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# Base Pressures in Supersonic Flow

*by*

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*and*

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1956

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# Base Pressures in Supersonic Flow

- By -
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23rd March, 1955.

## 1. Introduction and Description of Apparatus

The behaviour of the flow behind a blunt base in supersonic flow is in many ways closely related to what happens in interactions between shock waves and boundary-layers, as discussed in Ref. 1. Fig. 1 illustrates a typical flow pattern. At the base there are expansions which turn the flow inwards. Just behind these expansions there are shear layers between the fast-moving external flow and the region of comparatively dead air behind the base. The shear layers come together to form a wake, being deflected in the process by appropriate compression waves back approximately to the free-stream direction. The flow pattern in this compression region, the region A of Fig. 1, is very similar to that where a boundary-layer reattaches on to a wall after being separated by an oblique shock. There is little change of pressure between the base and the beginning of the compression region, and since the pressure downstream in the wake must be roughly equal to that in the free-stream, the base pressure is dependent on the amount of pressure increase the shear layers can withstand in the region A. Thus turbulent layers can withstand more than laminar ones, so that if the flow is turbulent in the region A the base pressure will be lower than if the flow is laminar. This is analogous to the dependence of the pressure rise at separation on the boundary-layer conditions in intersections between shock waves and boundary-layers.

Because the problem of base pressures is related to that of interactions between shock waves and boundary-layers, its investigation at the N.P.L. was a logical sequel to the earlier investigations reported in Ref. 1. The 2.6" × 1.5" direct discharge tunnel (see Ref. 1) was very suitable for this work for the same reason as before, namely because with it Mach number, Reynolds number, and model configuration are all independently variable over a wide range. As with the earlier investigation the aim of the work was to throw light on the fundamental processes of the flow rather than to accumulate ad hoc data. Hence only simple model shapes were studied. The principal shapes investigated were (a), two-dimensional wedges with base : chord ratios of 1/4 and 1/8, as in Fig. 2(a); (b) cones of 10° semi-angle, as in Fig. 2(b); and (c) cone-cylinder bodies of revolution with 30° semi-angle heads and lengths of 3 and 7 diameters, as in Fig. 2(c). In addition, the base pressure behind a shallow two-dimensional step as in Fig. 2(d) was measured at a free-stream Mach number of 3, and that behind a wedge on a plate, as in Fig. 2(e), forming a "half model" of the larger wedge of Fig. 2(a), was measured at Mach numbers of 3 and 4.

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## 2. Results and Discussion

Fig. 3 shows a typical curve of base pressure ratio $p_B/p_1$, where $p_B$ is the base pressure* and $p_1$ the free-stream pressure, plotted against the Reynolds number R based on model chord, with Schlieren photographs of the corresponding flow patterns in the base region. Figs. 4-6 are additional Schlieren photographs and Figs. 7-10 show curves of $p_B/p_1$ against R for the various model shapes tested at the free-stream Mach numbers M of 1.5, 2, 3 and 4.

### (a) General Features of the Base Pressure Curves and Flow Patterns

In general the curves of $p_B/p_1$ decrease at first with increasing R and then flatten off. There are corresponding changes in the flow patterns, as can be seen from Fig. 3. At low Reynolds numbers the shear layers behind the base are inclined only at a small angle to the free-stream direction, but they converge more sharply as the Reynolds number is increased. Where the base pressure curve has flattened off, the changes in the flow pattern with increasing Reynolds number are correspondingly small.

The base pressure curve for the shallow step at M = 3 (Fig. 9) differs from the other curves in being flat at low Reynolds numbers and then decreasing with further increase of Reynolds number. This is discussed further later.

The point marked T on the curve indicates the minimum Reynolds number for which the boundary-layer on the body just upstream of the base is turbulent. The position of transition was ascertained by the use of sublimation techniques and by using small pitot tubes resting on the surface. It will be noticed that in most cases the transition Reynolds number for bodies of revolution is considerably higher than for the two-dimensional wedges at the same Mach number. This is because transition on two-dimensional bodies is sensitive to any small imperfections in the leading-edge condition. Thus in Fig. 9 there are two curves for the fatter wedge with two different transition positions, one obtained when the leading-edge had some slight nicks in it, and the other obtained after these nicks had been carefully removed by stoning. The curve for the thin wedge at this Mach number also corresponds to a carefully smoothed leading-edge, and it can be seen that with such a leading edge the transition Reynolds number is roughly the same as with bodies of revolution. It was found much more difficult to ascertain the transition position with bodies of revolution than with two-dimensional bodies, probably because in the former cases transition seldom occurs symmetrically round the body.

The transition Reynolds numbers are rather low, even with bodies of revolution, and instead of tending to decrease with increasing Mach number, as is usual, they increase. This is probably because the free-stream turbulence level in the tunnel is high, so that the transition Reynolds numbers are lower than usual, particularly at the lower Mach numbers, where the contraction to the nozzle throat is less than at the higher Mach numbers. (cf.. Ref. 2).

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*$p_B$ was normally measured at the centre of the base with two-dimensional models and at half the base radius with bodies of revolution. With the two-dimensional models of Fig. 2(a) there were additional pressure tappings which showed that the base pressure is approximately uniform over the whole base.

No results obtained with the wedge on the plate (Fig. 2(e)) have been included in Figs. 9 and 10 for $M = 3$ and 4, although the wedge on the plate was tested at these Mach numbers. It was found that at $M = 3$ the base pressure curve was very nearly the same as for the fatter wedge of 2(a), whilst at $M = 4$ the curve was parallel to, but rather higher than, the curve for the fatter wedge. However this difference is probably not significant because the wall in the arrangement of Fig. 2(e) may well have been at a slight incidence to the flow. This would affect the base pressure directly, whereas with side-supported "free" wedges the base pressure is insensitive to small angles of incidence since the wake always alines itself along the free-stream direction.

(b) The Theory of Crocco and Lees

Considerable light is thrown on the base pressure problem by the theory of Crocco and Lees[3] and a brief outline of some of their conclusions is given now to facilitate the discussion of the results.

Crocco and Lees predict that the shape of the curve of base pressure ratio $p_B/p_1$ against Reynolds number $R$ should be as in Fig. 11. At very low Reynolds numbers the flow in the region A of Fig. 1 is completely laminar and the base pressure is then relatively high and insensitive to Reynolds number. At much higher Reynolds numbers the shear-layer flow in the region A is completely turbulent and the base pressure is then much lower, because the turbulent flow can withstand a larger pressure increase in the compression region. For intermediate Reynolds numbers transition occurs within the region A, moving closer to the base as the Reynolds number increases. The base pressure steadily falls as the proportion of turbulent flow in the compression region increases. When the shear-layer flow behind the base first becomes fully turbulent (which according to Crocco and Lees is when the boundary-layer just upstream of the base first becomes turbulent) the theory predicts that $p_B/p_1$ should be a minimum. Further increase of $R$ should cause $p_B/p_1$ to increase at first, and then ultimately to decrease gradually. This variation is associated with the variation in the thickness of the turbulent boundary-layer just upstream of the base. The thickness at first increases, as the transition position moves forward on the body, but when transition occurs near the leading-edge so that the effective origin of the turbulent layer becomes fixed, the boundary-layer thickness at the base of course falls with increasing Reynolds number. The theory predicts that the base pressure is greater when the ratio of the thickness of the boundary-layer just upstream of the base to the base height is greater. Hence the variation in boundary-layer thickness just described causes the variation in $p_B/p_1$ shown in Fig. 11 when the flow behind the base is turbulent, according to the theory. Also the base pressure curve for a body of smaller base : chord ratio should be higher than that for a fatter body.

(c) Comparison Between the Experimental Results and the Predictions of Crocco and Lees[3]

Many of the features just described are found in the experimental results, but there are some differences. In this section the points of comparison are discussed, item by item.

(i) Of the experimental results, only the base pressure curve for the shallow step at $M = 3$ shows a flat top at low Reynolds numbers. Presumably with the other bodies the flow in the compression region behind the base was always at least partially turbulent in the experiments. This is despite the fact that low Reynolds numbers $R$ were achieved, often as low as $0.1 \times 10^6$. However as mentioned before the

free-stream/

free-stream turbulence level in the tunnel is probably high, which could account for the failure to obtain laminar flow behind the base except with the shallow step. It is easier to obtain laminar flow with a smaller base height because then the Reynolds number based on the length from the base to the compression region behind it is smaller for a given Reynolds number R based on chord.

(ii) All the base pressure curves other than the curve for the shallow step at M = 3 and the curves for M = 1.5 show a marked decrease with increasing Reynolds number at low Reynolds numbers. This is associated with transition moving closer to the base, in the manner suggested by Crocco and Lees. The curves for bodies of revolution at M = 1.5, however, show an increase (in one case marked, in the other slight) with increasing Reynolds numbers for most of the range in which the boundary-layers at the base are laminar. One possible explanation is that the head shock, after reflection from the side walls of the tunnel, comes rather close to the base at this low Mach number, and may interfere with the flow. However this does not seem likely with the smallest chord models. An alternative explanation is that transition occurs in the shear layers behind the base before the compression region is reached, even though the boundary-layer flow is laminar. Transition would be more likely to occur at low Mach numbers because shear layers tend to be more stable at higher Mach numbers[4,5]. It would also be more likely to happen with the three-dimensional bodies tested in the present experiments than with the two-dimensional body tested. For the former have larger base : chord ratios than the latter, so that the Reynolds numbers based on the length from the base to the compression region behind it are larger for a given chord Reynolds number R. However there is a range of Reynolds number even for the two-dimensional body for which the base pressure ratio increases slightly with R when the boundary-layer flow is laminar. This is true also for the three-dimensional bodies at a Mach number of 2, so that all these results are consistent with the explanation in terms of transition in the shear layers. It remains to be explained why the base pressure should increase with Reynolds number under such conditions, (though the increase is in most cases slight.) There might be an effect analogous to that of boundary-layer thickness as predicted by Crocco and Lees to account for the increase. However it is argued later that boundary-layer thickness may not be very important with base : chord ratios as large as in most of the present experiments. An alternative cause for the increase might be that the character of the turbulent motion varies appreciably with Reynolds number immediately downstream of transition.

(iii) The minimum on the base pressure curves predicted by Crocco and Lees occurs in our results at the lower Mach numbers though not necessarily, as just mentioned, at the transition Reynolds number. There is little sign of such a minimum at M = 3 and none at all at M = 4.

The N.O.L. ballistics range data quoted by Kurzweg[6] and Bogdonoff's results[7], all obtained with bodies of revolution at Mach numbers of about 3, show a marked minimum. However, in the latter case the minimum position apparently occurs at a lower Reynolds number

The transition Reynolds number for Bogdonoff's data is apparently considerably higher than in the present experiments, and it is certainly much higher for the N.O.L. data. With higher transition Reynolds numbers, Crocco and Lees' explanation of the minimum on the base pressure curve might perhaps be more applicable than for lower transition Reynolds numbers. For it can be shown that for higher transition Reynolds numbers there is a greater proportional difference between the minimum turbulent boundary-layer thickness at the base (when transition is at the base) and the maximum thickness (when transition is fairly near the leading edge).

The effects of boundary-layer thickness on base pressure are, however, not clear. Crocco and Lees predict that, for instance, with turbulent boundary-layers of given thickness and with a given chord, the base pressure ratio $p_B/p_1$ increases very considerably for a change of base height : chord ratio from 1/3 to 1/10. According to their theory such an increase would occur both with two-dimensional bodies and with bodies of revolution. The theory of Cope[8] would also predict a big increase for bodies of revolution, but a similar analysis applied to two-dimensional bodies would not indicate any effect of boundary-layer thickness. Beastall and Eggink's experimental results[9] for the base pressure behind a two-dimensional step at a Mach number of 1.86 show very little change of base pressure ratio for step height : chord ratios varying from 1/10 to 1/20. The corresponding base height : chord ratios with a "free" wedge would vary from 1/5 to 1/10 because the flat plate on which the step is mounted corresponds to the axis of symmetry. This lack of variation for two-dimensional bodies might seem to favour Cope's theory rather than that of Crocco and Lees. However, it is shown later that, with bodies of revolution also, when due allowance is made for the "inviscid flow" effect of body shape on the pressure distribution, the effects of varying base : chord ratio over a 2 to 1 range have little effect on base pressure according to both our experiments and those of Chapman[10]. Thus there is experimental evidence in favour of the view that boundary-layer thickness only has a small effect on the base pressure ratio for base : chord ratios greater than 1/10. This might seem contrary to the fact that undoubtedly there often occurs a minimum on the base pressure curve, and such a minimum is predicted by Crocco and Lees and Cope to be a consequence of the boundary-layer thickness variation. However the experimental minimum does not always occur at the transition Reynolds number, as the theory requires, and it may well be that the reason for the minimum differs from that suggested by the theory. Thus the cause might be some variation in the character of the turbulent flow which may occur close to transition.

