SUPERSONIC FLOW SEPARATION ON A BACKWARD FACING STEP

by

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A portion of a Masters Thesis in Engineering.

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ABSTRACT

This paper describes an experimental survey of flow separation on backward facing steps having different heights at a Mach number of 2.4. Reattachment and critical points are found for three regimes, laminar, transitional, and turbulent. Reattachment occurs at a point where the pressure is 35% of the free stream value for turbulent flow, and 60% of this value in the laminar case. The length of the free shear layer is found to be one-half that of the separating streamline, a result which emphasizes the importance of the reattachment region. The flow downstream of the critical point is found to be relatively independent of the base flow. Disturbances in the spanwise direction are always observed in laminar flow but do not affect the base pressure.

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NOMENCLATURE

H	step height
M	Mach number
M_{pp}	maximum of perturbed pressure
N	reattachment or recompression parameter
N'	modified reattachment or recompression parameter
p	static pressure
p_t	total pressure
q	total velocity
Re_a	Reynolds number based on a
R_{pp}	reattachment location using perturbed pressure technique
R_{Hw}	reattachment location using hot wire
U	free stream velocity
u	local velocity component in the boundary layer parallel to U
x	distance along the model measured downstream from the base of the step
y	height measured from the surface of the model
$\eta = \frac{p_r}{p_t}$	efficiency of recompression relative to that of an isentropic process

Subscripts

1	conditions in the free stream ahead of separation
2	conditions in the free stream between expansion wave and recompression shock
3	conditions in the free stream after recompression shock
b	conditions in the base region
r	conditions at reattachment

s conditions at separation

_ condition on separating streamline

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1.0 INTRODUCTION

To improve heat transfer and structural characteristics on high speed vehicles it is often advantageous to employ body shapes with finite base area rather than closed shapes. The flow over a backward facing step is very similar in nature to flow over base regions on such bodies and is more convenient to use as a flow model. The flow separation which takes place on such shapes is of considerable practical importance since the pressure acting on the base makes a very large contribution to the drag.

The inviscid flow over a backward facing step is shown in Fig. 1. The flow reaching the lip S is deflected downward and expands to a pressure lower than the initial pressure. The flow follows the line SR, at R it reattaches and is turned back to its initial direction, this being accomplished by an oblique shock starting at R. Downstream of this shock the pressure rises to a value of p_3, which is nearly equal to the pressure upstream of separation. There is a corresponding increase in the Mach number at the expansion and a decrease after reattachment. The air in the region between the step and SR is at rest; this is referred to as the dead air or base region, the pressure in this region is equal to that in the free stream after expansion.

It is quite obvious that the boundary conditions ahead of separation and after reattachment could be satisfied for a variety of values of the physical variables in the separated flow region. Only one of these conditions most accurately approximates the actual viscous flow.

In real fluid flow (Fig. 1b) a mixing region exists between air moving in the free stream and air at rest along the interface SR. This will cause some flow to move out of the dead air region. When the flow reattaches, part of it will escape downstream and part of it will be turned back. It is the balance between the flow scavenged in the mixing region and the flow turned back which uniquely determines the solution.

As a result of viscous effects the dead air region no longer consists of fluid at rest, instead there is a slow clockwise circulation, as shown in Fig. 1b.

If there is no suction or blowing, in order to have an enclosed region containing the same fluid, there must exist a dividing streamline starting at the separation point and ending at the reattachment point.

Due to the finite thickness of the mixing region, the pressure rise at reattachment will not be abrupt but will be spread over a certain distance which will be a function of the thickness of the mixing region and the angle at which it impinges on the wall (see Fig. 1c).

Existing methods for solving such flows are not fully satisfactory. One of the earliest of such assumptions used to formulate a method was based on a hypothesis made independently by Chapman[1] and Korst.[2] This states that the fluid flowing in the mixing region experiences a pressure rise as it approaches the wall. If the fluid is able to withstand this pressure rise it will escape downstream, otherwise it will be reversed to the dead air region. On the dividing streamline the fluid is brought to rest with a final pressure equal to the static pressure at reattachment. This theory is based on the assumption of isentropic recompression. In other words, the dividing streamline starting at rest will accelerate as it travels downstream and will reattach when its total pressure equals the pressure at reattachment. In this theory the pressure at reattachment is taken to be equal to the pressure downstream of the recompression point.

Several experimental investigations by Nash,[3] Siriex[4] and Roshko and Thomke[5] show that this is not the case and that the pressure at reattachment is always smaller than the value far downstream, p_3, a result which is also found in this investigation. A critical reexamination and improvement of the Chapman-Korst criteria for reattachment has been initiated by Cook,[6] Siriex, et al.,[7] and several other workers.

Furthermore, a refined study of the reattachment region performed by Siriex and Carriere[8] emphasizes the complex character of this region and extablishes the existence of critical points, downstream of which the flow shows a certain independence from the base flow. Critical points also play a role in the theoretical work of Crocco and Lees[9] and Lees and Reeves.[10]

Another phenomenon which adds to the complexity of the reattachment region results from three dimensional effects consisting of variation in the flow characteristics in the spanwise direction. These appear in what was thought to be a purely two dimensional flow. This phenomenon was described by Ginoux[11] and was noted in further experiments. The effects of this phenomenon on reattachment are investigated in this paper.

The present paper describes some experiments in laminar and turbulent flows performed in the Berkeley 6X6 inch supersonic wind tunnel. Reattachment points are found using different techniques. The zero velocity line on the lower limit of the shear layer is investigated using hot wire probes. Velocity profiles before separation and in the separated layer are measured using a pitot tube. Finally, a study of the three dimensional effects in the reattachment region is attempted with the primary object of estimating the influence of these effects on the reattachment process.

2.0 DESCRIPTION OF APPROACHES AND EXPERIMENTAL TECHNIQUES

This investigation was performed in the 6×6 inch continuous flow supersonic wind tunnel of the Aeronautical Sciences Division of the University of California, Berkeley. The wind tunnel is of closed circuit variable density type. Due to equipment limitations it was decided to make all the experiments at the same Mach number. The value of $M = 2.4$ was chosen and variations of M due to boundary layer thickening were corrected by changing the angle of attack of the model. The model used was essentially a flat plate to which different steps could be fastened. The model and the steps contained pressure taps which were connected to an oil manometer (using dibutyl-phthalate). The stagnation pressure of the tunnel could be varied between 1.5 and 35 psia, and the stagnation temperature between 75°F and 150°F, permitting values of the Reynolds number per unit length between $0.01\ 10^6$ and $1\ 10^6$. At low values the stagnation pressure showed small fluctuations. In order to have instantaneous reading of all manometer tubes photographs of the manometer board were taken and the results subsequently reduced. Stagnation temperature varied by ±3°F from the desired value but the variation was over a long period, so that a correction was possible by checking the value of T before taking each data reading. The temperature of the body was stable to within ±2°, so that a constant-energy assumption was not violated.

The probes used were fixed on a traversing mechanism capable of moving on three axes with an accuracy of better than ±0.001 inch.

Since the base pressure was less than that in the test section the flow was susceptible to variations in the spanwise direction; to reduce them lucite fences were added on both sides of the model when $h \geq 0.25$. These effects did not strongly influence base pressure, but did affect the reattachment region.

The velocity profiles were determined by means of a flattened pitot tube having an overall height of 0.3 mm and an overall width of 1.6 mm; the wall thickness was 0.1 mm. The stainless steel tip was connected to a copper tube which could be bent and aligned with the flow. The alignment was always better than 5°, which gave accurate results due to the good directional characteristics of a pitot tube. The pressures were read on an oil manometer and a Betz manometer (using water as liquid) for low tunnel stagnation pressures; a mercury manometer and a Wianko pressure transducer were used for high tunnel stagnation pressures.

A hot wire probe was used to find the lower limit of the separated shear layer. On this line the velocity is at a minimum; the velocity in the direction of the flow is zero and the velocity in the perpendicular direction is very small. A minimum in the heat transfer from the wire was detectable when the wire was moved outward from the base region and through the shear layer. This minimum was very difficult to observe at small distances from the step $[(x/H) < 2$ for laminar flow and $(x/H) < 0.5$ for turbulent flow$]$. This is due to the fact that the velocities in that region are all very small and there is no clear minimum on the zero velocity line. Another reason could be that, even with a laminar shear layer, the flow in the base region is turbulent and the position of the lower limit of the shear layer is not steady. This has been observed by Tani[12] for subsonic flow. When the zero velocity line approached the wall, the minimum in hot wire transfer was very easily determined but the heat loss by radiation to the wall became large, so that a very small overheat ratio was used. The minimum in heat transfer from the wire was determined from the minimum of the resistance of the wire, when carrying a constant current. Wires of 0.0001 inch diameter were used for low stagnation pressures and wires of 0.0002 inch diameter for high p_o. The wire length varied between 0.7 and 0.9 mm. The point where the line forming the lower limit of the shear layer touches the wall is taken as the point of reattachment. The angle at which it merges with the wall is very small for the laminar case, and since points very close to the reattachment point are difficult to obtain, the error is thought to be relatively large. A much better accuracy was possible for the turbulent case.

