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Some Tests in a Slotted-Wall Tunnel with Various Slot-Entry Shapes

By

A. Chinneck, B.Sc., and Mrs. N. A. North,
of the Aerodynamics Division, N.P.L.

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A. Chinneck, B.Sc. and Mrs. N. A. North
of the Aerodynamics Division, N.P.L.

2nd January, 1957

SUMMARY

Tests have been made in the N.P.L. 9 in. × 3 in. high-speed tunnel to investigate the effect of slot-entry shape on the over-acceleration of the flow that occurs at supersonic speeds when the slots are of uniform width.

It is shown that tapering the slot alleviates this over-acceleration, but a straight taper extending for as much as 2 tunnel heights does not eliminate it. A special slot-entry shape has been tested which does eliminate it, and which produces an axial pressure variation of ±0.9%, over an axial distance equal to $1\frac{1}{2}$ tunnel heights, at a free-stream Mach number of 1.15.

List of Symbols Used

H	Total pressure of the main stream
h	Tunnel height at the beginning of the slots
p	Static pressure
W	Maximum width of the slots
w	Width of the slots at distance x
x	Distance downstream from the beginning of the slots.

1. Introduction

If the width of the slots in a slotted-wall high-speed tunnel is uniform over their whole length, the pressure distribution on the axis of the tunnel at supersonic speeds is similar to that encountered in a free jet and an over-acceleration near the beginning of the slots is followed by a compression. Work in America (e.g., Ref. 1) has shown that, by restricting the rate of expansion of the air at the beginning of the working section, the over-acceleration can be eliminated and the pressure on the centre line of the tunnel made to fall monotonically to a constant value.

There is a considerable amount of information on slot-entry shapes which are suitable for tunnels with slots in all their walls, but little information is available on the best shapes to use in tunnels of rectangular cross section with slots in two opposite walls only. Before the slotted walls for the larger tunnels at the N.P.L. were designed, it was therefore decided to make some tests in the 9 in. × 3 in. high-speed tunnel with various entry shapes to the slots in the two opposite walls of the working section.

2./

2. Description of the Walls

The slotted walls used spanned the 3 in. dimension of the 9 in. × 3 in. tunnel^2, and the distance between them was $7\frac{1}{2}$ in. They were made from wood and were joined at their upstream ends to wooden blocks which faired into the contraction to the working section (Fig. 1). The distance between the walls increased linearly by 0.006 in. per inch, to allow for the growth of the boundary layer along the working section.

Two slots, whose maximum width was 0.15 in. were cut in each wooden wall (Fig. 1). The maximum ratio of open to total area of the slotted walls was thus 0.10; based on the total periphery of the working section this ratio was 0.029.

The static pressure along the centre line of the working section was measured by traversing a static tube along it at the top speed of the tunnel, and several slot-entry shapes were tested. Initially a constant slot width was used (Fig. 1). The walls were then tested with a series of tapered slot-entry shapes, in which the area ratio increased linearly from zero at the beginning of the slots to its maximum value in a distance downstream equal to either $\frac{1}{2}$, 1, $1\frac{1}{2}$ or 2 tunnel heights. Tests were also made with some shaped, non-linear entry shapes. The contours of all the slot-entry shapes tested are shown in Fig. 2 where half the local slot width, w, expressed as a fraction of the maximum slot width, W, is plotted against the distance x downstream from the beginning of the slots expressed as a fraction of the tunnel height, at the beginning of the slots, h.

3. Discussion of the Results

(i) Constant slot width (Square entry)

The variation of axial static pressure, p, (expressed as a fraction of the total pressure, H, of the main stream of the tunnel) obtained with the constant width slots, at the top speed of the tunnel, is shown in Fig. 4. It will be seen that the pressure varies in the manner described in §.1, and that after a distance equal to about 1.7 tunnel heights from the beginning of the slots it assumes a value which is almost constant.

(ii) Straight Taper Entry Slots

The variations of axial static pressure for the four straight tapers tested (i.e., lengths equal to $\frac{1}{2}$, 1, $1\frac{1}{2}$, and 2 tunnel heights) are shown in Figs. 4-7.