Not only is there experimental evidence against the view that boundary-layer thickness is important, but it is possible to adduce a physical argument as well. The expansion springing from the base must accelerate the boundary-layer air so that just downstream of the base the part of the shear layer in which the velocity gradients are really large is much thinner than the boundary-layer upstream of the base. Outside of this region of high shear there will be, as in Fig. 12, a region of slight shear comparable in thickness with the boundary-layer thickness. It can easily be shown by inviscid-fluid theory that along any streamline the velocity gradient normal to the stream direction is reduced on passing through the sudden expansion in the ratio of the pressure at B to that at A (Fig. 12). Thus particularly with turbulent boundary-layers, where the velocity gradients in the outer part of the boundary-layer are small to start with, the situation downstream of the base is almost the same as if there were no boundary-layer upstream of the base. If there is sufficient distance between the base and the compression region

downstream/

downstream (as there will be if the base is of sufficient height) the region of high shear will have grown in thickness and absorbed by mixing the region of slight shear outside of it before the compression region has been reached. The profile will then be almost entirely independent of the original boundary-layer profile and thickness, particularly with turbulent boundary-layers. The boundary-layer thickness will accordingly have little effect on what happens to the flow in the compression region, and hence will not greatly affect the base pressure. If, however, the base height is small the profile of the shear-layer will still be somewhat as in Fig. 12 at the beginning of the compression region. The compression will then steepen the gradients in the region of slight shear, which will therefore have a significant effect on the profiles downstream of the compression and hence on the equilibrium of the compression region. Thus the base pressure might be expected to vary with the ratio of boundary-layer thickness to base height when this height is a very small proportion of the chord, but not when it is a larger proportion.

## 3. The Effects of Body Shape

With bodies of revolution the flow patterns downstream of the base and the ratios of the pressures to the free-stream pressure cannot be independent of body shape. Consider say a cone and a long cone-cylinder body of revolution. The pressure on the surface of the long body just upstream of the base is nearly equal to the free-stream pressure. On the surface of the cone the pressure is of course higher than the free-stream pressure, but if there were an expansion at the base turning the flow to the free-stream direction, the pressure would drop below that in the free-stream*. Hence if the flow angles just downstream of the base were the same with the cone as with the cone-cylinder, the base pressure ratio $p_B/p_1$ would be lower for the cone. Similarly the base pressure ratio for a short cone cylinder would be lower than for a long one, since for a short cone cylinder the pressure on the surface just upstream of the base is appreciably lower than the free-stream pressure.

With two-dimensional bodies, on the other hand, the base pressure ratio would be almost independent of body shape if the inclination of the flow just downstream of the base to the free-stream direction did not vary. The only differences would be due to shock losses, and with thickness : chord ratios up to, say $\frac{1}{4}$ the differences would be small.

In an attempt to present the results of Figs. 7 to 10 for bodies of revolution in such a form that they are independent of body shape, they are replotted in Fig. 13 as $p_B/\bar{p}$ against R, where $\bar{p}$ is the calculated pressure immediately downstream of the base on a hypothetical cylindrical extension of the body with the same diameter as that of the base. If $p_B/\bar{p}$ were the same with different bodies, the angle between the free-stream direction and the shear-layer flow just downstream of the base would be approximately the same. It can be seen from Fig. 13 that at the highest Reynolds numbers, where in most cases at least the flow in the compression region behind the base is turbulent, $p_B/\bar{p}$ is very roughly independent both of body shape and of R. In other words in our experiments with bodies of revolution, (the most slender of which was 7 base-diameters long,) the inclination of the shear layer flow just downstream of the base to the free-stream direction tends in the turbulent régime to be a function only of Mach number, independent of Reynolds number, of body shape, and of the ratio of the boundary-layer thickness to base diameter.

Chapman[10]/

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*For the pressure on the surface of the cone is less than that after a two-dimensional isentropic compression turning the flow by the semi-angle of the cone, but the expansion at the base is locally two-dimensional.

Chapman[10] correlates the results obtained with variously shaped bodies of revolution by assuming that the ratio $p_B/p'$ is invariant. The pressure $p'$ is similar to $\bar{p}$, being defined as the pressure on a hypothetical cylindrical extension of the body one diameter downstream of the base. It is assumed that $p'$ represents an effective free-stream pressure averaged over the region from the base to the compression region, which typically occurs at rather more than one diameter behind the base. The ratio $p_B/p'$ differs less from $p_B/p_1$ than does $p_B/\bar{p}$, so that Chapman's "correction" for body shape is rather less severe than ours. However, the data for turbulent boundary-layers given by Chapman[10] are correlated at least as well on our $p_B/\bar{p}$ basis as on Chapman's $p_B/p'$ basis.

For two-dimensional flow, the only data obtained in the present experiments for the effects of different body shapes are shown in Figs. 9 and 10. At high Reynolds numbers at $M = 3$ the base pressure ratio is approximately independent of R and the same for the two wedges tested. This suggests that with turbulent flow, the base pressure ratio $p_B/p_1$ is insensitive to R, to body shape, and to the ratio of boundary-layer thickness to base height, at any rate for base heights greater than 1/8 chord. Beastall and Eggink's results[9] for flow down a step confirm this. Chapman's results[11], obtained with base : chord ratios between 1/10 and 1/80 show, when plotted against boundary-layer thickness divided by base height, an appreciable variation of $p_B/p_1$ at a Mach number $M = 3.1$ but a much smaller variation at $M = 2.0$ and virtually none at $M = 1.5$. At all Mach numbers, however, Chapman's results are perfectly consistent with there being no significant effect of the ratio of boundary-layer thickness to base height for base heights greater than, say, 1/10 chord. Our results of Fig. 10 obtained at $M = 4$ show differences between the base pressure ratios $p_B/p_1$ with the two wedges even at high Reynolds numbers. However, as is shown in the next section, there is some evidence that at this Mach number and at the Reynolds numbers of the experiments the flow in the shear-layers downstream of the base is laminar even when the boundary-layer flow is turbulent. Such a return to laminar flow on passing through the expansions at the base is more likely to occur at high Mach numbers than at low ones, since shear-layers are more stable at high Mach numbers.

### (a) The Effects of Body Shape when Transition Occurs in the Compression Region Behind the Base

When the shear-layers leaving the base are laminar, the base pressure ratio $p_B/p_1$ is very sensitive to the position of transition in the interaction region, being much less when transition is close to the base than when it it further away. It is reasonable to expect that the distance of transition downstream of the base in terms of the base height or diameter h as unit of length would depend partly on the Reynolds number $R_h$ based on free-stream conditions and the length h, and partly on the Reynolds number R based on model chord. As pointed out earlier, the expansion at the base accelerates the boundary-layer air so that just downstream of the base the part of the shear-layer in which the velocity gradients are really large is much thinner than the boundary-layer upstream of the base. Hence if on passing through the expansion any disturbances in the upstream boundary-layer were damped out (in the same way that turbulence is reduced by the mean velocity rise in a wind-tunnel contraction), the "effective origin" of the shear-layer would be at the base, with fairly large base heights as used in the present experiments. Accordingly the transition distance downstream of the base would presumably depend mainly on $R_h$ and be almost independent of R. However if upstream disturbances are not damped out by the expansion, the transition distance will depend on R as well.

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In Fig. 14 the results of Figs. 7 to 10 for three-dimensional bodies are replotted as $p_B/\bar{p}$ against $R_h$, and in Fig. 15 the results for two-dimensional bodies at $M = 3$ and 4 are replotted as $p_B/p_1$ against $R_h$. From Figs. 13 and 14 it can be seen that the results for three-dimensional bodies correlate quite well when $p_B/\bar{p}$ is plotted against $R$, whilst the best correlation with two-dimensional bodies is obtained when $R_h$ is taken as the independent variable. This is perhaps not unreasonable since the base pressure tendsto be lower with two-dimensional bodies than with bodies of revolution, so that the expansions are stronger and any disturbances present in the upstream boundary-layer are more likely to be damped out.

However it must be borne in mind that different results are likely to be obtained from different wind tunnels, since the results with partially laminar flow in the compression region are critically dependent on the position of transition, and this in turn is affected by the tunnel turbulence level. It is perhaps because of differences in the latter that Chapman's results do not correlate on the same basis as ours. Chapman[10] suggests that when the boundary-layer is laminar $p_B/p'$ is a function of $hR^{\frac{1}{2}}/c$, where $h$ is the base height or diameter and $c$ is the chord. The expression $hR^{\frac{1}{2}}/c$ is roughly proportional to the ratio of the base height to the thickness of the laminar boundary-layer at the base. This ratio certainly cannot be the only relevant factor because it is not the only factor affecting the position of transition relative to the base. Furthermore with base heights which are not too small it can be argued as above that boundary-layer thickness should not be very relevant, though the argument applies less forcibly to laminar layers than to turbulent ones. However Chapman's three-dimensional results which are plotted in our way as $p_B/p_1$ against $R$ in Fig. 16, correlate quite well when $p_B/p'$ is plotted against $hR^{\frac{1}{2}}/c$, as can be seen from Fig. 17. They correlate nearly as well when plotted as $p_B/\bar{p}$ against $R_h$, as in Fig. 18, but the correlation is not very good when $p_B/\bar{p}$ is plotted against $R$, as in Fig. 19. Our results for bodies of revolution correlate less well when either $p_B/p'$ or $p_B/\bar{p}$ is plotted against $hR^{\frac{1}{2}}/c$ than when $p_B/\bar{p}$ is plotted against $R_h$, and much less well than when $p_B/\bar{p}$ is plotted against $R$. Similarly with our two-dimensional bodies better agreement is obtained with $R_h$ as independent variable than with $hR^{\frac{1}{2}}/c$. These differences from Chapman's findings are perhaps due to the fact that the transition Reynolds numbers were much higher in Chapman's tests than in ours. In any case it is obvious from the physical discussion presented earlier that none of the suggested methods of plotting the results takes account of all the relevant physical factors.

Fig. 15 shows that the two curves obtained with two-dimensional bodies at $M = 4$ agree quite well when plotted against $R_h$ even at high Reynolds numbers, whereas the discrepancy is much greater when the results are plotted against $R$, as in Fig. 10. This is perhaps an indication that laminar flow is re-established behind the base even with turbulent boundary-layers, since $R_h$ would only be expected to be relevant if it controls transition position. The flow photographs Figs. 4 and 5 are not inconsistent with this conjecture. The Reynolds number $R$ is the same, $3 \times 10^6$, in both these pictures, but the Mach that condensation of the air occurs in the very high Mach number region just outside the shear-layers at $M = 4$. Local Mach numbers as high as 5.6 are reached, and with the high stagnation pressures used (up to about 20 atmospheres) and atmospheric stagnation temperature there is certainly a danger of condensation. A rough calculation suggested that if condensation occurs without supercooling the measured flow angles would in fact be about 3° greater than the calculated ones. Such condensation would be most severe at the highest stagnation pressures, i.e., at the highest Reynolds numbers. It may be that this effect, rather than any re-establishment of laminar flow behind the base, is responsible for the fact that the base pressure curves do not flatten off at the highest Reynolds numbers achieved in our experiments at $M = 4$.

## 4. Comparison with Previous Measurements of Base Pressure for Turbulent Boundary-Layers

Although the foregoing discussion has suggested interpretations that differ in some ways from those previously current, the experiments are in reasonable agreement with previous experiments for the most important practical case, namely that of turbulent boundary-layers. This is illustrated by Figs. 20 and 21 which compare the present results for bodies of revolution and two-dimensional bodies respectively with the curves derived[10,11] by Chapman from a consideration of a large number of experimental results.

