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Low Speed Wind Tunnel Tests on Perforated Square flat plates normal to the airstream:

Drag and Velocity Fluctuation Measurements

By

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Low Speed Wind Tunnel Tests on Perforated Square Flat Plates Normal to the Airstream: Drag and Velocity Fluctuation Measurements

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B. G. de Bray, M.Sc.

SUMMARY

The effects of perforations upon the drag, and velocity fluctuations downstream, of square plates normal to the airstream are described.

It is shown that perforations can have a powerful effect upon the level of velocity fluctuations, particularly the low-frequency components, with only a comparatively small reduction in drag coefficient.

It is also shown that perforating the central region only of a square plate is as effective in reducing velocity fluctuations as perforating the whole plate while giving a slightly higher drag coefficient than the latter. On the other hand, perforations near the periphery only are less effective.

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1 Introduction

The work described in the present note is a continuation of the investigations into the behaviour of flat plates at high incidences, with particular reference to their use as air brakes.

Previous work[1,2] dealt with the effect of incidence and the shape and aspect ratio of solid (i.e. unperforated) plates.

At incidences of the order of 50° and above, the flow round a solid plate separates at the whole of the periphery of the plate and a bubble is formed behind the plate. This type of flow is usually associated with velocity fluctuations having large low-frequency components, which may cause vibration troubles in any installation of such a plate as an air brake.

The present work is an investigation into the effect of perforations on the drag and velocity fluctuations with this type of flow. Perforations admit air into the bubble and tend to reduce the general level of velocity fluctuations.

The work is limited to isolated square plates normal to the airstream. The presence of a body adjacent to one edge of the plate, as in an air brake installation, is not considered likely to have a major effect upon the findings[3].

2 Description of Tests

The experiments were made in the 4 ft × 3 ft tunnel at a speed of 140 ft/sec. The apparatus and technique used have been fully described in reference 2.

Details of the 5" × 5" square plates tested are given in Table I and Fig.1. The main series of plates (Nos.1 to 5) have 80 holes based on a square mesh of 0.5" pitch. In order to obtain the large perforation area of plate 6 it was necessary to use a roughly hexagonal mesh with 92 holes. Plate 4a was made in order to test the effect of individual hole area as against total hole area.

The numbering of the plates corresponds approximately to their free area ratio, e.g. plate No.1 has approximately 10%, plate No.2 20%, etc.

The perforations were sharp-edged in all cases.

Tests were made with plate No.4 to find the effect of perforating only part of the surface. For this purpose, successive rows of holes were blocked up, working from the centre outwards and then from the edge inwards.

The experiments consisted of:-

(i) Drag measurements, using a capacity-type drag balance.

(ii) Measurements of longitudinal velocity fluctuations in a plane 18" behind the plate, using a hot-wire placed normal to the airstream and radial to the axis of the plate. The distance of 18" was chosen to be clear of the bubble.

R.M.S. velocity fluctuations were measured at points along a radial line parallel to one pair of edges of the plates and to the 4 ft dimension of the tunnel.

In addition, frequency spectra were obtained at 4" radius, this position being approximately that at which the maximum total fluctuations occurred.

3 Presentation of Results

3.1 Drag measurements

Drag coefficients for the uniformly perforated plates are plotted in Fig.2 against free area ratio S_F/S. Fig.3 shows the drag coefficients for plate No.4 partly perforated. Starting with the solid plate, opening successive rows from the centre outward gave the upper curve, and opening the outer row (i.e. nearest the edges) first and working inward towards the centre gave the lower curve.

The drag coefficients are expressed in terms of the gross area of the plates, and are corrected for blockage by the semi-empirical method of Maskell[4].

3.2 Measurements of velocity fluctuations

The r.m.s. velocity fluctuations are presented as the ratios $\frac{u}{U_o}$, plotted against radial distances from the centre of the plates.

The spectra are presented in the form $nF(n)$ plotted against $\log n$. n is the non-dimensional frequency $\left(\frac{f\ell}{U_o}\right)$ and $F(n)$ the spectrum function, defined so that $F(n)\,dn$ is the contribution to $\frac{u^2}{U_o^2}$ of frequencies between n and $(n + dn)$.