The reattachment point was also obtained using another technique used by Roshko and Thomke.[5] It consists in perturbing the flow at each pressure tap and observing whether the perturbation gives an increase or a decrease in the measured pressure. If the perturbation is downstream of the pressure tap it will create a positive pressure gradient and a higher pressure will be recorded; if a lower pressure is recorded it will mean that the perturbation is upstream from the pressure tap. Experimentally this state was realized by bringing a very fine wire, attached to the arm of the traversing mechanism, to one side of each pressure tap, noting the pressure at each time; the same procedure was then repeated placing the wire at the other side of the pressure taps, and finally, an unperturbed pressure was recorded. The three curves obtained were plotted on the same graph and the point where they intersect is the reattachment point. (At that point, where the flow impinges normal to the surface the perturbed pressures and the unperturbed pressure are equal.) Figure 2 shows such a graph.

Flow variations in the transverse or spanwise direction were studied using the pitot tube described previously. The probe was moved transversely, always touching the wall at different stations downstream of the step. The pressure was read using a Wianko pressure transducer so that an amplification was possible when needed.

In all the tests when a probe had to penetrate into the base region special care was taken not to perturb the flow. The static pressures were observed and no data were taken when the base pressure varied by more than 1%. In some cases the flow was perturbed locally and, the base pressure being the same, it was assumed that there was no basic change in the flow configuration. By designing the probes carefully it was possible to reduce the perturbation to a minimum.

The leading edges of all models had a thickness in no case superior to 0.05 mm and were checked regularly under a microscope.

Different regimes, laminar, turbulent, and transitional, were observed using shadowgraph techniques. When it was desired to determine the onset of transition accurately a qualitative hot wire observation was made (see Figs. 17a,b,c).

3.0 RESULTS AND DISCUSSION

3.1 Laminar Separation

Separation is considered to be wholly laminar when the boundary layer remains laminar downstream of reattachment. In the present investigation separation was considered laminar when transition took place downstream of a certain critical point.

Figure 3 gives some pressure distributions, showing the variations of p/p_1 with the nondimensional distance x/H, for the same step height. Figures 4 - 6 give p/p_1 for three different steps and three different values of unit Reynolds number in the free stream (ahead of separation, i.e., condition "1"). From these curves the following observations can be made:

The base pressure is apparently a weak function of Reynolds number. Chapman's theory for laminar flow, which neglects the intial boundary layer, assumes complete independence of Reynolds number. However, for a longer free shear layer (higher step) the influence of Reynolds number becomes more marked; Re_H is apparently a more significant parameter.

Also apparent from Figs. 3 - 6 is the crowding of the p/p_1 curves in the reattachment region extending up to the location of the maximum of the perturbed pressures, M_{pp}. The meaning of this point will be explained later.

The values of p/p_1 on the step face not represented in these figures were always equal to p_b/p_1 represented on $x/H = 0$. This confirms the widely accepted assumption of constant pressure in the base region.

The points for negative values of x/H correspond to the region upstream of separation and show that the low pressure propagates upstream in the subsonic part of the approaching layer. This result was not found for turbulent boundary layers at separation and was used to detect the nature of the boundary layer.

The reattachment points, found using the perturbed pressures and the hot wire techniques, are represented in the same figures. Each of these points is placed directly below the actual value of p_r/p_1. In all cases R_{pp} is on the left of R_{Hw}, i.e., the value of $(p_r/p_1)_{Hw}$ is always larger than $(p_r/p_1)_{pp}$. This suggests that the reattaching streamline has a very small slope before reattaching normally, causing the orifice dam (in fact the small wire used to create the pressure perturbation) to intercept this streamline before it actually reattaches.

The points M_{pp} are all found between the limits represented on each graph, and they all correspond to the region where the curves p/p_1 start branching and diverging from each other. These points, as noted earlier, represent the maximum of the perturbed pressure. As found by Roshko[5] they are at the location where the flow suddenly accelerates. These points also correspond to the first critical point found by Siriex.[7] The latter was found by imposing different pressures downstream and noting that there exists a point downstream of which the value of p/p_1 can have no influence on the flow upstream of reattachment, provided that this value lies within a certain range. This means that for a flow separating and expanding from p_1 to p_2 the recompression waves, or shock, do not bring the pressure back to p_3, where p_3 is essentially equal to p_1. p_3 could lie between two limits, p_3' and p_3''.

The Chapman[1]-Korst[2] reattachment criteria $\bar{p}_t = p_r = p_3$ would give different solutions for the same flow assuming different values of p_3. It is true, however, that for the laminar flow the margin p_3', p_3''

is very small.

The main contradiction between the Chapman-Korst criterion and the experiment is that $p_r \neq p_3$. This has been noted in many experimental works. Nash[3] introduced the parameter N, called the reattachment or recompression parameter, and defined as:

$$N = \frac{p_r - p_b}{p_3 - p_b}$$

For the reason stated earlier, namely that p_3 is not uniquely determined, we will redefine N as

$$N' = \frac{p_r - p_b}{p_1 - p_b}$$

(which is the same as N if we assume that p_3 has the particular value p_1).

The values found for N' varied slightly with Reynolds number. Using the perturbed pressure technique to determine the reattachment point, R, N' had a mean value of 0.48 ±2%. Using a location for R determined by the hot wire technique, N' had a mean value of 0.60 ± 2%. The latter value is believed to be the best.

This parameter is of fundamental importance because it is used to determine the separating streamline. Cooke[6] takes $N = 0.5$, which apparently gives good results. This value, however, was determined empirically. Nash[3] found that N had a mean value of 0.35, but this was in turbulent flow. All other workers in the field seem to be taking $N = 1$ (i.e., $p_r = p_3$), except for Siriex,[7] who uses an angular criterion for reattachment and suggests that N should be in the range $0.35 < N < 1$.

Figure 7 shows the zero velocity line, or the lower limit of the shear layer. On this line $u = 0$, but $q \neq 0$. q will have a positive vertical direction in the first portion of this line (fluid entering the mixing region) and a negative vertical direction for the latter part (fluid reversed back into the base region). This line also delineates the lower limit of the shear layer beyond which the flow is generally considered to be inviscid. At small distances from separation the position of this line was very difficult to determine and there was a great deal of scatter. This is due to the fact that the value of u in the reversed flow is very close to zero. This line showed weak dependence on Reynolds number, which is in agreement with the pressure distribution.

Finally, a surprising result was that the distance from the step lip to the point where the pressure rise starts is always half the distance to the reattachment point or the end of the zero velocity line. This result means that the center of the recirculating flow is situated in the middle of the zero velocity line, i.e., the flow outward from the base region in the first half is equal to the flow reversed in the second half. This also means that the free shear layer extends only half way to the reattachment point, thus emphasizing the basic importance of the reattachment region in defining the flow field. Figure 8 shows velocity profiles taken at different distances from separation. On the same graph the zero velocity line is shown, together with the points where $\bar{u}/U_1 \doteq 0.589$, the latter points would be on the separation streamline according to Chapman's theory. The location of the points $\bar{u}/U_1 = 0.589$ is acceptable up to $x/H = 4$, thereafter $\bar{u}/U_1$ should be smaller if there is to be reattachment at $x/H = 0.785$. The velocity profiles also show that the zero velocity line is not the lower limit of the shear layer, at a certain distance above it the shear is still very small.

3.2 Three Dimensional Effects

Ginoux[11] found that when the separation is laminar three dimensional effects exist in the reattachment region; they are repeatable and apparently do not come from perturbations in the tunnel or the model itself. Ginoux's experiments were carried out for a wide range of step heights and in two different wind tunnels. These effects were observed using a coating of azobenzene and transverse pitot surveys at the wall. In this research only pitot data were taken and for the same Reynolds number and step height it was found that the wave length of the perturbation agreed very well with Ginoux's results. This confirms the fact that these effects are independent of model and wind tunnel. All the results agreed with those found previously. These effects disappear when transition occurs and are not found in turbulent flows.

Figure 9 shows the variation of pressure in a spanwise direction at different downstream stations of x/H. It can be seen very clearly that the peaks and valleys of pressure correspond to each other at different x/H. The amplitude increases downstream and decreases again at transition. The wave length on this figure is in the range $2 < \lambda < 4$. After the validity of these effects has been established, their effects on the base flow and on reattachment were investigated. This was motivated by the amplitude of the pressure differences; in Fig. 9, for example, the difference between peak and valley is of the same order of magnitude as that of $p_1 - p_b$ in the same flow.

Pitot surveys closer to the reattachment were made and it can be seen in Fig. 9 that the amplitude decreases when x/H gets smaller. For a value of x/H corresponding to the critical point the amplitude was extremely small, and no such effects were observed for still smaller values of x/H when using the pressure transducer and a very high amplification.

The static pressure corresponding to the peaks and valleys of p_t in Fig. 9 are very small, and, since they occur downstream of the critical point, they will not influence the flow up to reattachment. In other words, even in a two dimensional flow p_3 will not be uniform spanwise at the wall, but the variation of p_3 due to the three dimensional effects will always be in the range p_3', p_3'' for which the flow does not affect p_r.

The cause of these perturbations is not yet clear. One explanation could be that very small perturbations in the initial flow (not necessarily detectable) are amplified by the positive pressure gradient at reattachment. The dependence on step height and on initial boundary layer thickness can also be explained by the dependence of the pressure rise on these parameters. In other words, the pressure rise could cause an amplification of some wave lengths and not others.