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## List of Symbols

| | |
|---|---|
| $R$ | Reynolds number based on the chord of a wedge or the length of a body of revolution. |
| $M$ | free-stream Mach number. |
| $p$ | static pressure. |
| $p_1$ | $p$ in free-stream. |
| $p_B$ | $p$ at the base of a body. |
| $\bar{p}$ | calculated value of $p$ just downstream of base on a hypothetical cylindrical extension of a body of revolution (see page 6). |
| $p'$ | calculated value of $p$ one diameter downstream of base on a hypothetical cylindrical extension of a body of revolution (see page 7). |
| $h$ | base height or diameter. |
| $c$ | chord of a wedge or length of a body of revolution. |
| $R_h$ | Reynolds number based on length $h$. |

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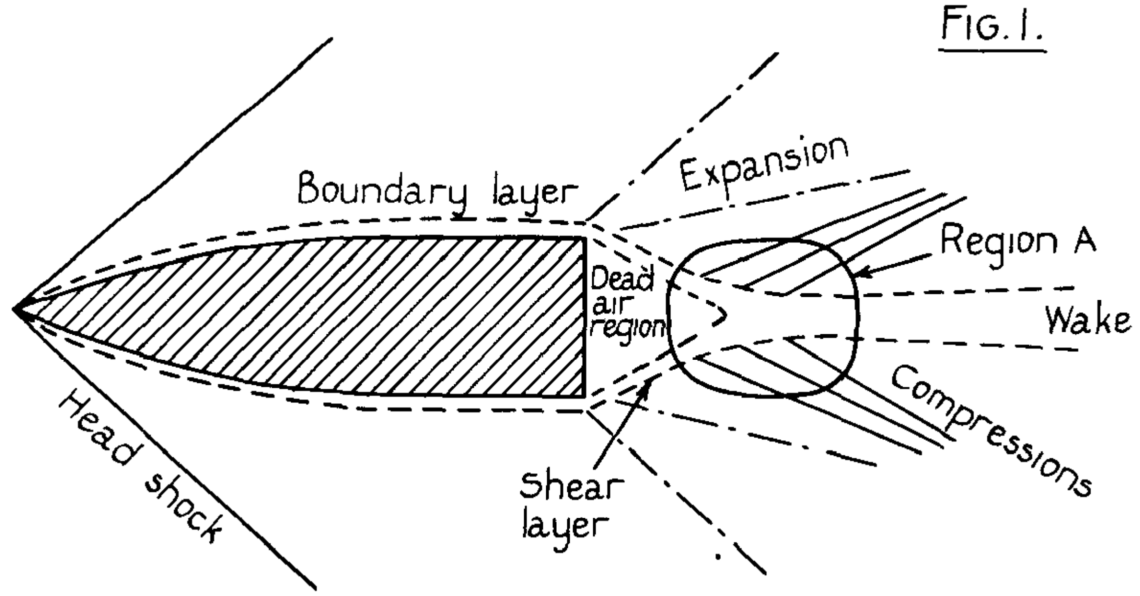
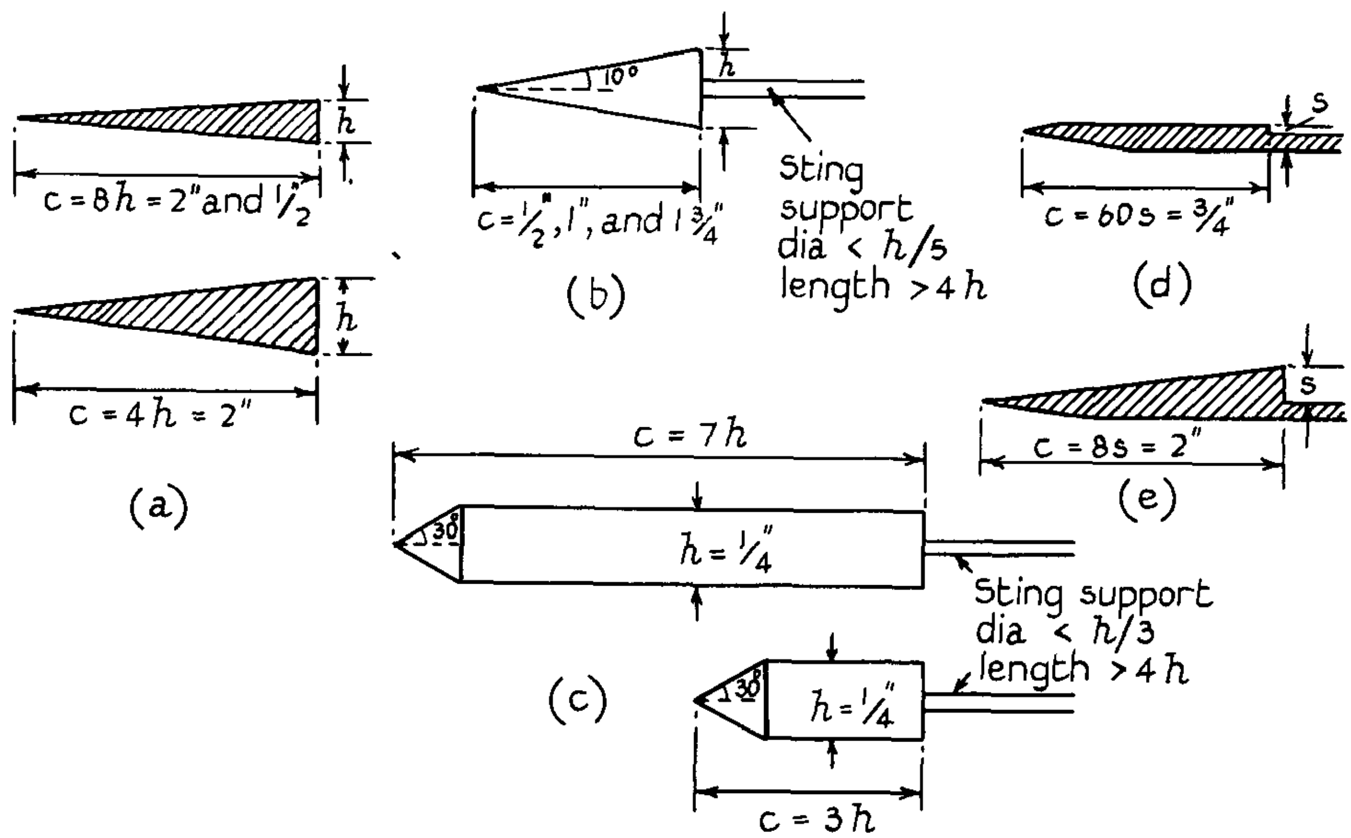
FIGS. 1 & 2.

FIG. 1.

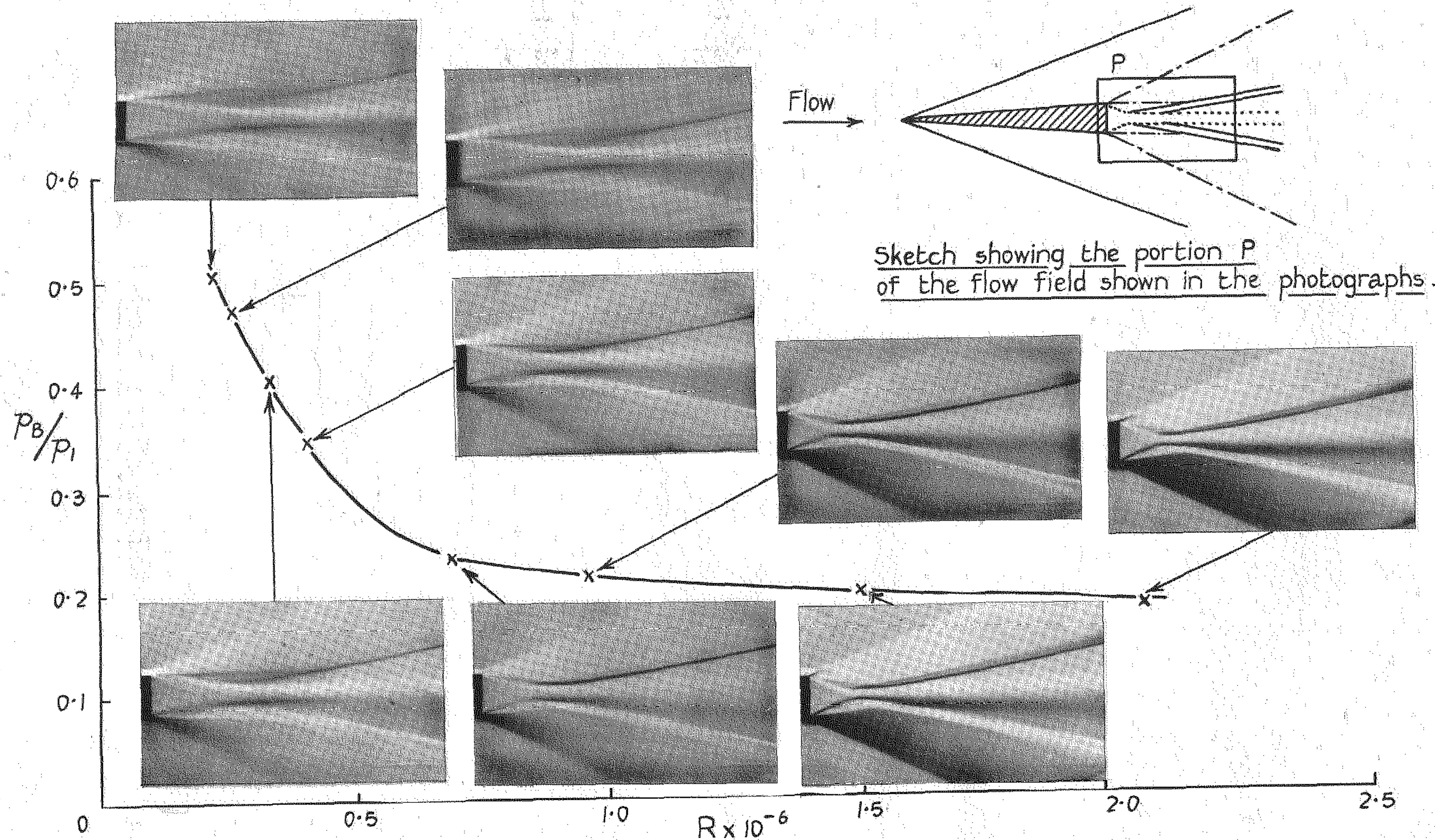



Typical flow pattern.

FIG 2.




Details of the models tested




The base pressure on a two-dimensional wedge as a function of Reynolds number and the corresponding flow patterns at a free-stream Mach number of 3.

FIG. 3.

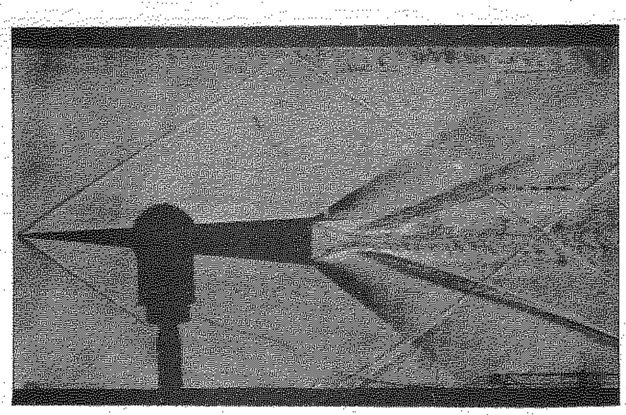


FIG. 4. Vertical knife edge schlieren photograph of a two-dimensional wedge. $M = 2$ $R = 3 \times 10^6$

The vertical support at the centre of the wedge is outside the tunnel.

