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An Experimental Investigation of Flow Surrounding an Airfoil With a Jet Exhausting From the Lower Surface

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SUMMARY

An experimental investigation was carried out to study the aerodynamics of an airfoil with a rectangular jet issuing from the lower surface at seventy percent of the chord; with and without a ground plane. Measurements include surface pressures on the airfoil and the total pressure profiles in the near wake. These measurements were made at jet to free stream velocity ratios ranging from 0.5 to 5.0.

The measurements indicated a significant positive and negative pressure regions on the lower surface of the airfoil ahead and after the nozzle exit respectively. The extent and intensity of these regions increase with increase in velocity ratio for the range covered here. The upper surface pressure distribution with velocity ratio show no significant variation. The presence of the ground plane, for height h, greater than one chord seem to have little influence on the overall pressure distribution of the airfoil. The airfoil wake centerline moves up with velocity ratio as compared to that of the free airfoil (without the jet).

Nomenclature

C	Chord of the airfoil
C_ℓ	$\int_0^c c_p \, d(\frac{x}{c})$
C_p	$(p - p_\infty)/q_\infty$
C_{m_o}	$\int_0^c C_p (\frac{x}{c}) \, d(\frac{x}{c})$
p	Surface pressure on the airfoil
p_T	Total pressure
p_∞	Free stream pressure
q_∞	$\frac{1}{2} \rho_\infty U_\infty^2$
R	U_J/U_∞
U_J	Mean velocity at the center of the nozzle exit
U_∞	Free stream velocity
ρ_∞	Free stream density

Acknowledgements

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The authors appreciate the expert help given by Mr. Joel Young construction of the test section and the model. We would like to thank the members of the Joint Institute for Aeronautics and Acoustics for helpful suggestions during the analysis phase of the work.

The typing of Ms. Carolyn Edwards was appreciated.

1. INTRODUCTION

The aerodynamic effects of propulsive jets providing lift forces during hover and transition flight of V/STOL aircraft are significant and poorly understood. Under hover conditions, the entrainment of air by the jet can cause a reduction in pressure on the lower surface of the airfoil or airframe resulting in loss of lift. In addition significant pitching mements are introduced on the aircraft. At forward speed there are similar conditions occur but favorable lift effects usually cause increased drag. The proximity of ground plane can enhance the aerodynamic effects both in favorable and unfavorable ways. Because of the complex nature of the jet-cross flow interaction and the induced aerodynamic effects, most of what is known came from testing of various configurations.

Investigations involving simple geometries, such as an axismmetric jet issuing from an airfoil or a flat plate have been carried out for some time[1,2,3]. A survey of the aerodynamics of jets pertinent to V/STOL aircraft was done by Skifstad[4], and included in this survey was some analysis of the data for free jets and impinging jets. Several references related to this subject have been compiled by Perkins and Mendenhall[5]. In addition, they developed a correlation method to predict the surface pressure distribution on an infinite plate from which a jet is issuing. More recently Yen[6] examined the experimental and analytical results on the aerodynamics of a jet in a cross flow. Although the measurements cited in previous works have contributed significantly to the present understanding of a jet in a cross flow problem, a gap still exists to provide the information about the flow regions ahead and after the jet.

Recent experiments showed that non-asixymmetric nozzles exiting at or near the trailing edge of a lifting surface offer advanced air craft configurations for V/STOL aircraft. One of the benefits identified for non axisymmetric exhaust nozzles if located near the trailing edge is increased lift attributed to induced aerodynamics created by the nozzle exhaust flow. Previous research[7] in this area have emphasized jets of high aspect ratio over the low aspect ratio jets.

The purpose of this investigation is to study the aerodynamic properties of an airfoil with a rectangular jet placed in the lower surface of it near the trailing edge. Emphasis will be placed on studying the flow regions ahead and after the jet. Also included in the investigation is a study of the effect of a ground plane on the above configuration. The experiment to be described is preliminary in nature and aimed at obtaining only the gross properties of the flow field. Based on the observations from this investigation, a program to study the detailed structure of the flowfield will be initiated.

2. NATURE OF THE PROBLEM

The problem concerned here is a determination of the flow field of an airfoil resulting from a jet issuing normal to it in a uniform cross flow with and without the ground plane as shown in figure 2.1. The interaction between the jet and cross flow in the presence of an airfoil is characterized by the following parameters: the geometry of the airfoil, angle of attack of the airfoil, free stream velocity, Reynolds number based on the chord of the airfoil, the nozzle configuration, location and orientation of the jet with respect to the airfoil, velocity or Mach number at the nozzle exit, Reynolds number of the jet, and nature of the conditions at the nozzle exit. If the ground plane is present, the following additional parameters will also enter into the problem: the configuration of the ground plane and the location of the ground plane with respect to the airfoil.

The main interest here is the determination of the surface pressure on the airfoil and the over all flow field. Such a determination and examination of how it varies with various parameters require a clear understanding of not only the jet structure but also the flow field on the surface due to the presence of the jet at different conditions of the parameters. The structure of the flow field is characterized by the mean and fluctuating velocity fields and the mean and fluctuating pressures on the surface.

The goal of the experimental program is to understand the main physical features of such flow and obtain satisfactory relations between the flow characteristics and the many parameters governing them.

A comparison of the flow parameters for some experimental STOL research aircraft with the paremeters which were used in the present investigation is shown in the table below. The data and a detailed description of using type mentioned in that table have been presented by Hu[8].

Wing type	Jet angle	Velocity ratio	Jet speed m/sec	Aircraft model
Augmentor	20° to 90°	3.3 to 1.4	100	DHC-5
Lift fan	45° to 90°	10.4 to 1.4	100 ∿ 160	Ryan XV-5
Present Investigation	90°	5.0 to 0.5	15 ∿ 75	

The airfoil used is the same as the one used by Hackett[9]. An aspect ratio of 10 was selected for the nozzle and oriented with its short edges paralles to the stream. It was located at 70 percent of the chord, in the lower surface of the airfoil. The inlet section of the nozzle was designed such that the jet exits normal to the chord. A free stream velocities of 15m/s was selected. Mean velocity at the nozzle exit was varied from 7.5m/s to 75m/sec. To simulate a ground plane a flexiglass plate was introduced between the lower surface of the airfoil and one of the wind tunnel test section walls. The height of the ground plane with respect to the airfoil was varied to 0.2c to 1.5c (c being the chord of the airfoil). For the experiments reported here the angle of attack of the airfoil was zero degrees.

3. EXPERIMENTAL APPARATUS, INSTRUMENTATION AND PROCEDURES

3.1 The Wind Tunnel

A subsonic open circuit wind tunnel was used for the experiments to be described here. The entrance of the tunnel was designed to provide a minimum turbulence level in the test section. The entrance section has a 16:1 contraction ratio. The detail construction of the wind tunnel is given in Reference 10.

The test section was rectangular in cross section and was made of 1.9 cm thick plexiglass. The dimensions of the test section were 1.22m long and 0.46 deep and 0.33m height. The interior walls were finished to give an aerodynamically smooth surface. A photograph of the test section with the model in place is shown in Figure 3.1a. A schematic of the test section is shown in Figure 3.1b. Also shown in the figure is the simulated ground plane placed at a height h, from the chord of the airfoil.

3.2 The Model

The airfoil section was taken from reference 9, which was derived from a supercritical airfoil design. The geometry and ordinates of the section are shown in the Figure 3.2. Because of the incorporation of the nozzle, the model was made up of several plexiglass parts. The span and chord of the wing section are 33cm and 15cm respectively, which results in an aspect-ratio of 2.2. The wing section extends from one side wall of the test section to the other, establishing the two dimensional flow. A rectangular nozzle of aspect ratio 10 with its long and short dimensions of 50mm and 5mm respectively was selected. The nozzle was located at 70 percent of the chord with its long dimension normal to the free stream. The settling chamber for the nozzle was of circular cross section and extends along the span of the wing as shown in Figure 3.3. The air was supplied to the settling chamber from both ends of the wing section. To ensure a uniform flow at the exit of the nozzle, adjustable vanes were placed inside the settling chamber as shown in Figure 3.4. With the optimum adjustment of the vanes, a slight variation of the mean velocity (about 10 percent) was noticed along the long dimension of the nozzle exit.

To simulate the ground plane, a 0.65cm thick, 33c, wide and 45cm long plexiglass plate was used. The height of the plate with respect to the airfoil (see Figure 3.1b) can be adjusted from 1.5cm to 18cm. To avoid any flow seperation at the leading edge of the plate a 45° sharp edge was provided.

3.3 Measurements

The center section of the wing (midspan) was fitted with 27 pressure taps each having a dimension of about 0.5mm in diameter. The location of these taps are given in a table included in Figure 3.2. These taps were connected to a 24 port scanning valve through a metal tubing. The measurements were primarily confined to the central plane (midspan) of the wing section. Measurements included the surface pressure measurements on the airfoil and total pressure measurements in the wake of the airfoil. These measurements were taken at one free stream velocity and at several nozzle exit velocities. The coefficients of lift, and moment about the leading edge, were calculated from the C_p distribution around the airfoil.

3.4 Procedures

The experiment was divided in two parts. In the first part of the experiment, the pressure distribution on the airfoil and in the near wake due to a jet issuing from the lower surface was studied. In the second part, the pressure distribution on the airfoil and in the near wake was studied with the simulation of a ground plane. The measurements in both cases are confined to static pressure on the airfoil and the total pressure in the wake.

A free stream velocity of 15m/sec was selected. This velocity was maintained constant to an accuracy better than one percent. The exit velocity of the nozzle was varied from 7.5m/sec to 75m/sec. The nozzle exit velocity was maintained constant to an accuracy of about 5 percent. The mean velocity was fairly uniform across the small dimension of the nozzle, while some non uniformity (about 10 percent) was noticed along the long dimension of the nozzle.

Surface pressure measurements were made at several velocity ratios (nozzle exit velocity/freestream velocity) both with and without the ground plane. Using a 20 tube total pressure rack, wake measurements were made at several stations as indicated in Figure 3.5. A cartesian coordinate system (x,y,z) was used with x axis oriented along the center line of the wing section with its origin at the leading edge as shown in Figure 3.5.

For most of the present measurements errors were estimated to be of the order of about five percent.

3.5 Corrections to Measurements

The testing of V/STOL models in wind tunnels presents many problems that are very different from those encountered in testing of conventional type airfoils and aircraft, where the testing techniques are relatively well understood[11]. V/STOL models such as the one tested have relatively large wake deflection angle and high energy which presents one of the most difficult problems that is encountered in wind tunnel testing of V/STOL type of vehicles. The primary work in wind tunnel wall effects and their corrections for V/STOL configurations was done by Heyson[12]. Studies covering the limits on the minimum speed V/STOL wind tunnel test was done by Rae[13]. Recently Morgason and Hoad[14] gave an account of V/STOL aircraft model in wind tunnel testing from model design to data reduction. In most of the instances the model used is a fan in wing configuration.

Another factor to take into account is the flow impingement on the test section floor. In a wind tunnel with the air moving with respect to the model and to the ground plane, there is a boundary layer on the floor. Jet exhausting from the model can impinge on the floor at appropriate test conditions and flow forward of and under the model effecting the overall flow field significantly. This problem can be minimized by using a moving belt ground plane. Several investigations have been carried out on this subject by Hackett et al[9]. In the free airfoil testing (without the simulation of the ground plane) for the present case, because of the relatively small width (D = 5mm) of the nozzle exit and large distance from the jet exit plane to the wind tunnel wall (60D), wall effects caused by seperation of the test section boundary layer due to jet impingement were small. Care was, therefore, taken when interperting the data particularly at high velocity ratios with the ground plane present and close to the airfoil.

Since this investigation was intended as a guide to further detailed study, quanitative corrections to the data for the above mentioned causes were not applied to the data. However, in most instances the relative comparisions of the data should still be valid.

4. RESULTS AND DISCUSSION

The following part is divided into two sections. The first section presents the results of flow past an airfoil with the jet issuing from the lower surface in a uniform stream. The second section deals with the results of the above configuration with the simulation of a ground plane. Interpretations and discussions are presented together with the data.

4.1 Jet In A Cross Flow

Surface Pressure Distributions

The static pressure on the surface of the airfoil from which a rectangular jet is issued into a uniform stream is measured at velocity ratios R (nozzle exit velocity, U_e/free stream velocity, U_∞), ranging from 0 to 5. The normalized static pressure distributions at the midspan of the airfoil are shown in Figure 4.1. Also included in the figure is the location of the center of the slot, which is at seventy percent of the chord. Interesting observations from this figure are: the positive pressure region in front of the jet and a negative pressure region behind the jet on the lower surface of the airfoil, and very little change in the variation of C_p on the upper surface with increase in velocity ratio, R. The positive region ahead of the jet can be attributed to the blockage of the free stream by the jet, the extent of which increases with an increase in velocity ratio U_j/U_∞ less than about 2, which is a low energy situation. A measure of this effect is provided by the magnitude of C_p at sixty percent of the chord, and Figure 4.2 shows this as a function of R. It is observed that the magnitude of C_p reaches a value of about 0.8 at R equal to 2.0 and for greater than

2.0, it remains almost constant. Another region of interest is between the jet and the trailing edge. The magnitude of the pressure coefficient in this region is nagative. In the present configuration, minimum value of C_p occurs at .8 of the chord and has a value of about two for a velocity ratio of 5, and its variation with R is shown in Figure 4.2. Within the scatter of the data it appears that for R less than two, C_p varies linearly with R as shown in the figure. This low pressure region is essentially responsible for many of the changes in the gross aerodynamic characteristics of the airfoil, to be noted later. On the contrary to the various changes observed in the lower surface pressure distributions with R, the pressure distribution on the upper surface depict very little change.

Lift and moment coefficients can be calculated from the above pressure distributions, and the results are shown in figrues 4.3 and 4.4. The variation of the coefficient, C_ℓ and C_m calculations are as follows. The component due to the momentum of the jet are not included here. For lift variations of figures 4.3 three distinct regions are noted. In the first region, which is designated from R equals to zero to two, the magnitude of C_ℓ increases monotonically and reaches a maximum value of about 0.3 at R equal to two. This increase is a result of the positive pressure ahead of the jet which increases with R. The region between R equal to two and three is designated as the second, where a substantial drop in C_ℓ is noted. This drop can be attributed to the drop in the magnitude of C_p in negative pressure region (seperated region) behind the jet, while the magnitude of C_p in positive pressure region ahead of the jet remains fairly constant. The third region, which is designated for R greater than three, little change in C_ℓ is noted. This may be due to the fact that the recirculation region (the negative pressure region) does not change very much with furthur increase in R. However furthur experiments are needed to confirm this. For the moment data of Figure 4.4, the nose up moment is defined as positive. For R less than about three, the magnitude of the coefficient is negative while for R greater than three it is positive. As seen from the variation of C_p distributions with R, these changes in $C_{m_{LE}}$ are caused by the flow regions ahead and behind the jet on the lower surface of the airfoil.

Wake Measurements

The total pressure distribution across the wake of the airfoil is measured at three different axial locations and at several locations along the span with and without the jet (Ref. Figure 3.5). As will be shown later, the flow resembles that of the flow past a two dimensional airfoil, thus only the profiles in the positive xz plane are shown here. These results are shown in Figures 4.5 ∿ 4.9. The distance z is normalized with respect to the chord, C of the airfoil, and C_p is defined at $(P_T-P_\infty)q_\infty$.

The normalized total pressure profiles at the midspan, without the jet, are shown in Figure 4.5. It is observed that the wake centerline, which is drawn through the minimum C_{p_T}, lies below the chord line of the airfoil. The flow is uniform on both sides of the airfoil as noted by the magnitude of C_{p_T}, which is equal to unity. To evaluate the two dimensionality of the flow past the airfoil, wake profiles at three different spanwise locations were measured. Typical profiles are shown in Figure 4.6. When compared these with profiles at corresponding locations of the midspan, the differences are found to be quiet small, thus indicating the flow is two dimensional for the position considered.

The normalized total pressure profiles of the wake with the jet exhauting at 60m/s or R equal to 4 are shown in figure 4.7. Figure 4.7a represent the profile at an axial location of 1.2c (ie at a distance of 0.2c behind the trailing edge). It is observed that most of the wake of the airfoil is situated above the chord line as compared to the case without the jet, where the wake lies below the chord line (figure 4.5). One can also identify the jet region from the magnitude of C_p which in this case is greater than one. The region between the jet and the wake of the airfoil is the low pressure region or recirculation zone. Figure 4.7b represents a profile at an axial location of 1.5c. As before one can identify both the wake of the airfoil and jet. In the seperated region, there seems to be two regions of low pressure with a high pressure interface between them. Similar observations can also be made from the profile at a location 2c, as shown in Figure 4.7c. Flow visualization and furthur quantitative measurements are needed to interpret these results.

To study the variation of the wake profiles along the span of the airfoil measurements are made at two spanwise locations as shown in Figures 4.8 and 4.9. At a transverse location of 0.33 it appears that the wake centerline coincides with the chord line and for x greater than 1.5c the influence of the jet on the profile seem to be quite minimal. Figure 4.9 depicts profiles at a spanwise location of 0.67c. When compared to the profiles at corresponding locations for an airfoil without the jet, the differences are quiet small. From this observation, one may conclude that the presence of the jet is not felt for spanwise distance y, greater than or equal to 0.67c or two times the long dimension of the nozzle. From these measurements one can deduce the center of the jet with downstream distance and the result is shown in Figure 4.10. The curve display the characteristics similar to the ones discussed in the literature. For comparision purposes data from Ref. 2 is included in the figure for a velocity ratio of 8. It is worthy of note here that at an axial distance of 40 or 20cm, from the nozzle exit the location of the center of the jet is about 7cm from the tunnel floor, thus indicating that the wall corrections may not be necessary.

The features observed from the wake measurements are schematically shown in Figure 4.11. The figure is drawn to scale. One of the observations is that the wake of the airfoil close to the trailing edge moves up with the presence of the jet as compared to that of a free airfoil. It also appears that furthur away from the trailing edge, the wake approaches the jet off wake.

4.2 Impingement In A Cross Flow

The configuration here is the same as the one used above except the simulation of a ground plane. This is acheived by placing a plexiglass plate between the airfoil and the test section wall as shown in Figure 3.1b. The distance, h between the airfoil and the plate can be adjusted within a range of 0.2c to 1.5c. For h greater than one chord, the surface pressure distributions around the airfoil showed very little change as compared with a free airfoil under the same operating conditions, both with and without the jet. This being the case, all the results to be discribed here are for the case where h is equal to 0.5c. Since, no wall corrections are applied to the data, results should be treated with some care. However, relative comparisons may still be valid.

Surface Pressure Distributions

The normalized static pressure (C_p) distribution at the midspan of the airfoil is shown in figure 4.12. As before, the abscissa x is normalized with respect to the chord, C and the pressure coefficient is defined as $(p-p_\infty)/q_\infty$. The positive and negative pressure regions on the lower surface of the airfoil are clearly seen in the figure. When compared at corresponding operating conditions the overall features of the distribution looks very much similar to ones shown in figure 4.1 for out of GE. The magnitude of C_p

at sixty percent and eighty percent of the chord on the lower surface of the airfoil is plotted against the velocity ratio, R and is shown in figure 4.13. Also included in the figure is the data for the free airfoil. It is observed that within the scatter of the experiment, the variation of C_p at these locations with R is similar to that of a free airfoil. As in the case of a free airfoil, the upper surface C_p distribution show very little change with R.

The lift and moment coefficients can be calculated from the above pressure distributions and the results are shown in figures 4.14 and 4.15. The variation of the lift coefficient with velocity ratio is presented in figure 4.14. Also included in the figure is the data for the free airfoil. For values of R less than 4, the magnitude of C_ℓ is consistantly higher when compared to a free airfoil at corresponding velocity ratios. Thus the presence of the plate improves the lift of the airfoil for the values of R less than or equal to about 4. As will be shown later, that for the most part of the flow around the airfoil and in particular between the plate and the airfoil, the magnitude of the velocity is equal to the free stream velocity, thus avoiding any errors in C_ℓ caused by the variation of the freestream velocity. The variation of the moment coefficient with velocity ratio is shown in figure 4.15. The variation with R looks very much similar to one observed for a free airfoil.