3.3 Transitional Separation

Transitional separation is defined as that in which transition starts upstream of the critical point. This is very important because when transition moves upstream in the reattaching layer the flow shows a very strong dependence on Reynolds number. This has been very satisfactorily explained by Chapman, Kuehn and Larson.[1]

Figure 10 represents some pressure curves for the same step and different Reynolds number. The strong dependence on Reynolds number is very clearly seen; a very fast variation in the reattachment region causes a rapid change in the base pressure. The pressure distributions are not crowded together in contrast to laminar flow. It is, however, clear that these curves coalesce again at $p/p_1 \cong 0.9$, and there is a region of several step heights where p does not vary significantly. This leveling off is not accidental and should be of importance because it extends over a distance frequently longer than the free shear layer length. The maximum of the perturbed pressure (not represented in Fig. 10) was situated at the same p/p_1 and its distance from the step corresponded to the end of the level pressure region (there was a great deal of scatter and M_{pp} could not be very accurately determined). This phenomenon appeared also when the flow was completely turbulent; it is not attributed to transition effects. An explanation is attempted in the next section.

The portions of the reattachment points are also represented in Fig. 10. As in the laminar case, the set of points found with the hot wire gives larger values for p_r/p_1 than those resulting from the perturbed pressures. However, the difference becomes small for higher Re_H (lower base pressures).

The values of the reattachment factor N' were

$$(N')_{Hw} = 0.47$$

and

$$(N')_{pp} = 0.43$$

which are respectively smaller than the values found in the laminar case. The reason for this decrease is explained in the next section.

Figure 11 shows the zero-velocity lines corresponding to the same flow conditions as in Fig. 10. The relative scatter of the points on this graph agrees well with the strong dependence on Re_H noted earlier.

3.4 Turbulent Separation

Turbulent flow was established when transition took place upstream of separation. Figure 13 shows p/p_1 distributions for different Reynolds numbers. Note that the base pressure is not influenced by Reynolds number; the independence of the Reynolds number is even more pronounced than in laminar flow. This is due to the fact that p_b reaches a limit conditioned by the maximum deviation that the inviscid flow (at conditions M_2) can sustain through the recompression shock. Figure 13 also shows that the negative pressure gradient at separation does not propagate upstream as in the laminar case. This does not seem to be true for the case of $Re_H = 0.868\ 10^5$, but it is believed that this flow is of transitional type.

The crowding of p/p_1 in the reattachment region is to be expected. The reattachment points using the two techniques are very close to each other and do not show such a large difference as in the laminar case; this suggests, in conformity with previous interpretations, that the separating streamline has a large slope before impinging on the wall.

The mean values of N' found are:

$$(N')_{Hw} = 0.36$$

$$(N')_{pp} = 0.34$$

Nash, noting that there is a good deal of scatter, gives the mean value of $N = 0.35$.

The location of M_{pp} is represented in Fig. 13, and it corresponds to the beginning of the leveling off of the pressures. The value of M_{pp} or the critical point is seen to correspond to the neck of the wake in Fig. 14. All this suggests that the recompression is very fast up to M_{pp}, and then levels off and increases slowly further downstream. The development downstream is apparently independent of the base region flow. This is consistent with the results of Siriex, Mirande and Delery,[7] who found a second critical point, situated somewhere close and downstream of R, and up to which, with judicious choice of reduced variables, the flow can be represented by a unique curve.

The smaller values of N' obtained in turbulent flow, $N' = 0.36$, as compared to $N' = 0.60$ for laminar flow, are to be expected. The base pressure being lower means that less flow is reversed to that region and more flow escapes downstream. The value of N' conditioning the choice of $\bar{u}/U$ on the separating streamline should then be smaller if we are to have more flow escaping downstream.

This decrease in the value of the reattachment parameter seems to take place mainly in the transitional regime; it decreases from 0.60 very rapidly to 0.36, and then keeps a constant value. This strong variation with Reynolds number in the transitional regime makes it very difficult to choose the separating streamline in this case.

4.0 CONCLUSIONS

The main results of this survey are as follows;

The free shear layer is found to be shorter than expected on the basis of previous experiments. Its length is approximately half that of the separating streamline. This emphasizes the influence of the reattachment on the base flow behavior.

Reattachment was found to occur at a pressure equal to 60% of the pressure in the initial stream for the laminar case, and 35% of the same pressure in the turbulent case. It was found to vary between those two values in transitional flow.

The region starting at the pressure rise and finishing at the critical point was found to have a strong influence on the base pressure. The pressure downstream of the critical point has no influence on the flow provided it lies within a certain range.

The three dimensional effects are an intrinsic part of the laminar flow; they are repeatable and independent of the conditions of the experiment. They have no influence, however, on the base pressure.

The scatter observed when the zero velocity line was determined close to the step suggests that the flow in the step region could be turbulent even when the shear layer is laminar throughout; this is, however, a speculation at this point.

The shear layer in the laminar case is confined to a small thickness and the shear does not become important until a certain distance from the zero velocity line.

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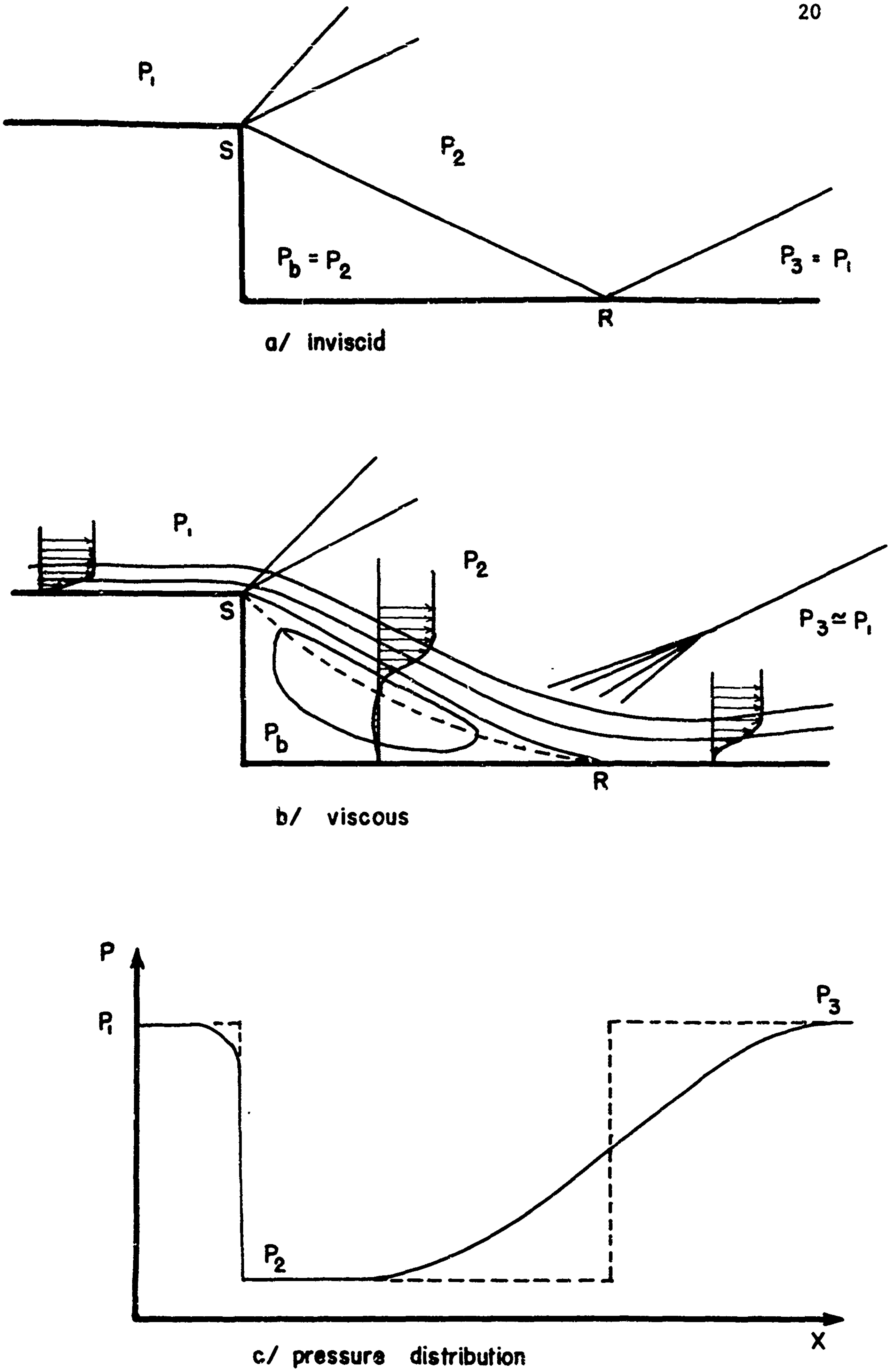


