the 'horse collar' at full scale.

The best 37*130 mm auxiliary intake geometry was also tested with the main intake lip profile sharpened in the manner shown in the inset of figure 4. The resulting characteristic is also included in figure 13. The reduction in performance is shown to be very small in comparison to that measured - the unmodified configuration under similar conditions. This would be due to the fact that with an auxiliary intake installed, the main intake delivered only a portion of the total engine air flow, so that the engine face pressure recovery is proportionally less sensitive to the main intake lip separation.

The internal surface static pressure distribution along the upper surface of the air intake duct is presented in figure 14 in terms of P_s/P_a versus distance from the engine face. These pressures were recorded at the operating condition corresponding to simulated engine speed of 12000 RPM and marked (**) on the best auxiliary intake characteristic shown in figure 13. The static pressure distributions are compared, at the same operating condition, with the corresponding values measured at model scale with the basic unmodified configuration of Jindivik. In the portion of the duct upstream of the aperture, figure 14 shows that the static pressure values measured for the model modified with an auxiliary intake are higher than those measured downstream. This would be due to the fact that the flow passing through the main intake is only a portion of the engine air flow. It is also obvious that these modified duct static pressures are always higher than those obtained with basic unmodified configuration, along the entire length of the air intake duct. This conclusion provides a good case for eliminating the need for the splitter currently used in Jindivik installations to prevent duct collapse due the presence of the high suction pressures (or low static pressures) shown in figure 14. This is especially true in the portion of the duct upstream of the auxiliary intake.

3.2.4 Distortion Tolerance.

The total pressure distribution at the engine face for both the existing duct and the one modified with the best auxiliary intake geometry at the operating condition corresponding to N = 12000 RPM (y/x = 3.52 and A = 48 cm^2) and marked (**) in figure 13, are compared in figure 15. It is obvious that the improvements in pressure recovery were gained at the expense of increased flow distortion at the engine face. These distortions were evaluated in terms of the coefficients: DC(60), DC(rad) and DC(cir), which are defined in Appendix 1. The three distortion coefficients calculated for both geometries are also shown in figure 15 for an engine speed of 12000 RPM. All were found to be within the acceptable ranges specified by the engine manufacturer, Rolls Royce, and listed in Appendix 1. Similar calculations were carried out again for both geometries, but at the engine design speed of N = 13800 RPM. The results are not presented here but all showed that the distortion factors were within the manufacturer's acceptable range, with the exception of DC(60) = 0.35 corresponding to the profiled lip auxiliary intake geometry. This observation influenced the choice of configuration adopted for the wind tunnel tests described in reference 1, where it is shown that other practical geometries yielded acceptable levels of engine face flow distortions at all test conditions.

3.2.5 Tests with Cross Wind

The sensitivity of intake performance to the effect of cross-winds was examined on the model with 9 m/sec air jet from an electric fan, blowing at 90 degrees to the duct centreline. Both the unmodified configuration and the one modified with the 37*130 profiled lip auxiliary intake were tested under this cross wind condition. The pressure - mass flow characteristics obtained for both geometries are compared with those measured with no cross wind in figure 16. The effect of the cross wind in both cases was negligible, which was not surprising, in view of the fact that the cross wind speed was small relative to local flow velocities of the order of 150 m/sec at either of the main or auxiliary intakes.

4. CONCLUSIONS.

The main conclusions of this investigation are:

1. The measured pressure recovery at the engine face was found to vary with auxiliary intake aperture size, aspect ratio, lip profile and to a lesser extent with location in the upper surface of the air intake duct:

   a- For an auxiliary intake with a fixed lip profile, the pressure recovery improved with aperture area until a maximum was reached at a certain aperture size. Beyond this limit, performance appeared not to benefit from larger aperture areas.

   b- For an auxiliary intake with both fixed aperture area and lip profile , pressure recovery improved with aspect ratio y/x until a maximum was reached at a certain y/x. Increasing y/x beyond this limit appeared to be detrimental to pressure recovery. This limiting y/x was found to decrease with aperture area, but yielded the same maximum pressure recovery which occurred at approximately a fixed aperture width for all aperture areas investigated.

   c- As expected, profiling the auxiliary intake lip improved engine face pressure recovery, with maximum benefits being measured in the higher ranges of aspect ratio y/x.

2. Over the entire range of engine air mass flow or engine rotational speeds, the best aerodynamic performance in terms of pressure recovery achieved with a profiled lip auxiliary intake was marginally greater than that

obtained with the "horse collar" currently used in full scale Jindivik installations for engine test purposes.

3. The improvement in pressure recovery was in general found to be at the expense of some flow distortions at the engine face as compared to the unmodified configuration. The calculated DC(60), DC(rad) or DC(cir) were found to be dependent on intake geometry and range of engine speed. With the exception of DC(60) = 0.35 for the profiled lip auxiliary intake geometry at N = 13800 RPM, all distortion coefficients were found to be within the acceptable range specified by the engine manufacturer.

4. Compared to the unmodified configuration, the performance, in terms of engine face pressure recovery, of the air intake duct modified with an auxiliary intake, exhibited less sensitivity to the profile of the main intake lip.

5. The effect of cross wind, up to 9 m/sec, on engine face pressure recovery was found to be negligible. This was the case for both the unmodified duct, and the one modified with an auxiliary intake configurations.

ACKNOWLEDGMENT

The author would take this opportunity to express his thanks to Mr. S. A. Fisher of the Propulsion Branch - ARL for his support and useful comments. The support of Mr. M. A. Fisher of the same Branch in carrying out the model tests and maintaining the test rig are gratefully acknowledged.

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APPENDIX

The uniformity of total pressure distribution at the engine face is important in relation to compressor blade stressing and flow stability. Departure from this uniformity, which is more commonly termed as distortion, can produce some harmful effects on the compressor and its operation. The two main effects are, firstly the excess aerodynamic loading associated with blade rotation, and secondly, reduction in the safe operational range of the compressor by shifting the surge line into the region of higher compressor mass flow. Expressions for the quantitative measure of total pressure distortion are given in Ref. 4 and in Ref. 5. The coefficients which are usually used in UK and by Rolls Royce for steady state conditions, are given below:

1. At all of the face annulus:

$$DC(60) = (P_{t.av} - P_{t.av.min60})/[1/2\rho V^2]$$

   Where $P_{t.av}$: Average total pressure at the engine face.

   $P_{t.av.min60}$: Minimum average total pressure over a 60° sector of the engine face.

2. Along any radial total pressure rake at constant angle in the face annulus:

$$DC(rad) = (P_{t.max} - P_{t.min})/[1/2\rho V^2]$$

3. Around any circumferential total pressure ring at constant radius in the face annulus:

$$DC(cir) = (P_{t.max} - P_{t.min})/[1/2\rho V^2]$$

The upper limits for these coefficients as specified by the engine manufacturer, Rolls Royce, for the Viper II engine, are:

DC(60)	steady state	= 0.30
	transient	= 0.50
DC(rad) & DC(cir)	steady state	= 0.90
	transient	= 1.10