Wake Measurements

The power off total pressure distribution across the wake behind the trailing edge of an airfoil was measured at 3 different axial locations of 1.2c, 1.5c and 2.0c at the mid span. These results are dipcited in figures 4.16 and 4.17. The normalized total pressure profiles in the wake at the midspan, without the jet are shown in figure 4.16. Also shown in the figure is the location of the plate. It can be seen that in this case the center line of the wake seems to coincide with the axis or the chord line, where as the center-line in the free airfoil lies below the x axis. Also noted in the figure is the magnitude of C_p, which is equal to 1 between the airfoil and the plate and above the airfoil, thus indicating the free stream flow past the airfoil. In addition to these observations figure 4.16c, shows the wake of the plate. Some low pressure region is observed between the plate and the airfoil. Furthur investigation is necessary to explain some of these observations.

The normalized total pressure profiles in the wake of the airfoil with the jet exhausting at 60m/sec (R = 4) are shown in figure 4.17. Figure 4.17a represents the profile at x/c equal to 1.2. Two strong negative pressure regions (For recirculation regions), seperated by a small region of positive pressure is observed. The high velocity region close to the wall can be seen in the figure clearly. Similar observations are made at a location of 1.5c except with more positive pressure regions, as shown in figure 4.17b. Figure 4.17c shows the profiles at x/c equal 2.0. It is interesting to note the disappearence of the wake of the airfoil and a small low pressure region between the airfoil and the plate. The wake of the plate can also be seen in the figure.

Conclusions

From this exploratory investigation and for the case of flow past an airfoil with a jet issuing from the lower surface the following conclusions are made. The static pressure distribution on the lower surface of the airfoil shows a positive and negative pressure region ahead and behind the jet respectively. Most of the gross changes that occur in C_ℓ and C_m with velocity ratio are primarily due to the changes in the pressure distribution in those regions mentioned above. The variation of coefficient of lift with velocity ratio display three regions each corresponds to a different behavior of C_ℓ. In the first region which extends up to a velocity ratio of 2.0, the magnitude of C_ℓ increases monotonically and reached a maxumum value of about 0.3 at R equal to two. In the second regions which ends at R equals 3.0, a substantial drop in C_ℓ is noted. For R greater than 3.0, which is designated as third region the magnitude of C_ℓ shows little variation with R. From the total pressure profiles in the wake, it is observed that airfoil wake center line moves up with velocity ratio when compared to a free airfoil. A large negative pressure region is observed between the jet and the airfoil

For the case of flow past an airfoil with a jet issuing from the lower surface and impinging on a plate, the following conclusions are made: For h/c greater than or equal to 1.0, the static pressure distribution on the surface of the airfoil show little variation when compared with a free airfoil at corresponding conditions. For h/c equal to 0.5, the C_p distribution show features similar to that of a free airfoil. Except for higher magnitude of C_ℓ for R less than about 4, the variation with R looks very much similar to that of a free airfoil. As in the previous case the wake profiles display the negative pressure region between the jet and the wake.

Due to the preliminary nature of the experiment care should be taken in deducing any numerical information from the data. However, trends and relative comparisons may still be valid. The present studies were exploratory and are not complete enough to enable a detailed understanding of the complex flow development of the jet and the flow around the airfoil. All the implications of the results obtained are not yet fully understood. Furthur detailed investigations are clearly needed to study the flow details at the nozzle exit and the flow structure around it on the surface of the airfoil. Furthermore, mean and turbulent velocity measurements should be made both in the wake and in the flow field around the jet to document the flow structure.

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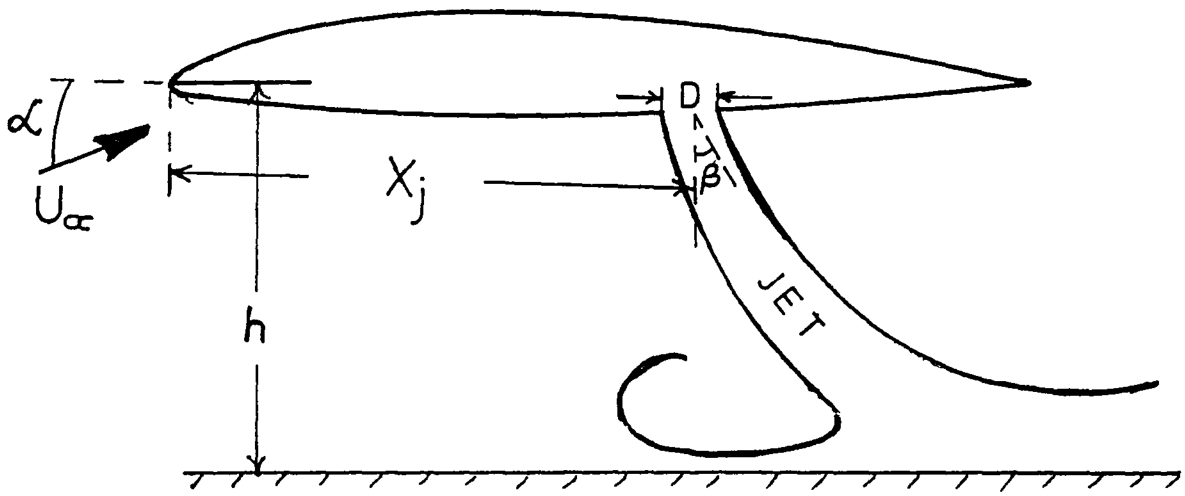


Figure 2.1 Schematic of the Configuration

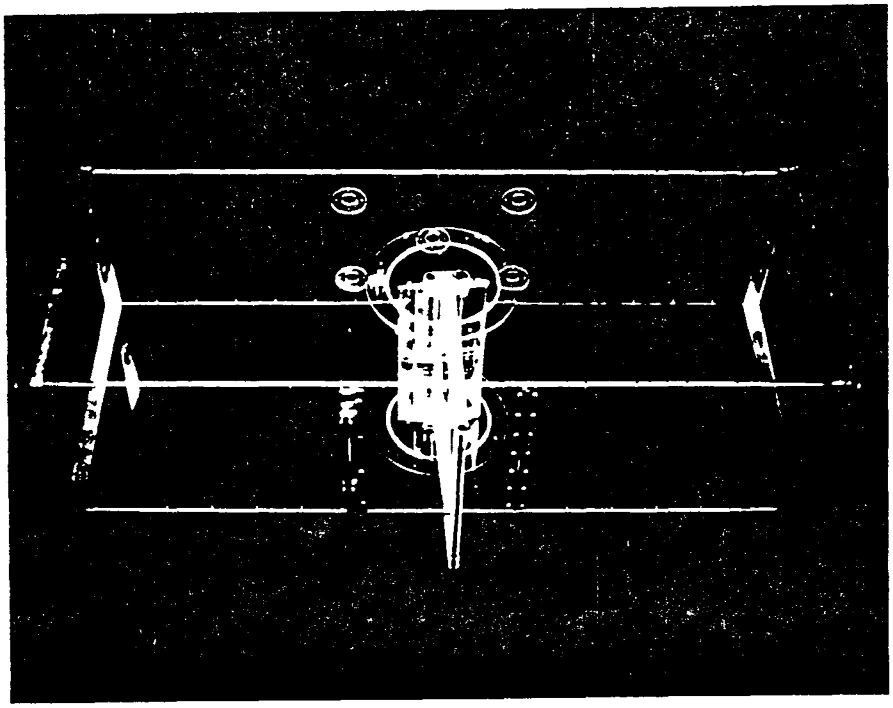


Figure 3.1a Photograph of the test section with the model in place

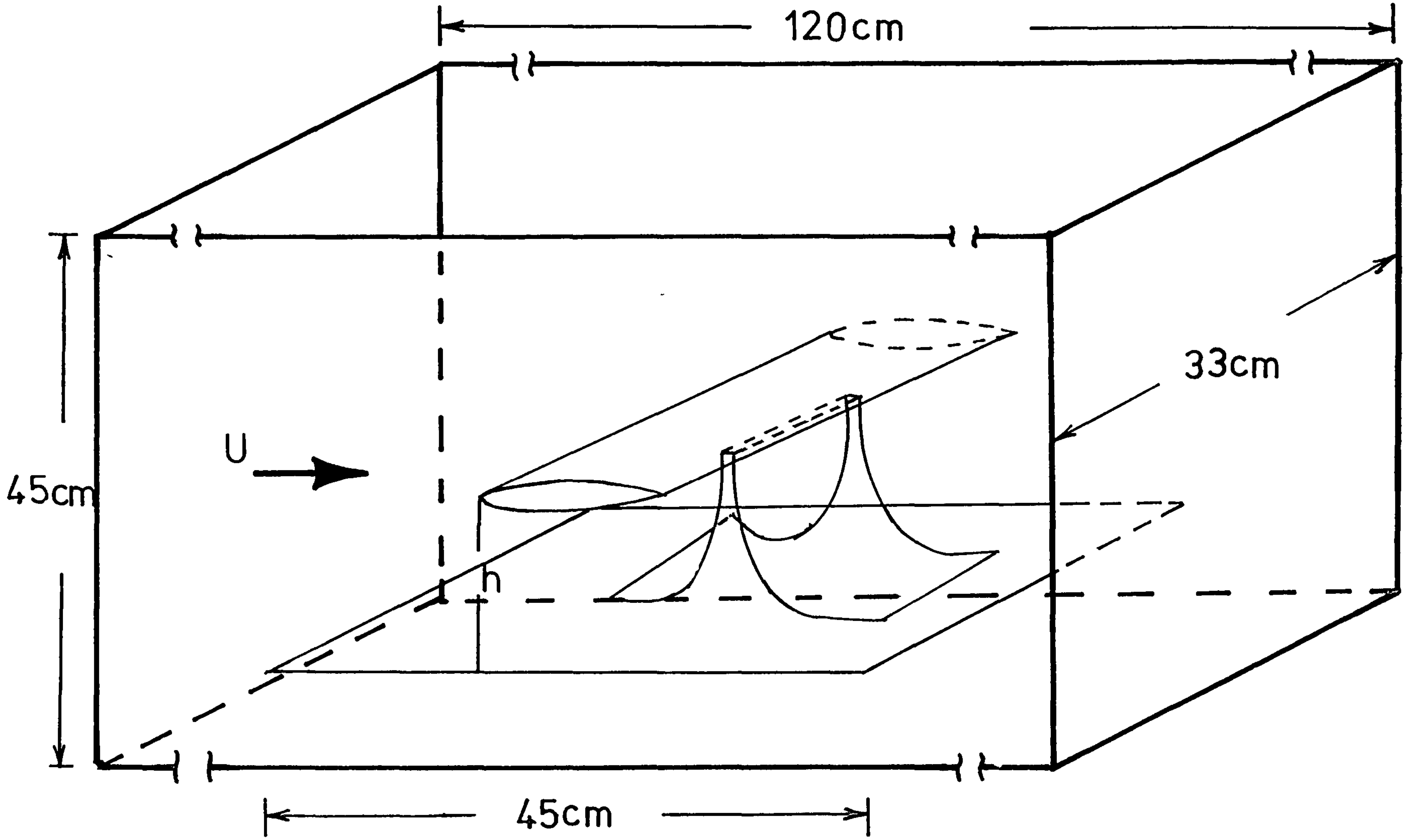
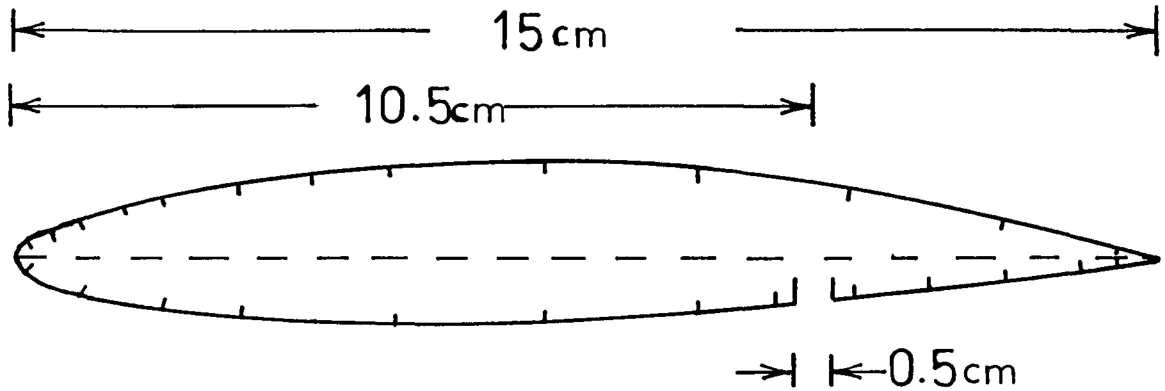


Figure 3.1b Schematic arrangement of the model in the test section



Static Pressure Tap Locations

X/C	YU/C	YL/C
0	1	1
.013	2	
.033	3	27
.06	4	
.1	5	26
.133	6	
.2	7	25
.267	8	
.333	9	24
.467	10	23
.6	11	22
.667		21
.733	12	20
.8		19
.867	13	18
.933		17
.967	14	16
1.000	15	15

Ordinates of the Wing Section

X/C	YU/C	YL/C
0	0	0
.10	.015	- .015
.20	.020	- .020
.049	.032	- .033
.099	.045	- .045
.148	.056	- .050
.198	.064	- .053
.247	.071	- .055
.296	.077	- .056
.395	.082	- .056
.494	.083	- .053
.593	.079	- .049
.692	.069	- .042
.791	.051	- .032
.889	.028	- .019
.988	.002	- .003
1.000	0	0