It follows that:-

$$\frac{u^2}{U_o^2} = \int_0^\infty F(n)\,dn$$

$$= \int_0^\infty nF(n)\,d(\log n).$$

In the case of spectra, the mean square of the analyser output Δu^2 is measured over a bandwidth Δn ($\frac{\Delta n}{n}$ being small), so that:-

$$F(n) = \frac{\Delta u^2}{(U_o^2 \Delta n)}$$

and $$nF(n) = \frac{\Delta u^2}{(U_o^2 \varepsilon_A)} \text{ approximately,}$$

where $\varepsilon_A = \frac{\Delta n}{n}$, the analyser bandwidth ratio.

Figs. 4(a & b) give the r.m.s. velocity fluctuations $\frac{u}{U_o}$ in a plane 18" downstream of the plate. The maximum fluctuations occur at about 4" radius $\left(\frac{y}{\sqrt{S}} = 0.8\right)$ in all cases, so this radius was selected for the spectra, which are plotted in Figs. 5(a&b). In addition, spectra (not shown) were obtained at 8" radius to determine the main shedding frequency, which can be done more accurately where the general turbulence level is low.

In order to assess the relative merits of the plates tested from the point of view of the low-frequency component of the velocity fluctuations, which is the most important component in causing buffeting when such plates are used as air brakes, the $nF(n)$ curves were integrated between limits $n = 0.01$ and $n = 0.05$, the results converted to units of $\frac{u}{U_o}$, and plotted in Fig.6.

$$\left[\frac{u}{U_o}\right]_{n=0.01}^{n=0.05} = \sqrt{\int_{0.01}^{0.05} nF(n) \log n} \,.$$

The range of frequencies covered by the chosen limits of n, taking representative values of U_o and $\sqrt{S}$ are as follows:-

U_o	$\sqrt{S}$	f	
		$n = 0.01$	$n = 0.05$
800	2	4.0	20.0
	3	2.7	13.3
500	2	2.5	12.5
	3	1.7	8.3

4 Discussion of Results

Considering first the uniformly perforated plates, increase in the free area ratio $\frac{S_F}{S}$ gives progressive reductions in C_D (Fig.2), r.m.s. velocity fluctuations (Fig.4a), and $nF(n)$ (Fig.5a). Up to $\frac{S_F}{S} = 0.35$, the main shedding frequency (shown by the position of the peaks of the spectra) remains constant at $n = 0.115$, but the peak amplitudes decrease progressively. Beyond $\frac{S_F}{S} = 0.35$ the shedding peak does not appear. The curves of Fig.5a can therefore be divided into two distinct groups.

The reduction in $nF(n)$ with increase in free area ratio is more marked in the frequency range below $n = 0.115$ than at higher frequencies. This reduction is shown in Fig.6, which also shows a break in the curve at the point at which shedding is suppressed.

Of the two arrangements of partially perforated plates tested, that with central perforations, $\frac{S_F}{S} = 0.25$, gave as low $\frac{u}{U_o}$ values as a uniformly perforated plate with $\frac{S_F}{S} = 0.40$, and a drag coefficient 6% higher. On the other hand, perforations near the edges only gave higher $\frac{u}{U_o}$ values than a uniformly perforated plate of equal $\frac{S_F}{S}$ value (0.29), and a drag coefficient 16% lower.

These results for partial perforations are associated with the values of the main shedding frequencies (Fig.5b), which are largely determined by the size and shape of the unperforated portions. These consist, respectively, of a hollow square rim about 1" wide and 20" peripheral length, and a solid square with about 3" sides. The latter, as expected, gave a shedding frequency somewhat higher than for the solid 5" square plate. The shedding frequency for a square rim is unknown, but if it be considered as a strip of high aspect ratio, closed end to end, previous experiments[2] indicate a value of n much higher than for a square, together with a higher C_D.

A shedding frequency associated with the spacing between individual holes (0.5" for the 80 hole plates) was not detected, probably due to the relatively large distance downstream to the measuring plane.

The single test with very small holes (plate 4a) did not show any scale effect for the size of individual holes, either upon C_D or velocity fluctuations. (Compare plates 4 and 4a in Figs. 2, 4a and 5a). This result will not necessarily apply to a case where shedding occurs.

5 Conclusions

For the isolated square plates tested, uniform perforations give substantial reductions in the level of velocity fluctuations, at the expense of comparatively small reductions in drag coefficient.

The reductions in fluctuations are more marked at the low-frequency end of the spectrum, this being the more important range of frequencies from the point of view of buffeting in the wake when using these plates as air brakes.