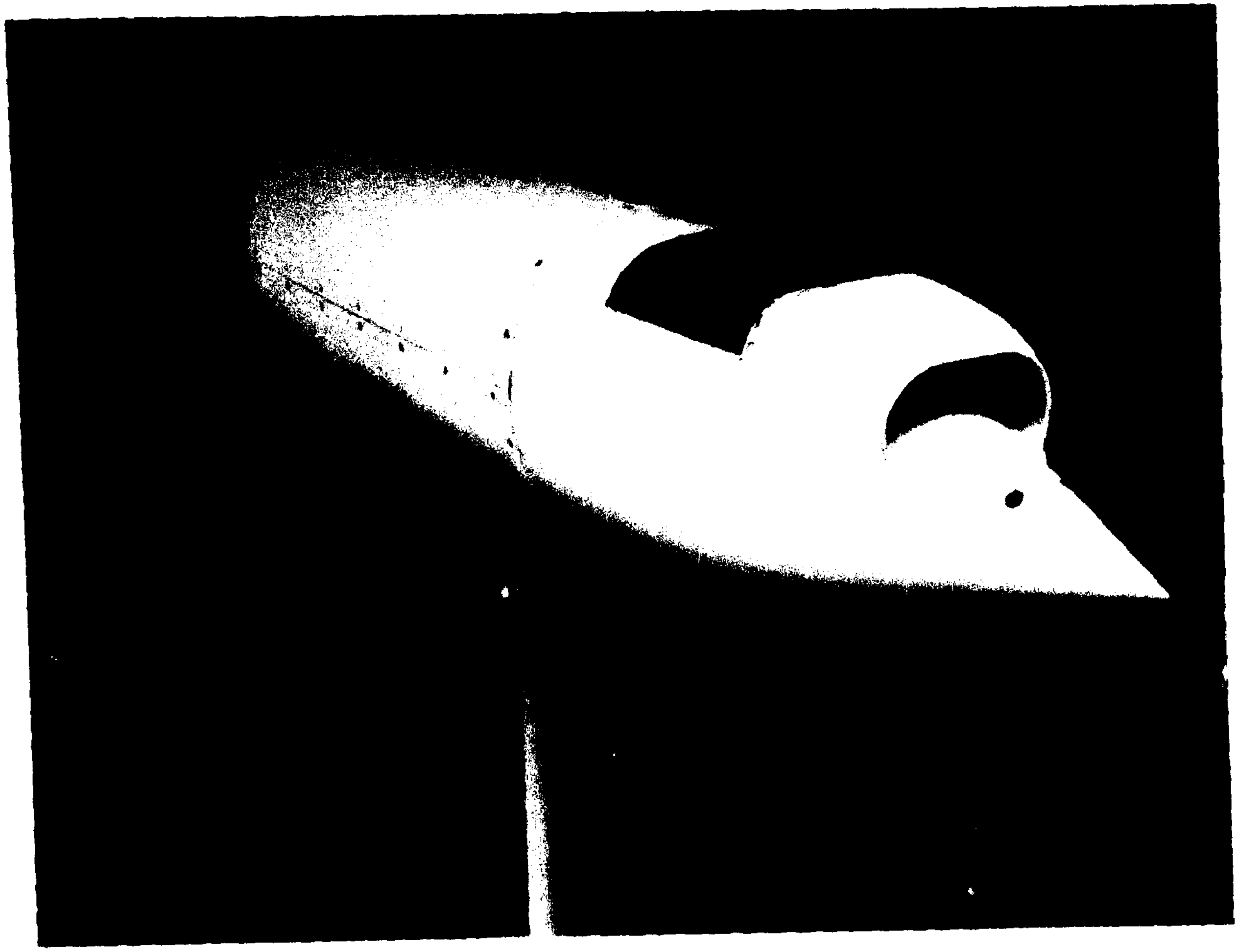
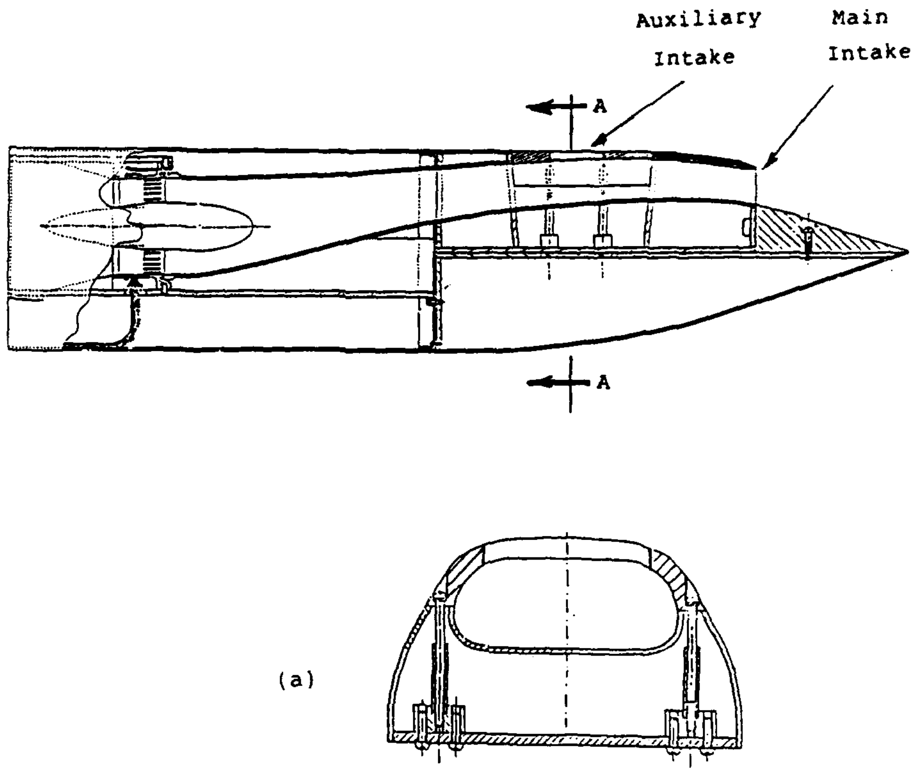
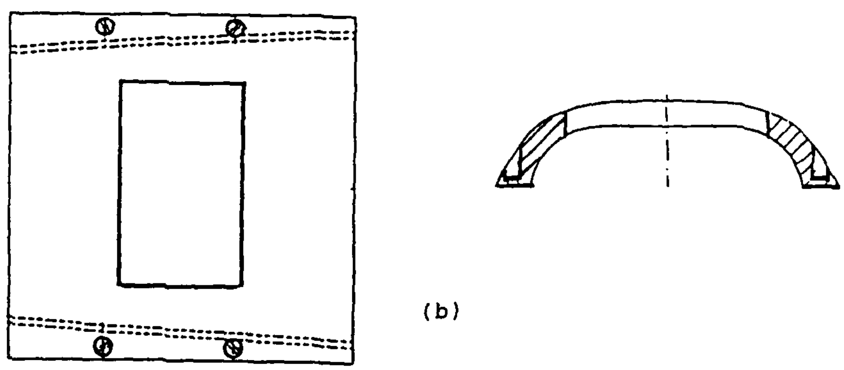


FIGURE 1: PHOTOGRAPH OF THE 1/4 MODEL SCALE OF THE JINDIVIK AIR INTAKE SYSTEM



(a)

SECTION A - A



(b)

FIGURE 2: (a) AND (b)