Figure 3.2 Co-ordinates and geometry of the airfoil

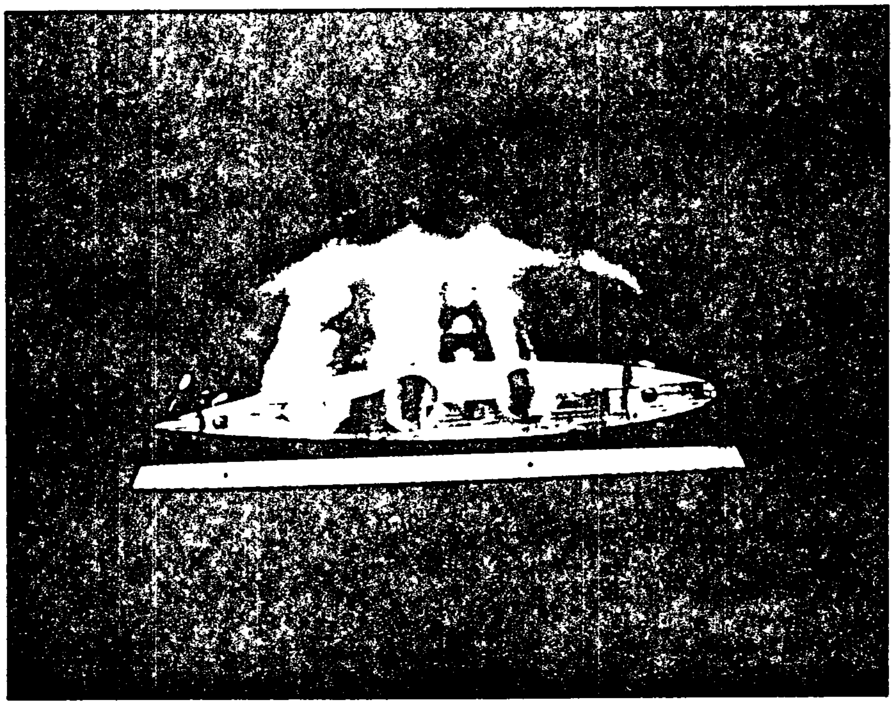


Figure 3.3 End view of the airfoil

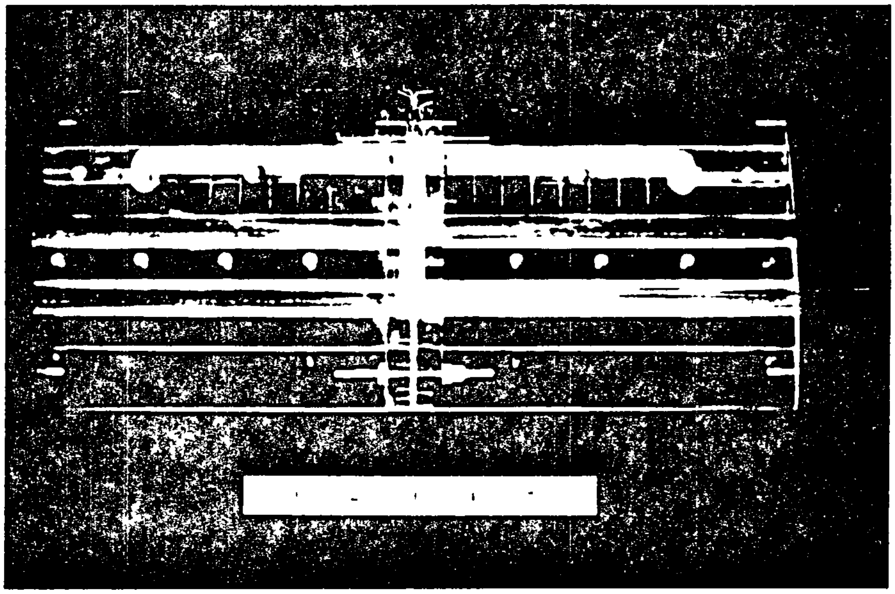


Figure 3.4 Top view of the airfoil

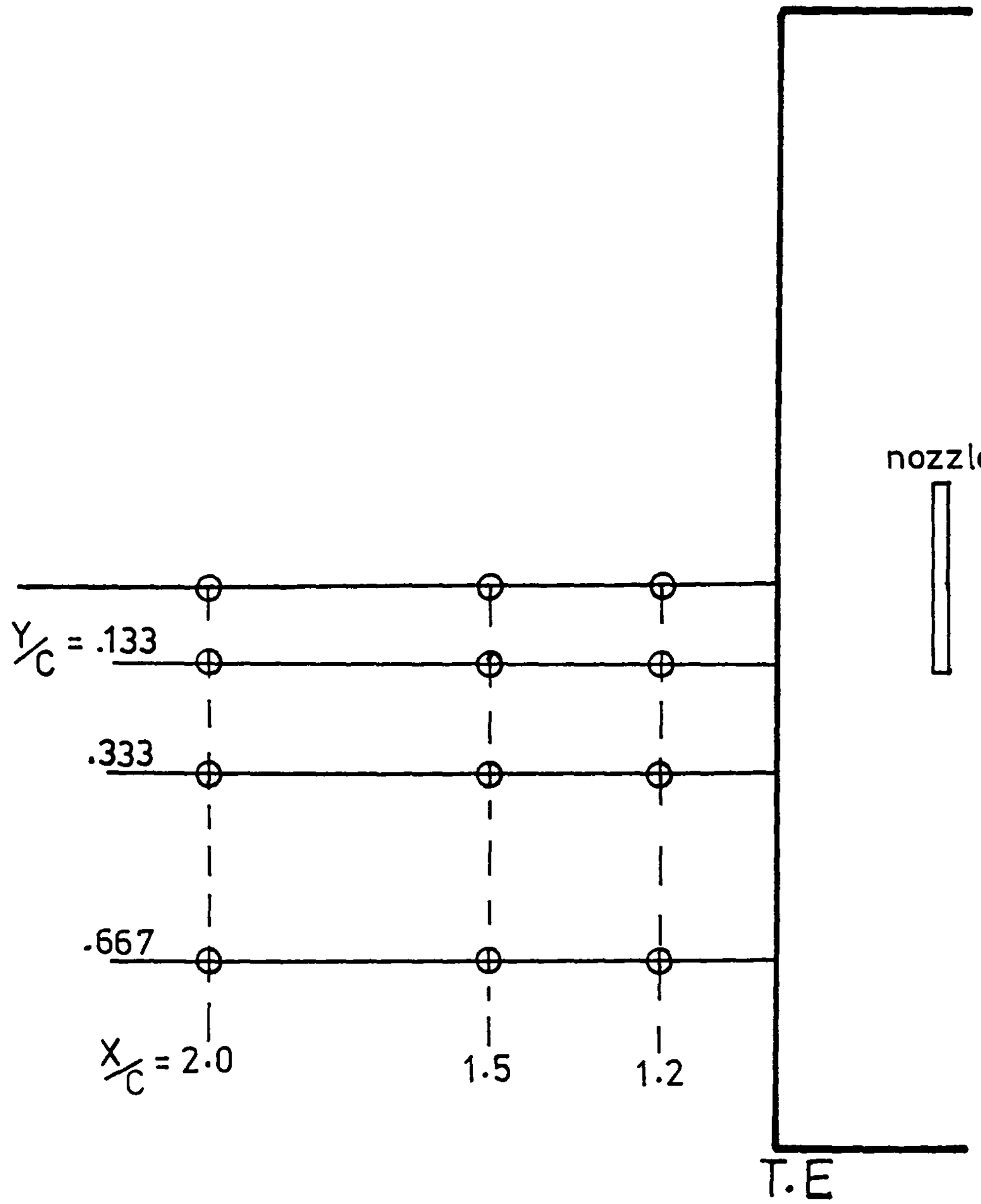
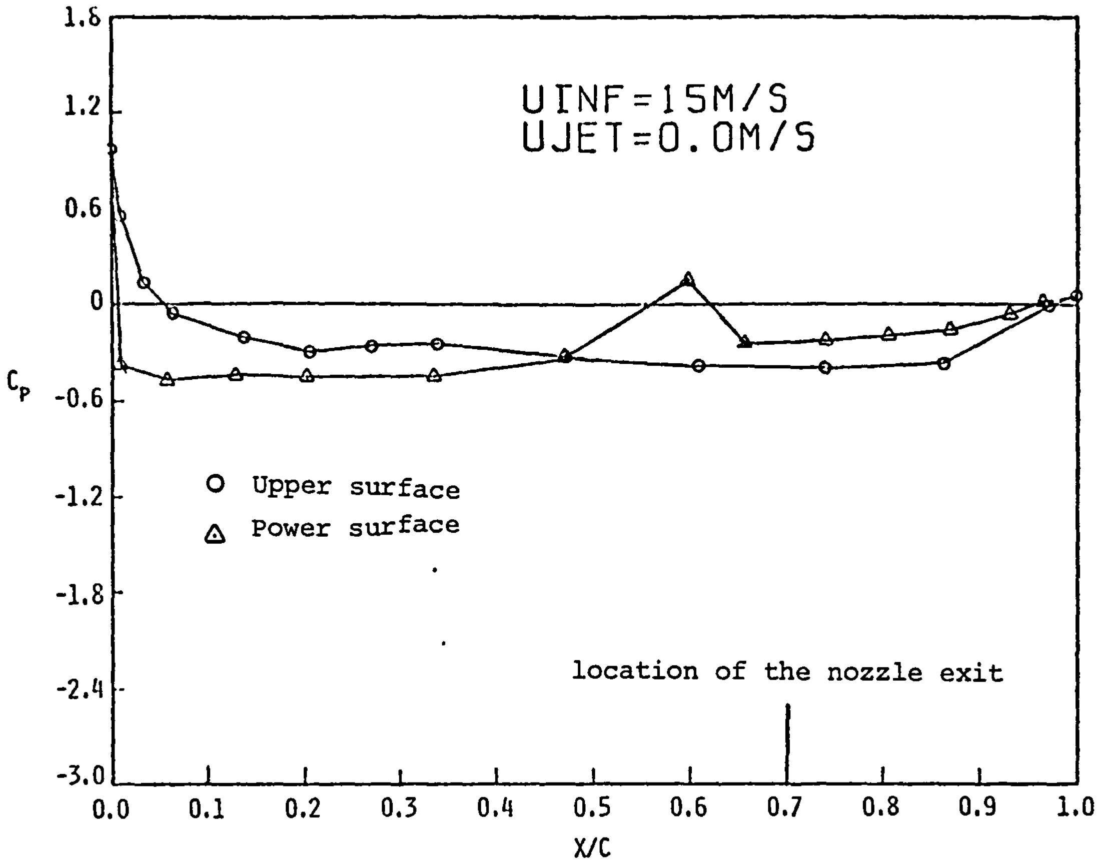


Figure 3.5 Wake measurement locations



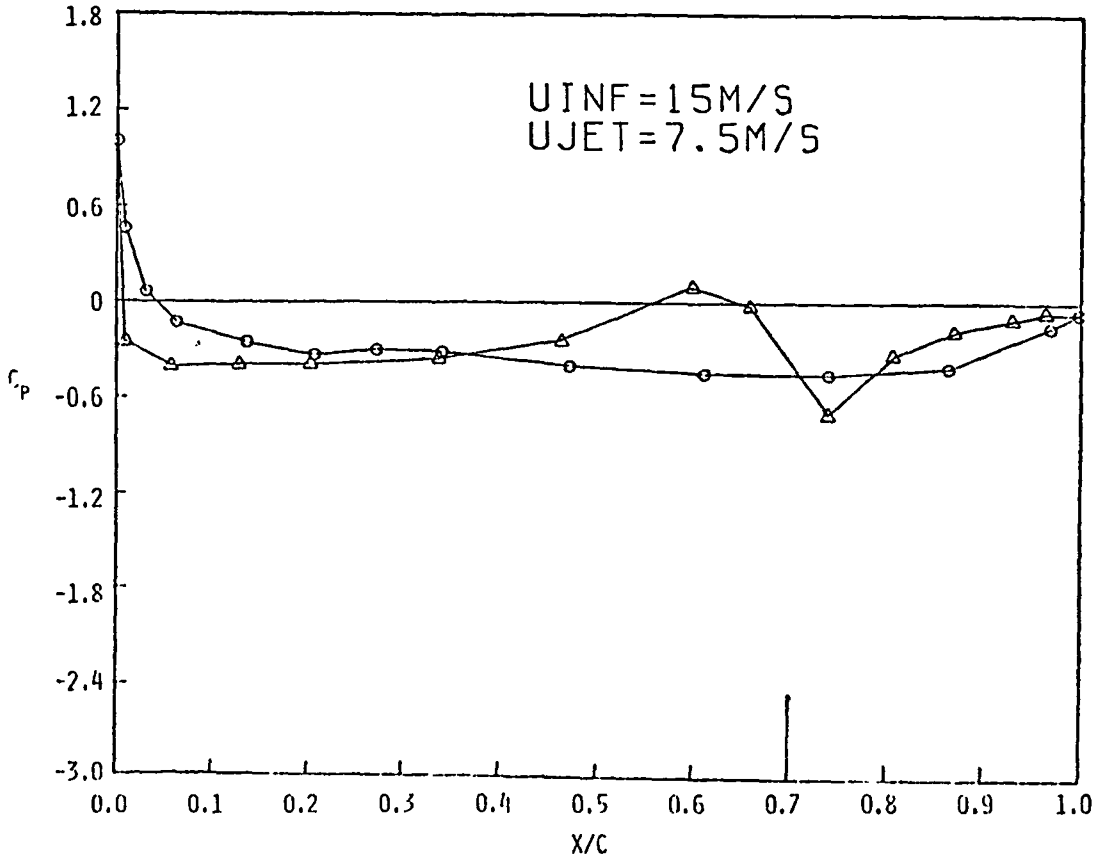
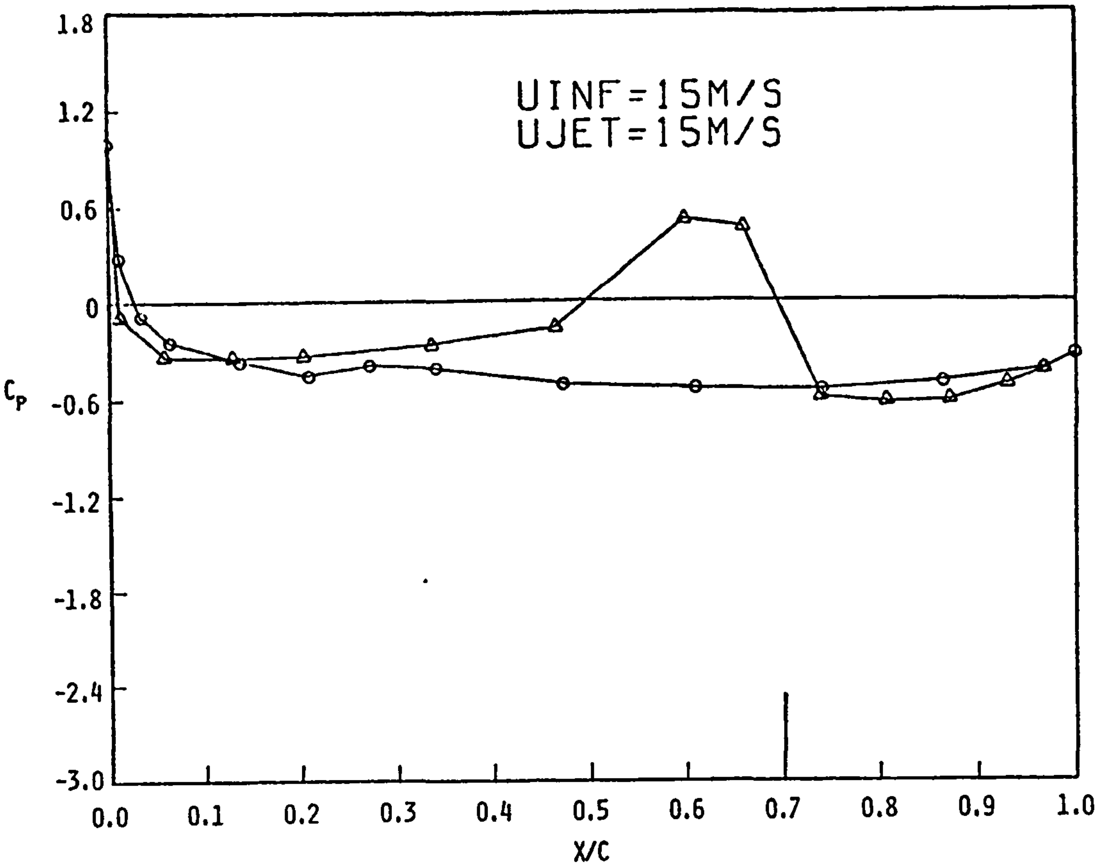


Figure 4.1 continued



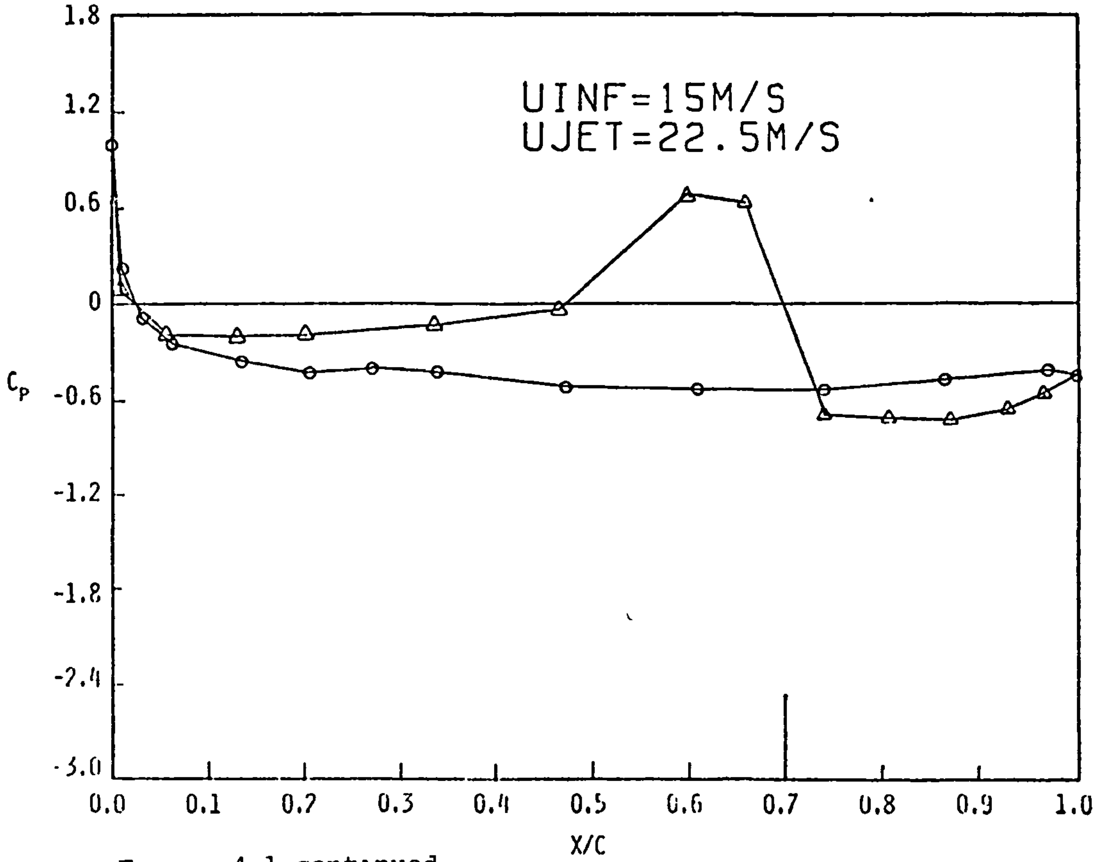
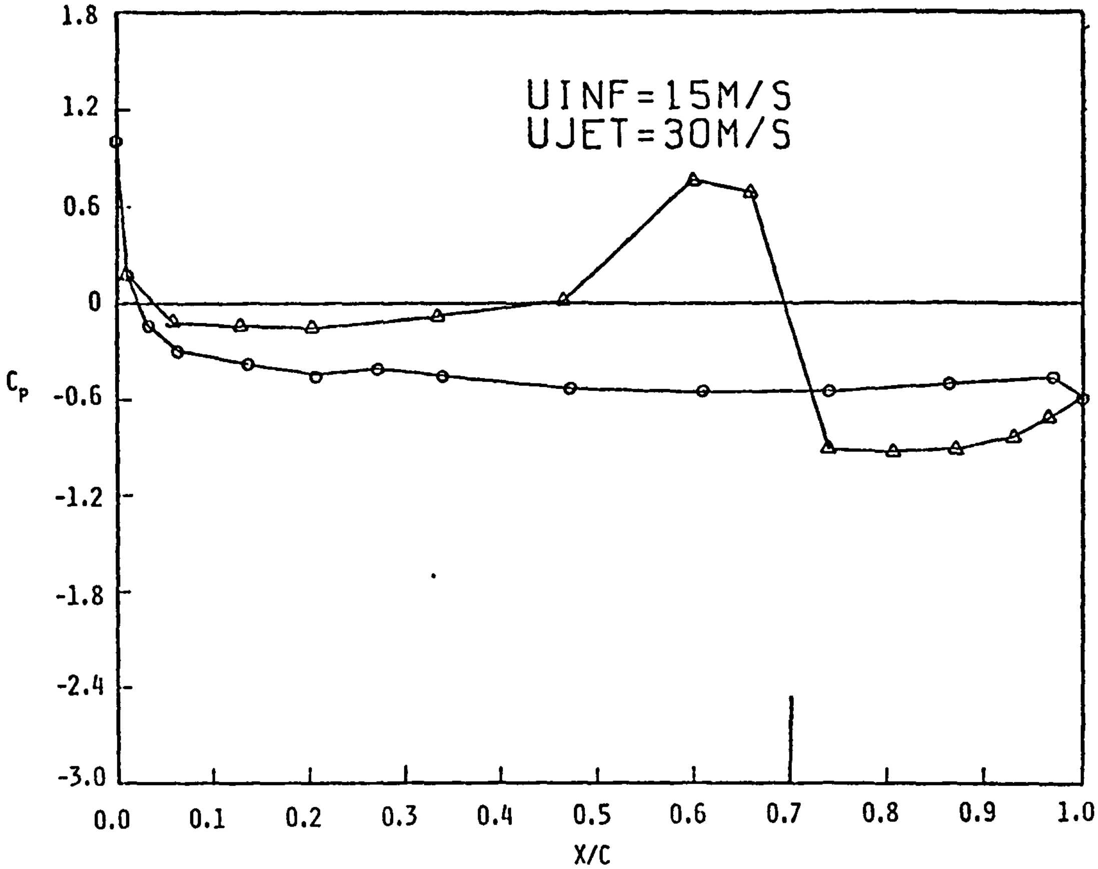