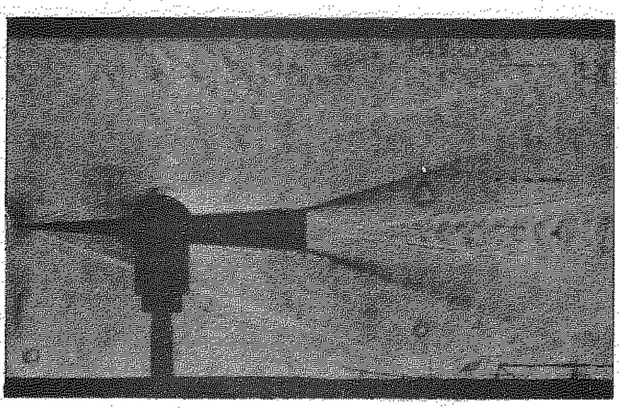


FIG. 5. As in Fig. 4, but at $M = 4$

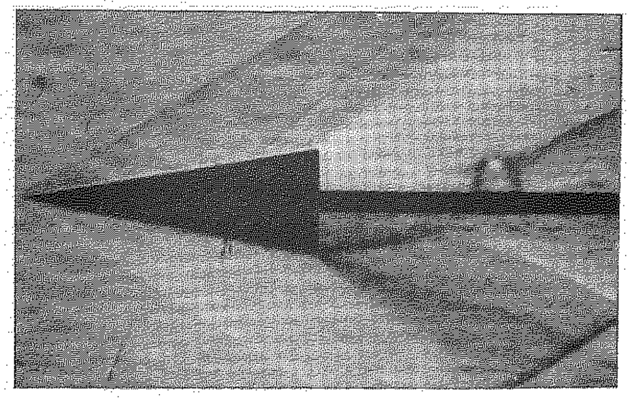
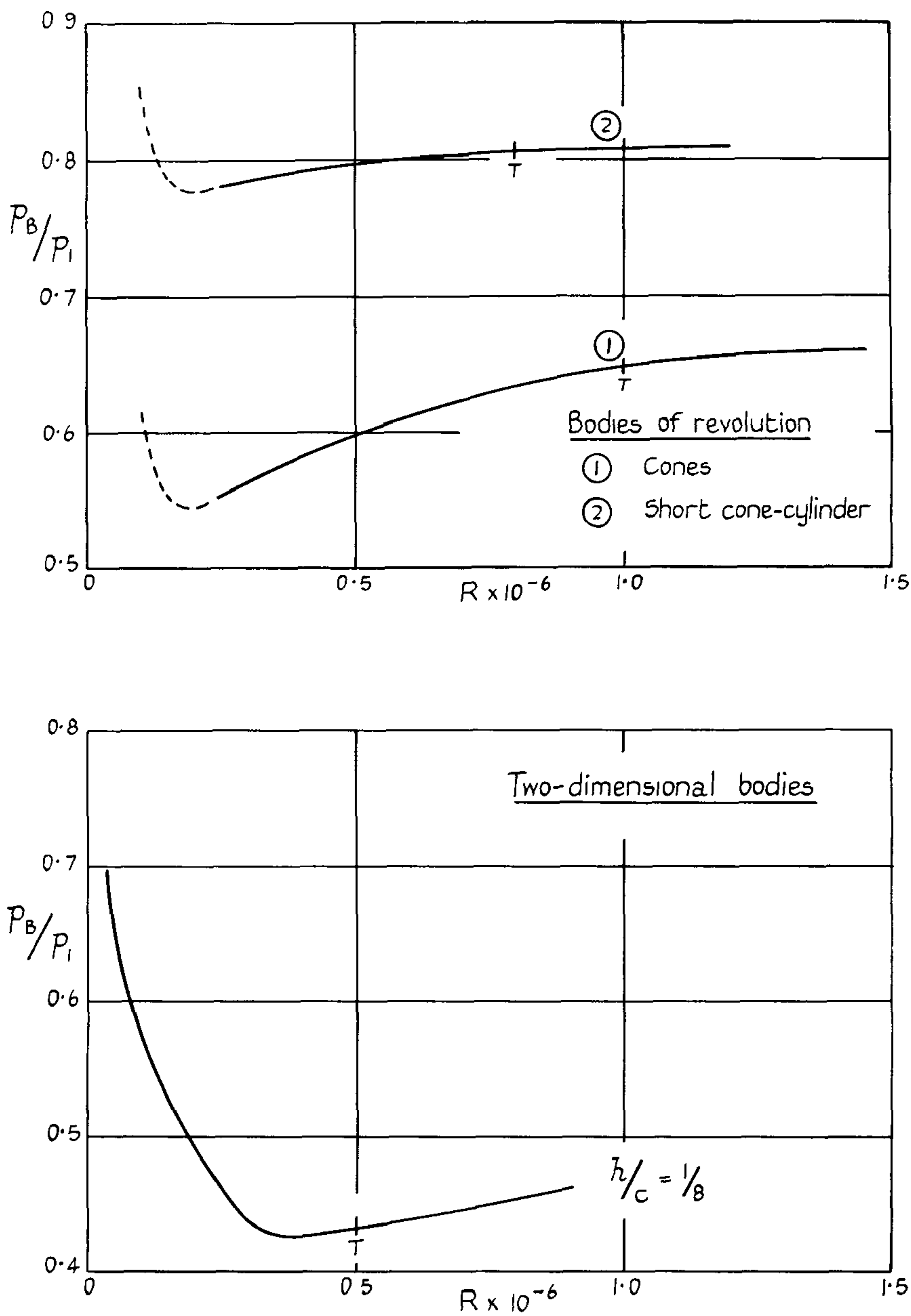


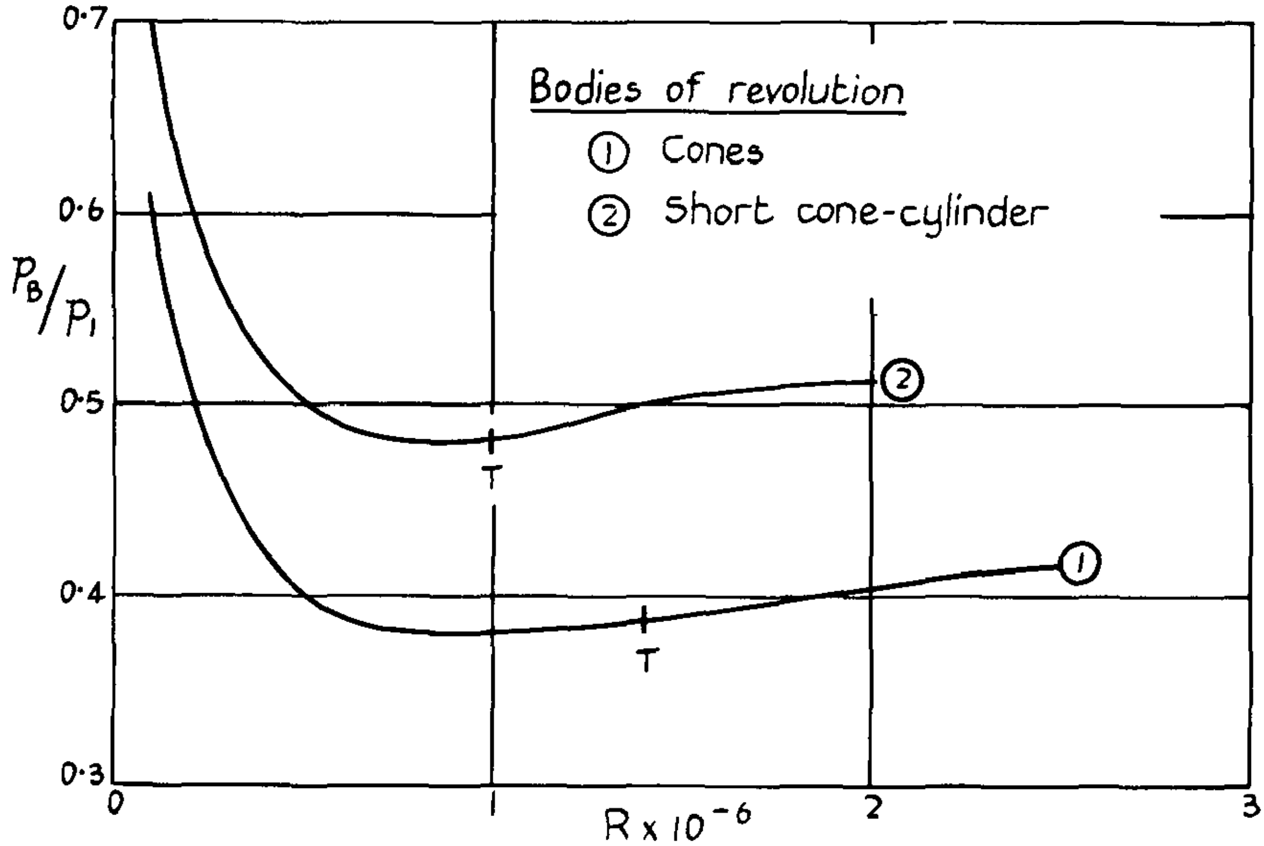
FIG. 6. Horizontal knife edge schlieren photograph of a cone. $M = 2$ $R = 0{\cdot}45 \times 10^6$

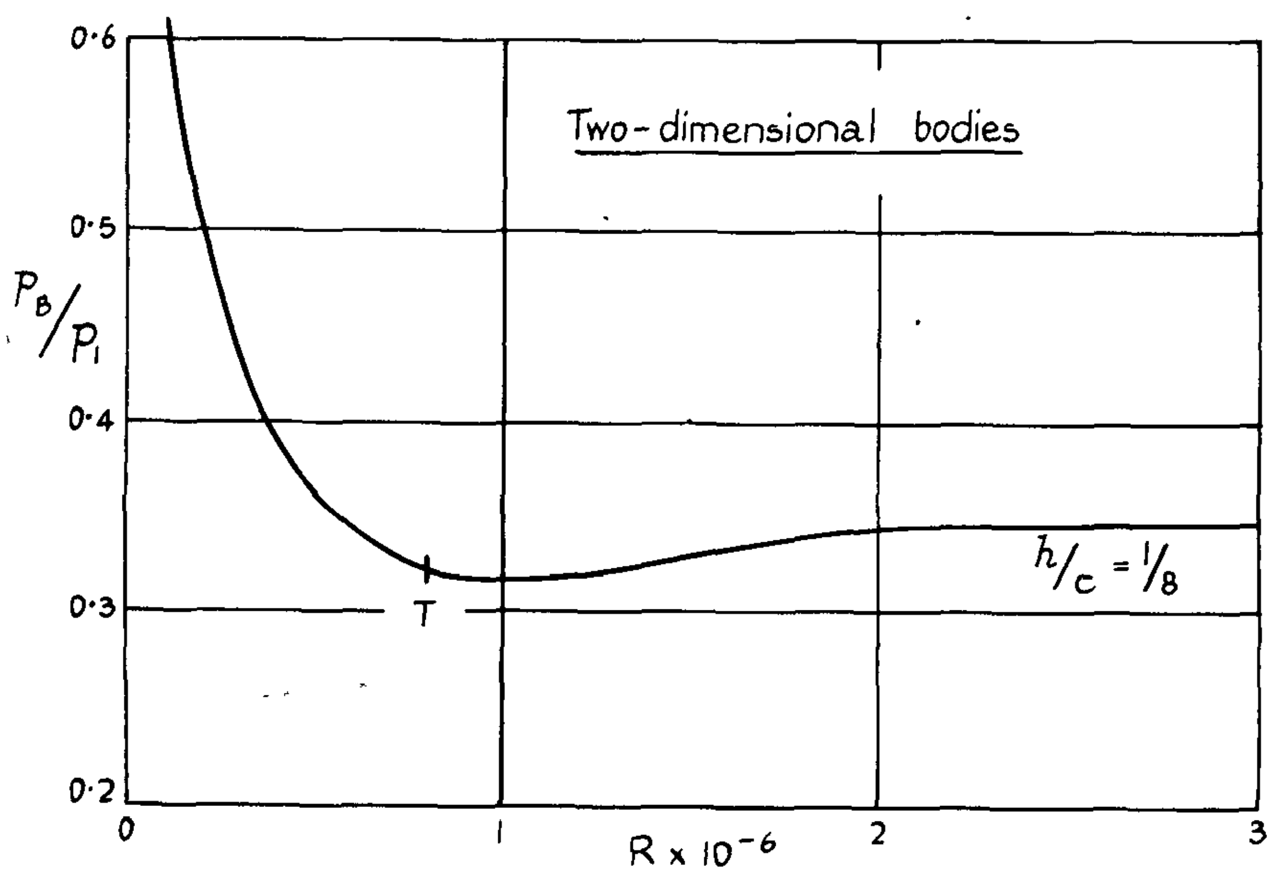
FIG 7.