FIG. I FLOW OVER A BACKWARD FACING STEP

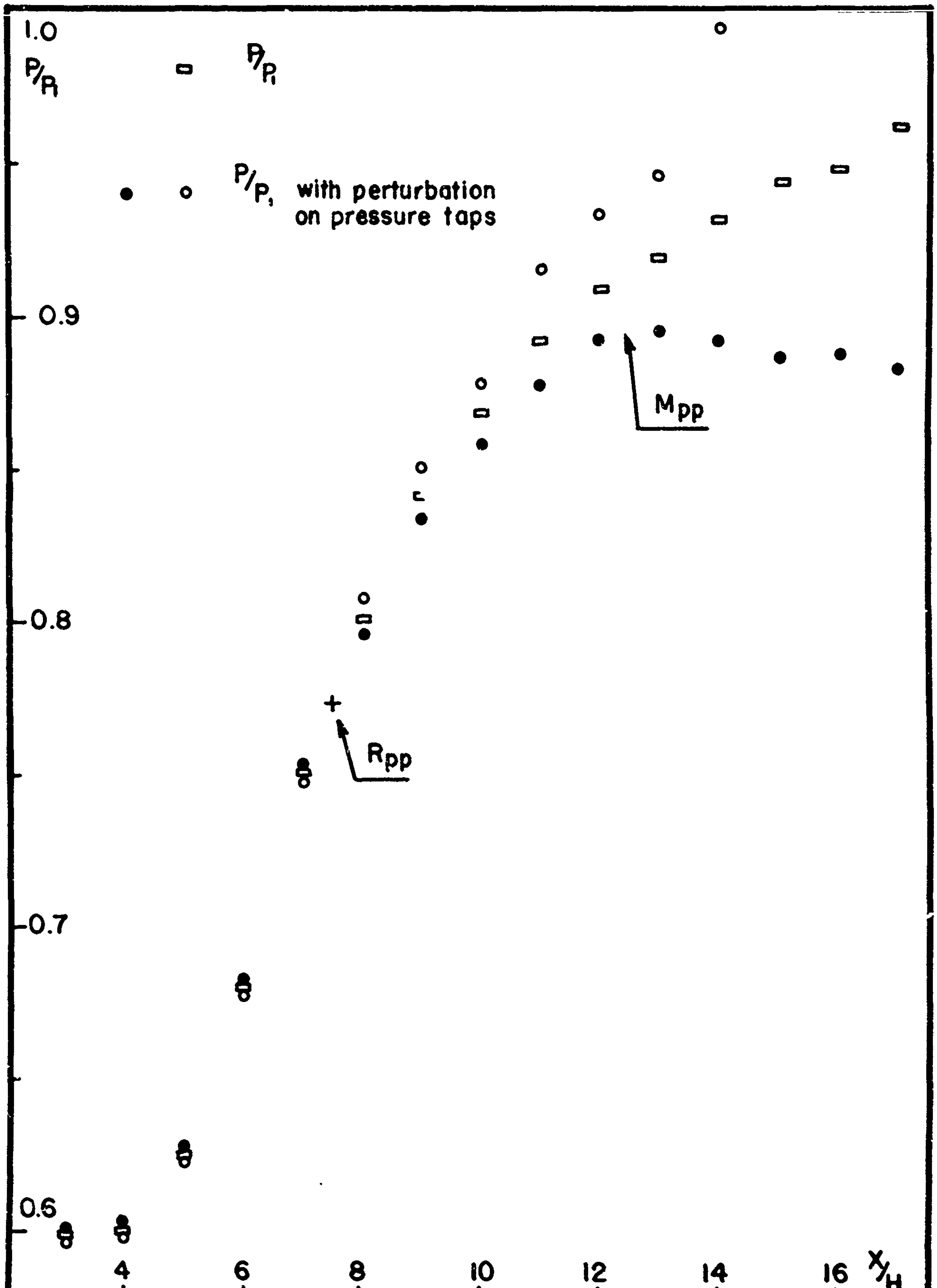


FIG.2 PRESSURE PERTURBATION TECHNIQUE

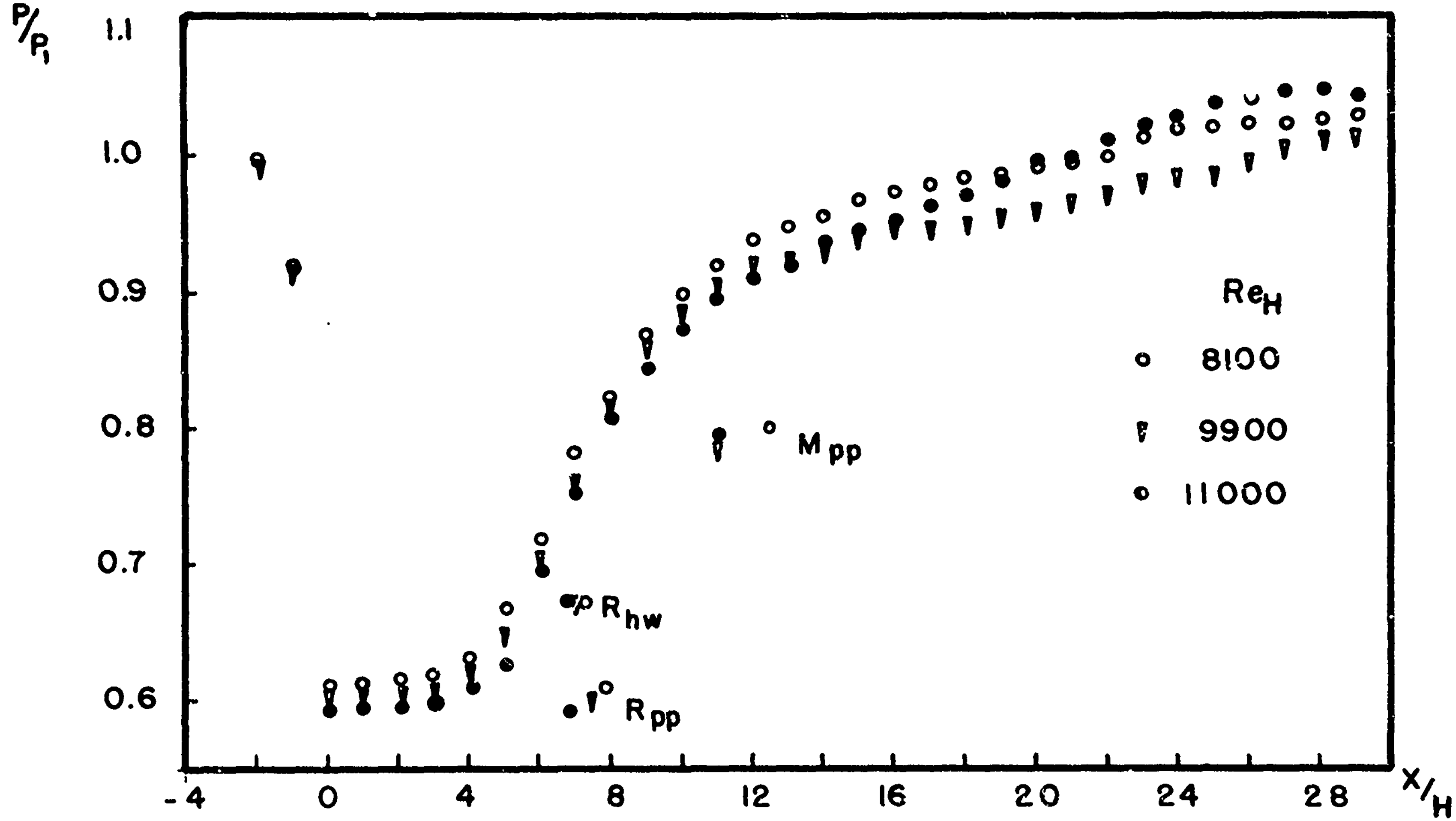


FIG.3 PRESSURE DISTRIBUTION IN LAMINAR FLOW

H=0.130"