Figure 4.1 continued



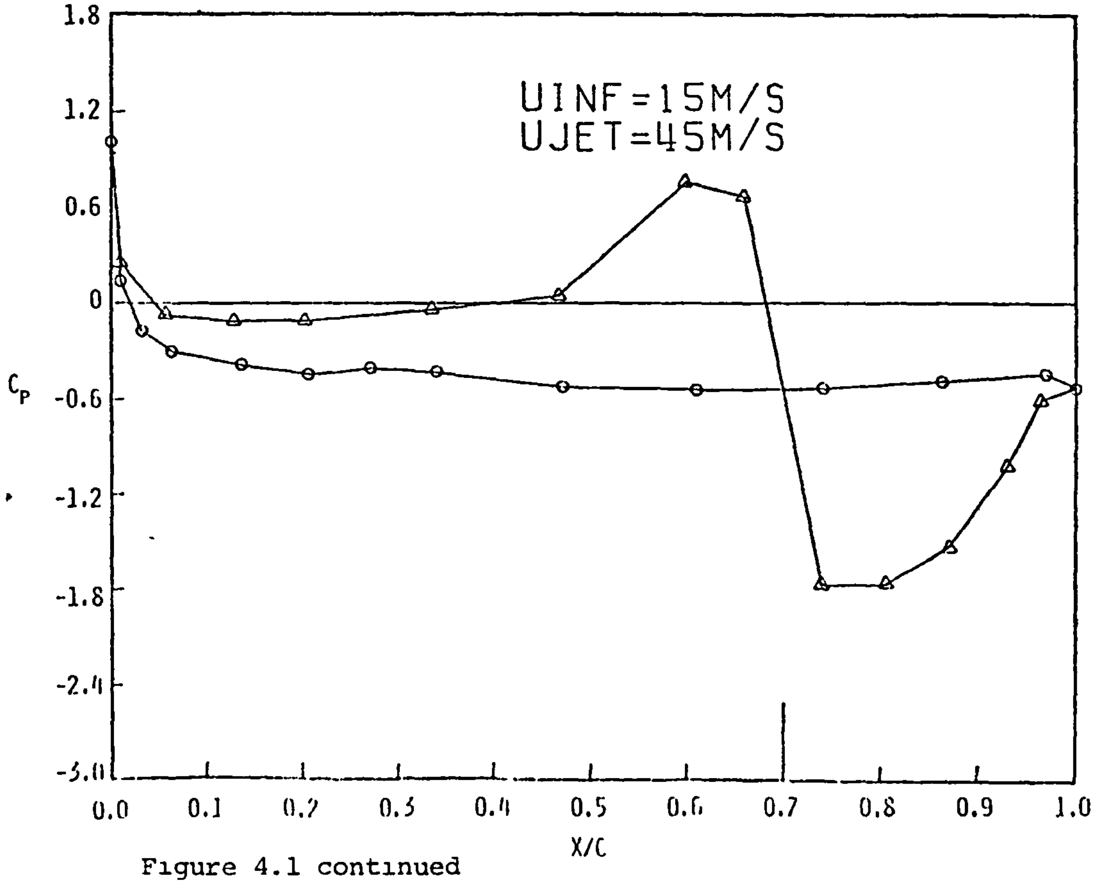


Figure 4.1 continued

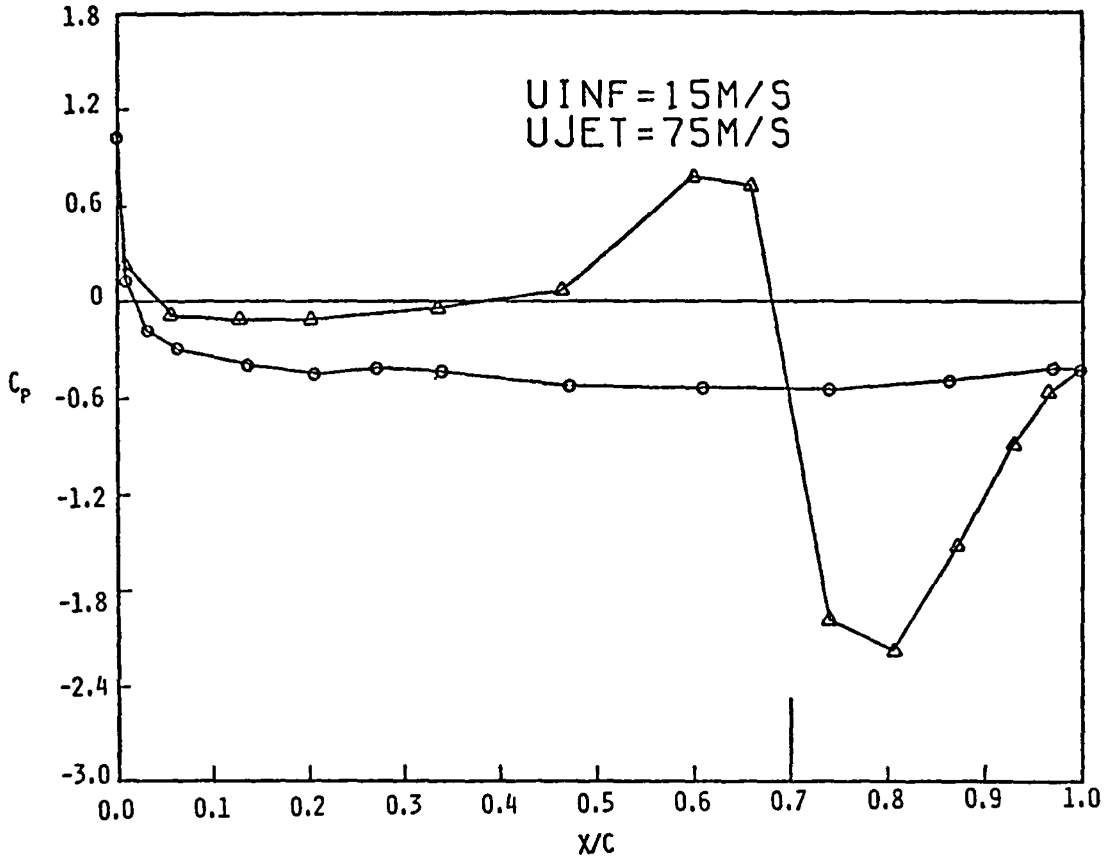


Figure 4.1 Surface pressure distribution of the airfoil at different velocity ratios

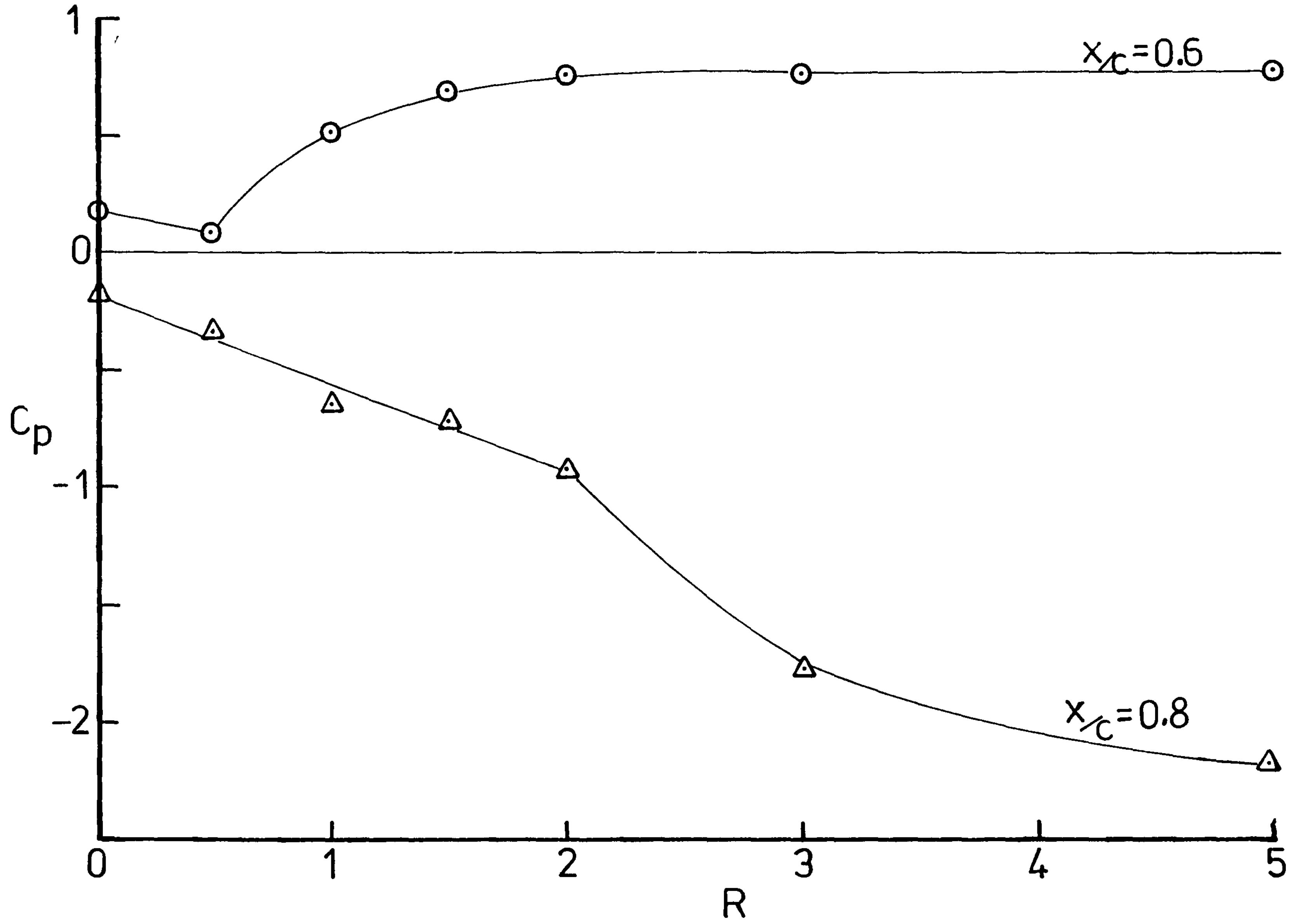


Figure 4.2 Variation of C_p at 60 and 80 percent of the chord with velocity ratio

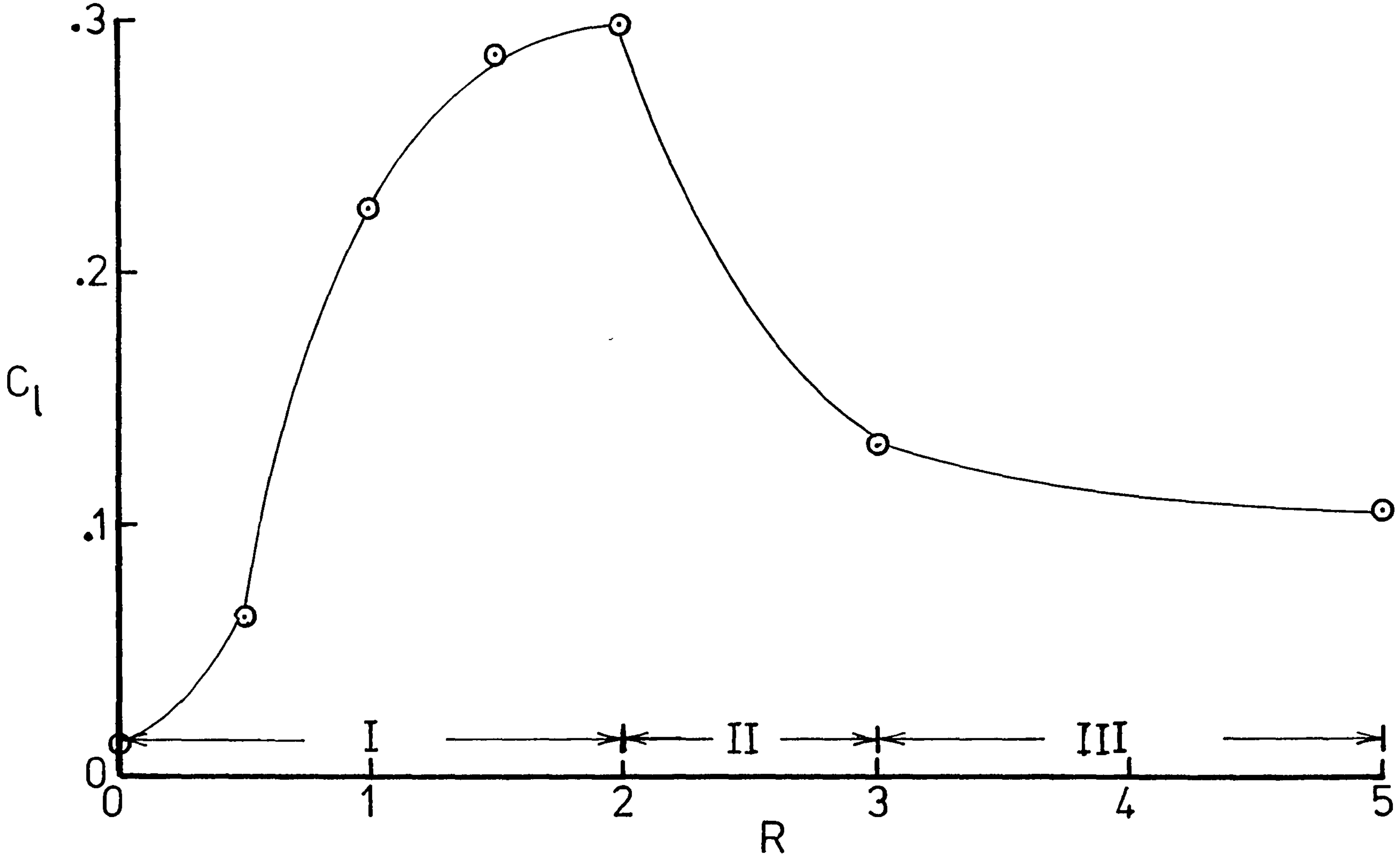


Figure 4.3 Variation of lift coefficient with velocity ratio

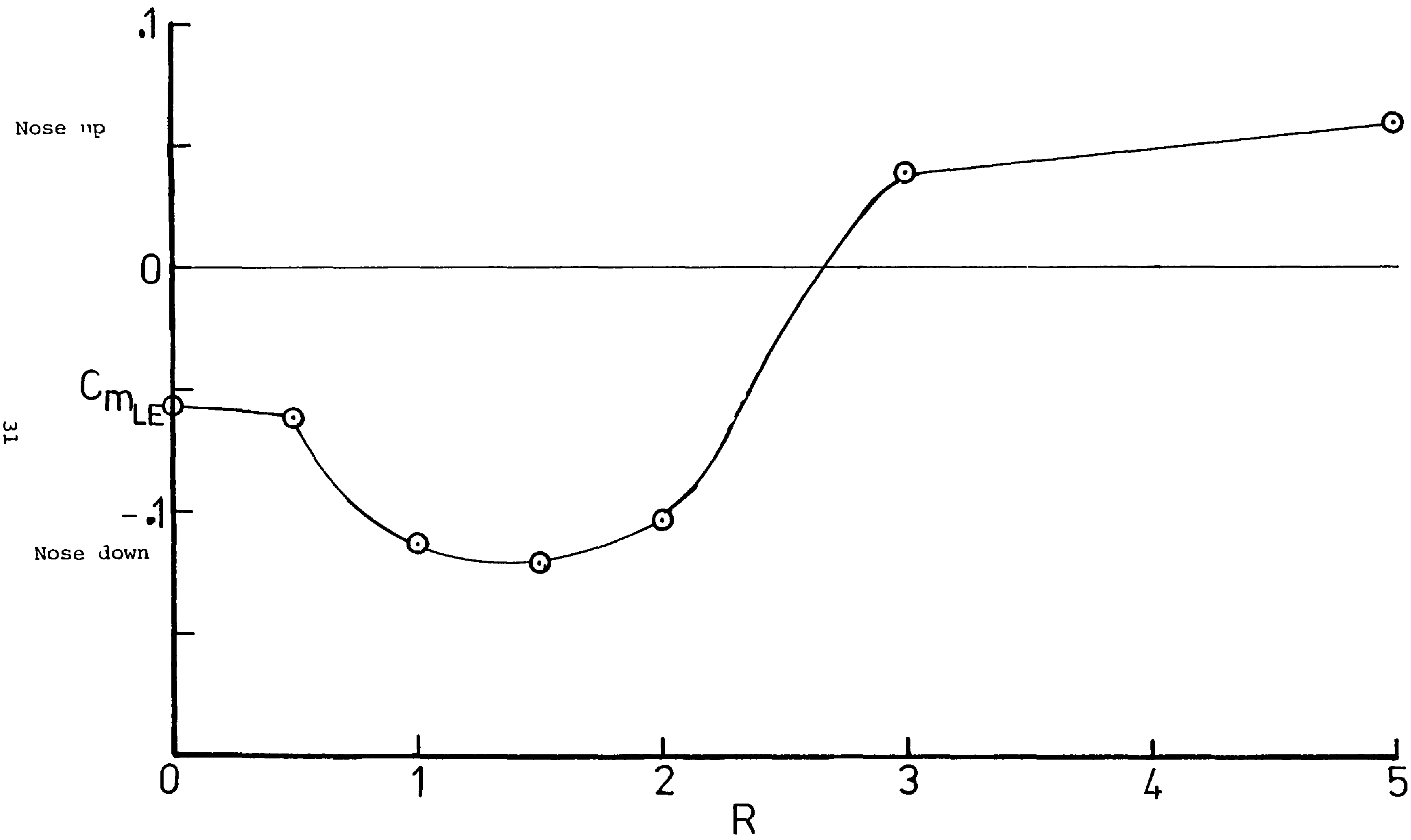


Figure 4.4 Variation of the moment coefficient with velocity ratio

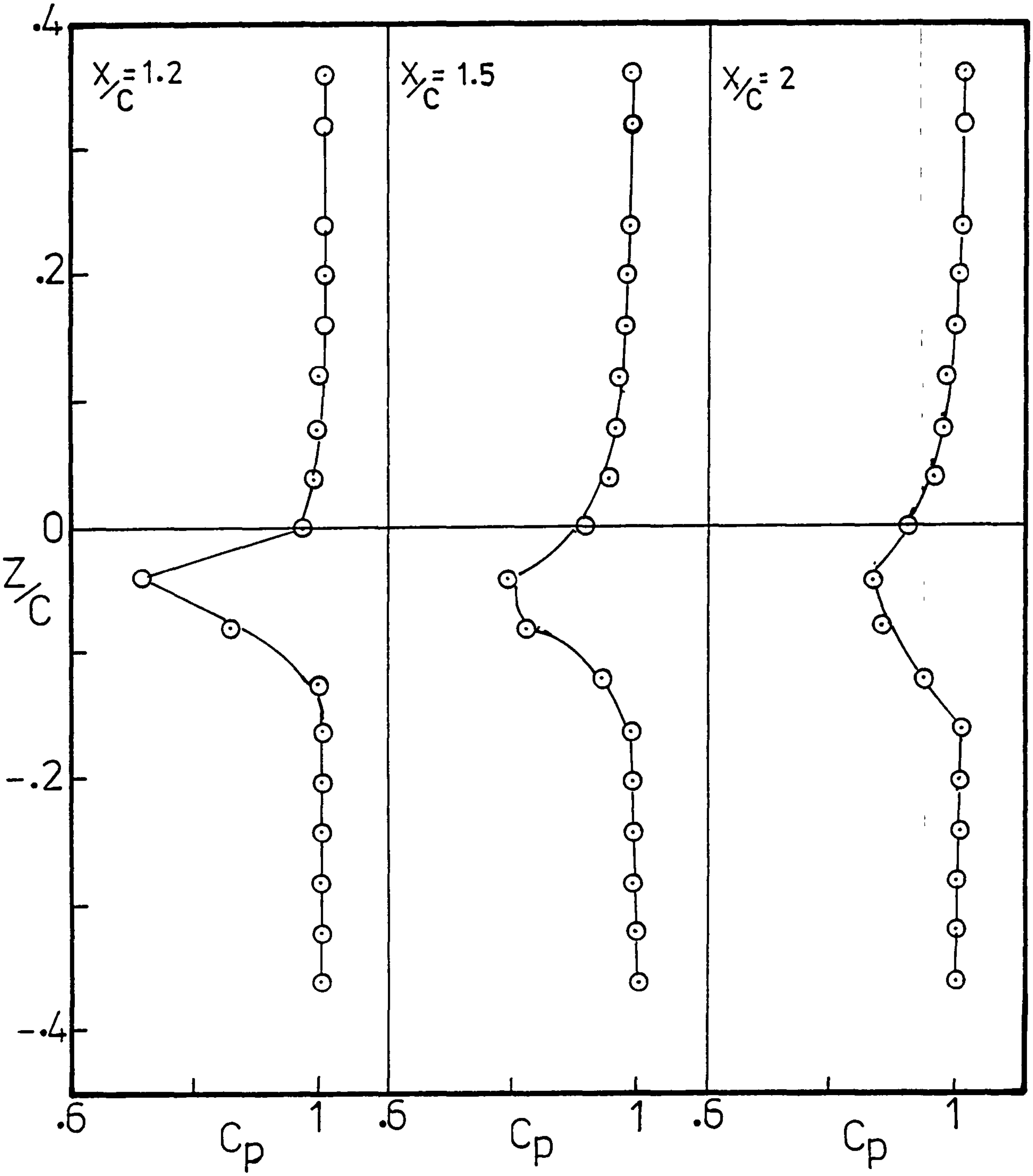


Figure 4.5 Wake profiles of the airfoil at the mid span without the jet

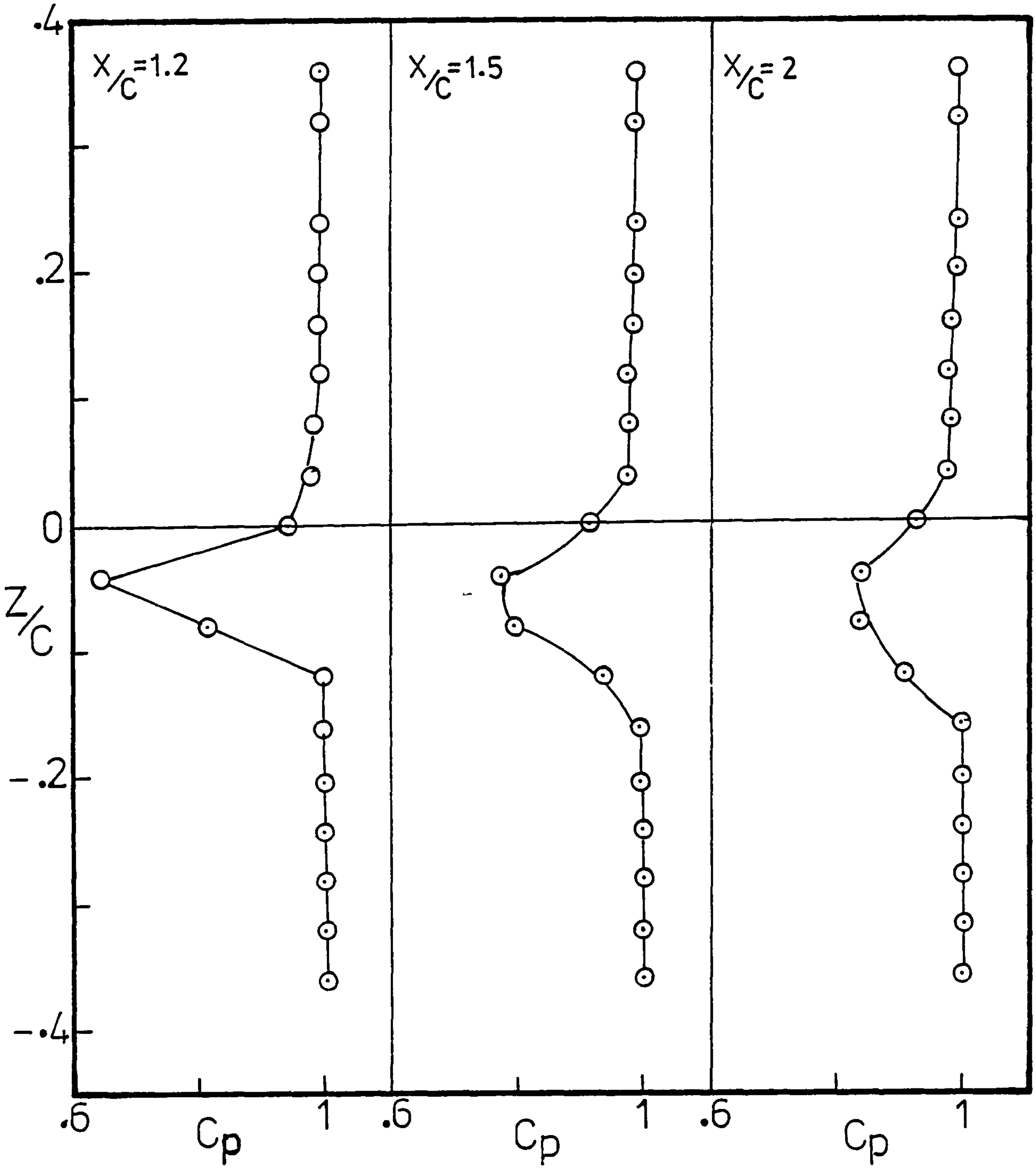


Figure 4.6 Wake profiles of the airfoil at 0.67c along the span, with out the jet