The variation of base pressure ratio with Reynolds number at a Mach number of 1·5

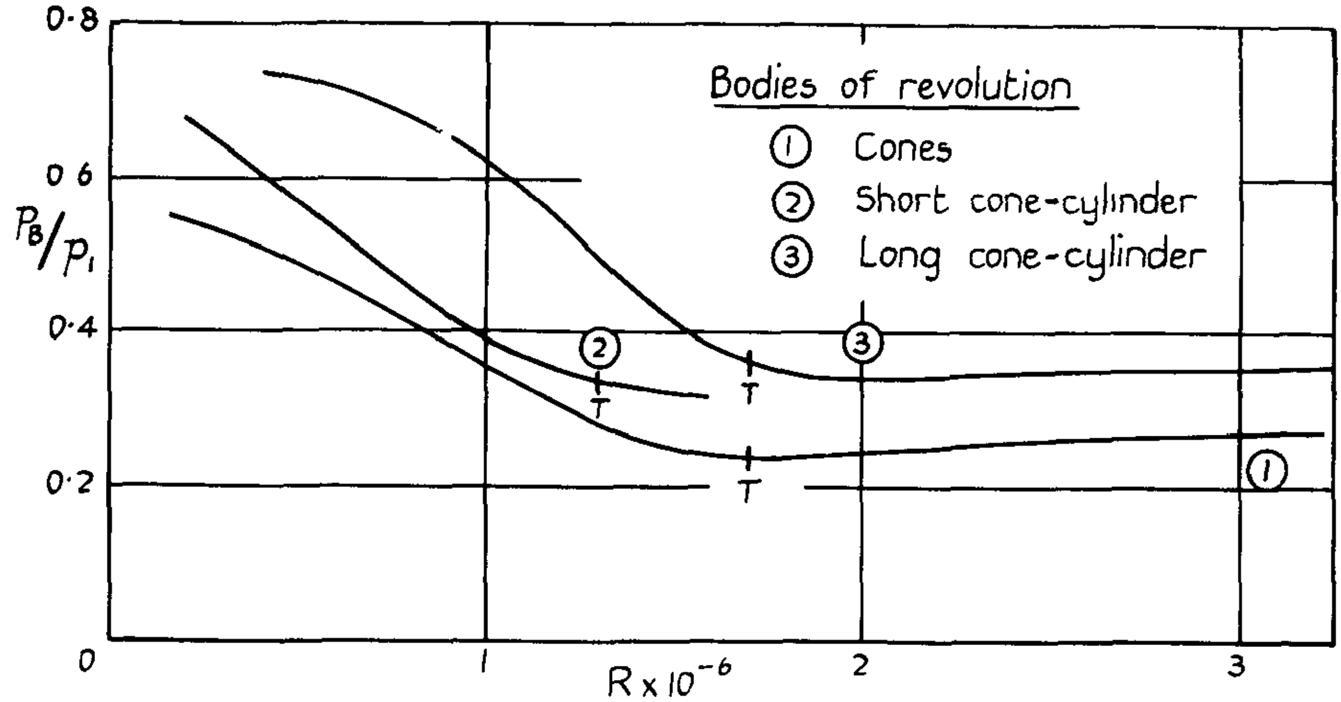
FIG 8.

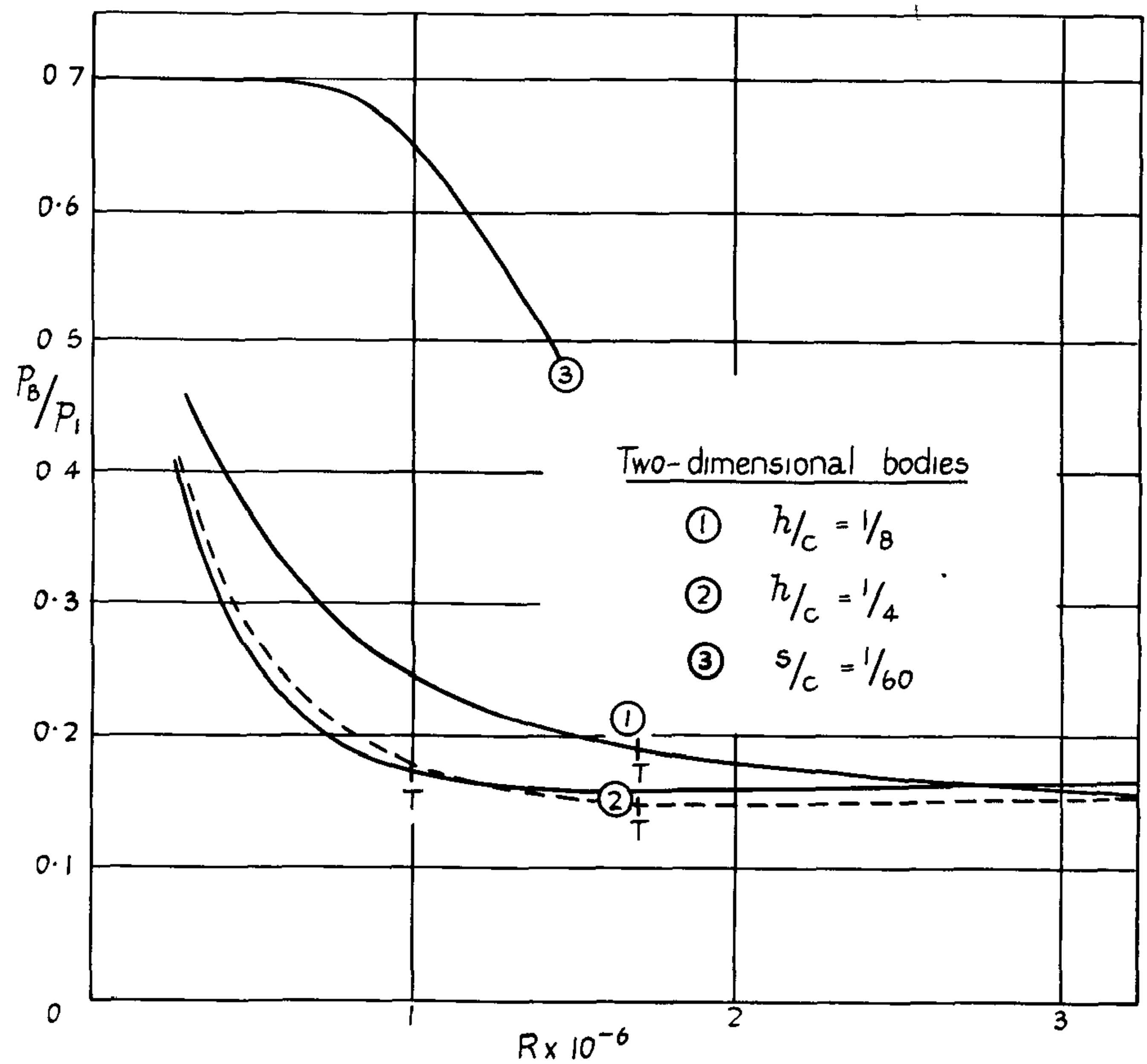



The variation of base pressure ratio with Reynolds number at a Mach number of 2

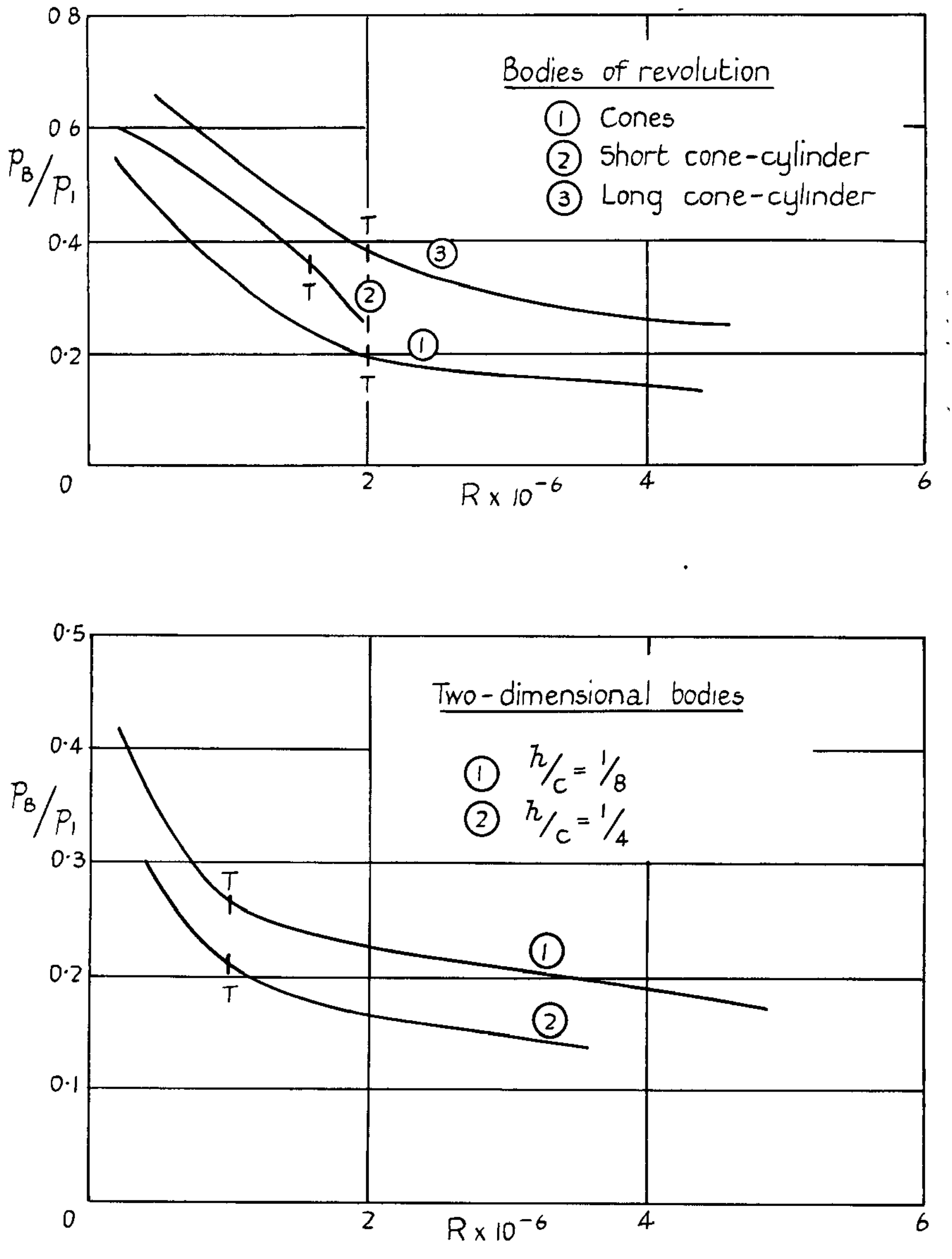
FIG. 9.




The variation of base pressure ratio with Reynolds number at a Mach number of 3

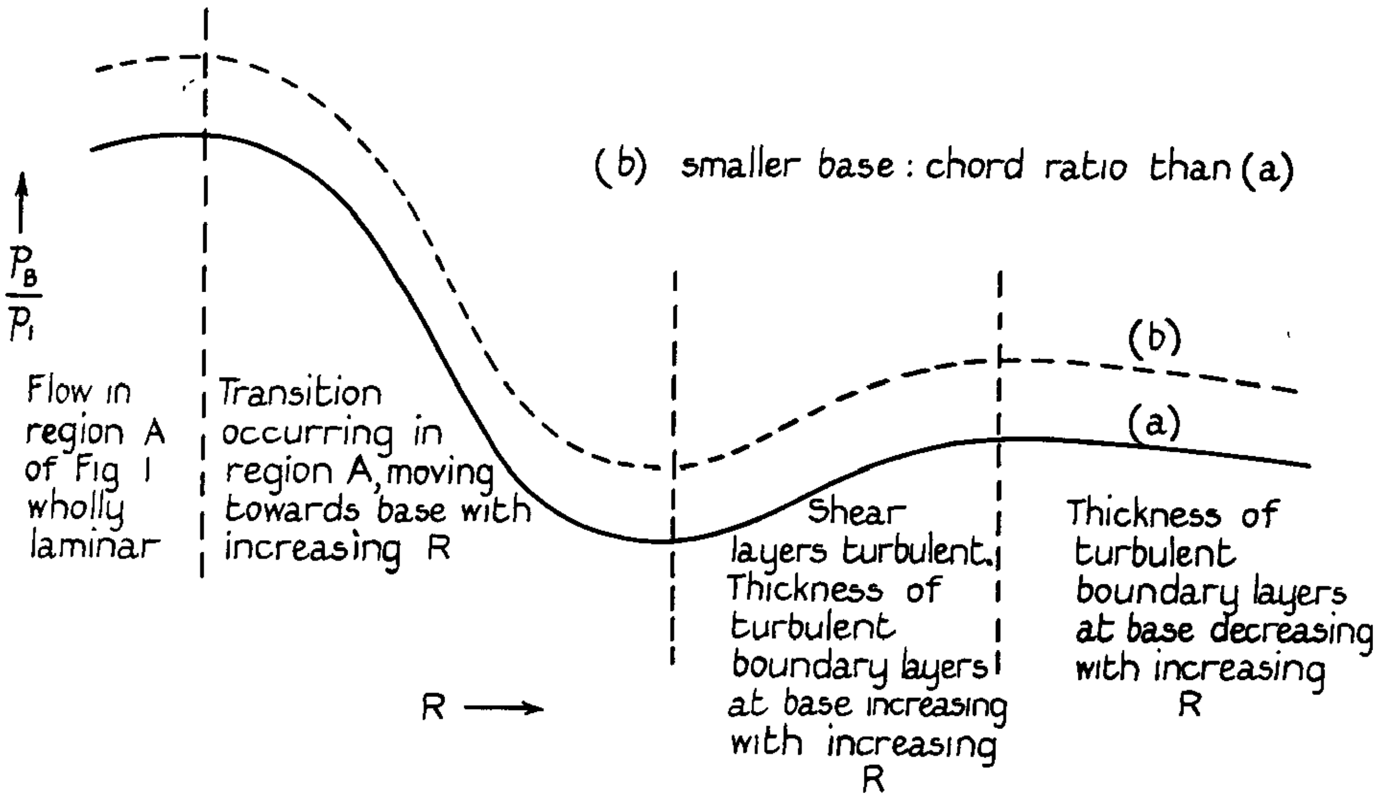
FIG 10.