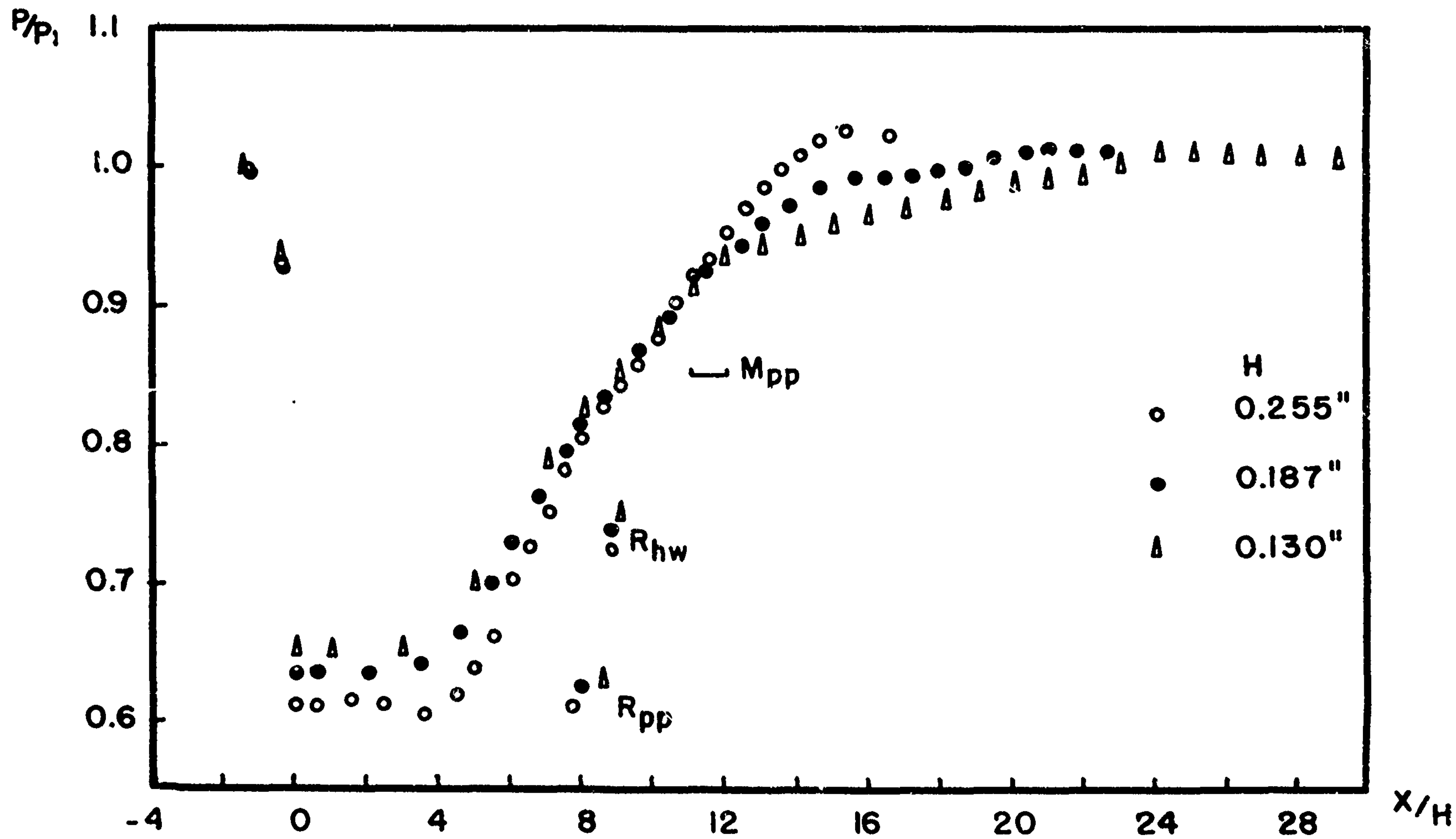


FIG. 4 PRESSURE DISTRIBUTION FOR DIFFERENT STEPS

AT $Re_{/inch} = 0.35 \quad 10^5$

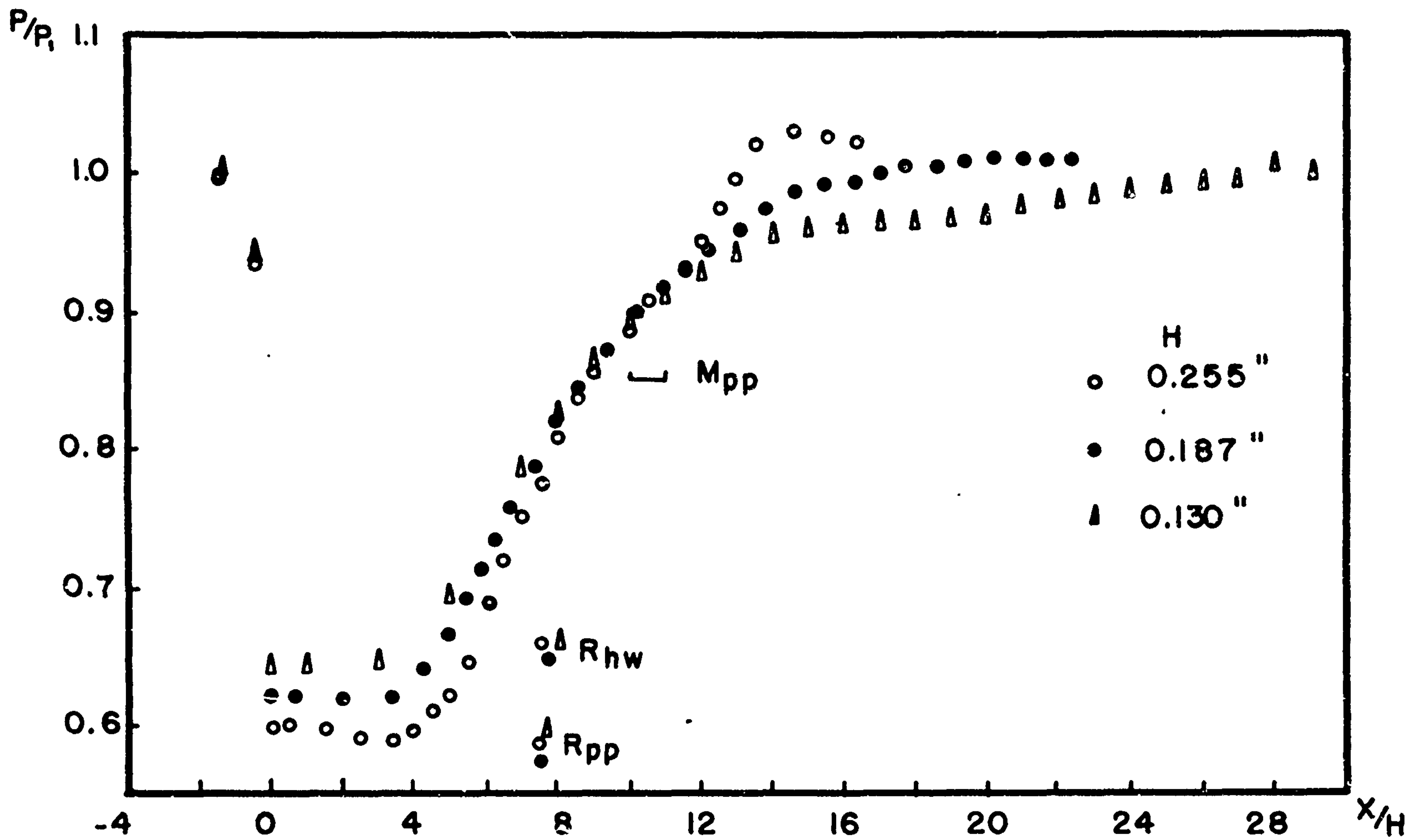


FIG. 5 PRESSURE DISTRIBUTION FOR DIFFERENT STEPS

AT $Re/_{inch} = 0.49 \; 10^5$

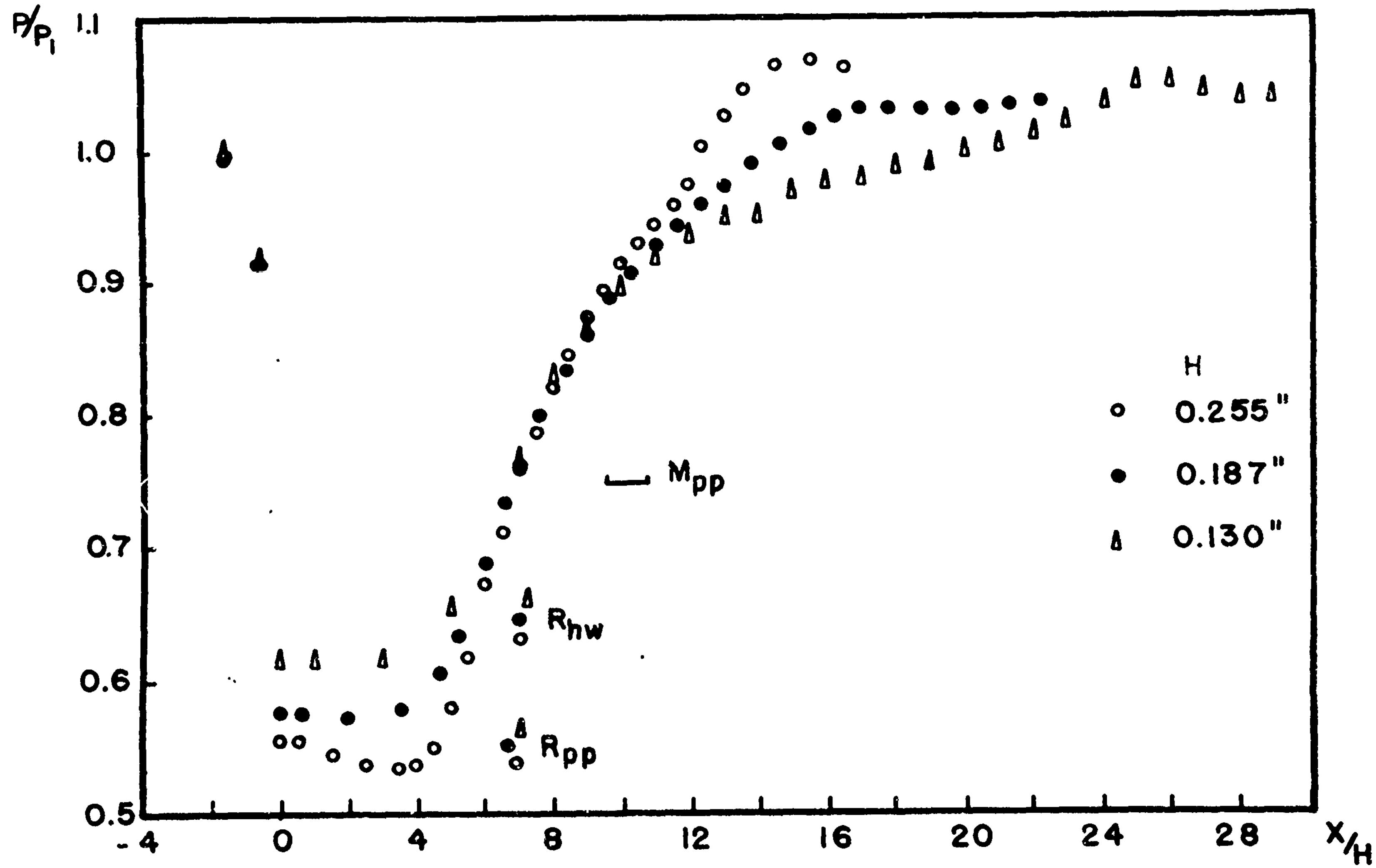