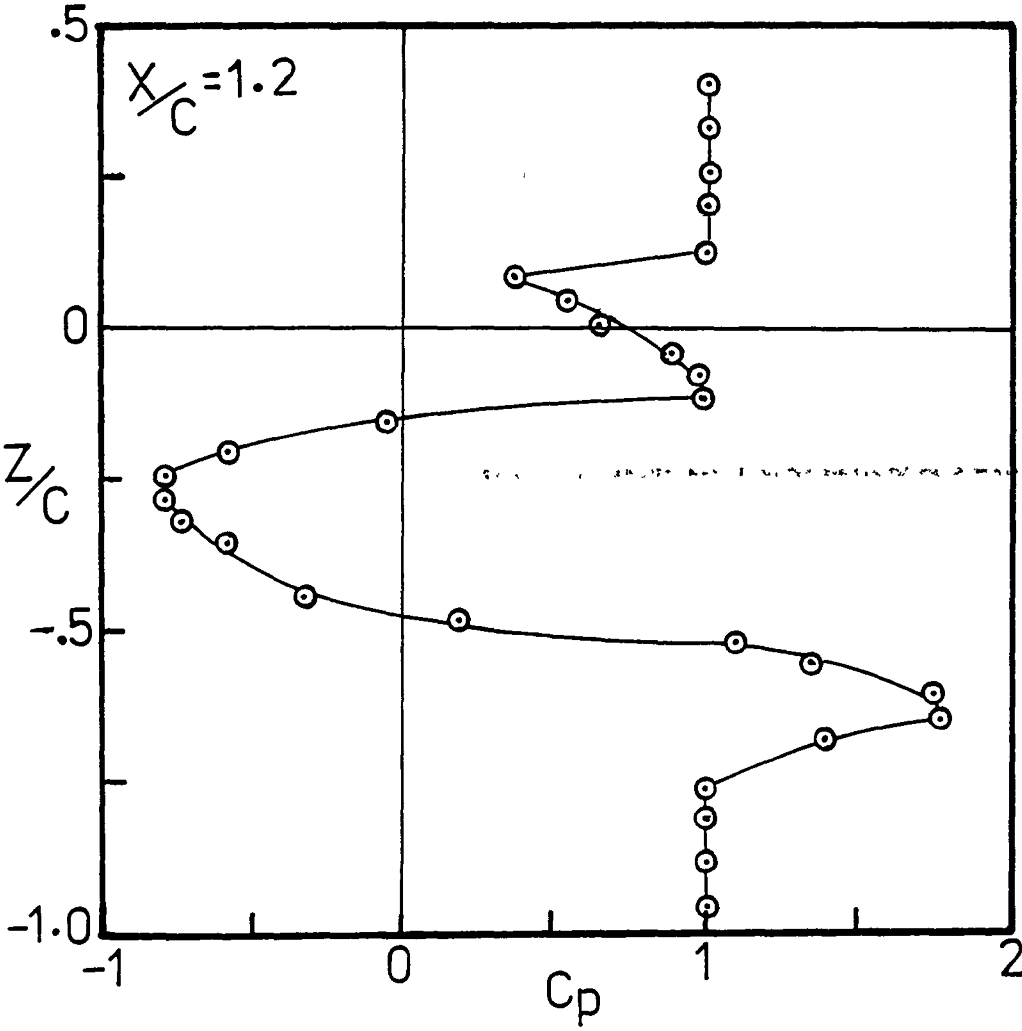


Figure 4.7a Wake profile at 1.2c with the jet ; R = 4 measurements at midspan

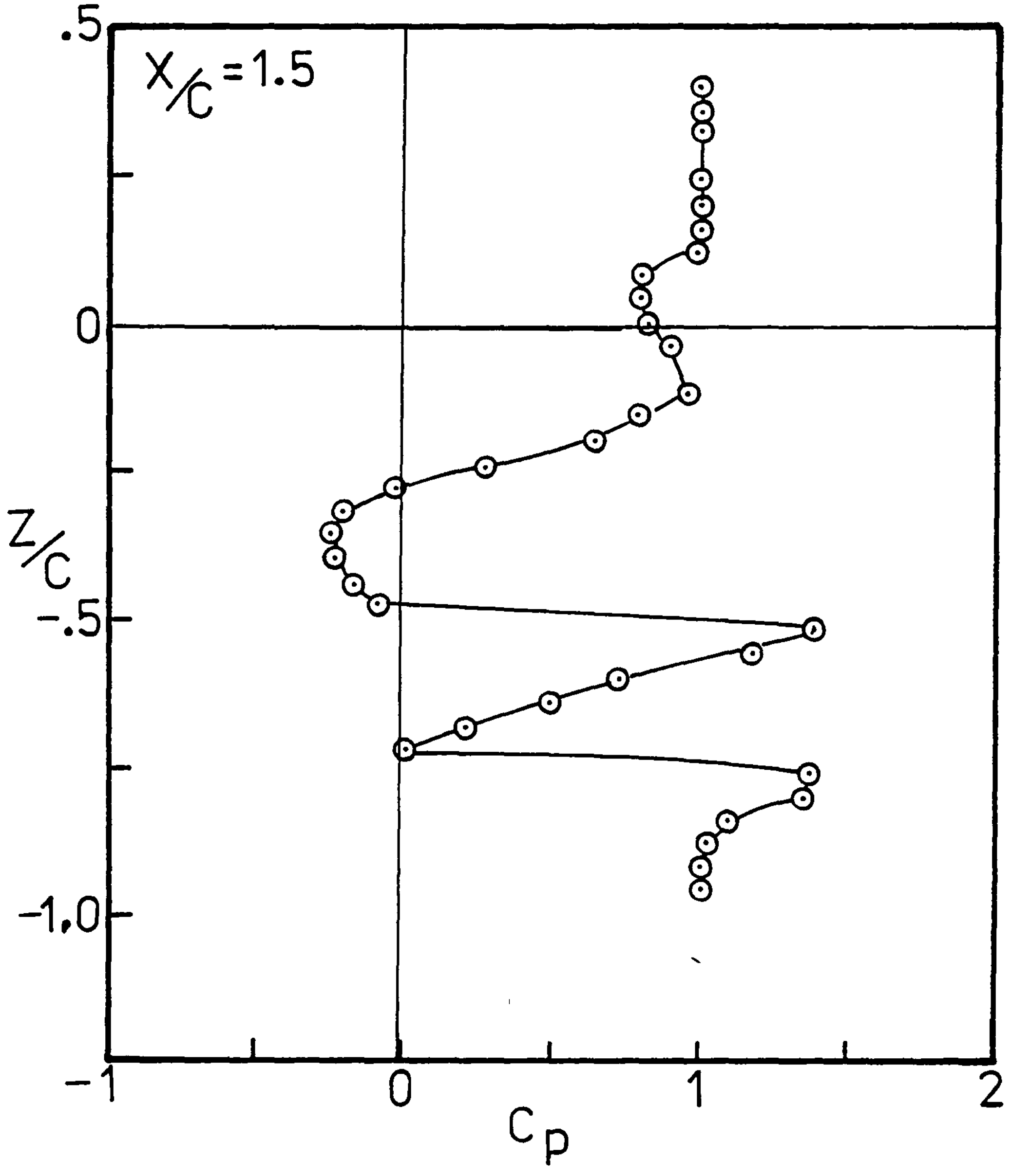


Figure 4.7b Wake profile at 1.5c with the jet

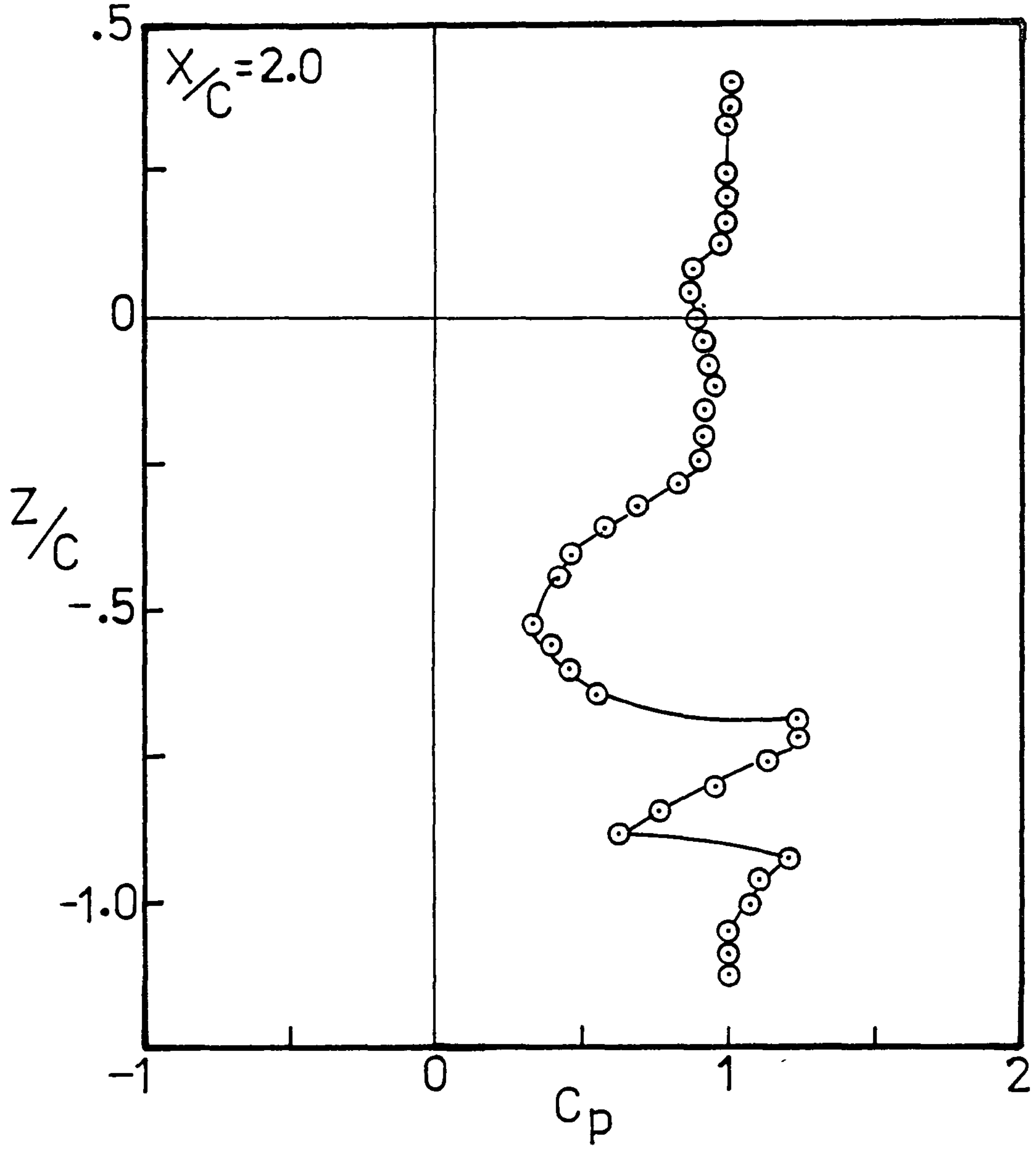


Figure 4.7c Wake profile at 2c with the jet

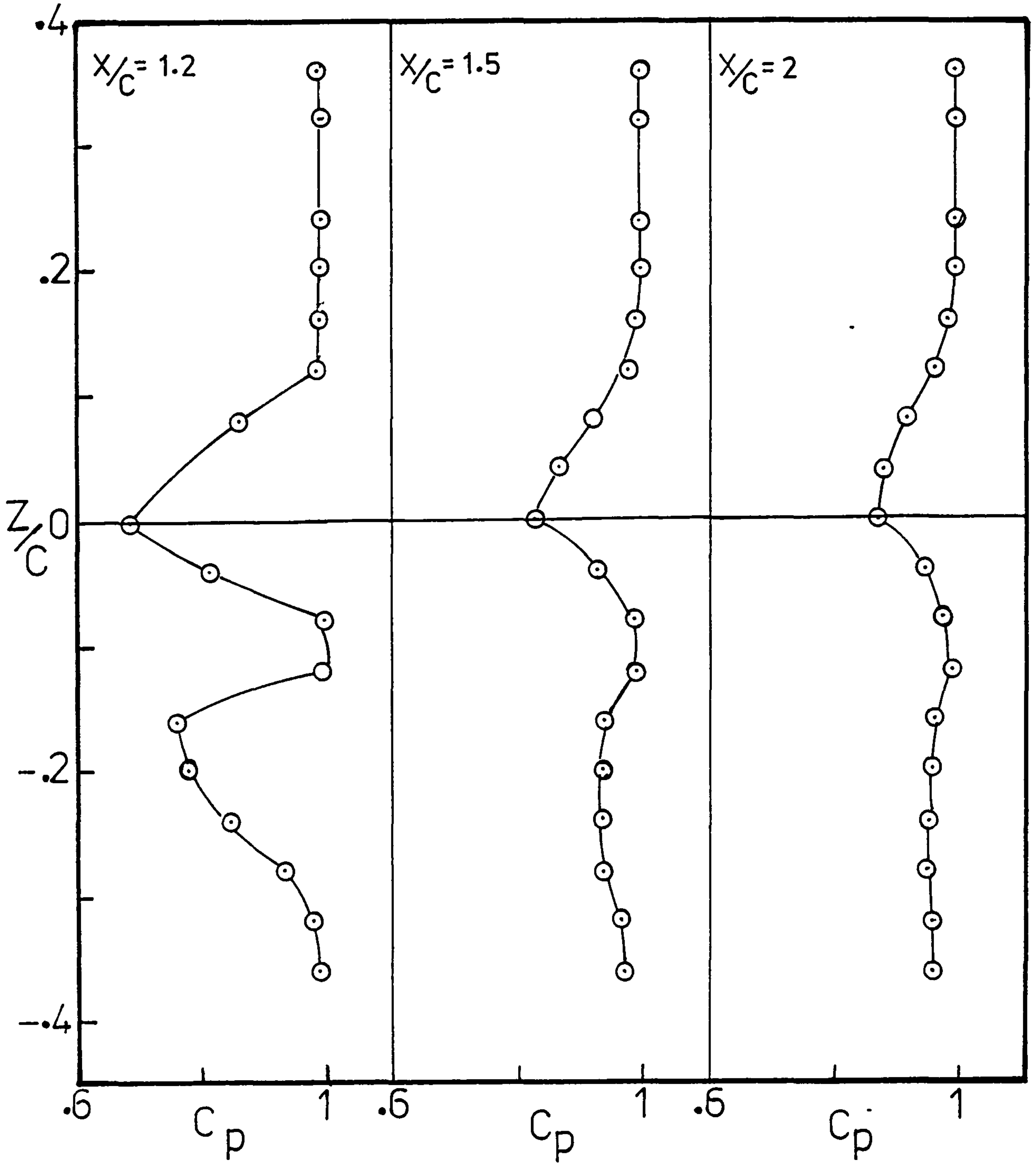


Figure 4.8 Wake profiles at .33c along the span with the jet; R = 4

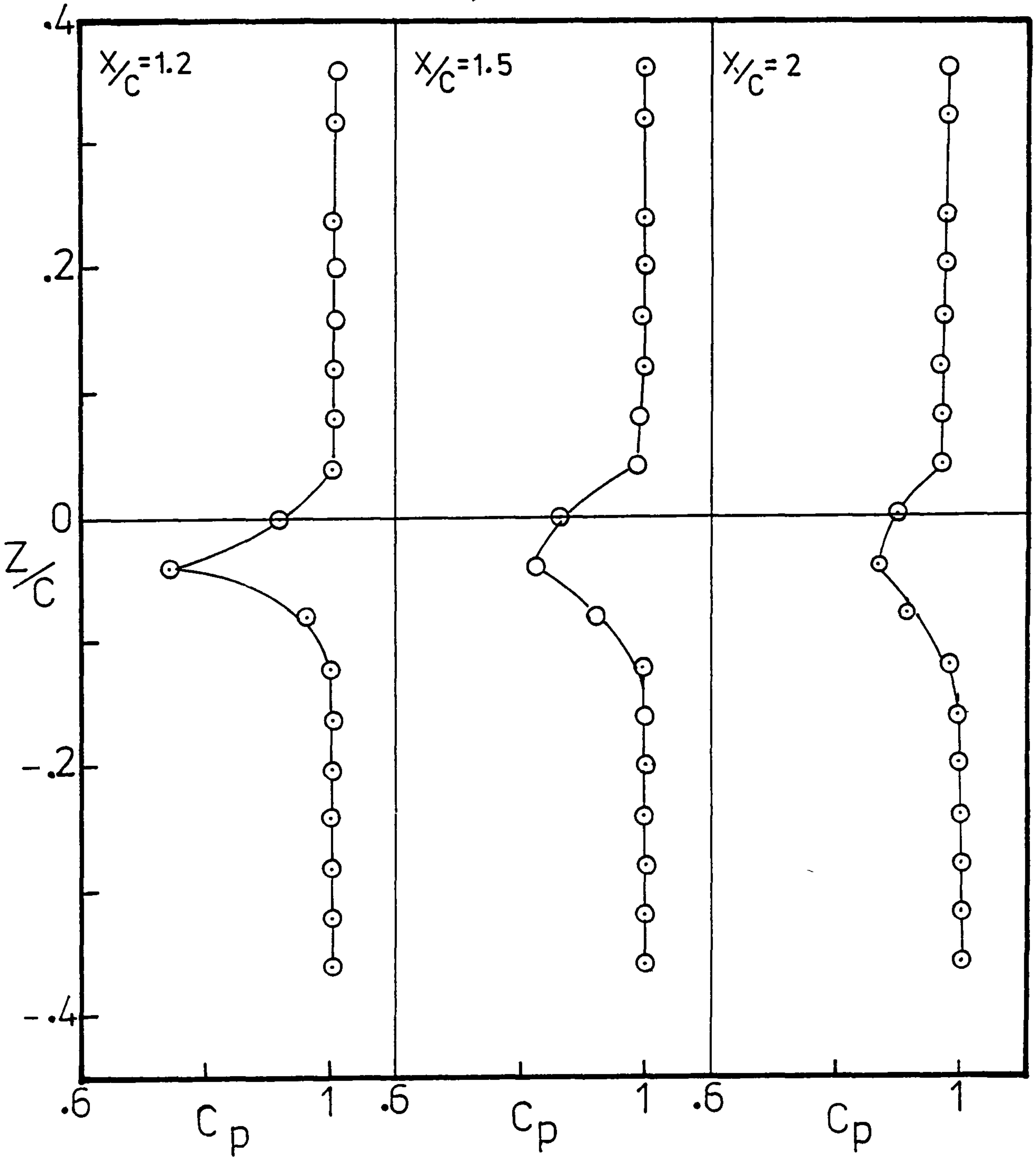