The variation of base pressure ratio with Reynolds number at a Mach number of 4.

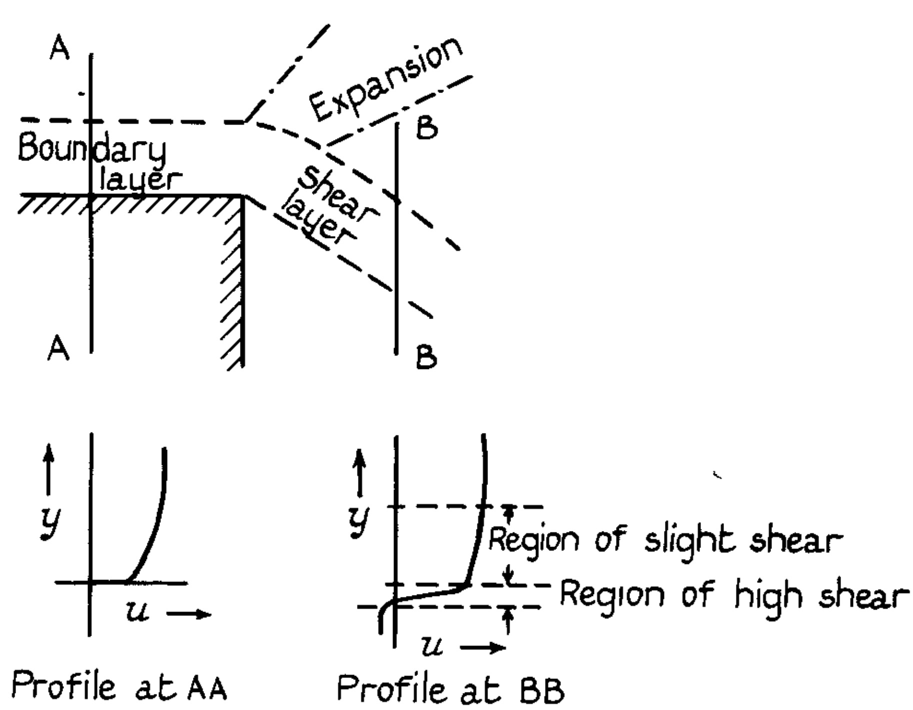
FIGS 11 & 12.

FIG. 11.



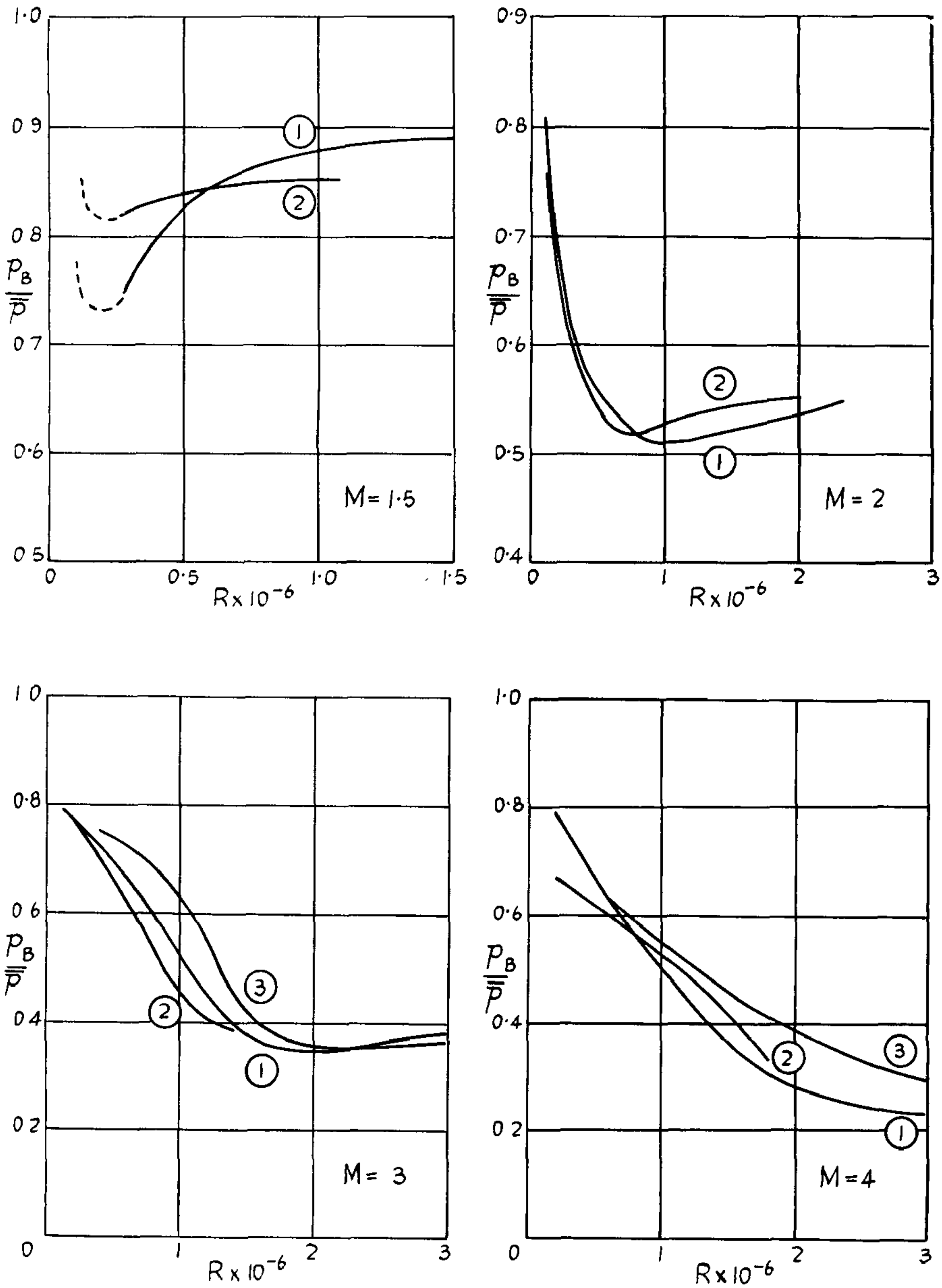

Sketch showing the variation of base pressure with Reynolds number according to Crocco and Lees.

FIG. 12.




Velocity profiles near the base.

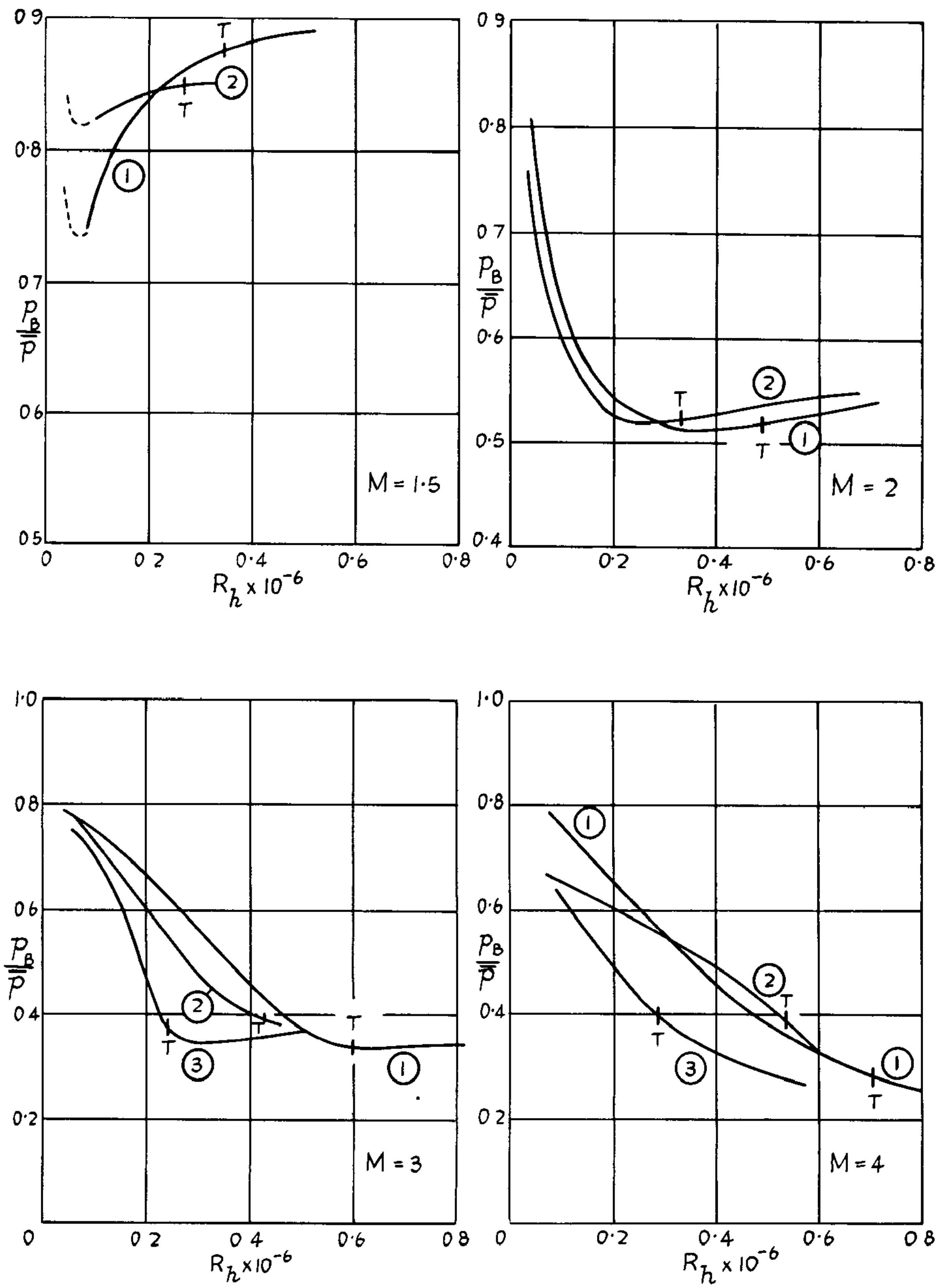
FIG. 13.




"Corrected" base pressure ratio as a function of Reynolds number for bodies of revolution at various Mach numbers.