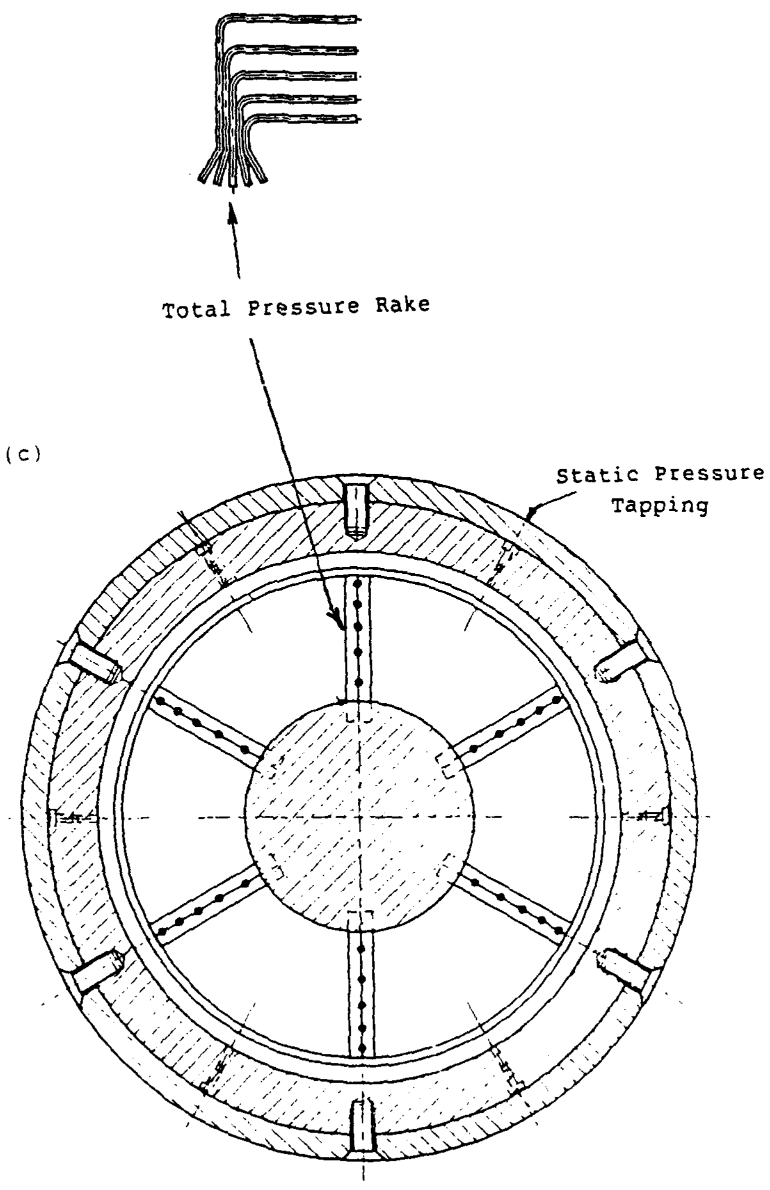


FIGURE 2: DETAILS OF THE 1/4 MODEL SCALE OF THE JINDIVIK
AIR INTAKE SYSTEM.
(a) SECTIONAL VIEWS OF JINDIVIK MODEL
(b) DETAILS OF THE AUXILIARY INTAKE PLUG
(c) DETAILS OF THE TOTAL PRESSURE RAKE

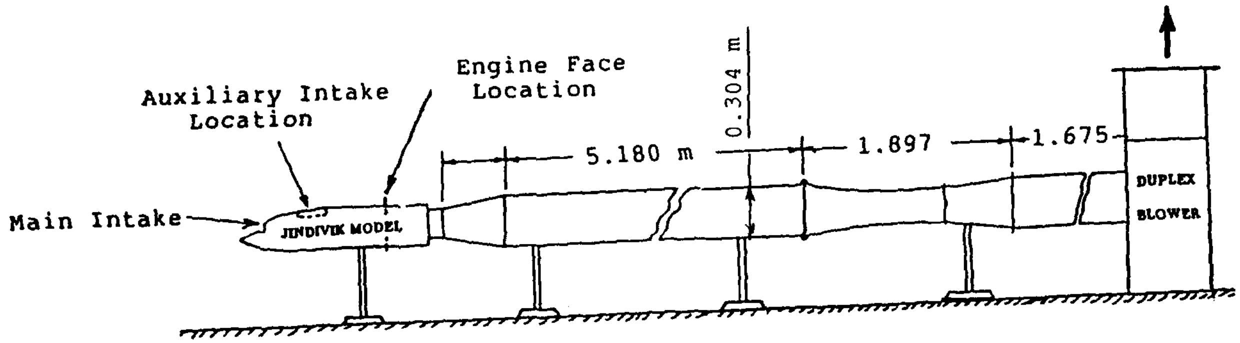


FIGURE 3: EXPERIMENTAL SETUP OF THE JINDIVIK INTAKE MODEL. - STATIC TEST RIG

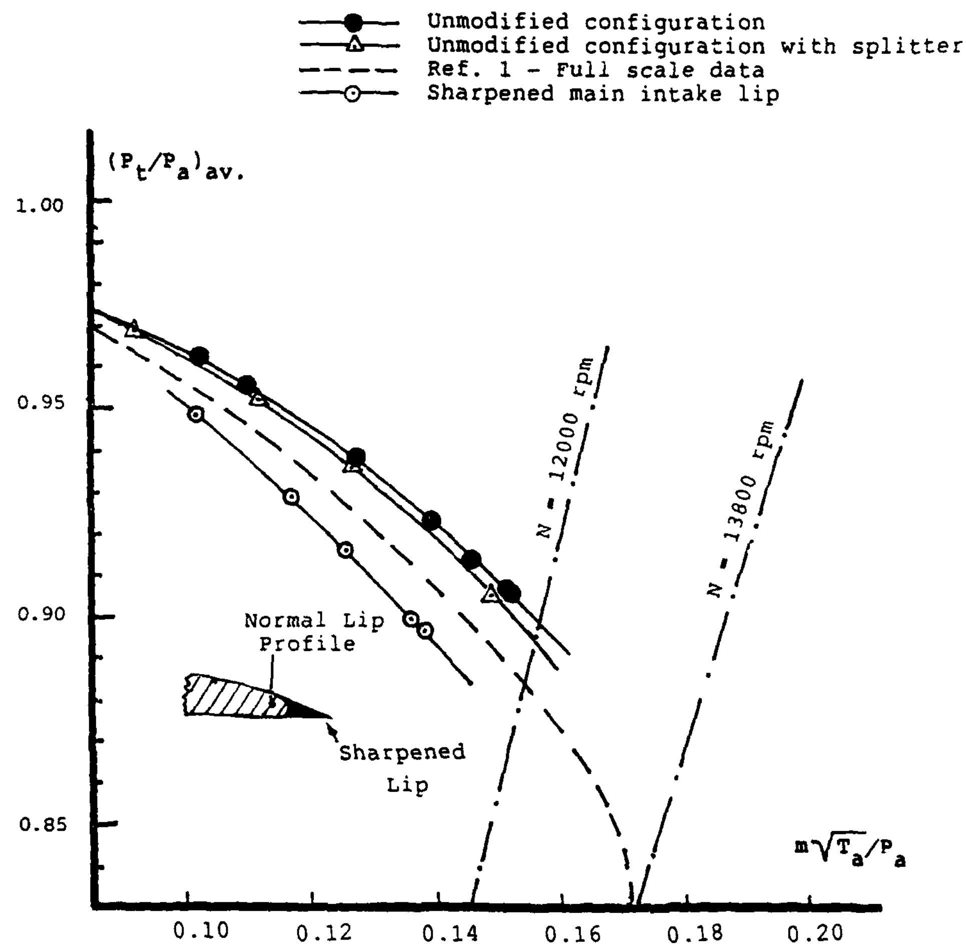


FIGURE 4: COMPARISON BETWEEN THE MODEL AND FULL SCALE PRESSURE RECOVERIES FOR THE UNMODIFIED JINDIVIK AIR INTAKE DUCT.