Figure 4.9 Wake profiles at 0.67c along the span with the jet; R = 4

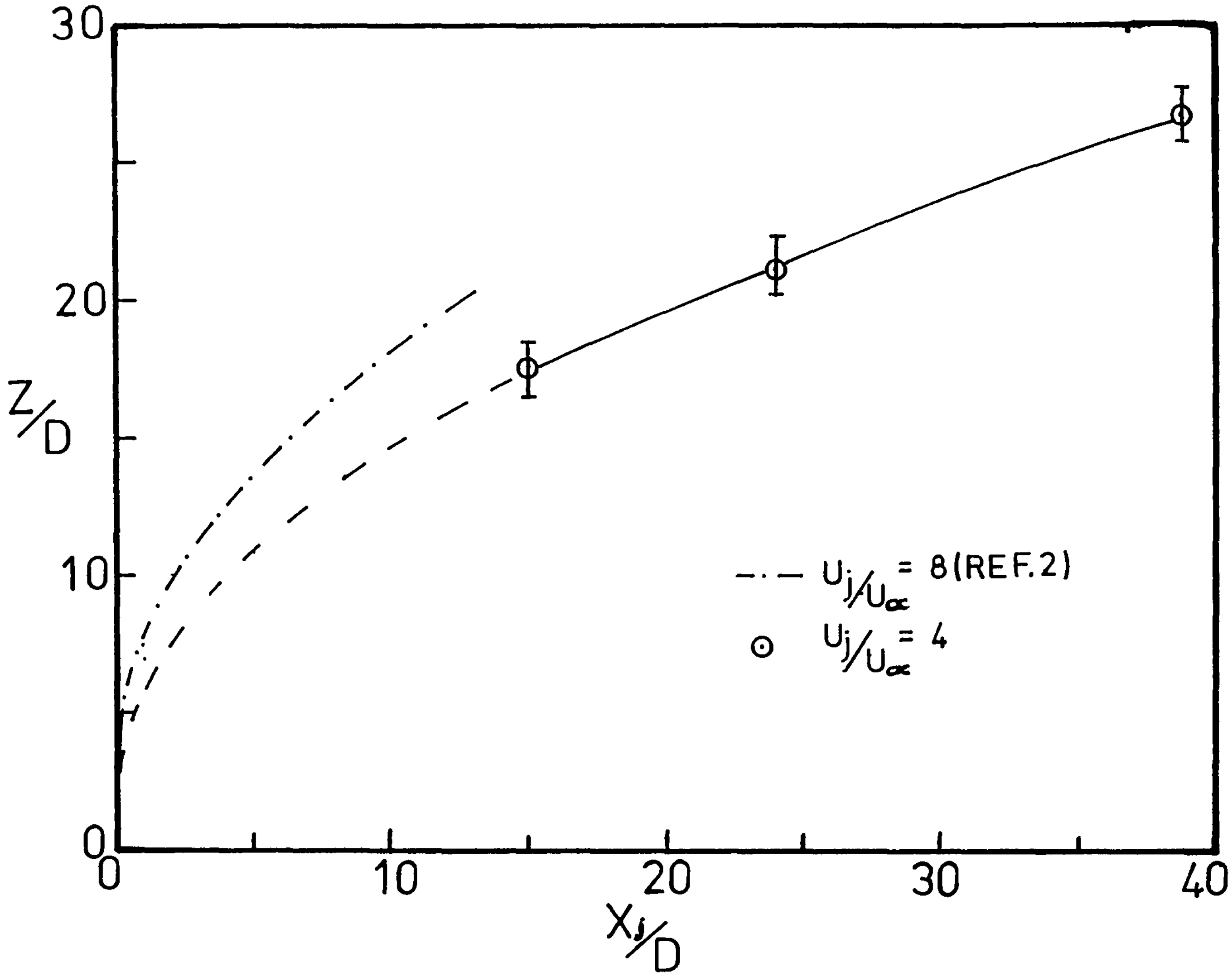


Figure 4.10 Center line of the jet with down stream distance

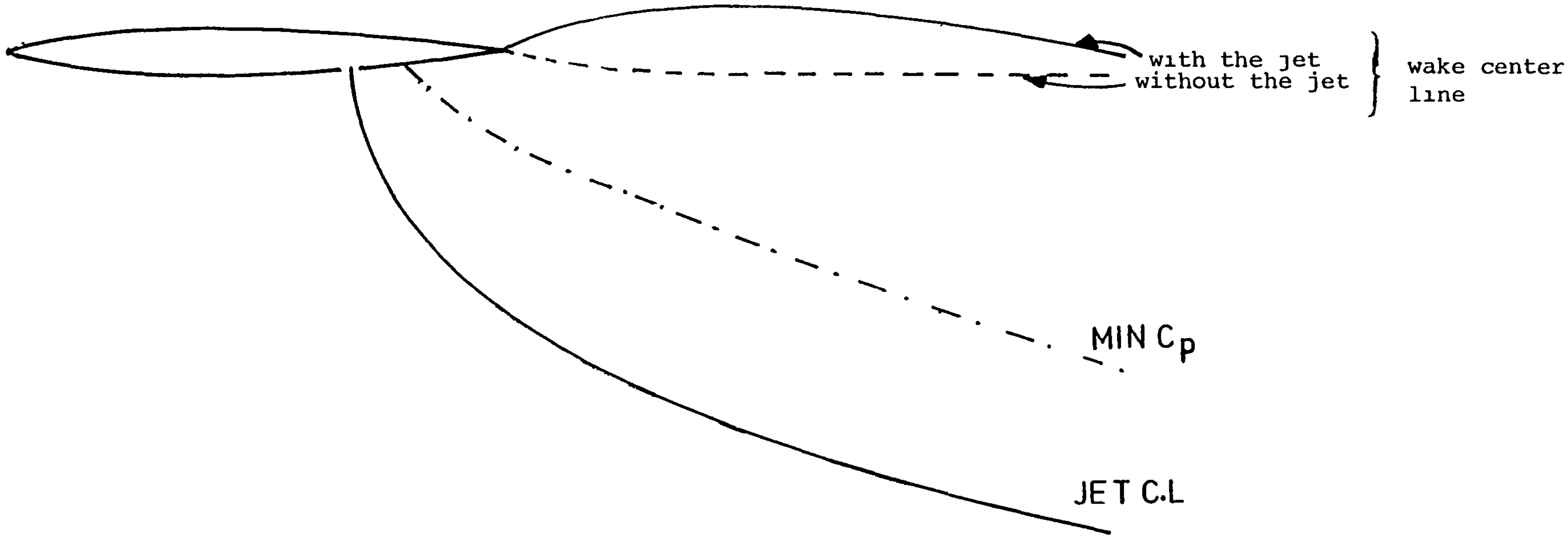
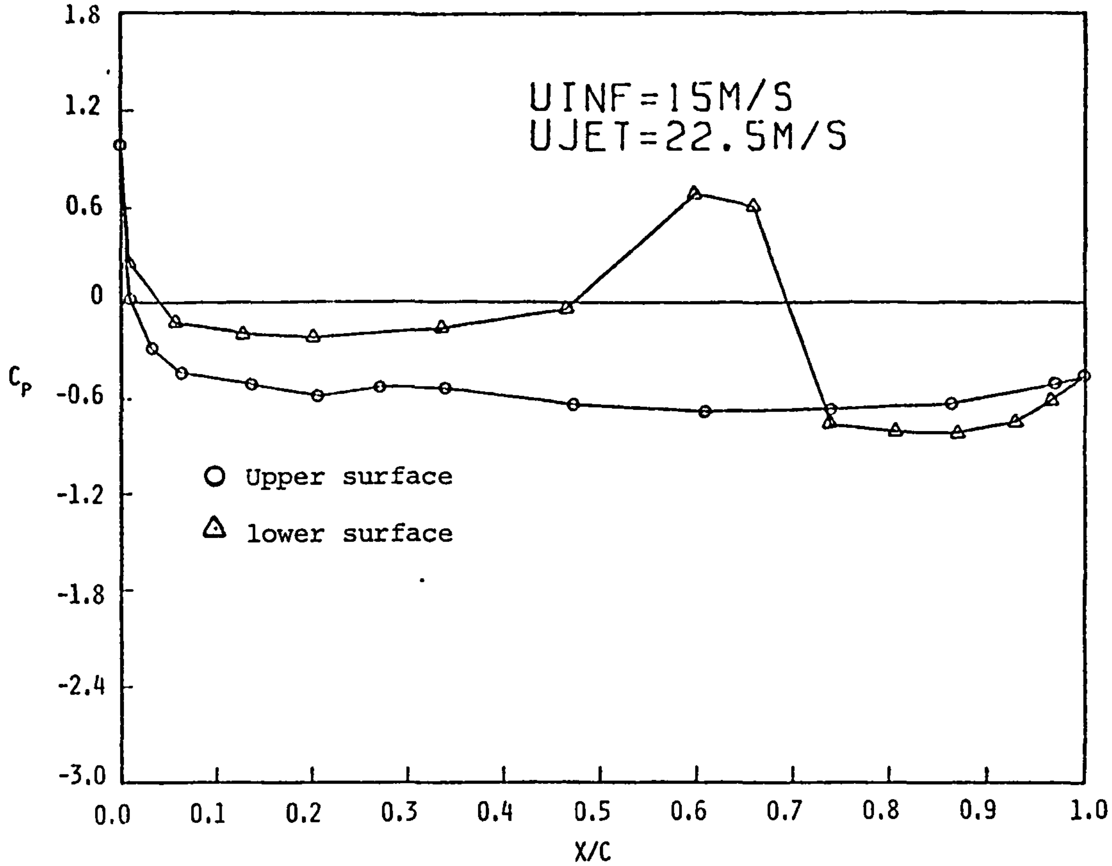


Figure 4.11 Schematic of the wake and jet center lines



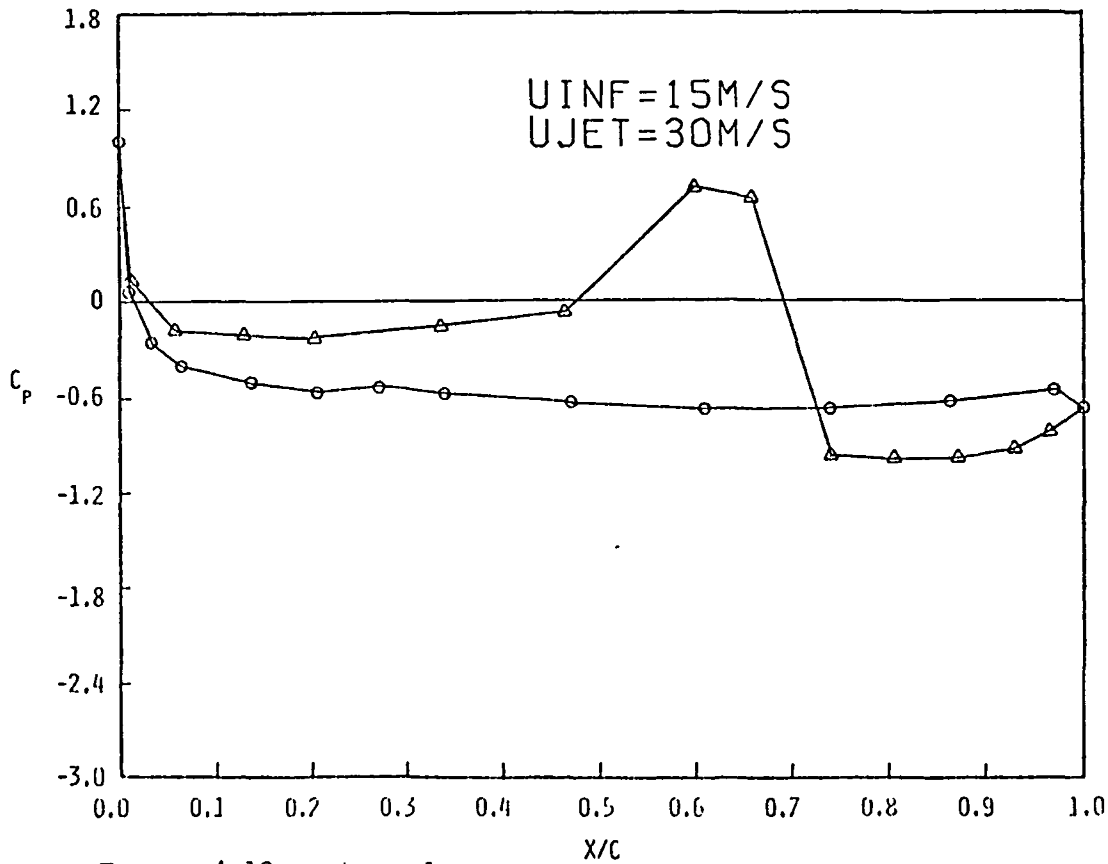
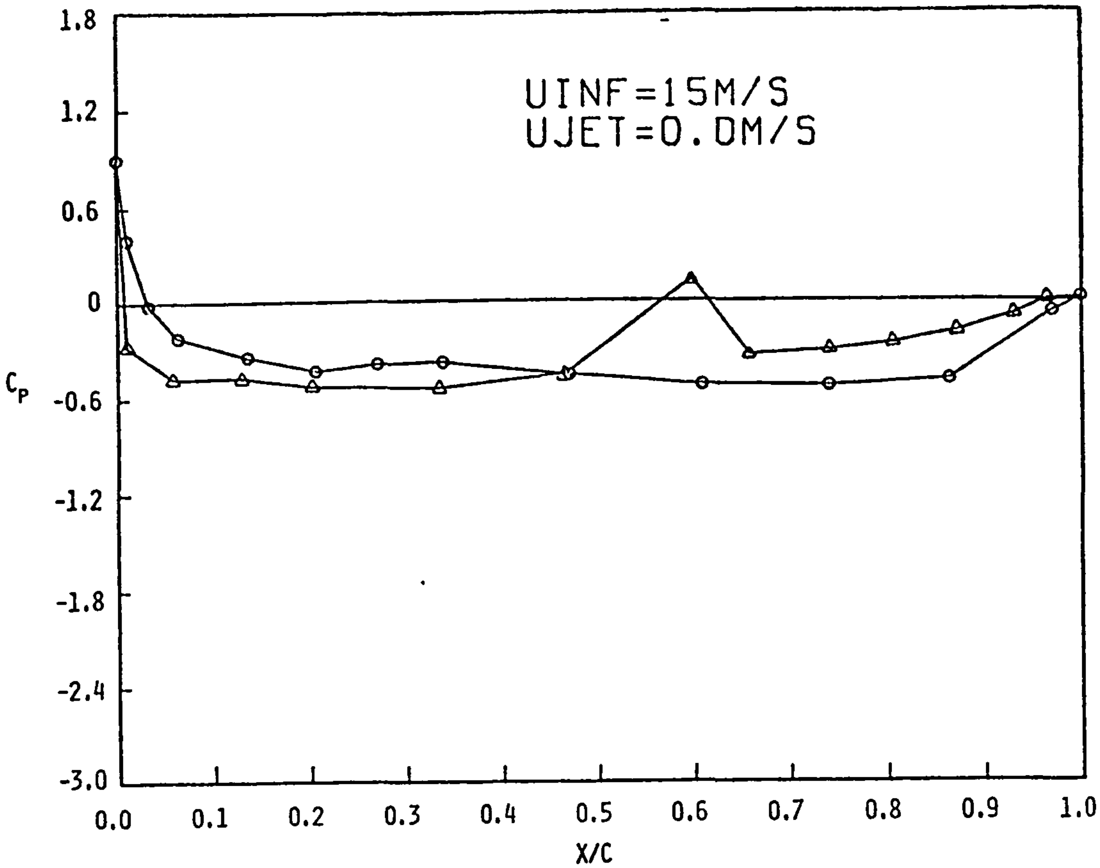
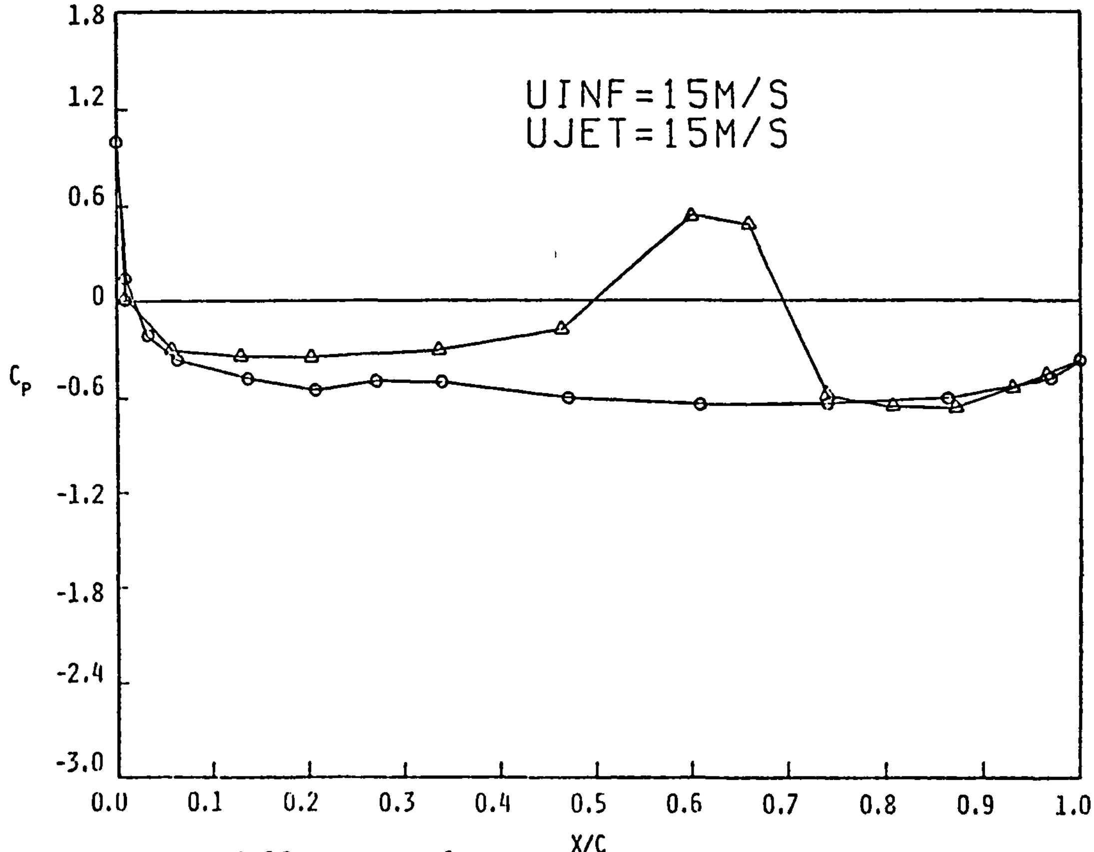