The effect of the taper at the beginning of the slots was to reduce the rate of decrease of pressure at the beginning of the working section, although even with the longest taper tested (Fig. 7) the over-acceleration was not completely eliminated. The minimum pressure was reached further downstream and its value was not as low as that obtained with the square-entry slots.

With the shortest amount of taper the effect of the compression immediately downstream from the over-acceleration was observed in almost the same position as that found with the square-entry slots (Fig. 4). The distributions downstream from this compression were almost indistinguishable from each other.

Each increase in the length of the taper caused the position at which the minimum pressure occurred to move further downstream and its value to increase. The consequent pressure rise also moved downstream, the amplitude of the pressure variation was reduced and the value of the mean pressure was decreased.

The amplitude of the total Mach number variation (corresponding to the pressure variation shown in Figs. 3-7) fell from 6% for the square-entry slots to $2\frac{1}{2}$% for the taper extending for two tunnel heights. The mean Mach number increased from 1.13 to 1.15.

The Mach number variation in the tunnel between the positions equal to 1 and 2 tunnel heights downstream from the beginning of the slots was not affected quite as much by the introduction of the taper. The variation in this region fell from ±1.6% for the square-entry slots to ±1.2% for the taper extending for 2 tunnel heights.

(iii) Slot-entry Shape A

It has been shown in §.3 (ii) above that even when the slot-entry is tapered for a distance equal to 2 tunnel heights, the over-acceleration is not completely eliminated. The entry to the slots was therefore shaped to the contour shown as Shape A in Fig. 2. This entry shape is derived from one of the shapes given in Ref. 1, and the full width of the slot is reached at a distance downstream from the beginning of the slots of 1.43 tunnel heights.

The axial pressure distribution is shown in Fig. 8. It will be seen that the over-acceleration was virtually eliminated and that the pressure fell monotonically to a constant value, which was reached at a distance of 0.8 tunnel heights downstream from the beginning of the slots. The uniformity of the pressure distribution decreased somewhat after a distance of about 1.6 tunnel heights from the beginning of the slots.

The distributions obtained with the slot-entry shape A and the $1\frac{1}{2}$ tunnel-height taper are compared in Fig. 9. The pressure distribution for the slot-entry shape A was very much more uniform; the maximum variation in Mach number was ±0.9%, whereas that for the tapered entry was ±1.5%.

(iv) Slot-entry Shape B

Examination of the axial pressure distribution obtained with the slot-entry shape A (see Fig. 8 and 3 (iii) above) showed that the pressure reached a constant value at a position 0.8 tunnel heights from the beginning of the slots. The Mach line through this position originates from a point 0.53 tunnel heights along the entry slot. It therefore seemed reasonable to assume that the shape of the slot downstream from this position was not important. On this assumption the slot-entry shape B (Fig. 2) was designed. Up to a position 0.53 tunnel heights from the beginning of the slot it had the same contour as shape A; from this position the width increased rapidly to reach the full slot width at a total distance of 1.0 tunnel heights.

The pressure distribution obtained with this slot-entry shape is shown in Fig. 10, and is compared with that obtained for shape A in Fig. 11. It will be seen that the pressure variation is worse for shape B, than for shape A, although a comparison of Figs. 9 and 11 shows that shape B was better than the $1\frac{1}{2}$ tunnel-height taper.

The fact that the slot-entry shapes A and B do not give the same distribution of pressure along the axis shows that the downstream portion of shape A, that was neglected in designing shape B, must have some effect on the flow. It is most likely that the assumption of straight Mach lines, made in assessing the passive portion of the slot-entry shape A, is invalid.

(v) Slot-entry Shape C

The working section of the N.P.L. 20 in. × 8 in. high-speed tunnel is fairly short in comparison with its height. It was therefore decided to try a shaped entry slot which would run out in about $\frac{1}{2}$ tunnel height. The slots were therefore contoured to the shape C (Fig. 2).