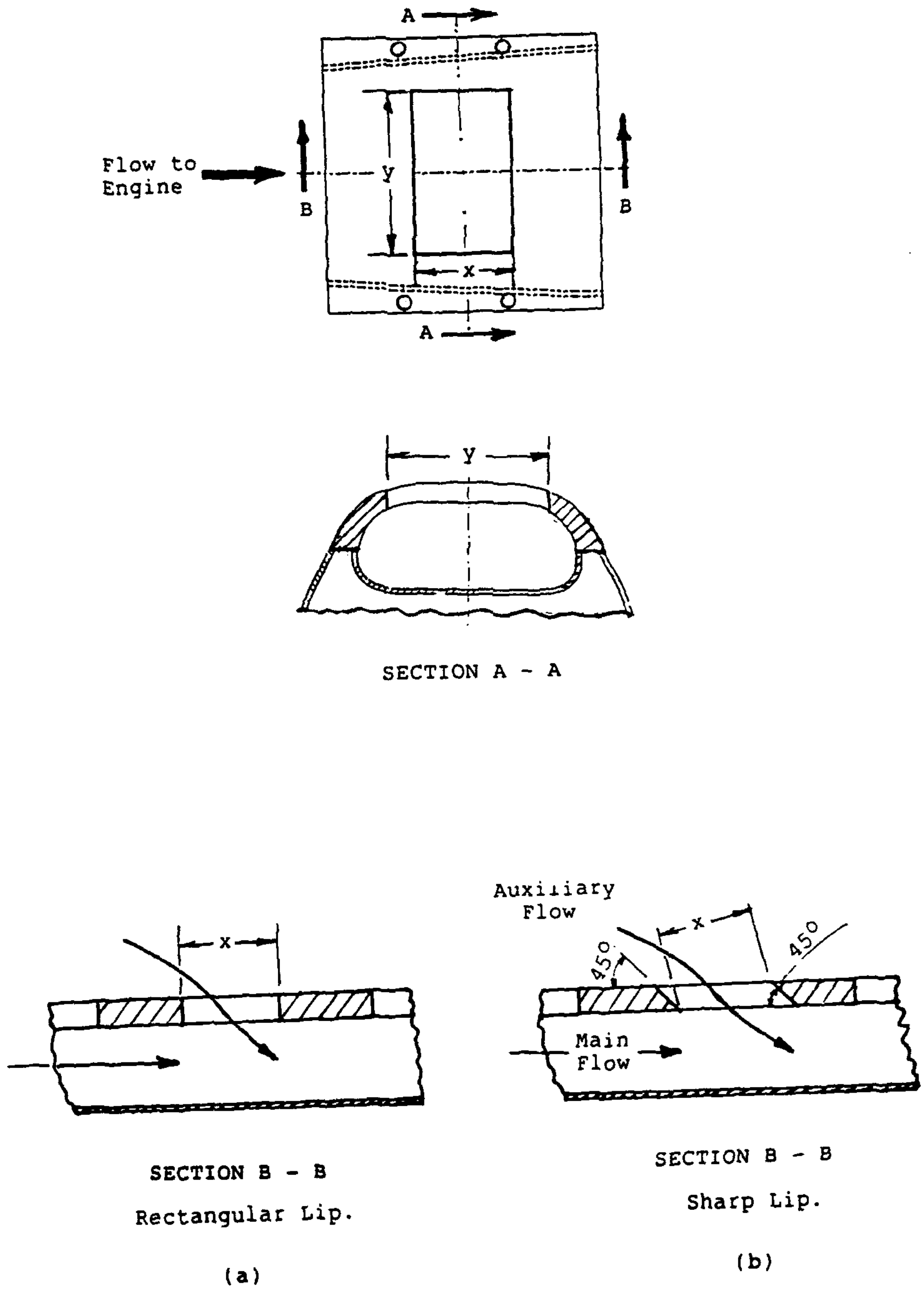


FIGURE 5: DETAILS OF AUXILIARY INTAKE LIP PROFILE.
a- RECTANGULAR LIP.
b- SHARP TRIANGULAR LIP.

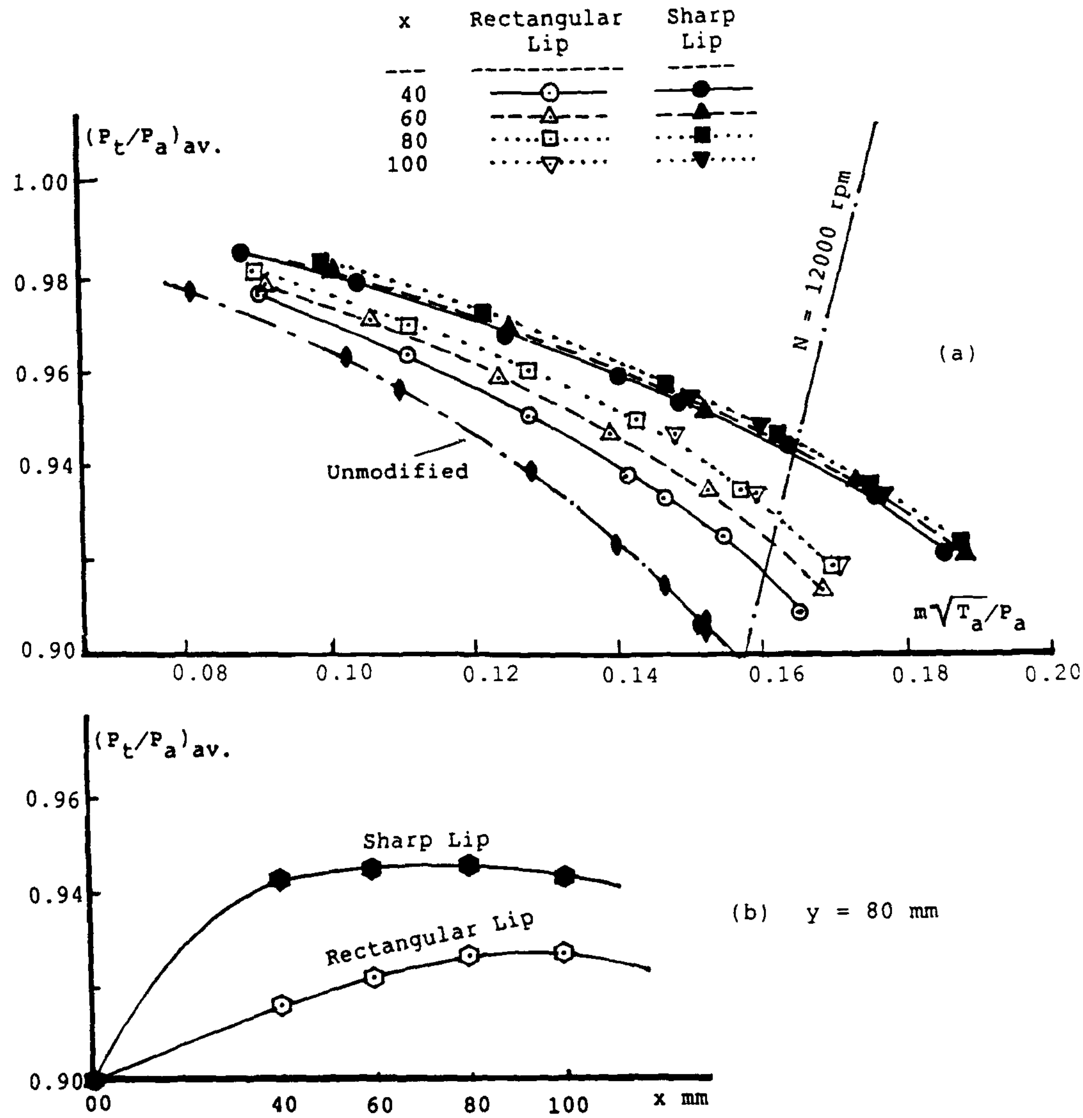


FIGURE 6: COMPARISON BETWEEN RECTANGULAR AND SHARP LIPPED AUXILIARY INTAKES PERFORMANCE, WITH VARIABLE AXIAL WIDTH, BUT WITH A FIXED LATERAL LENGTH.

a- PRESSURE RECOVERY VERSUS ENGINE MASS FLOW PARAMETER

b- PRESSURE RECOVERY VERSUS APERTURE AREA OR AXIAL WIDTH, AT A FIXED N = 1200 RMP.