Figure 4.12 continued





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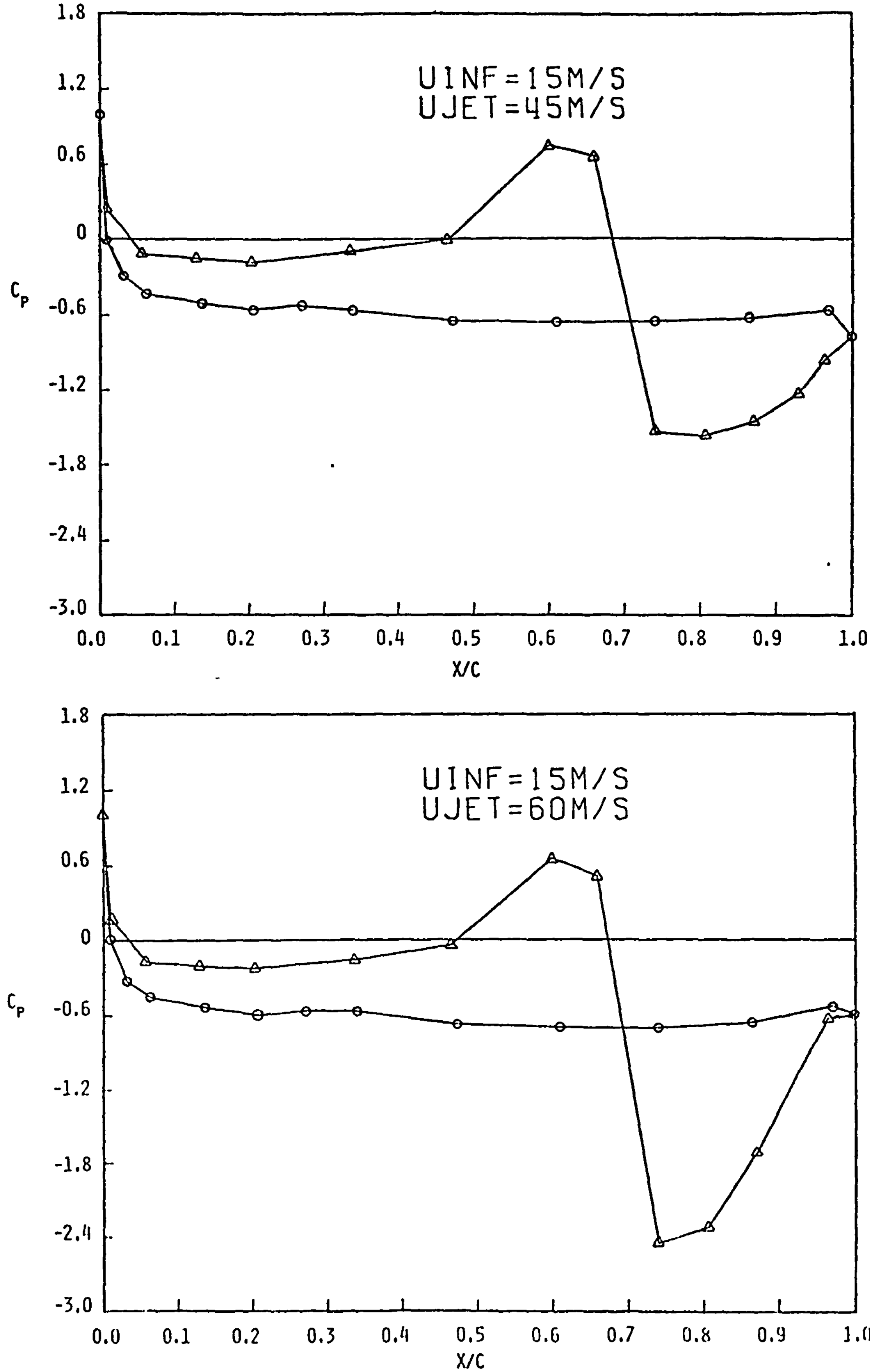

Figure 4.12 Surface pressure distribution of the airfoil with the ground plane simulation, at different velocity ratios (h/c=0.5)

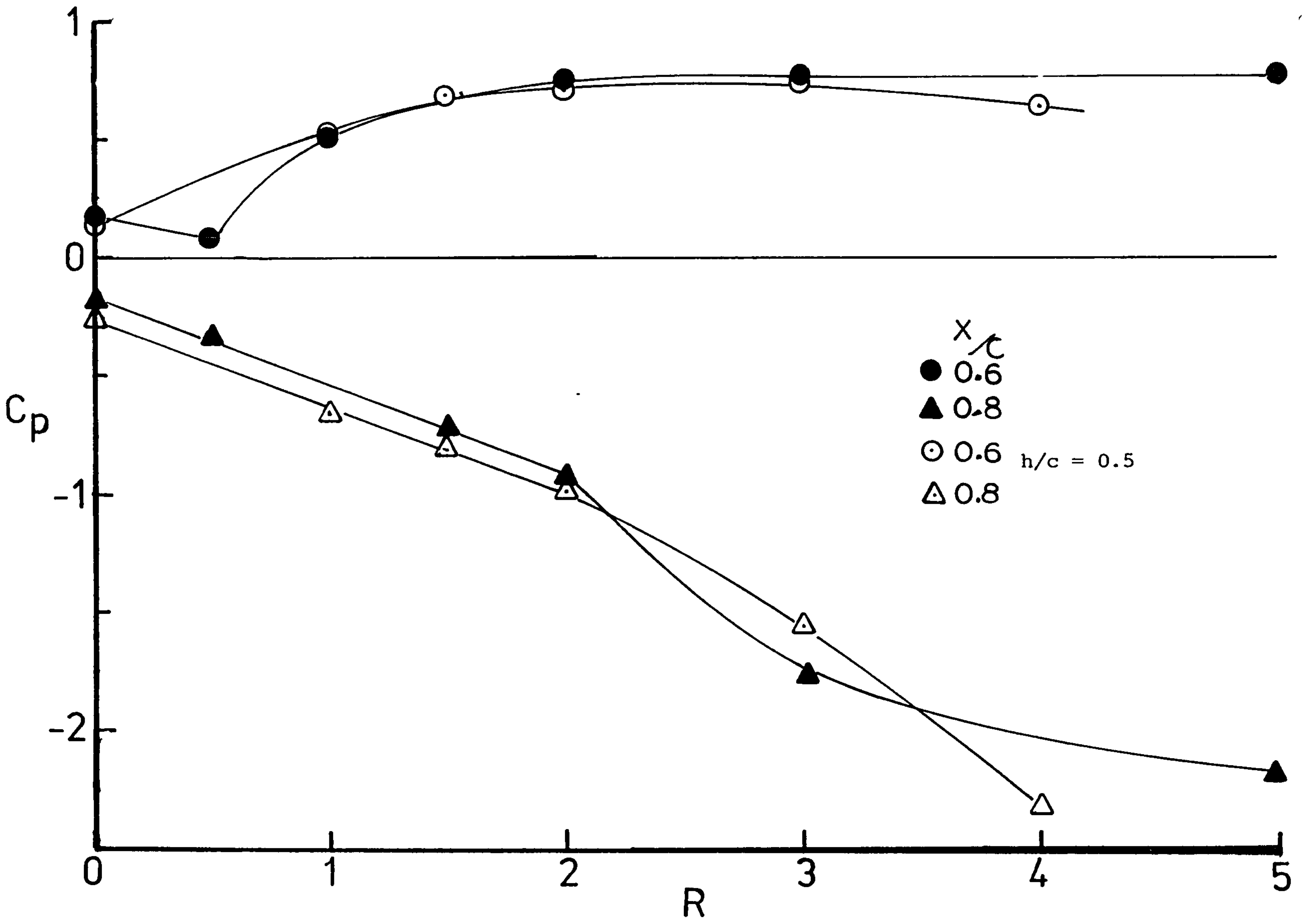

Figure 4.13 Variation of the C_p at 60 and 80 percent of the chord with velocity ratio

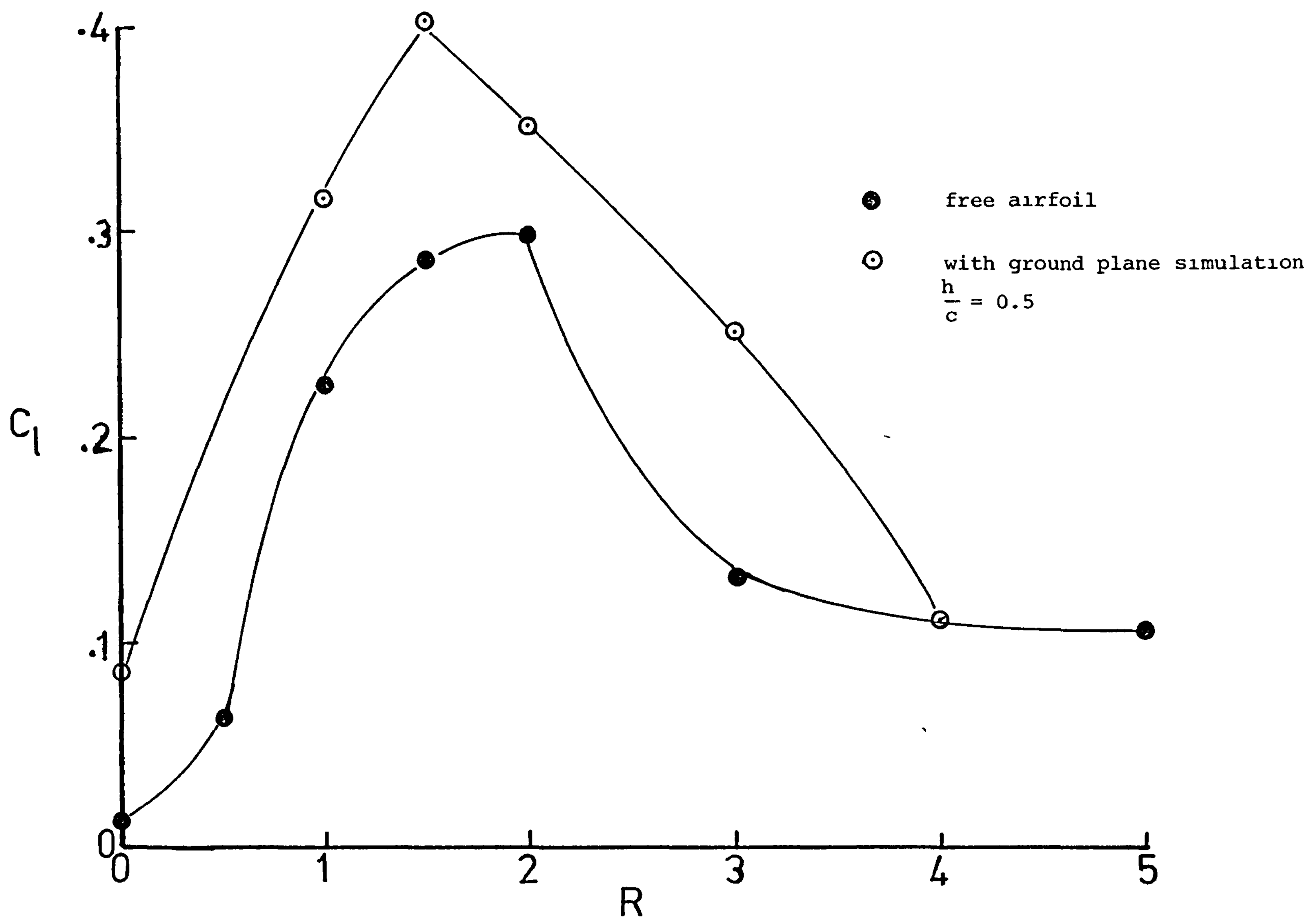

Figure 4.14 variation of the coefficient of left with velocity ratio

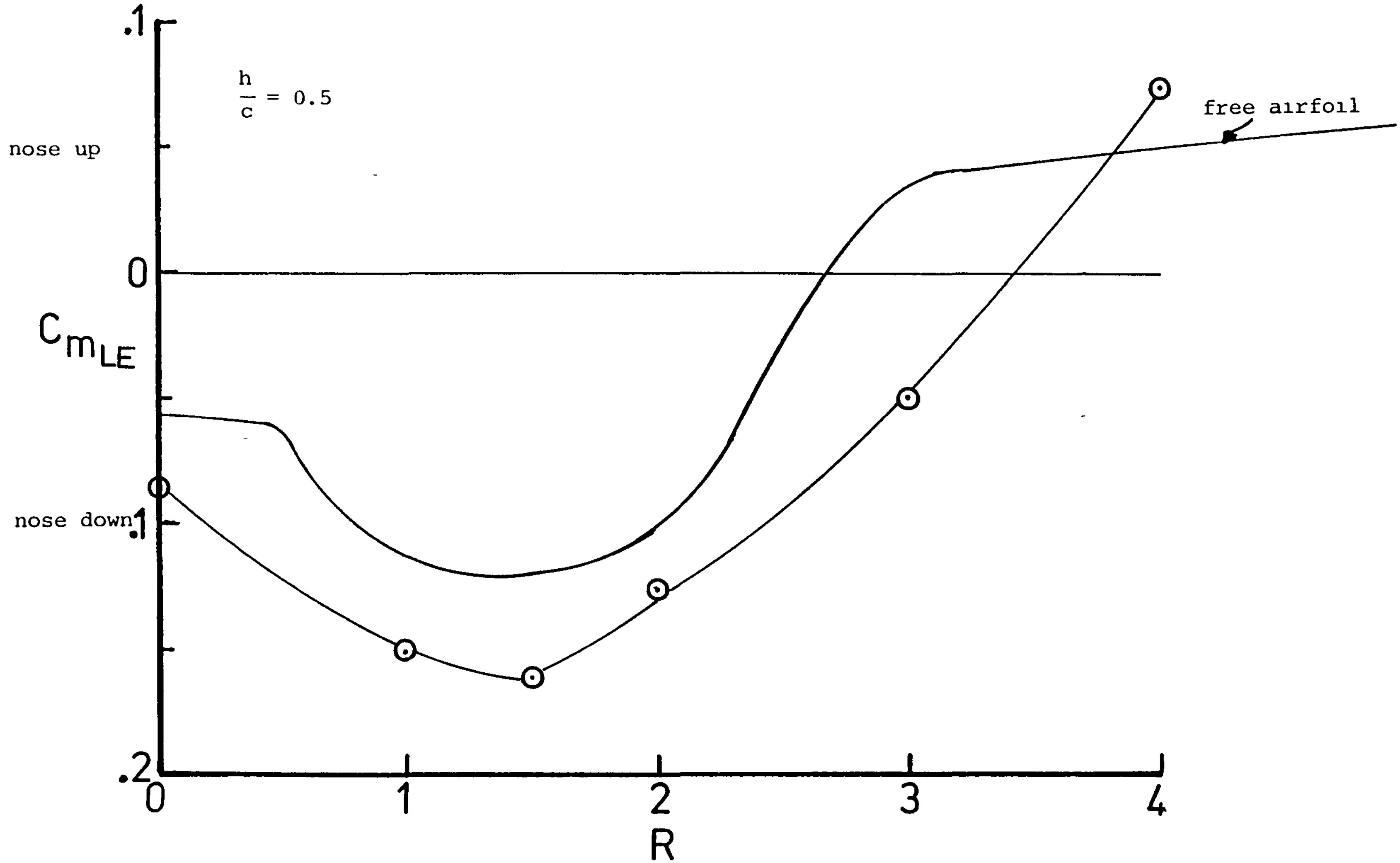

Figure 4.15 Variation of the moment coefficient with velocity ratio

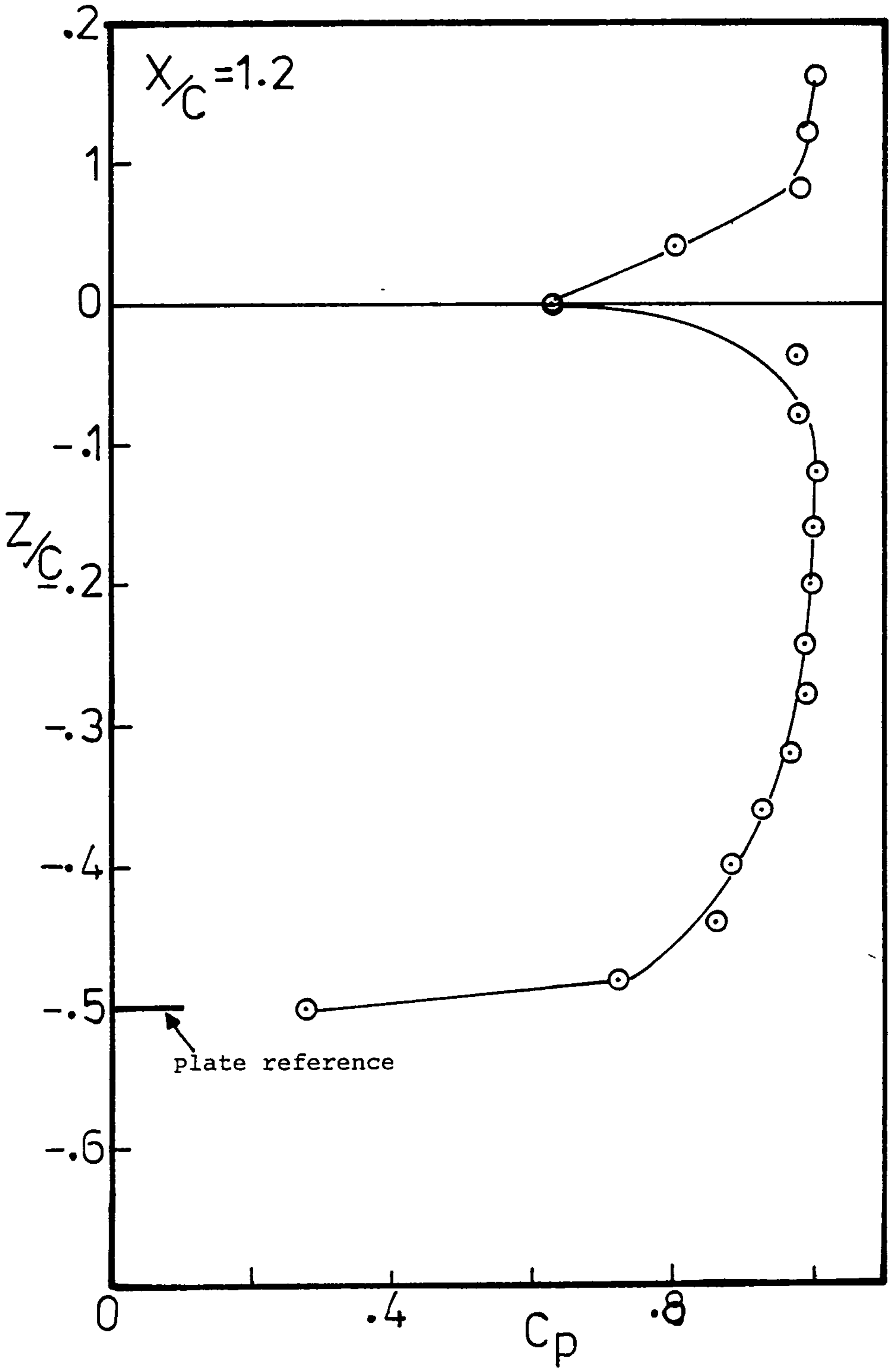

Figure 4.16a Wake profile at 1.2c without the jet (h/c = 0.5)