The pressure distribution obtained is shown in Fig. 12, and this is compared in Fig. 13 with that for $\frac{1}{2}$ tunnel-height taper. It will be seen that the differences between them are small.

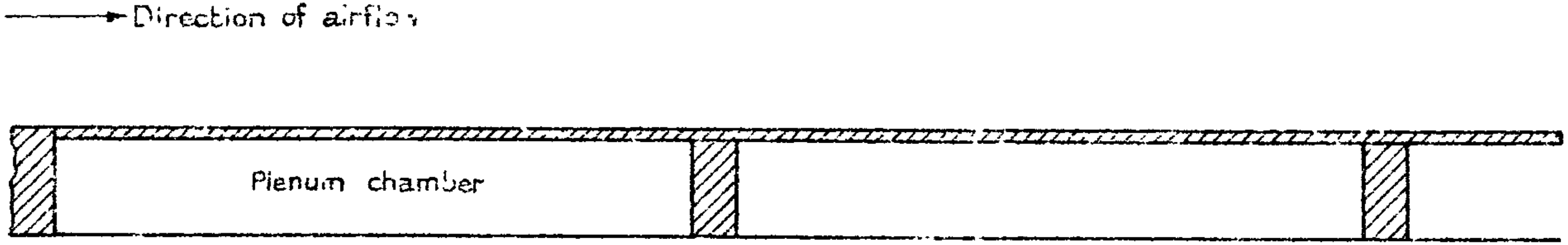
4. Conclusions

The over-acceleration of the flow in the main stream, that occurs at supersonic speeds with slotted wall liners in which the slots are of constant width, can be reduced by tapering the slots so that the full width is not reached until some distance downstream. However, a taper that extends for a distance downstream of as much as 2 tunnel heights does not completely eliminate this over-acceleration.

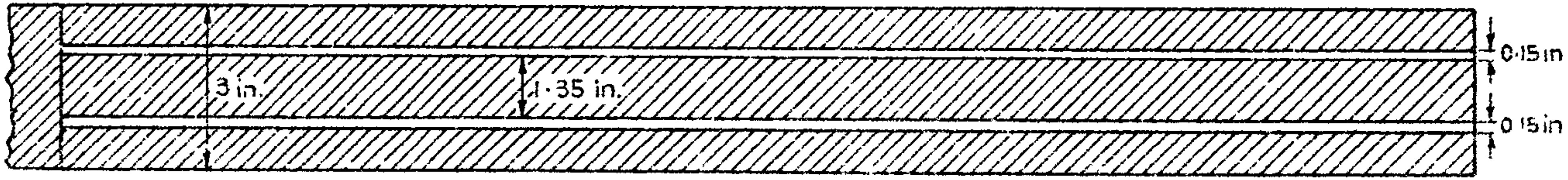
A slot-entry shape, based on some work at N.A.C.A., in which the full width is reached in slightly less than $1\frac{1}{2}$ tunnel heights, has been tested and has been found to give a smooth acceleration of the flow to a constant Mach number. A modification to this slot shape to reduce its length has not proved to be successful.

References

No.	Author(s)	Title, etc.
1	Vernon G. Ward, Charles F. Whitcomb and Merwin D. Pearson	Air-flow and power characteristics of the Langley 16-foot transonic tunnel with slotted test section. A.R.C. 15,580. 26th January, 1953
2	D. W. Holder and R. J. North	The 9 in. × 3 in. induced-flow high-speed wind tunnel at the N.P.L. R. & M. 2781. June, 1949.