FIG.6 PRESSURE DISTRIBUTION FOR DIFFERENT STEPS

AT $Re/_{inch} = 0.62 \quad 10^5$

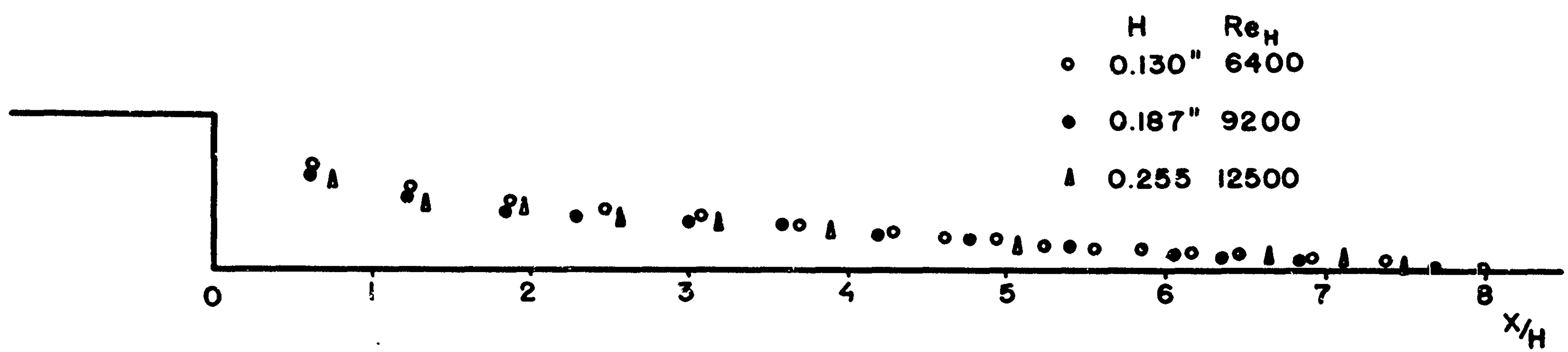


FIG.7 ZERO VELOCITY LINES IN LAMINAR FLOW

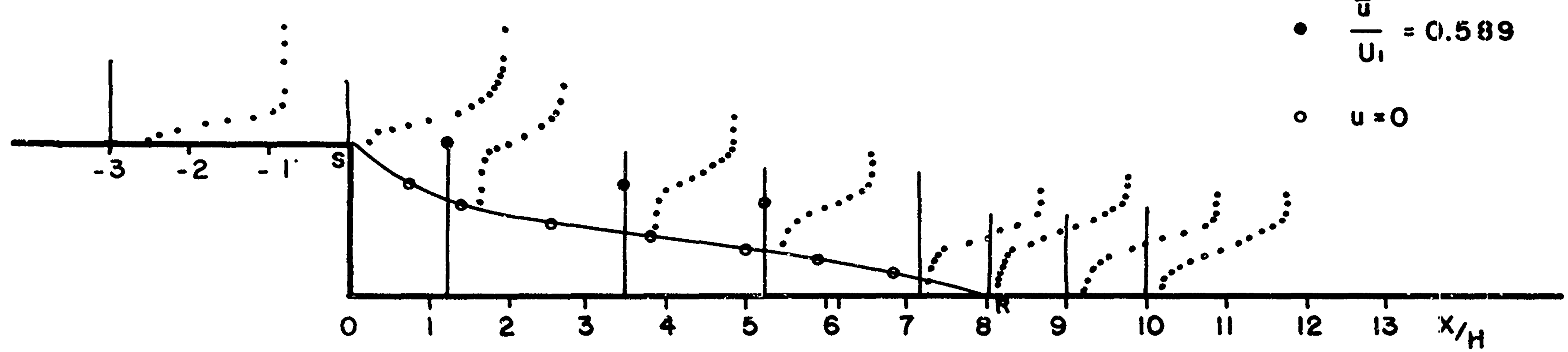


FIG.8 VELOCITY PROFILES IN SHEAR LAYER

H = 0.130" Re_H = 6400

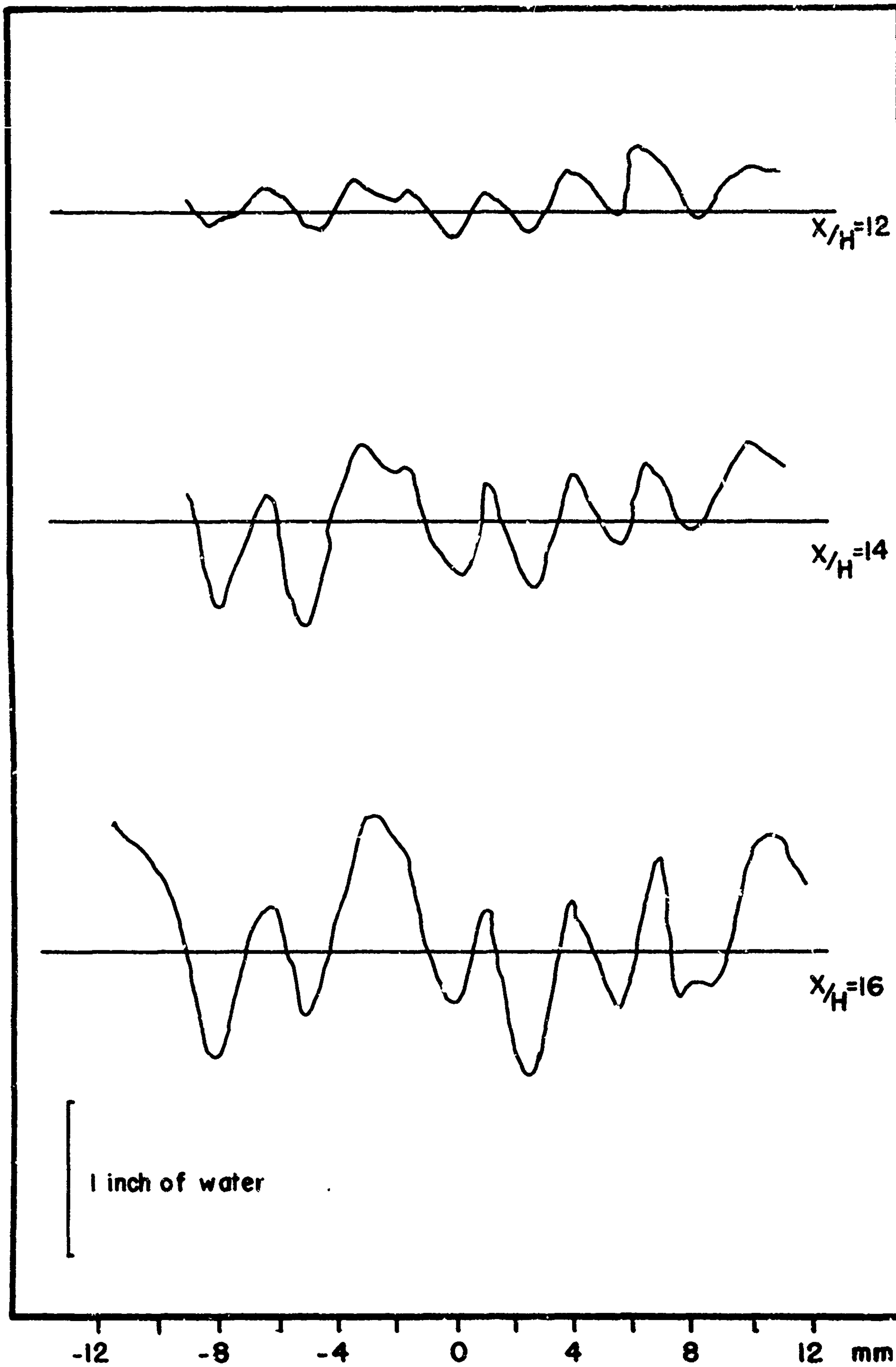