A free area ratio of 0.40 (with uniform perforations) gives a reduction in the low-frequency component of velocity fluctuations to about one-third of that for an unperforated plate, with a loss in drag coefficient of less than 20%. It is suggested that this value of 0.40 should be a minimum for design purposes.

With free area ratios larger than 0.40, the gain in fluctuation level becomes less but the loss in drag greater.

A somewhat better arrangement is to perforate only the central portion, leaving an unperforated rim. In the arrangement tested, such a plate with a free area ratio of 0.25 gave as low velocity fluctuations as a uniformly perforated plate with a ratio 0.40, with 6% higher drag coefficient.

Perforating near the edges only is less effective than uniform perforating from the point of view of both drag and velocity fluctuations.

A single test to determine the effect of size of individual holes gave negligible scale effect.

List of Symbols

C_D	=	Drag coefficient, corrected for blockage
S	=	Gross area of plate (sq ft)
S_F	=	Free area of plate (total area of perforations) (sq ft)
U_o	=	Tunnel speed, corrected for blockage
f	=	frequency (cycles/sec)
n	=	$\frac{f\sqrt{S}}{U_o}$
u	=	root mean square value of longitudinal velocity fluctuations
y	=	transverse distance from axis of plate
$F(n)$	=	Spectrum function (see para. 3.2)
Δu^2	=	mean square value of velocity fluctuations passed by analyser
Δn	=	analyser bandwidth
ε_A	=	$\frac{\Delta n}{n}$ = analyser bandwidth ratio
$\left[\frac{u}{U_o}\right]_{n=0.01}^{n=0.05}$	=	mean value of $\frac{u}{U_o}$ between n values of 0.01 and 0.05

REFERENCES

No.	Author	Title, etc
1	R. Fail, T.B. Owen, R.C.W. Eyre	Preliminary low speed wind tunnel tests on flat plates and air brakes: flow, vibration and balance measurements. C.P.251. January 1955.
2	R. Fail, J.A. Lawford, R.C.W. Eyre	Low speed experiments on the wake characteristics of flat plates normal to an airstream. To be published
3	T.B. Owen	Low speed static and fluctuating pressure distributions on a cylindrical body with a square flat plate air brake. C.P.288. January 1956.
4	E.C. Maskell	A theory of wind tunnel blockage effects on stalled flows. To be published.

TABLE I

Particulars of Perforated Plates

Plate Ref.No.	No. of Holes	Hole Dia. (ins)	Free Area Ratio ($\frac{S_F}{S}$)
1	80	0.214	0.114
2	"	0.280	0.197
3	"	0.341	0.292
3.5	"	0.372	0.347
4	"	0.406	0.414
4a	2600	0.069	0.395
5	80	0.454	0.517
6	92	0.472	0.643