(a) Side view

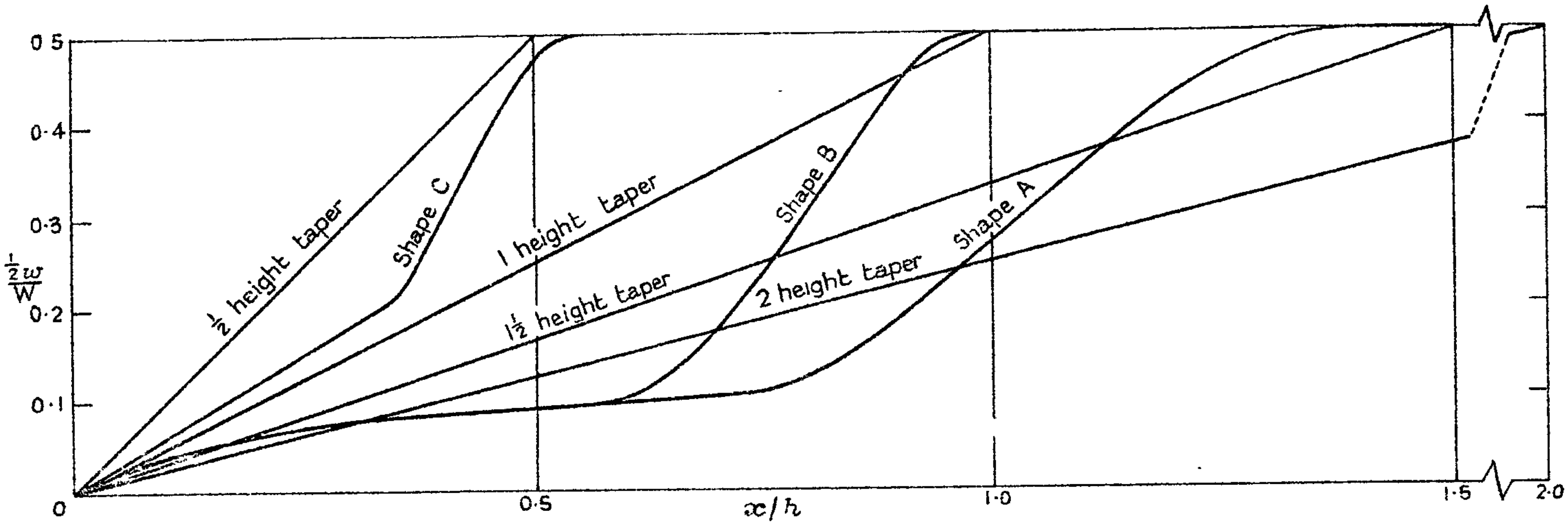


(b) Plan view

Diagram illustrating the position of the slots in the slotted walls

Fig. 1.

FIG 2



The contours of the various slot-entry shapes

FIGS. 3-5.

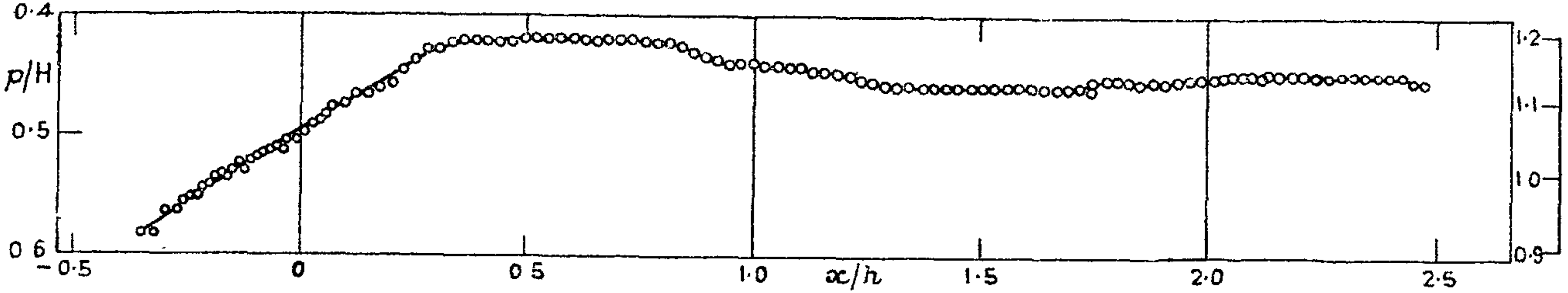


FIG 3.