(1) Cones (2) Short cone-cylinder (3) Long cone-cylinder

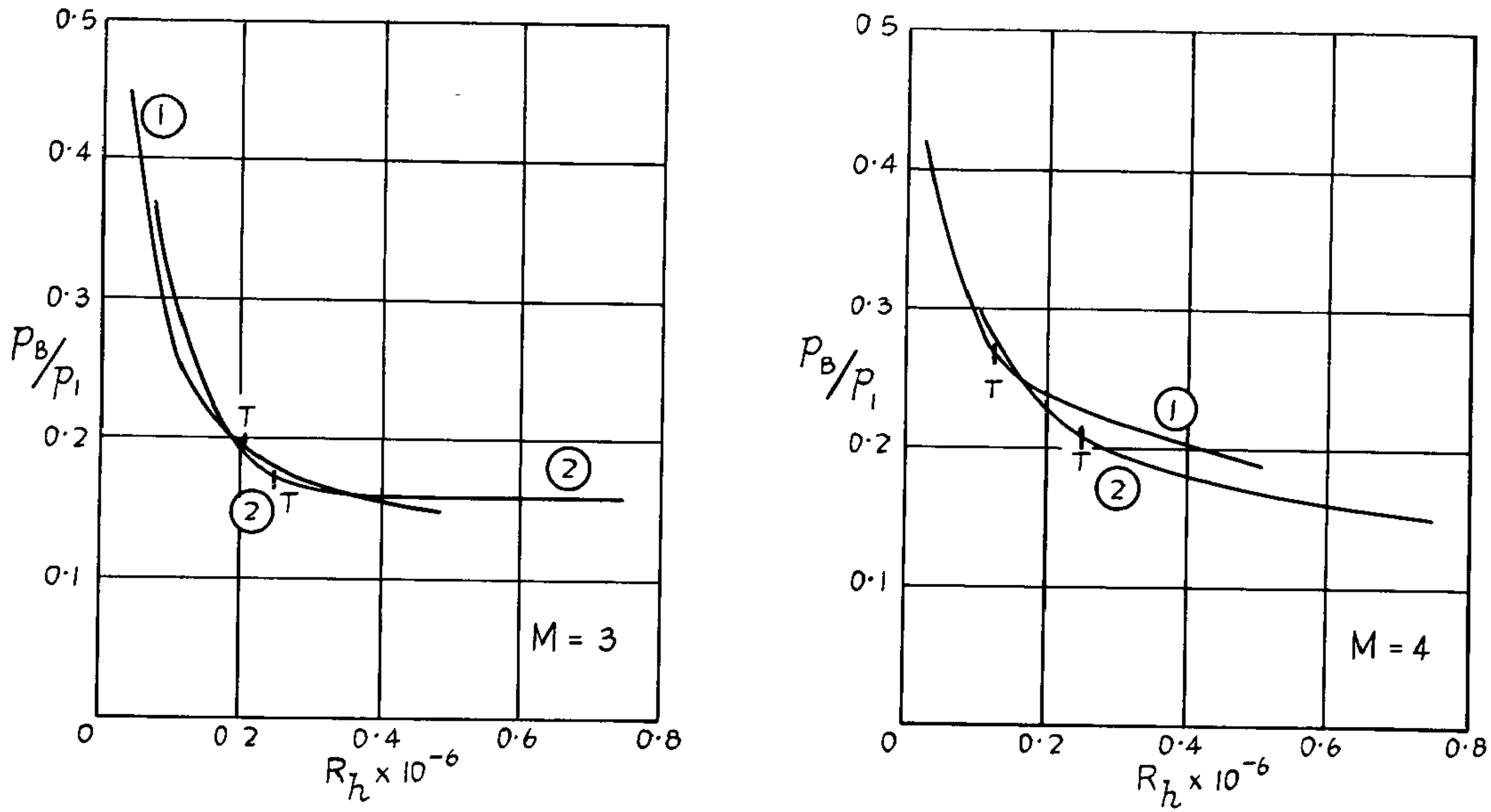
FIG 14




"Corrected" base pressure ratio as a function of Reynolds number based on base-diameter $h$ for bodies of revolution at various Mach numbers

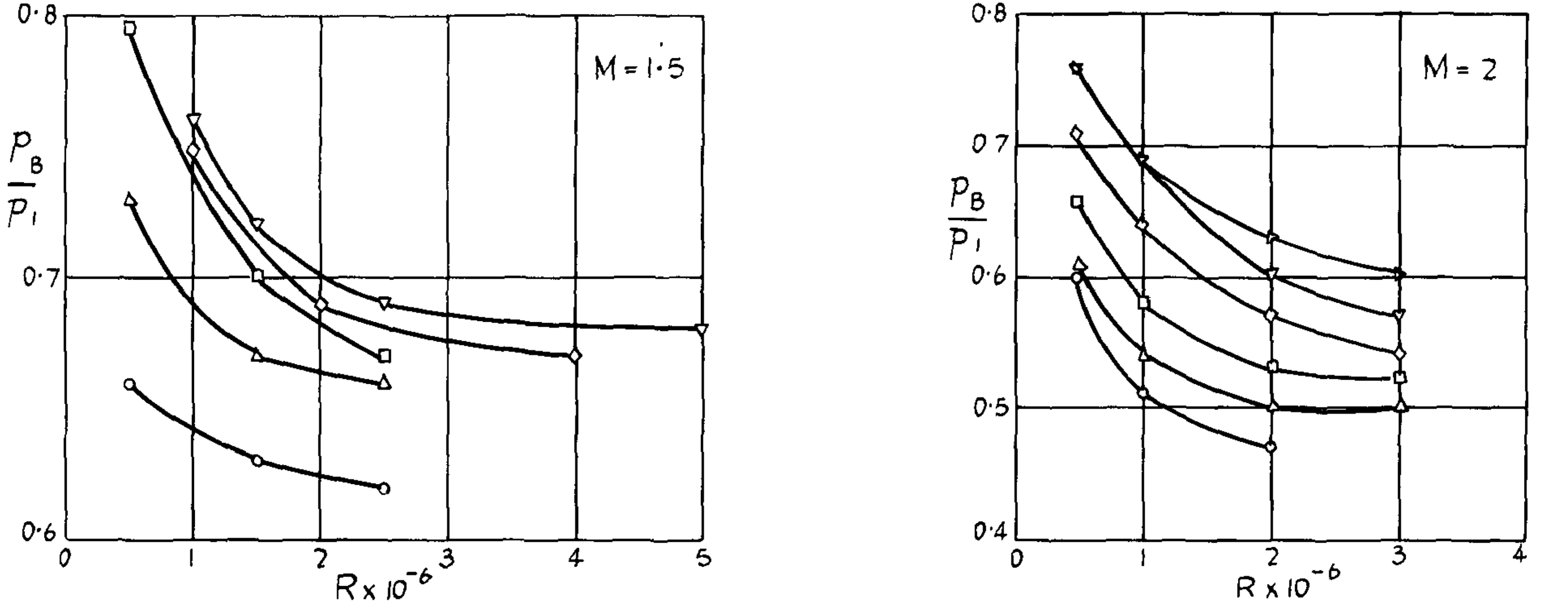
(1) Cones (2) Short cone-cylinder (3) Long cone-cylinder

FIG 15




Base pressure ratio as a function of Reynolds number based on base height $h$ for wedges at Mach numbers of 3 and 4

(1) $h/c = 1/8$ (2) $h/c = 1/4$




Chapman's results for various bodies of revolution (Shapes shown in ref 10, same symbols).
Base pressure ratio as a function of Reynolds number for Mach numbers of 1·5 and 2

FIG 16.

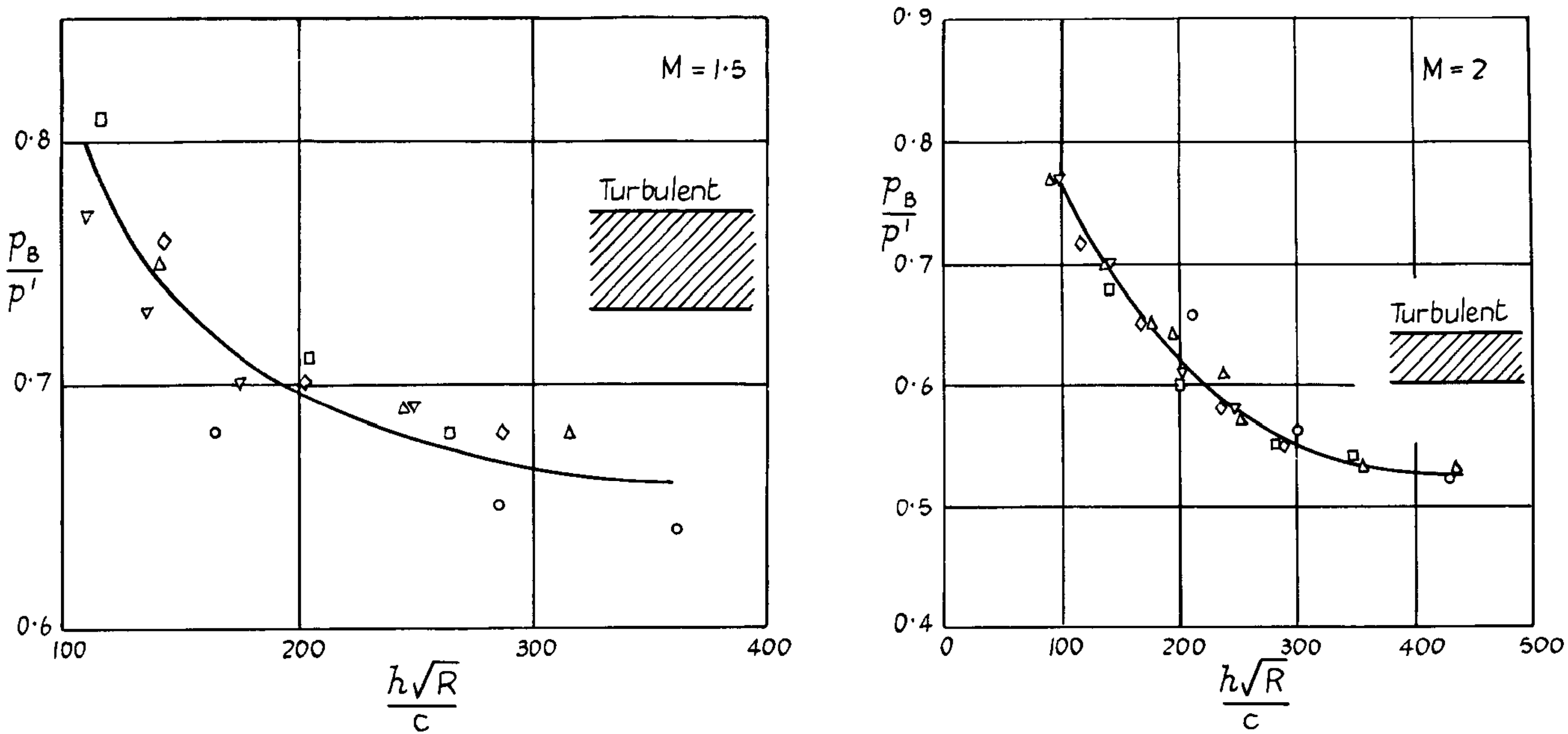



FIG 17.

As in Fig 16, but with Chapman's "corrected" base pressure ratio, $p_B/p'$, plotted as a function of the factor $h\sqrt{R}/c$, which is proportional to the ratio of base height to boundary layer thickness