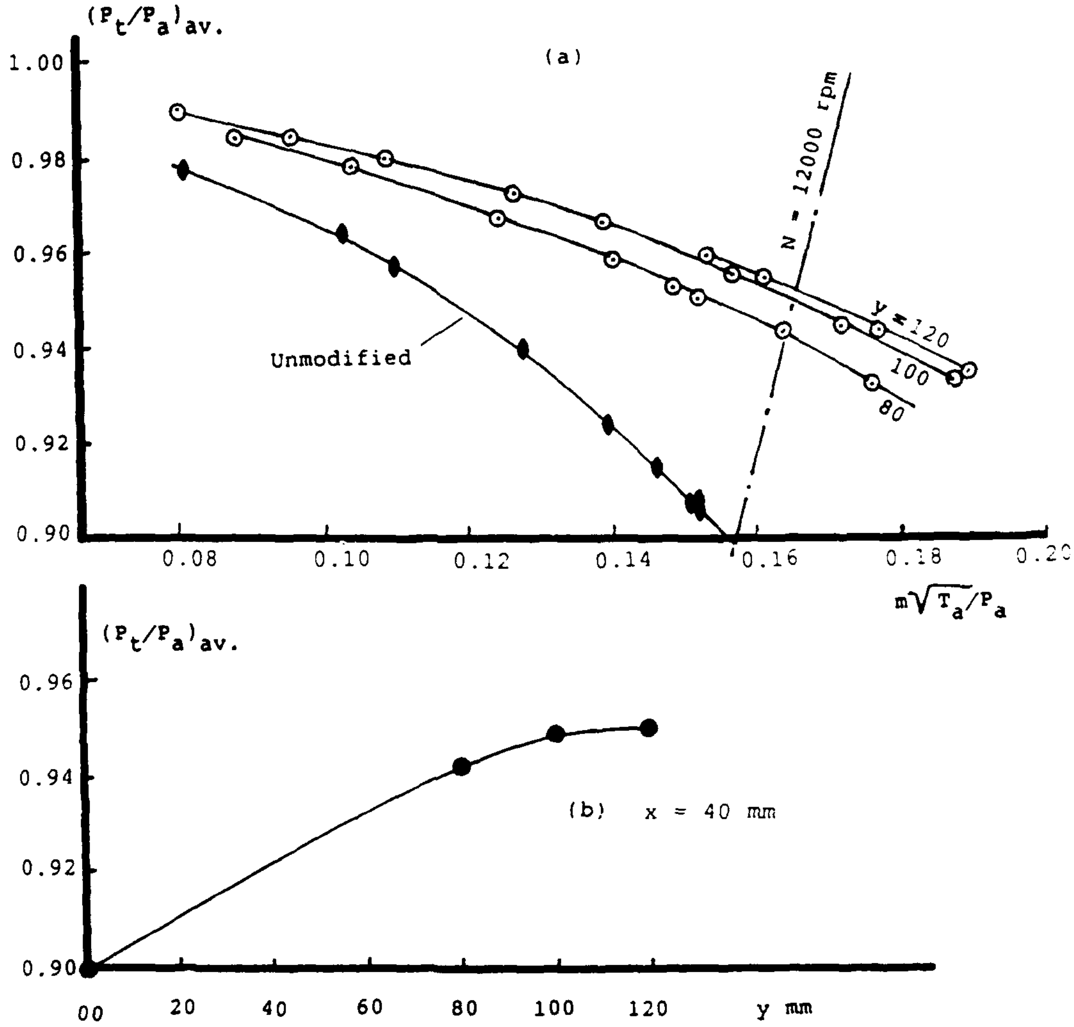


FIGURE 7: SHARP LIPPED AUXILIARY INTAKE PERFORMANCE, VARIABLE LATERAL LENGTH, BUT WITH A FIXED AXIAL WIDTH.

a- PRESSURE RECOVERY VERSUS ENGINE MASS FLOW PARAMETER.

b- PRESSURE RECOVERY VERSUS APERTURE AREA OR AXIAL WIDTH, AT THE FIXED ENGINE SPEED OF N = 1200 RMP.

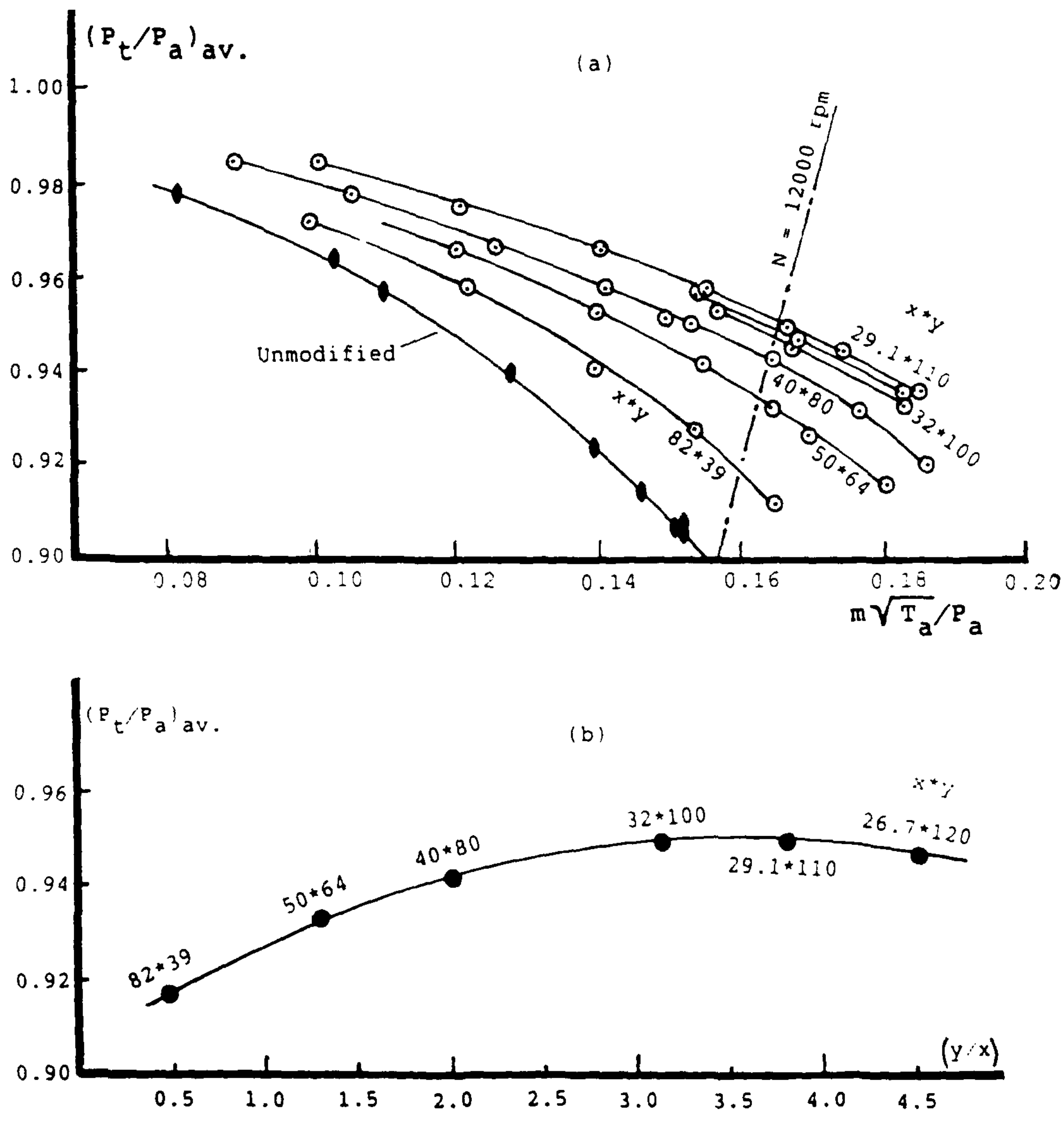


FIGURE 8: PERFORMANCE OF SHARP LIPPED AUXILIARY INTAKE OF FIXED APERTURE AREA A = 32 cm^2, BUT WITH VARIABLE ASPECT RATIO.

a- PRESSURE RECOVERY VERSUS ENGINE MASS FLOW PARAMETER.

b- PRESSURE RECOVERY VERSUS ASPECT RATIO FOR THE FIXED ENGINE SPEED OF N = 1200 RPM.