Axial pressure distribution at top speed; square entry to slots

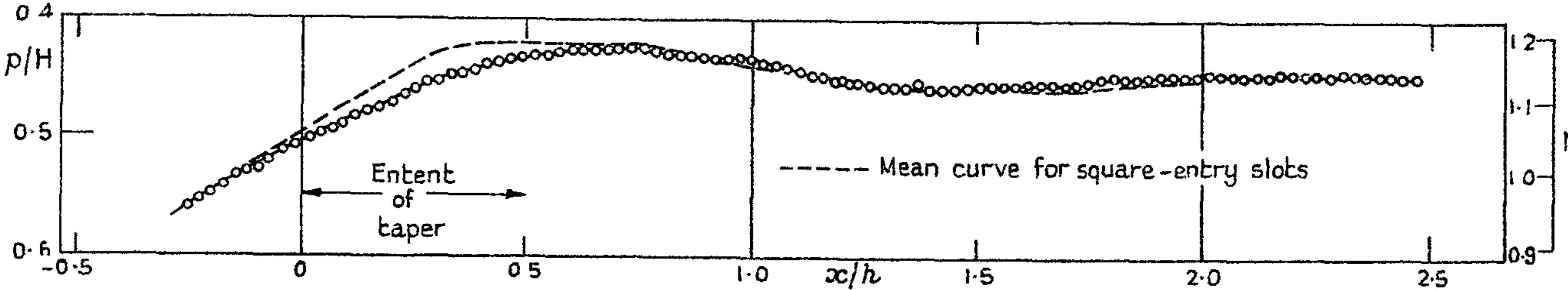


FIG.4.

Axial pressure distribution at top speed; entry to slots tapered for ½ tunnel height

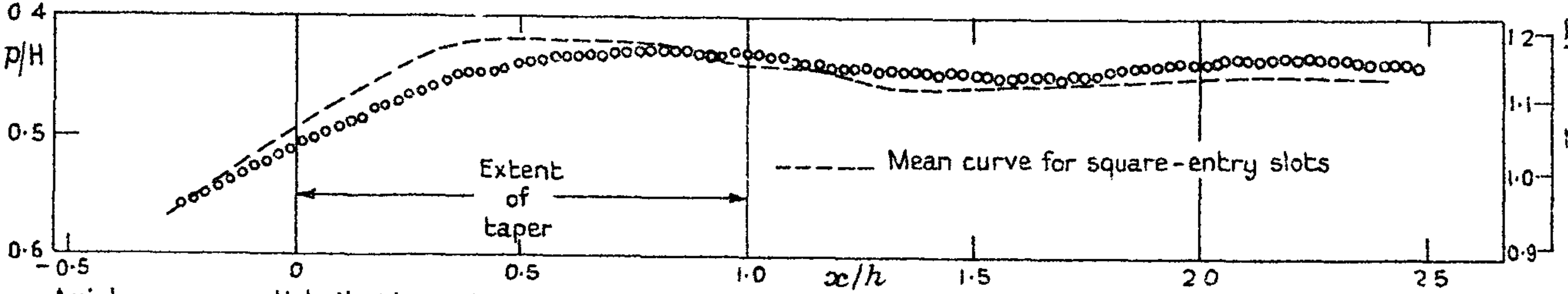
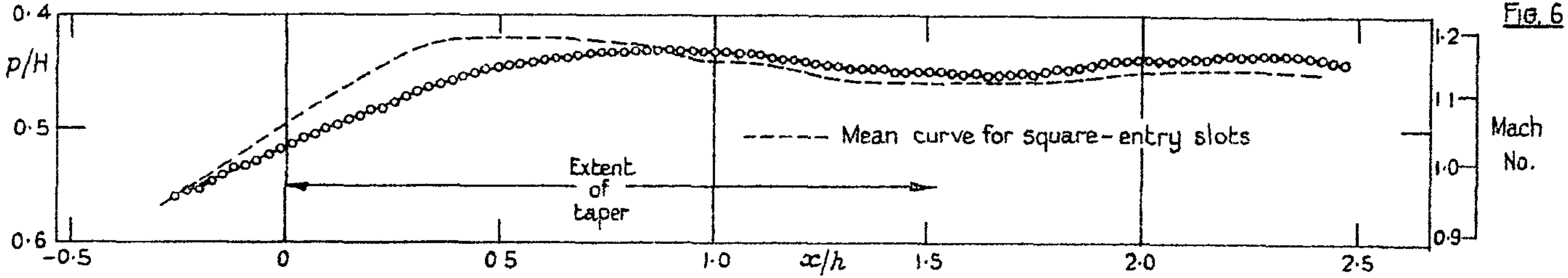