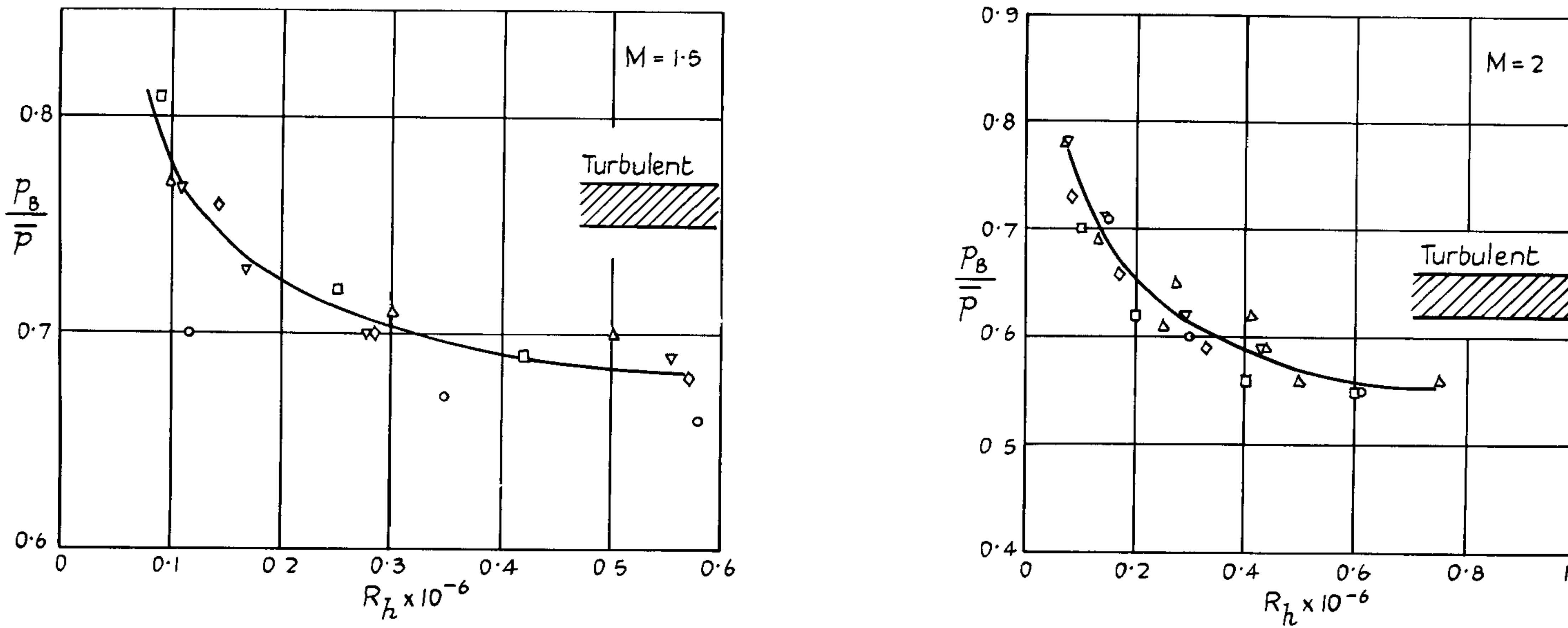
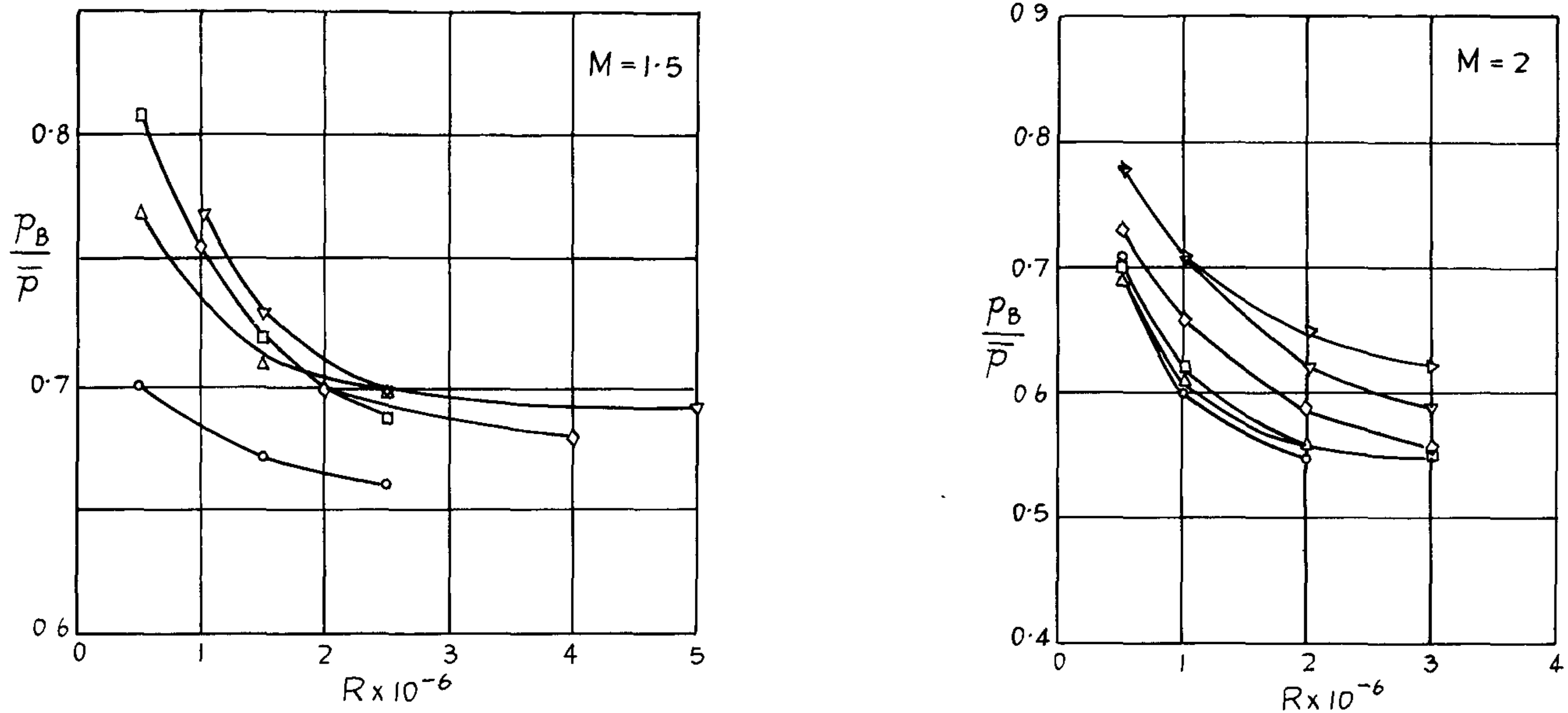



FIG 18

As in Fig 16, but with our "corrected" base pressure ratio, $p_B / \bar{p}$, plotted as a function of the Reynolds number based on base height

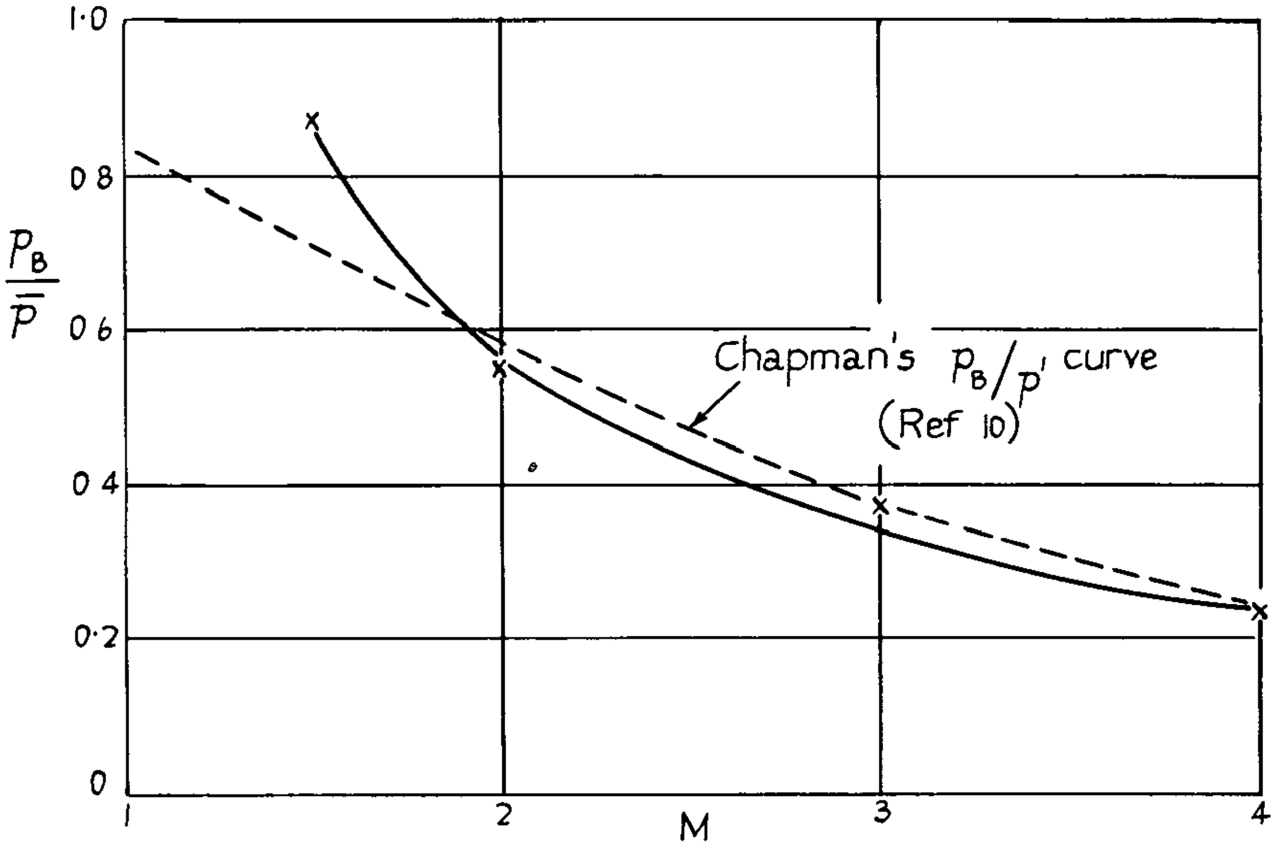



As in Fig 16, but with our "corrected" base pressure ratio, $p_B/\bar{p}$, plotted as a function of the chord Reynolds number

FIG 19

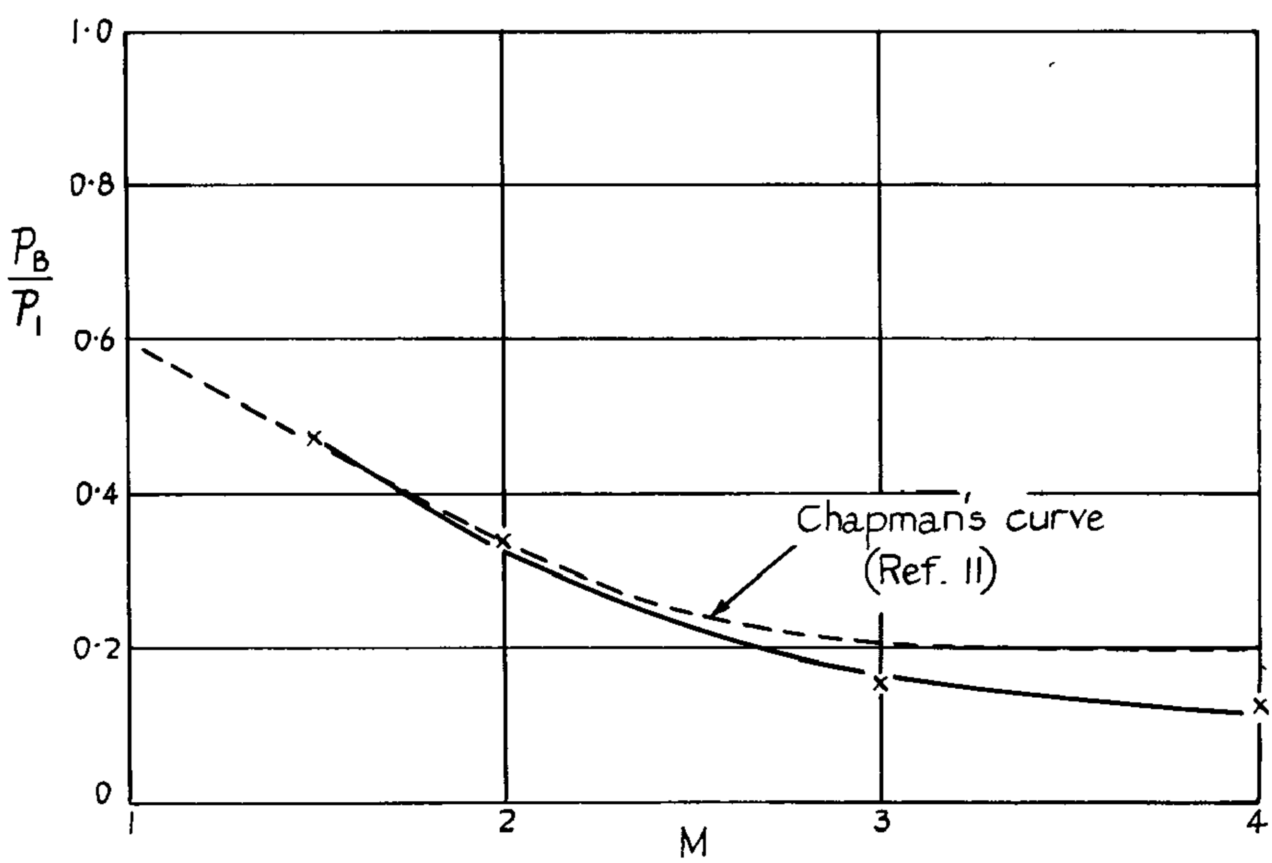
FIGS 20 & 21

FIG 20.




"Corrected" base pressure ratio with turbulent flow as a function of Mach number for bodies of revolution

FIG 21.




Base pressure ratio with turbulent flow as a function of Mach number for two-dimensional bodies.

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