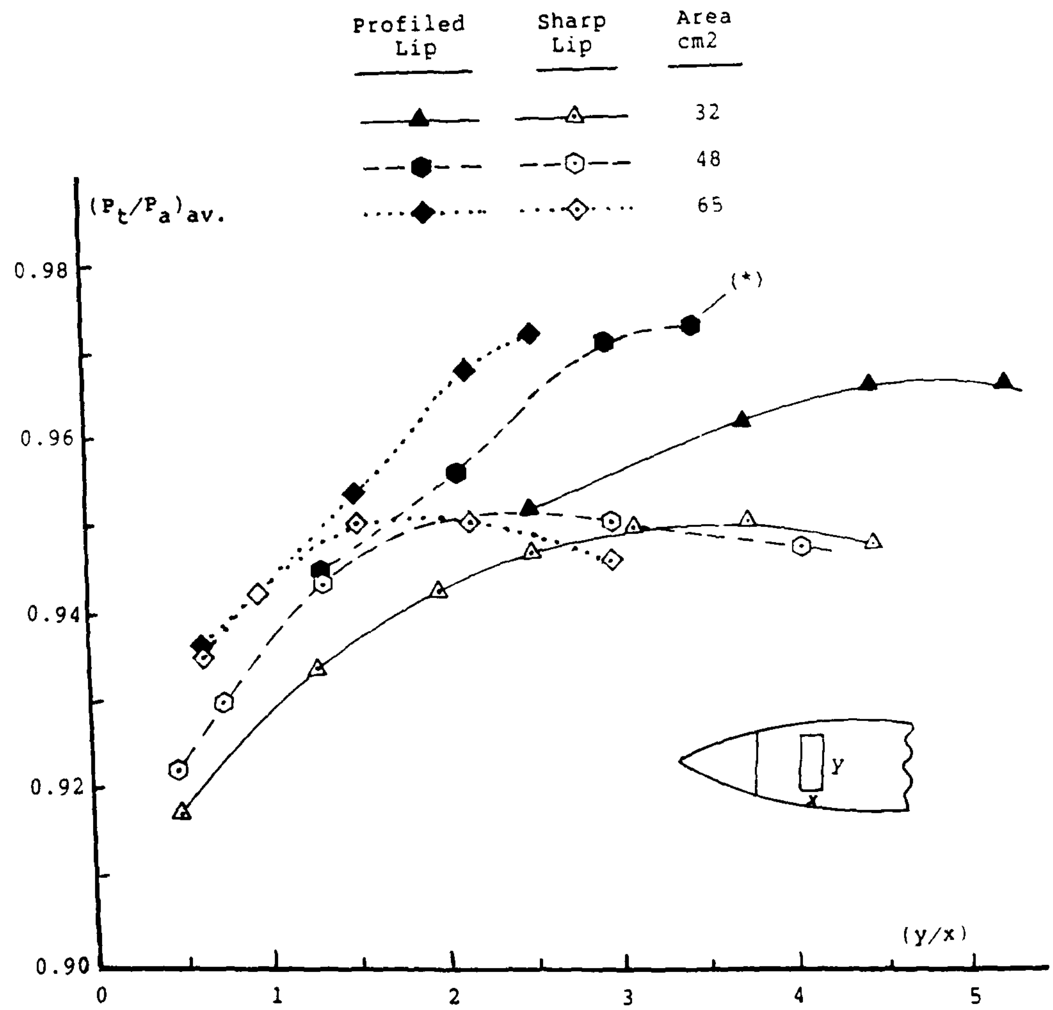


FIGURE 9: EFFECT OF AUXILIARY INTAKE APERTURE ASPECT RATIO ON ENGINE FACE PRESSURE RECOVERY FOR VARIOUS APERTURE AREAS AND LIP PROFILES, AT THE FIXED ENGINE SPEED; N = 12000 RPM.

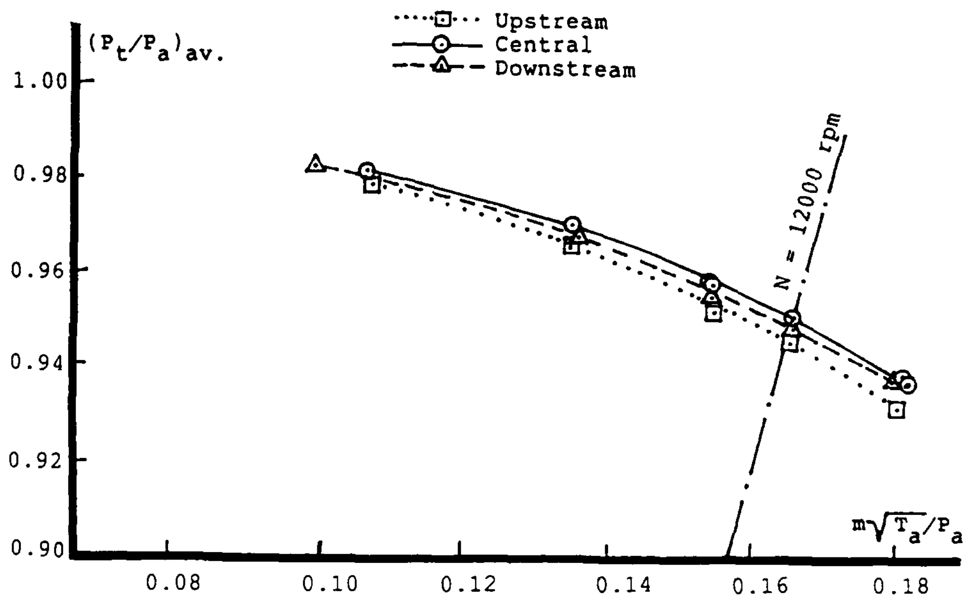
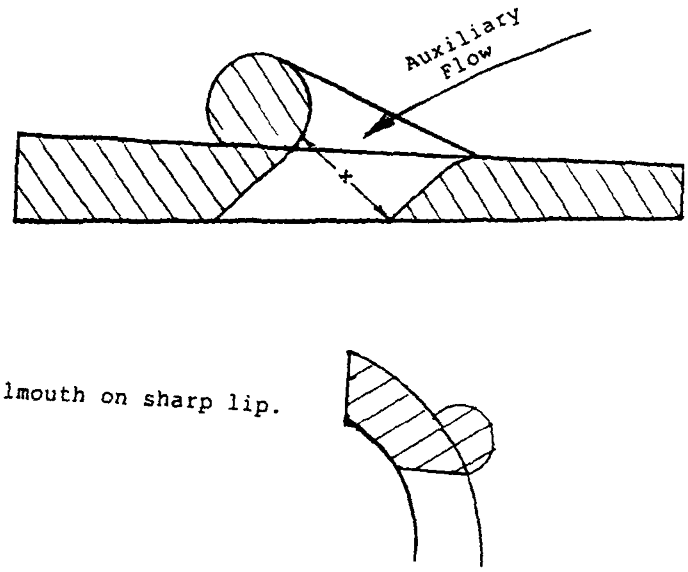
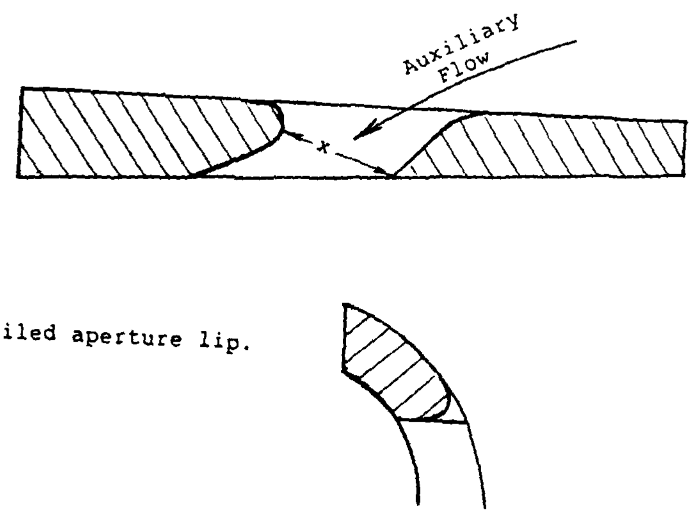


FIGURE 10: EFFECT OF AUXILIARY INTAKE LOCATION ON ENGINE FACE PRESSURE RECOVERY FOR A = 32 CM^2 WITH SHARP LIPPED APERTURE. (x = 29.1mm, y = 110 mm.)



a- Bellmouth on sharp lip.



b- Profiled aperture lip.

FIGURE 11: DETAILS OF AUXILIARY INTAKE LIP GEOMETRY.