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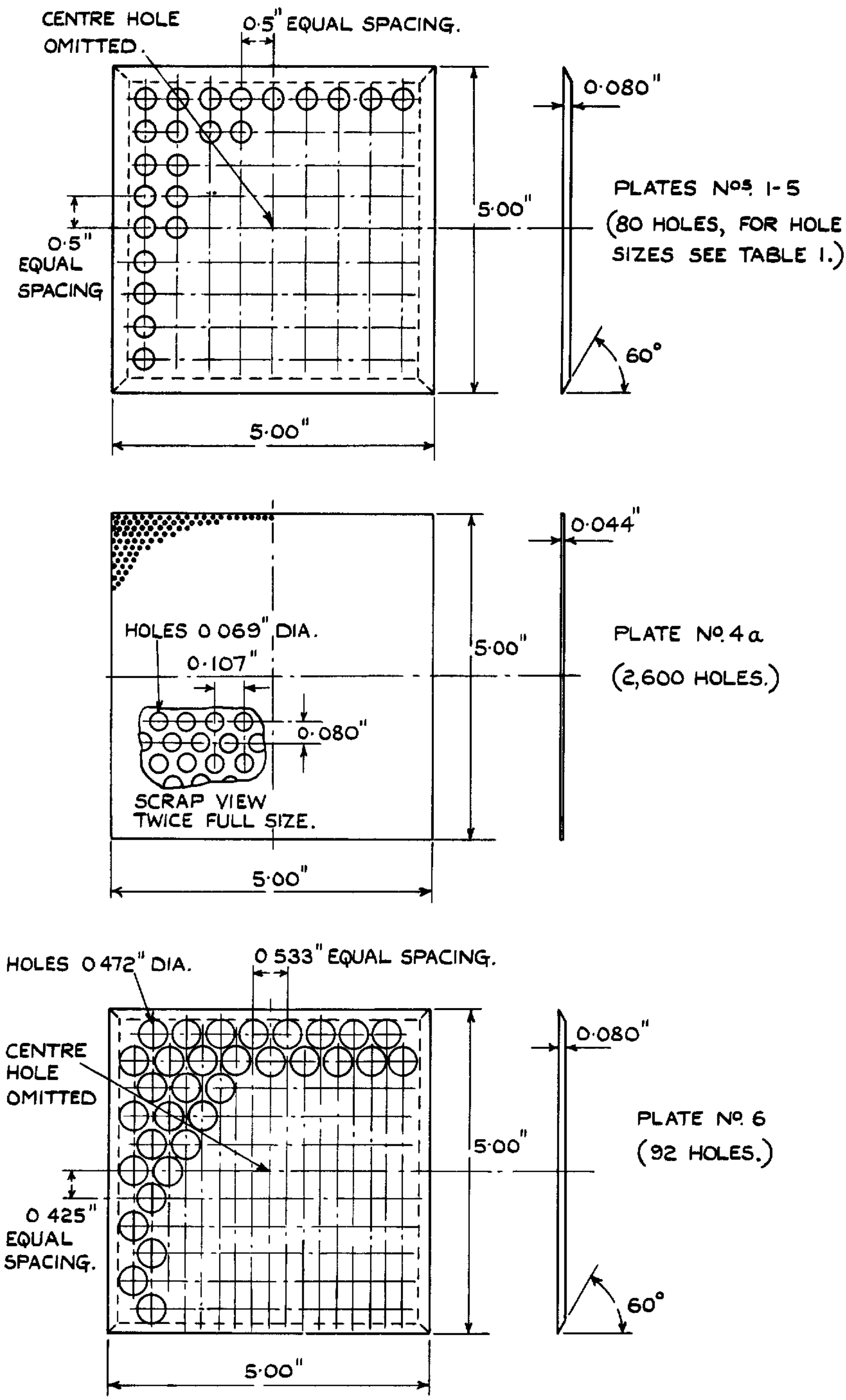


FIG. 1. DETAILS OF PERFORATED PLATES.