FIG 5

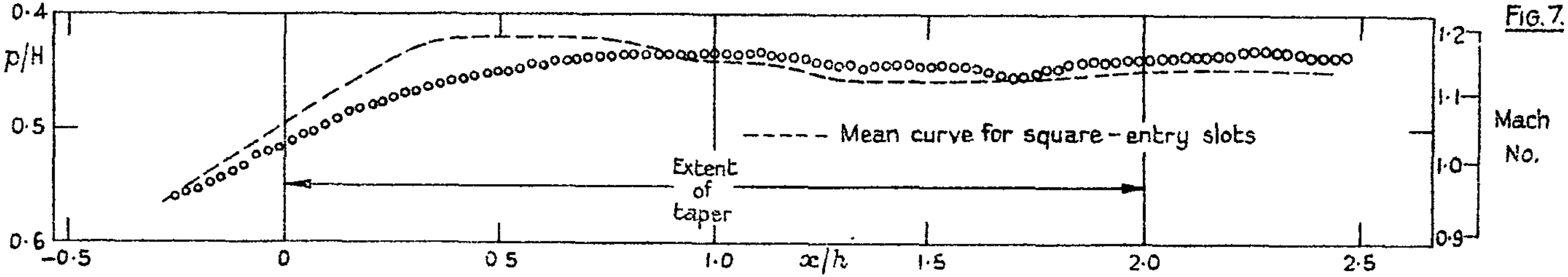
Axial pressure distribution at top speed; entry to slots tapered for 1 tunnel height

Fig. 6



Axial pressure distribution at top speed; entry to slots tapered for $1\frac{1}{2}$ tunnel heights

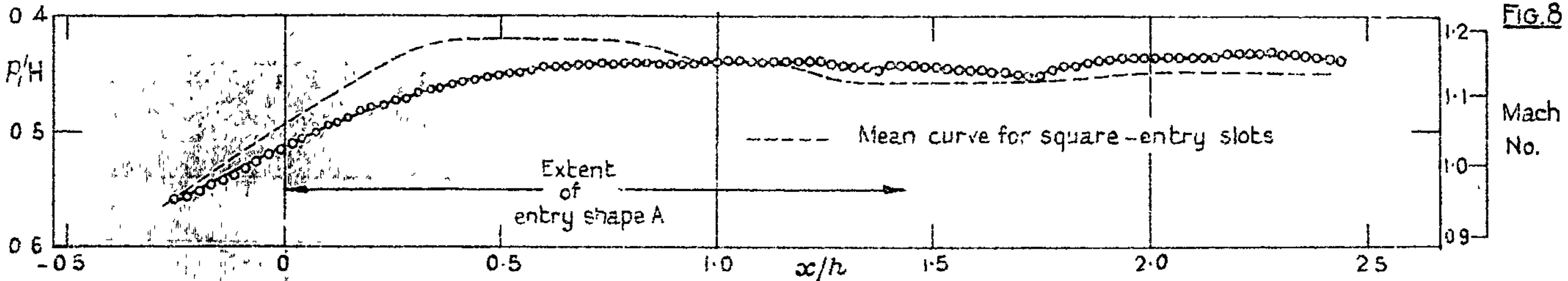
Fig. 7.