FIG.9 THREE DIMENSIONAL EFFECTS IN THE REATTACHEMENT REGION

H = 0.130 Re_H = 9900

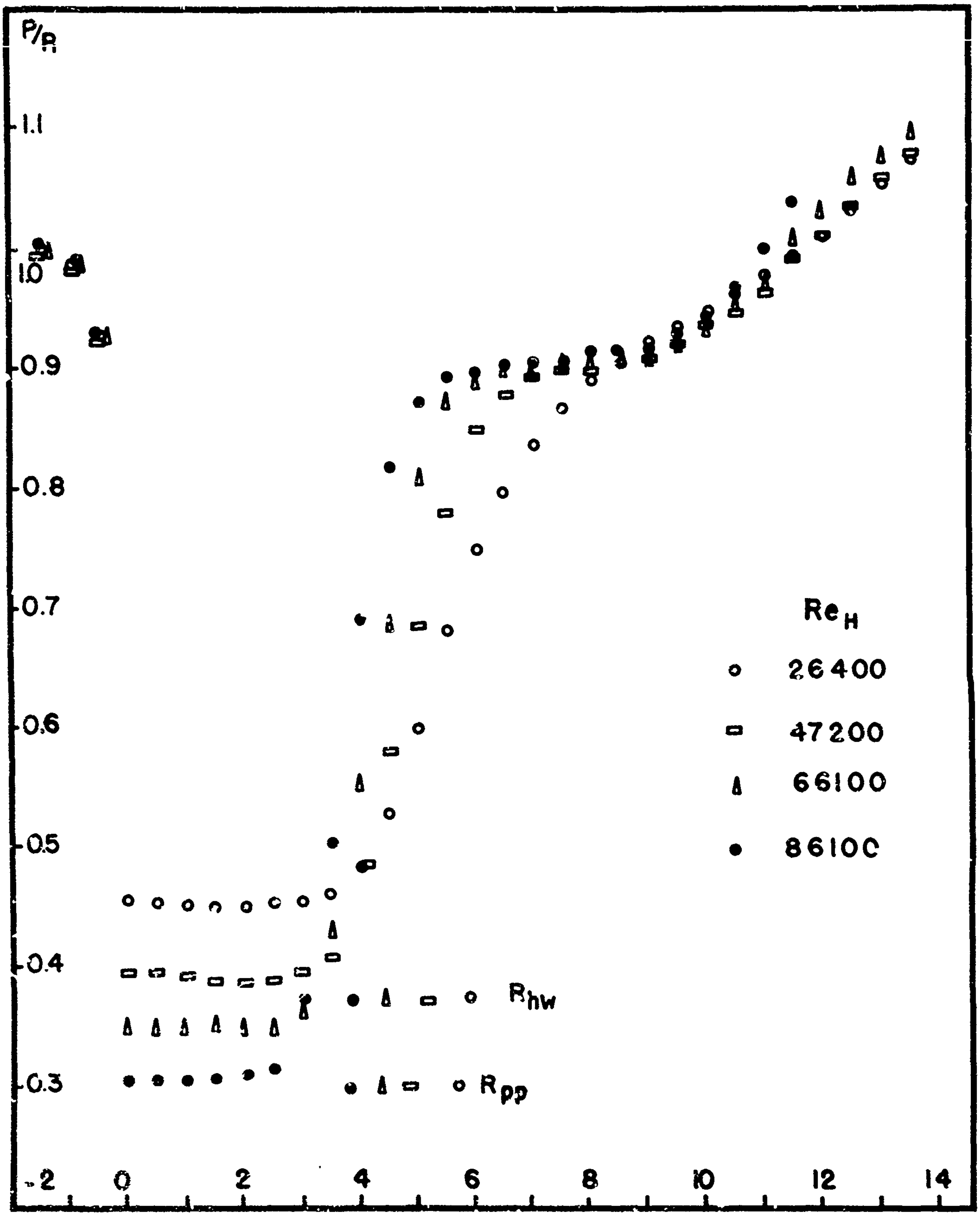


FIG.10 PRESSURE DISTRIBUTION IN TRANSITIONAL FLOW

H = 0.255"

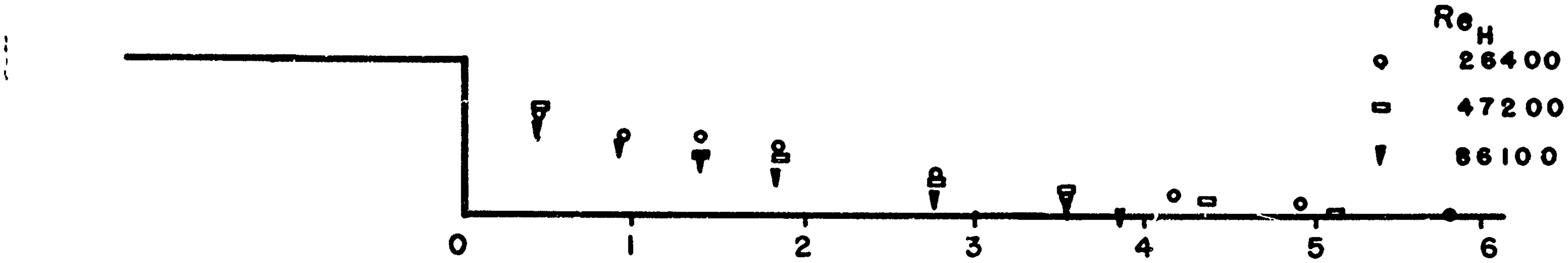


FIG. 11 ZERO VELOCITY LINES IN TRANSITIONAL FLOW. H=0.255"