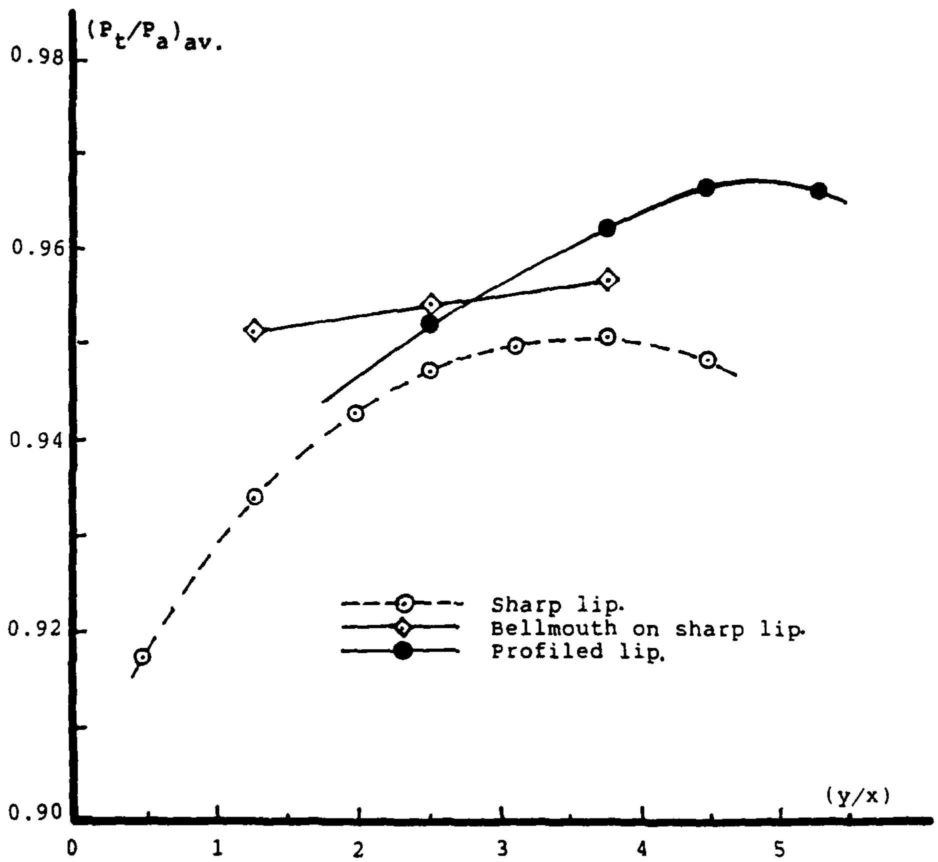


FIGURE 12: COMPARISON OF AUXILIARY INTAKE PERFORMANCE OBTAINED FOR DIFFERENT APERTURE LIP PROFILES, BUT AT A FIXED APERTURE AREA; $A = 32\ cm^2$, AND FIXED $N = 12000$ RPM.

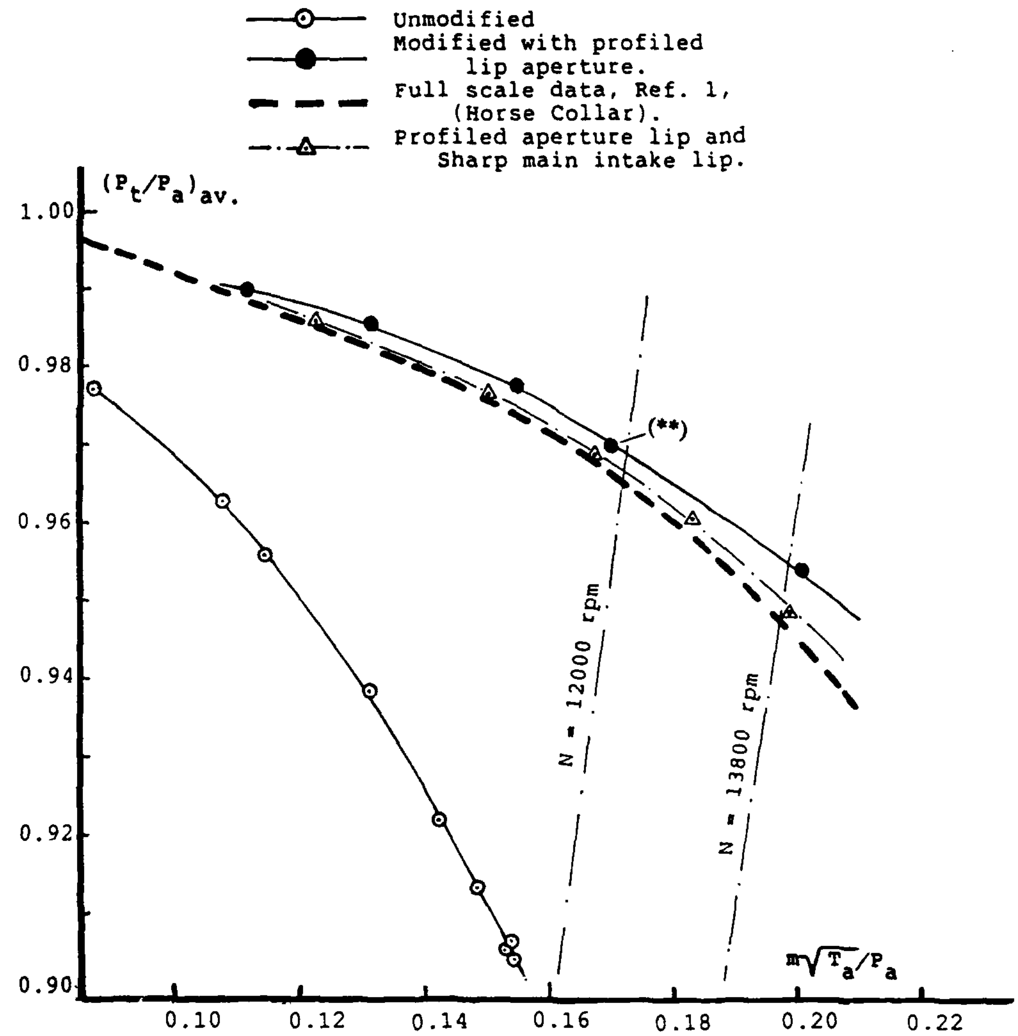


FIGURE 13: PERFORMANCE OF BEST PROFILED LIPPED AUXILIARY INTAKE COMPARED WITH THAT OF THE HORSE COLLAR AT FULL SCALE, AND WITH THAT OF SHARP MAIN INTAKE LIP AT MODEL SCALE.

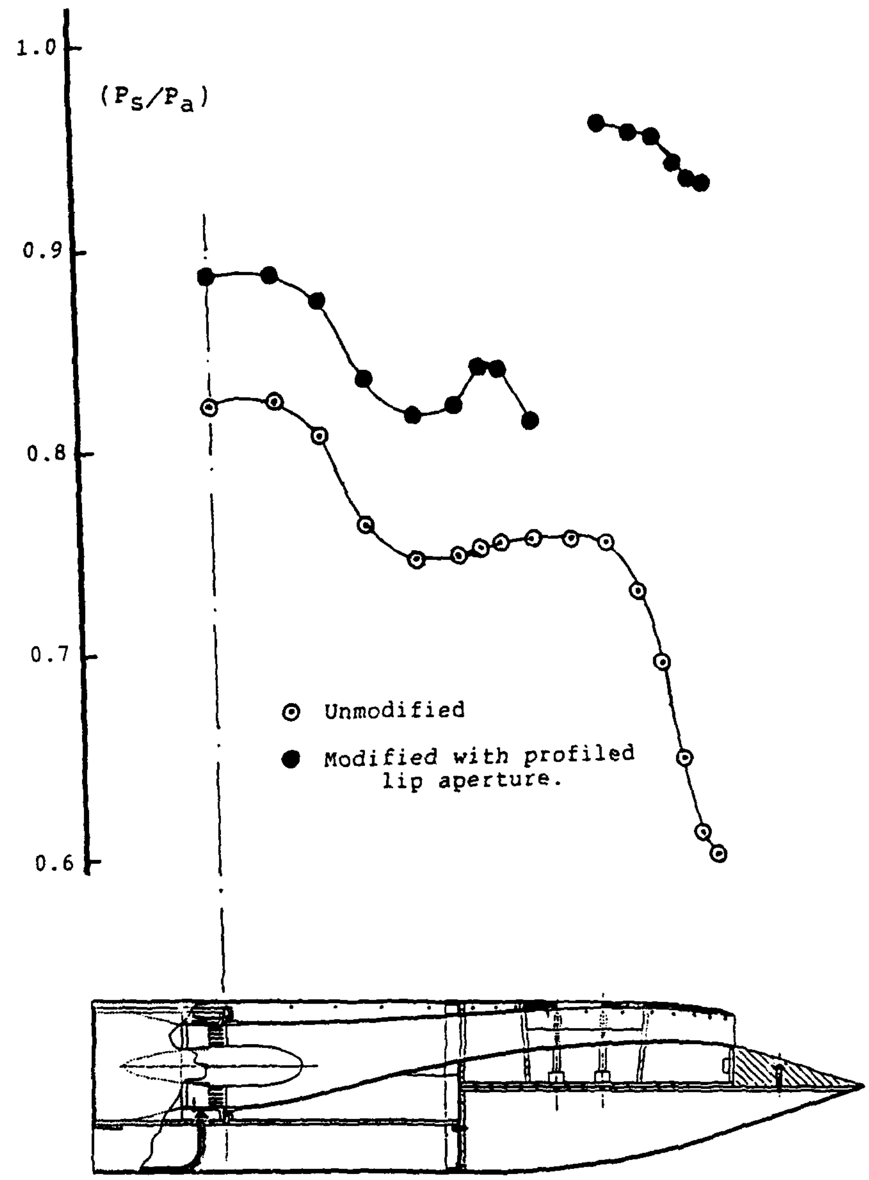


FIGURE 14: INTERNAL SURFACE STATIC PRESSURE DISTRIBUTION ALONG THE AIR INTAKE DUCT AXIAL DIRECTION.