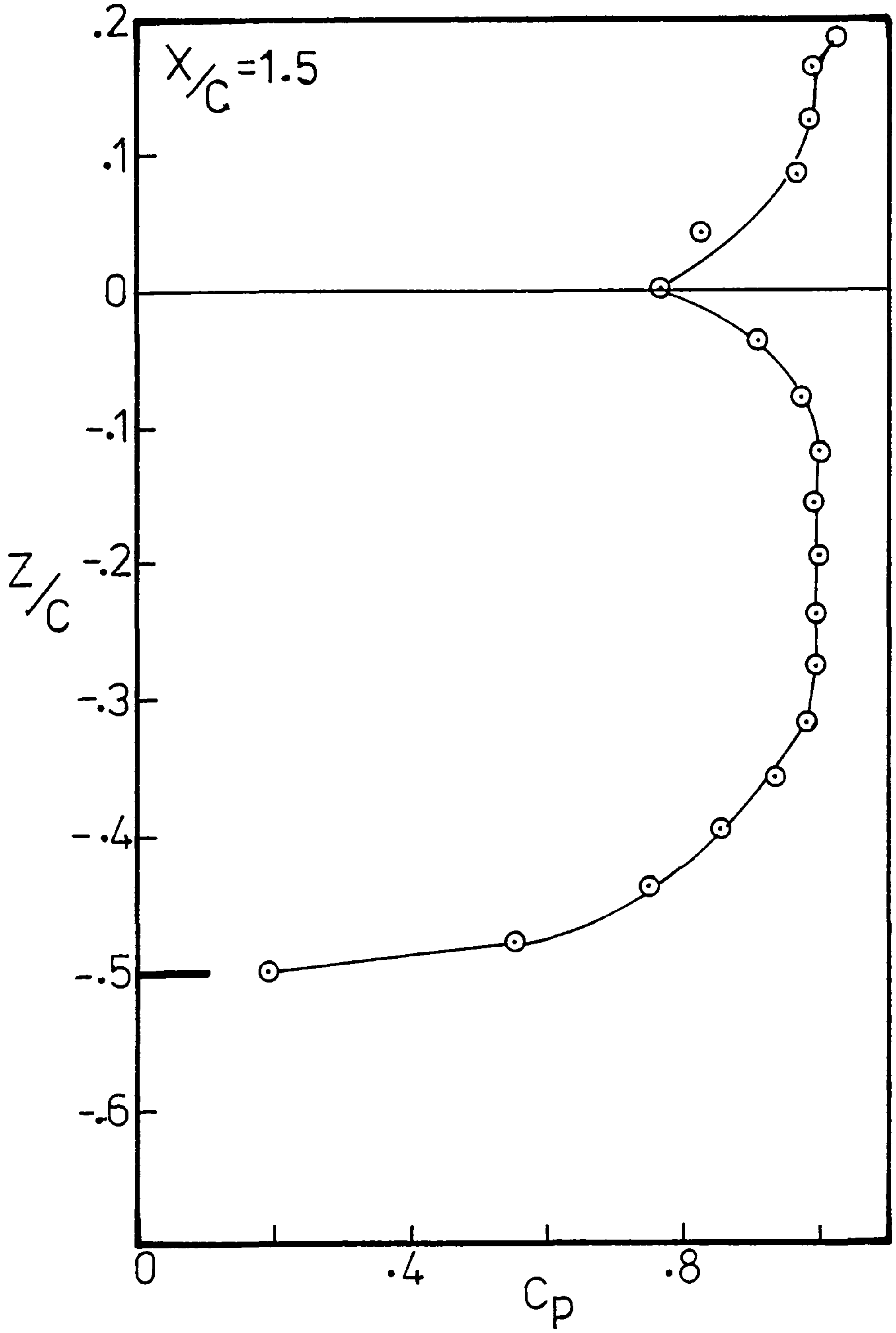

Figure 4.16b Wake profile at 1.5c without the jet (h/c = 0.5)

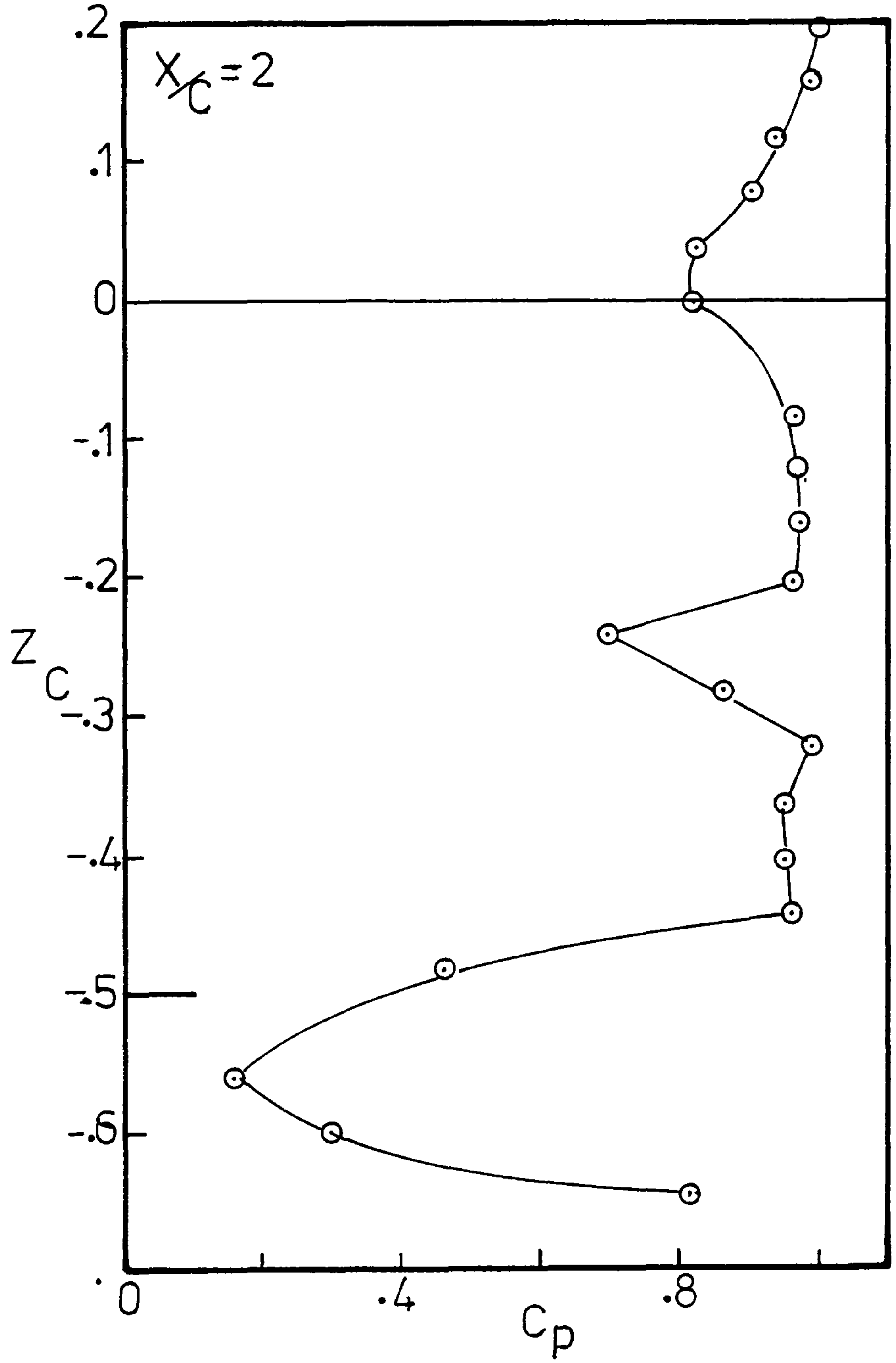

Figure 4.16c Wake profile at 2c without the jet (h/c = 0.5)

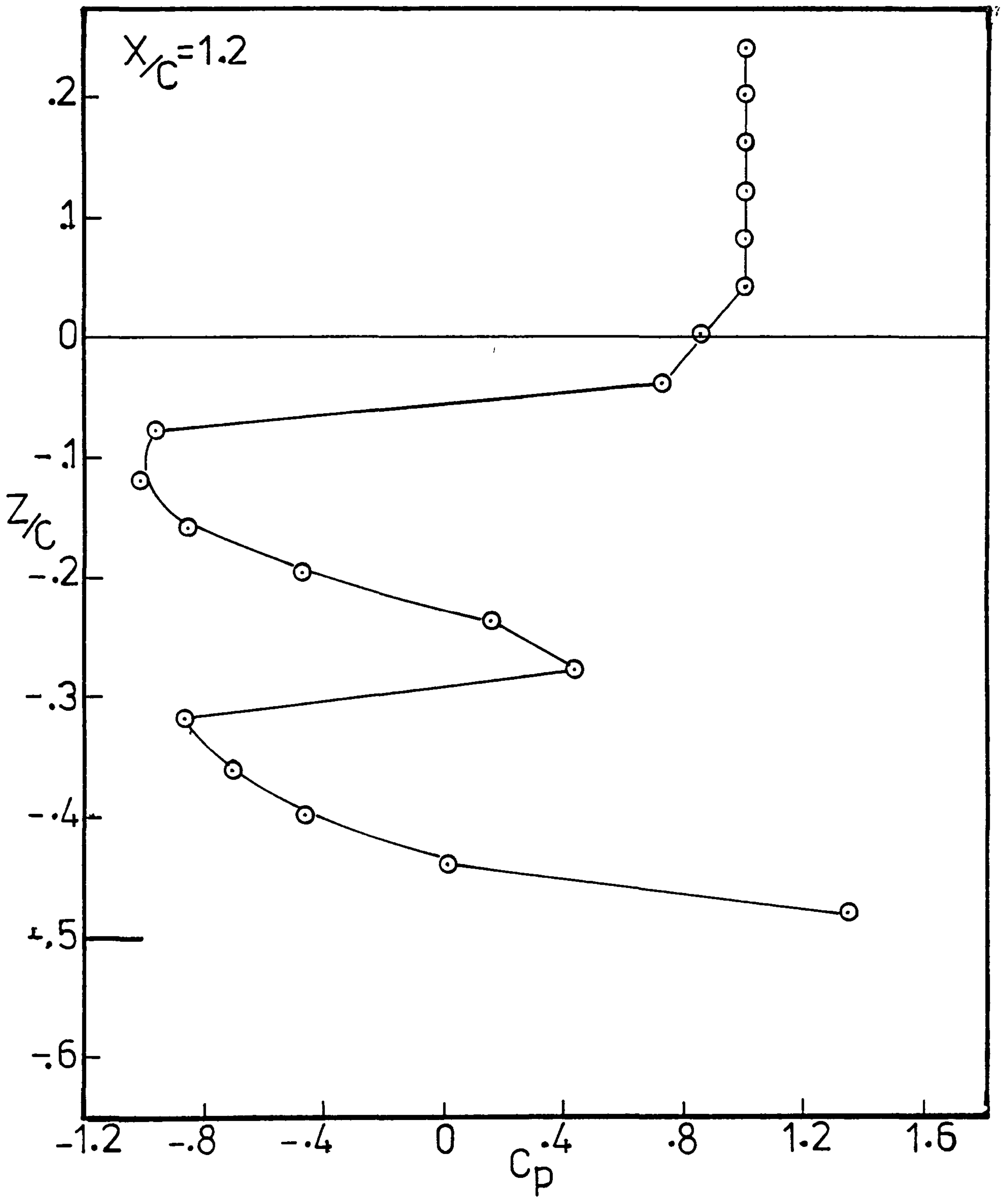

Figure 4.17a Wake profile at 1.2c with the jet (h/c = 0.5)

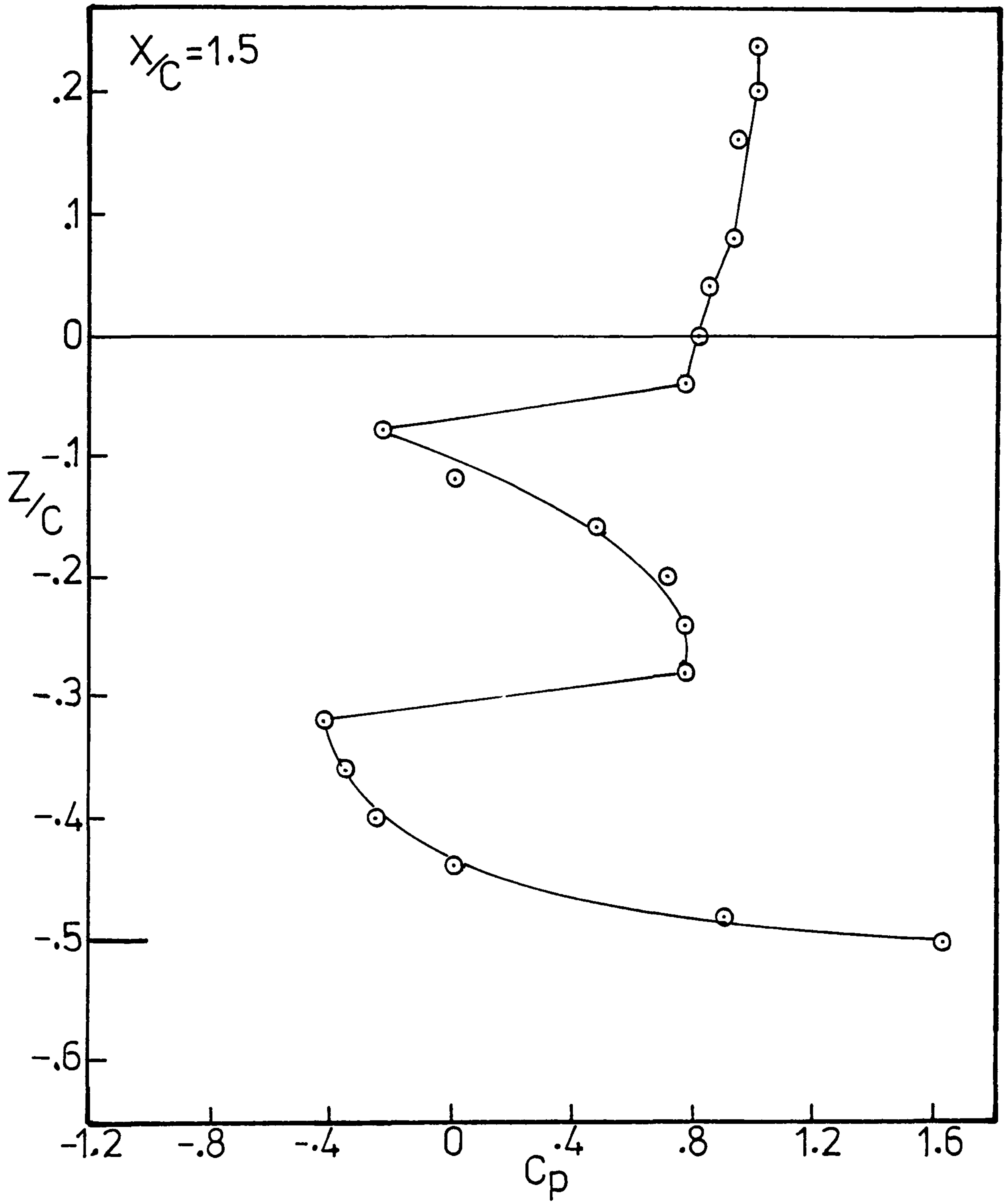

Figure 4.17b Wake profile at 1.5c with the jet (h/c = 0.5)

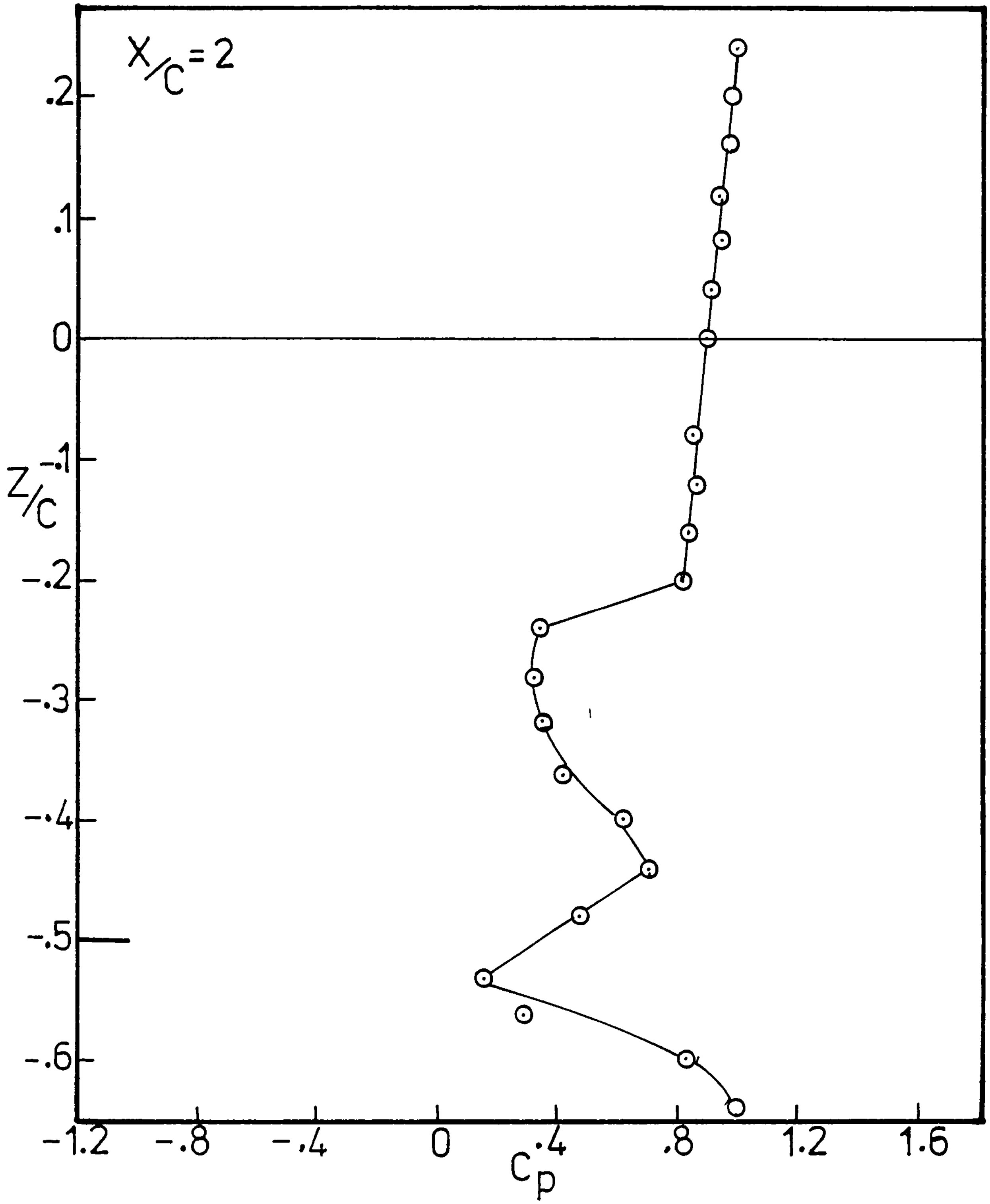

Figure 4.17c Wake profile at 2c with the jet (h/c = 0.5)

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16. Abstract

An experimental investigation was carried out to study the aerodynamics of an airfoil with a rectangular jet issuing from the lower surface at seventy percent of the chord; with and without a ground plane. Measurements include surface pressure on the airfoil and the total pressure profiles in the near wake. These measurements were made at jet to free stream velocity ratios ranging from 0.5 to 5.0.

The measurements indicated a significant positive and negative pressure retions on the lower surface of the airfoil ahead and after the nozzle exit respectively. The extent and intensity of these regions increase with increase in velocity ratio for the range covered here. The upper surface pressure distribution with velocity ratio show no significant variation. The presence of the ground plane, for height h, greater than one chord seem to have little influence on the overall pressure distribution of the airfoil. The airfoil wake certerline moves up with velocity ratio as compared to that of the free airfoil (without the jet).

17. Key Words (Suggested by Author(s))	18. Distribution Statement
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