Axial pressure distribution at top speed; entry to slots tapered for 2 tunnel heights

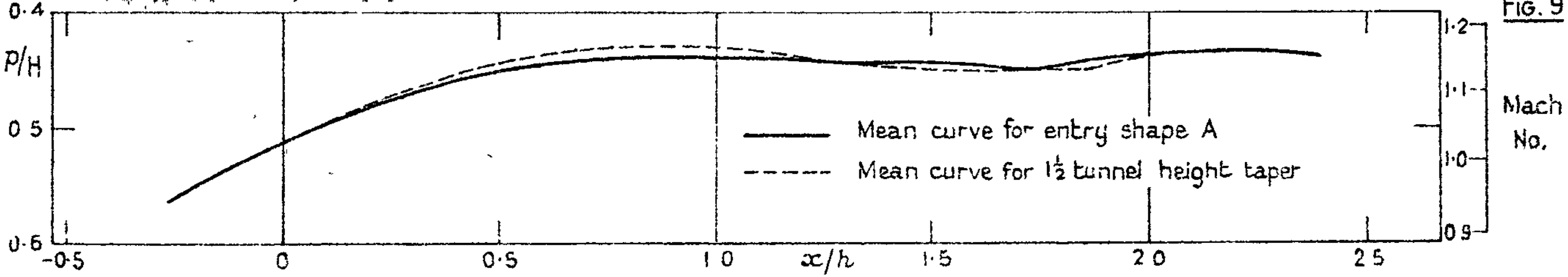
Figs 6 & 7.

FIG. 8



Axial pressure distribution at top speed; entry to slots shaped to shape A (Fig 3)

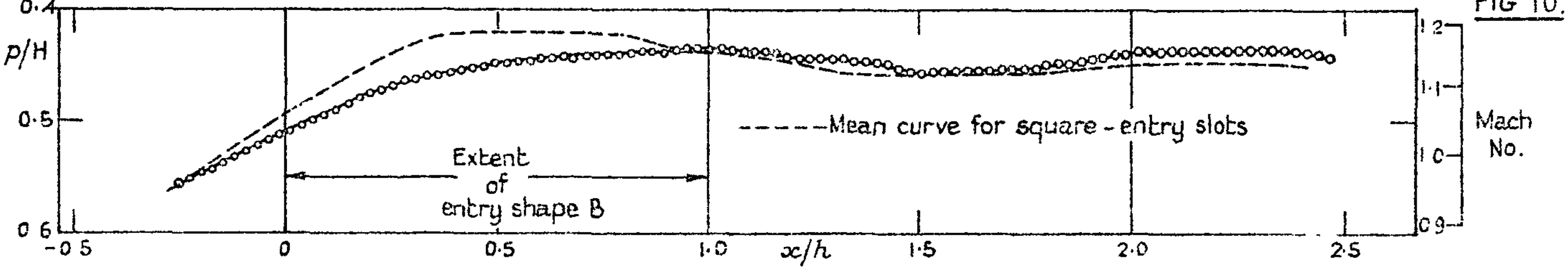
FIG. 9



Comparison of the axial pressure distributions at top speed for slot entry shape A and straight taper extending for 1½ tunnel heights.

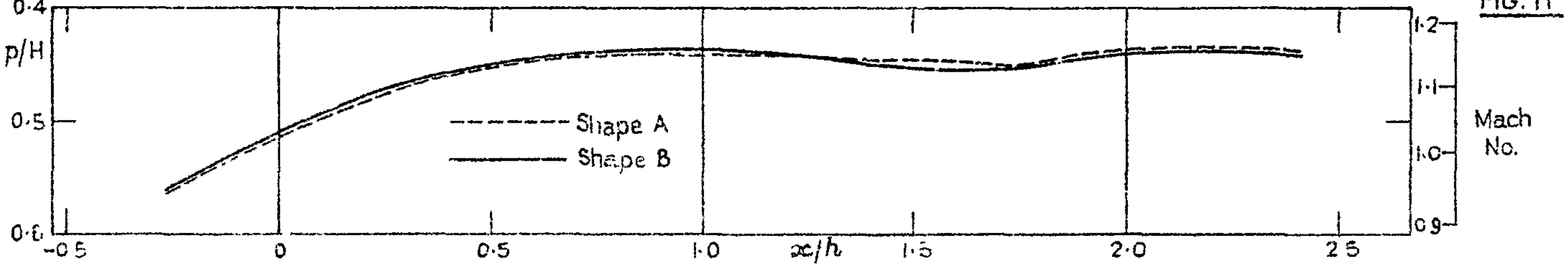
FIGS 8 & 9.