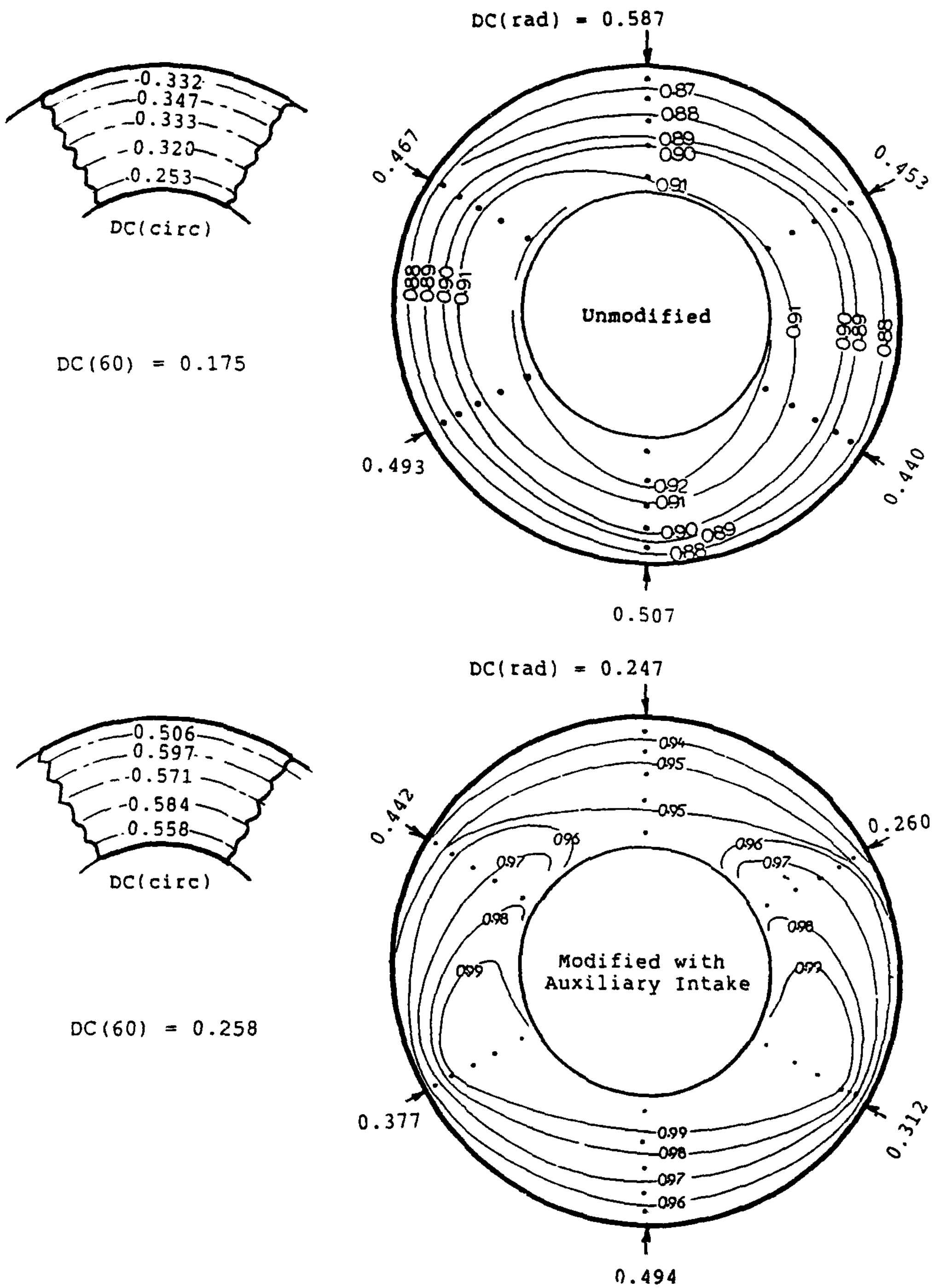


FIGURE 15: COMPARISON BETWEEN THE UNMODIFIED AIR INTAKE DUCT AND THE ONE MODIFIED WITH THE BEST PROFILED LIPPED AUXILIARY INTAKE IN TERMS OF TOTAL PRESSURE DISTRIBUTION AT THE ENGINE FACE. N = 12000 RPM.

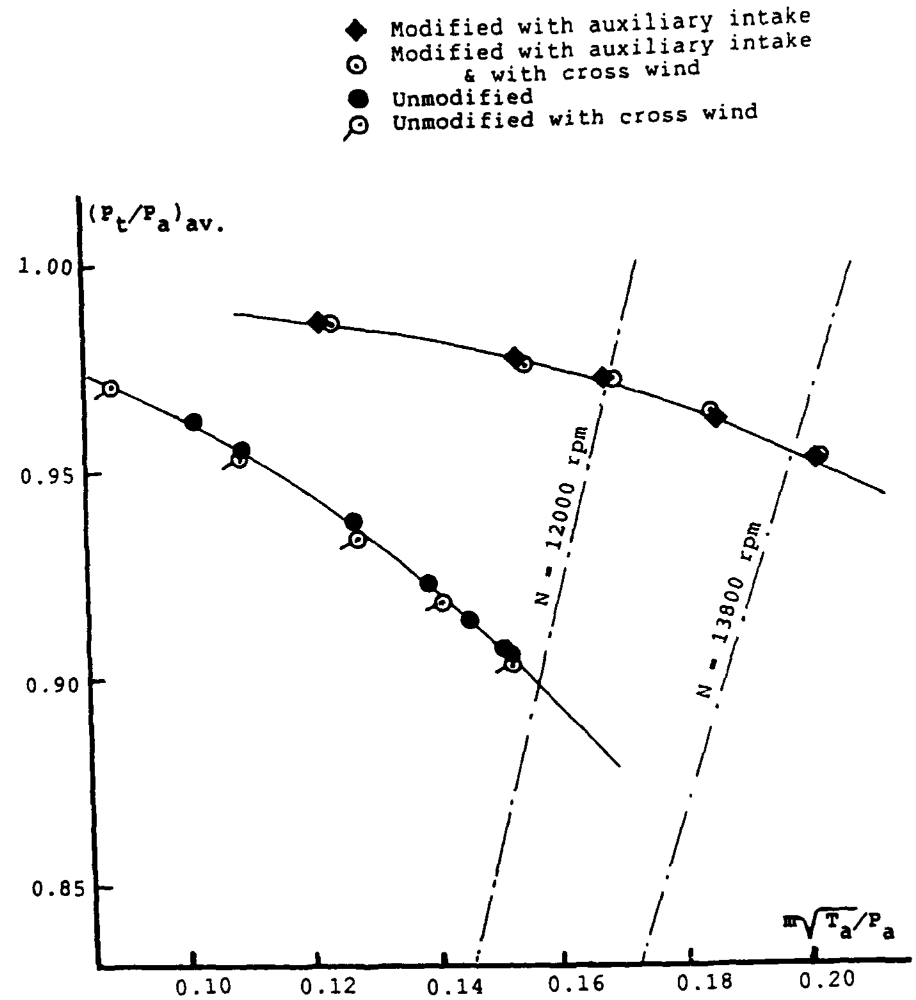


FIGURE 16: EFFECT OF CROSS WIND ON ENGINE FACE PRESSURE RECOVERY.

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16. ABSTRACT
Results are presented for an R & D program to improve the take-off performance of the Jindivik target aircraft. The engine air intake duct of Jindivik is aerodynamically optimised for altitude and high subsonic cruise, and scope for its modification, for improved performance at take-off, was limited to the incorporation of an auxiliary intake system which is only deployed during take-off and is closed in flight. The auxiliary intake concept was explored experimentally with a 1/4 model scale of Jindivik air intake duct, and involved both static testing and tests with forward speeds in the wind tunnel. This report covers the aerodynamic aspects of the static phase of the program, at which conditions substantial improvements in pressure recovery with acceptable levels of flow distortion at the engine face have been demonstrated for simple intake modifications.

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