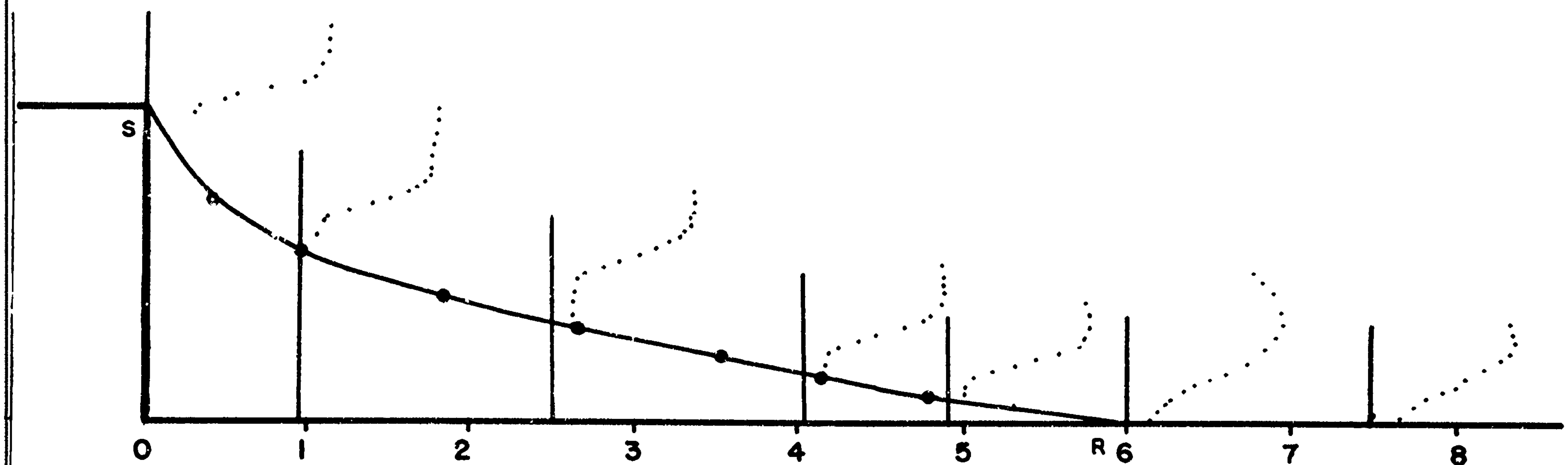


FIG.12 VELOCITY PROFILES IN SHEAR LAYER. H=0.255" Re_H = 26400

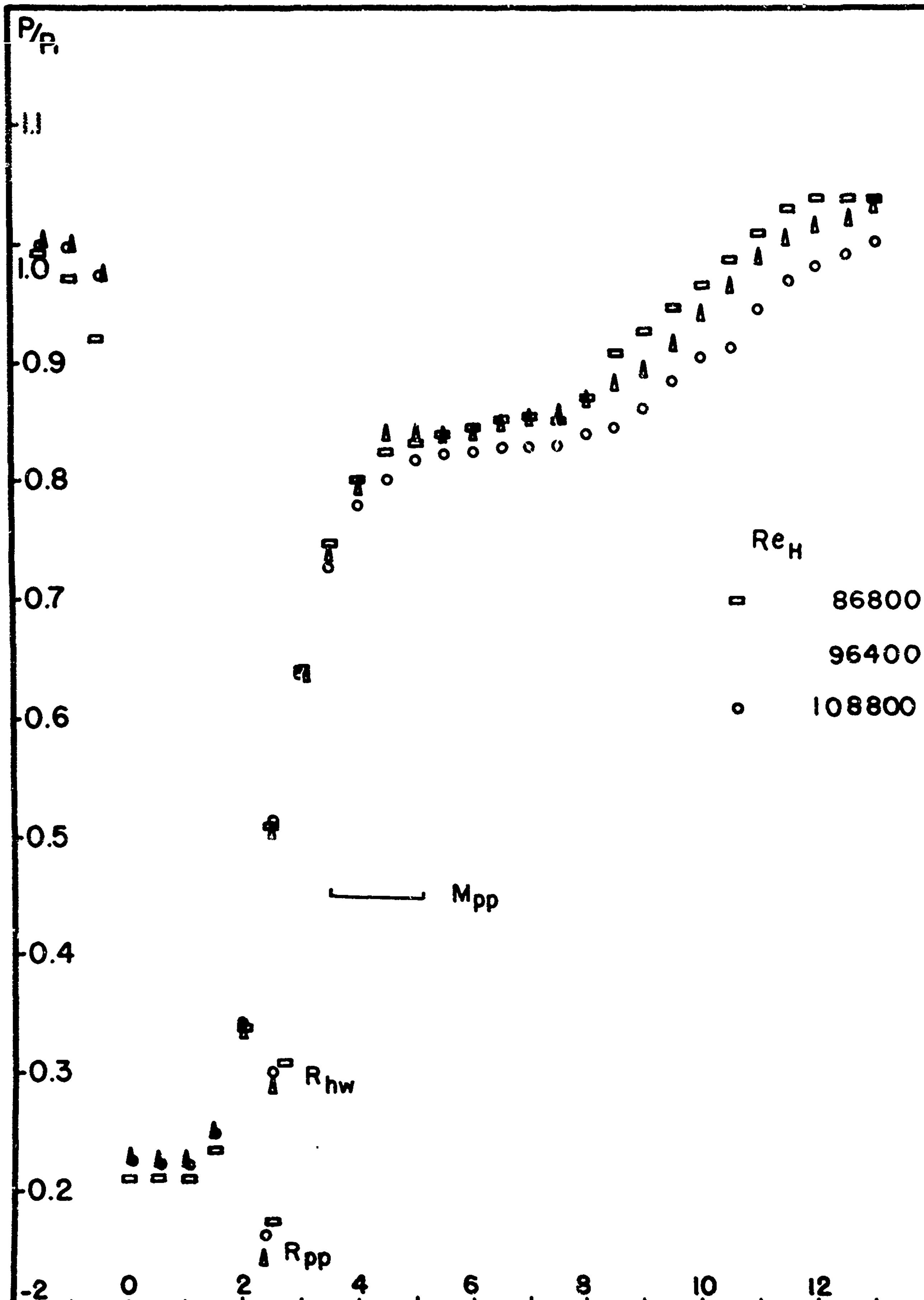


FIG.13 PRESSURE DISTRIRUTION IN TURBULENT FLOW

H =0.255"

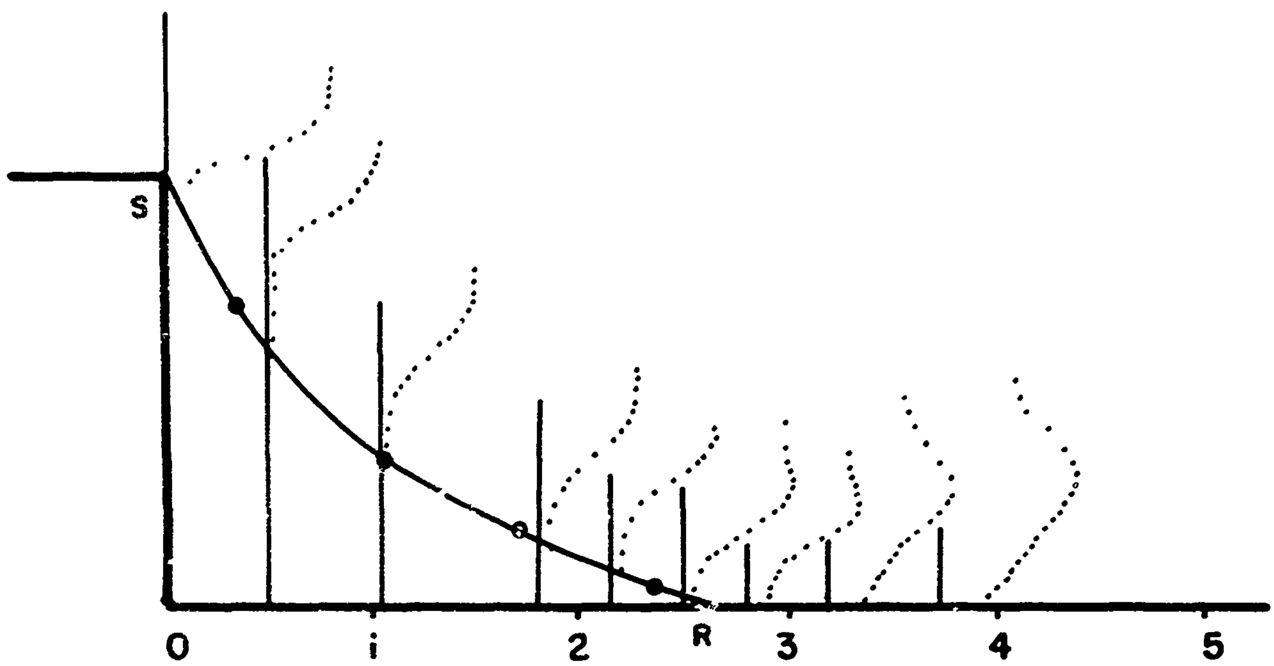


FIG. 14 VELOCITY PROFILES IN TURBULENT SHEAR LAYER.

H = 0.255" Re_H = 94600

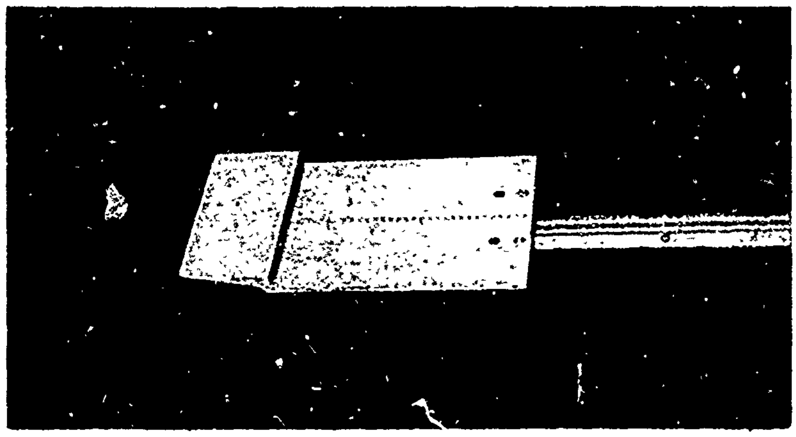


FIG. 15 VIEW OF THE MODEL

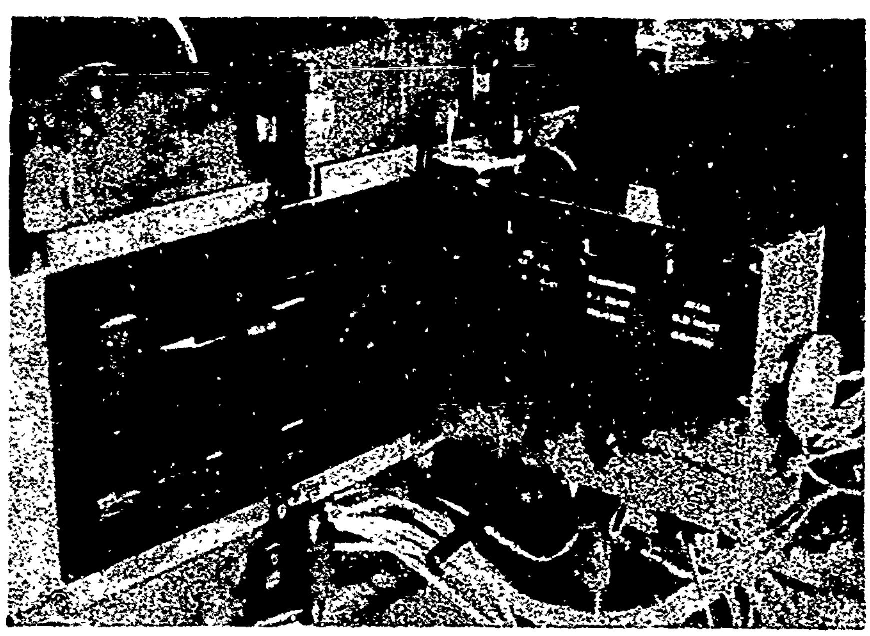
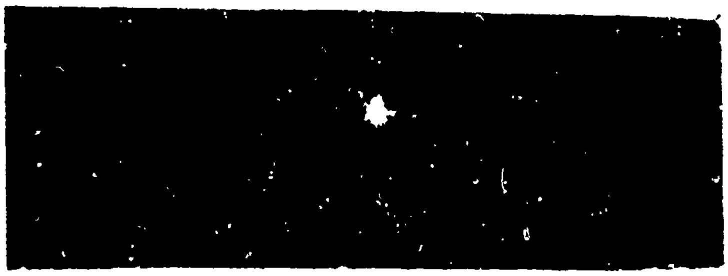


FIG. 16 MODEL MOUNTED IN THE TEST SECTION



a/ LAMINAR

b/ TRANSITIONAL

c/ TURBULENT

FIG. 17 SHADOWGRAPH VIEWS OF THE FLOW

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13 ABSTRACT

This paper describes an experimental survey of flow separation on backward facing steps having different heights at a Mach number of 2.4. Reattachment and critical points are found for three regimes, laminar, transitional, and turbulent. Reattachment occurs at a point where the pressure is 35% of the free stream value for turbulent flow, and 60% of this value in the laminar case. The length of the free shear layer is found to be one-half that of the separating streamline, a result which emphasizes the importance of the reattachment region. The flow downstream of the critical point is found to be relatively independent of the base flow. Disturbances in the spanwise direction are always observed in laminar flow but do not affect the base pressure.

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KEY WORDS	LINK A		LINK B		LINK C	
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