FIG 10.



Axial pressure distribution at top speed; entry to slots shaped to shape B (Fig. 3)

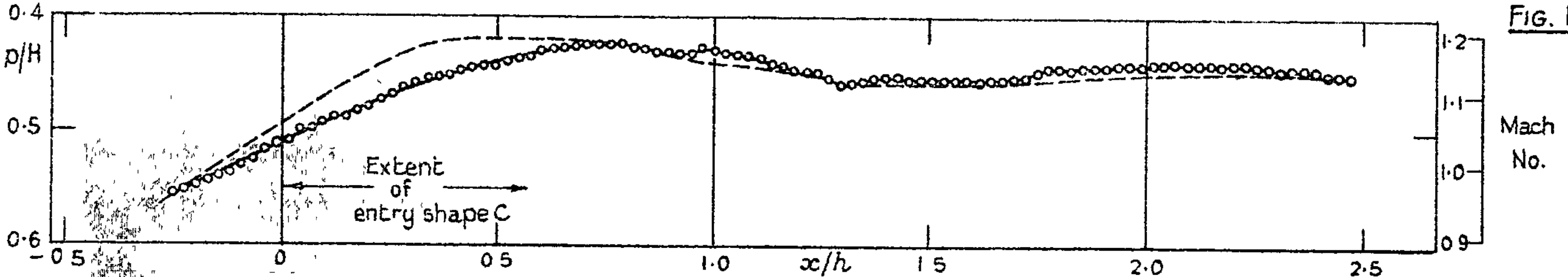
FIG. 11



Comparison of the axial pressure distributions at top speed for slot entry shapes A and B.

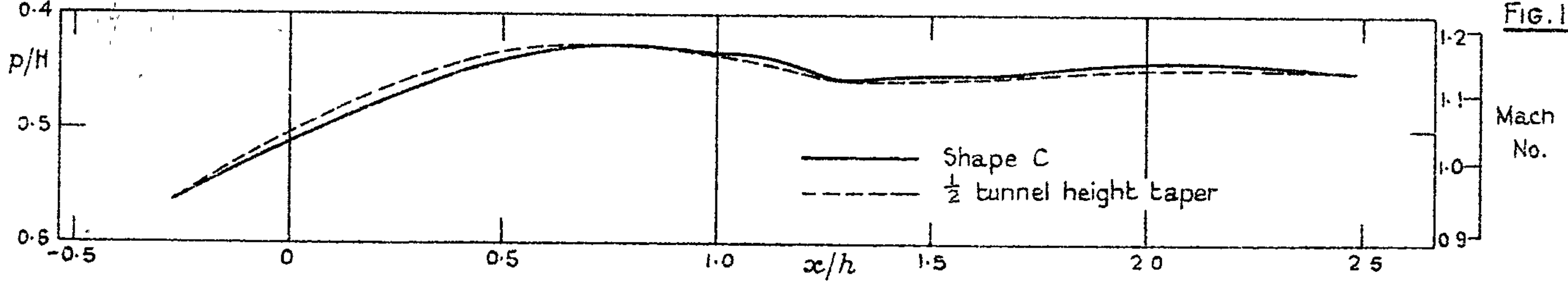
FIGS. 12 & 13

FIG. 12.



Axial pressure distribution at top speed; entry to slots shaped to shape C (Fig 3)

FIG. 13



Comparison of the axial pressure distributions at top speed for slot entry shapes C and straight taper extending for $\frac{1}{2}$ tunnel height

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