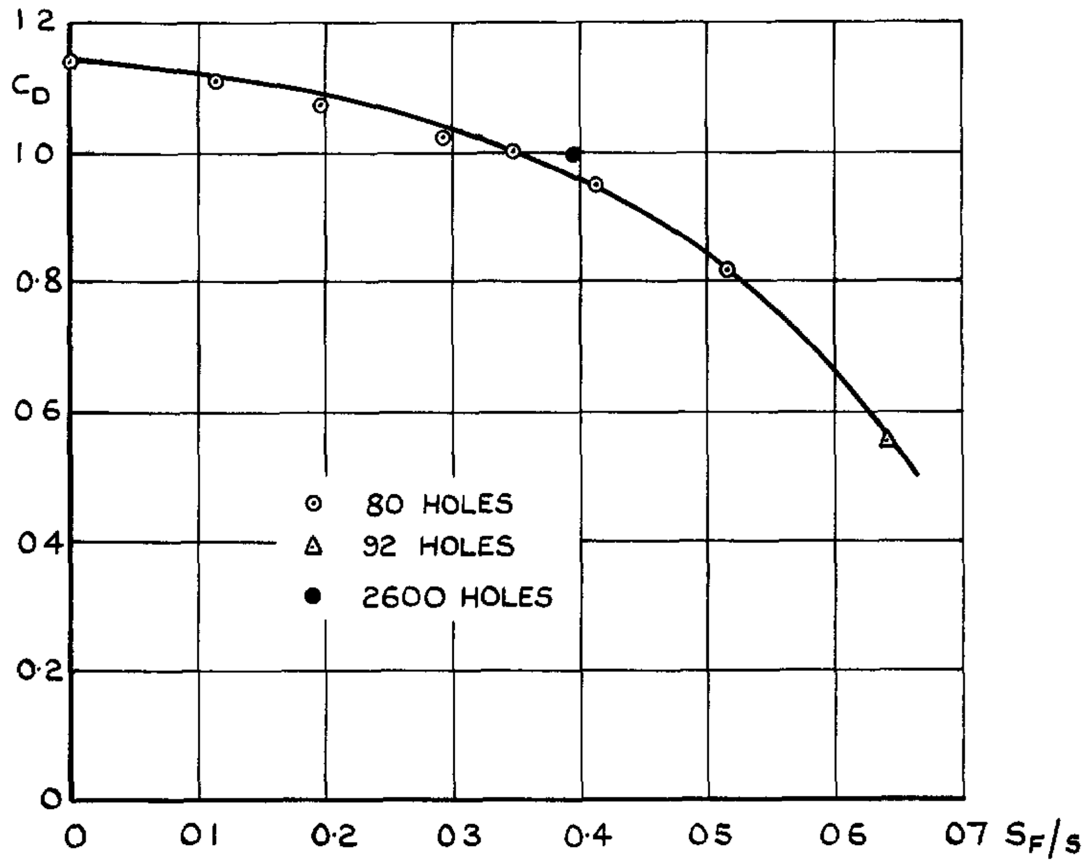


FIG. 2. DRAG OF UNIFORMLY PERFORATED PLATES.

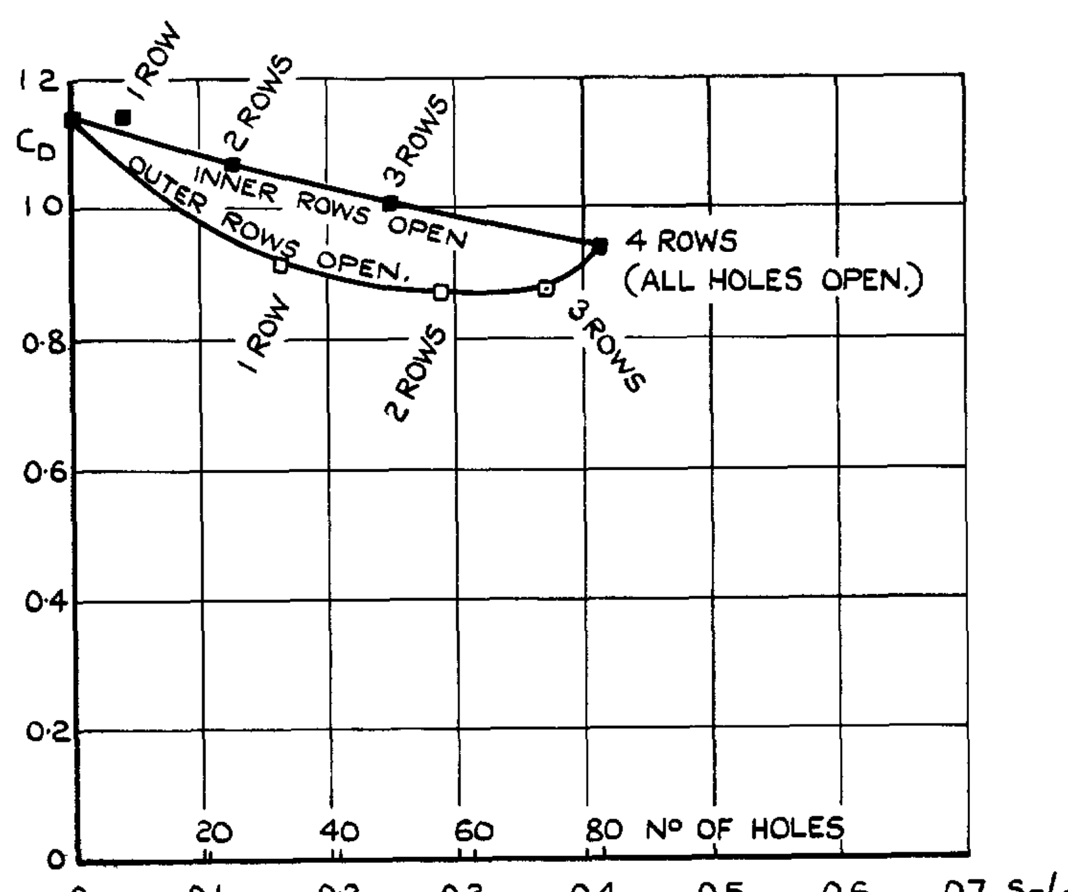
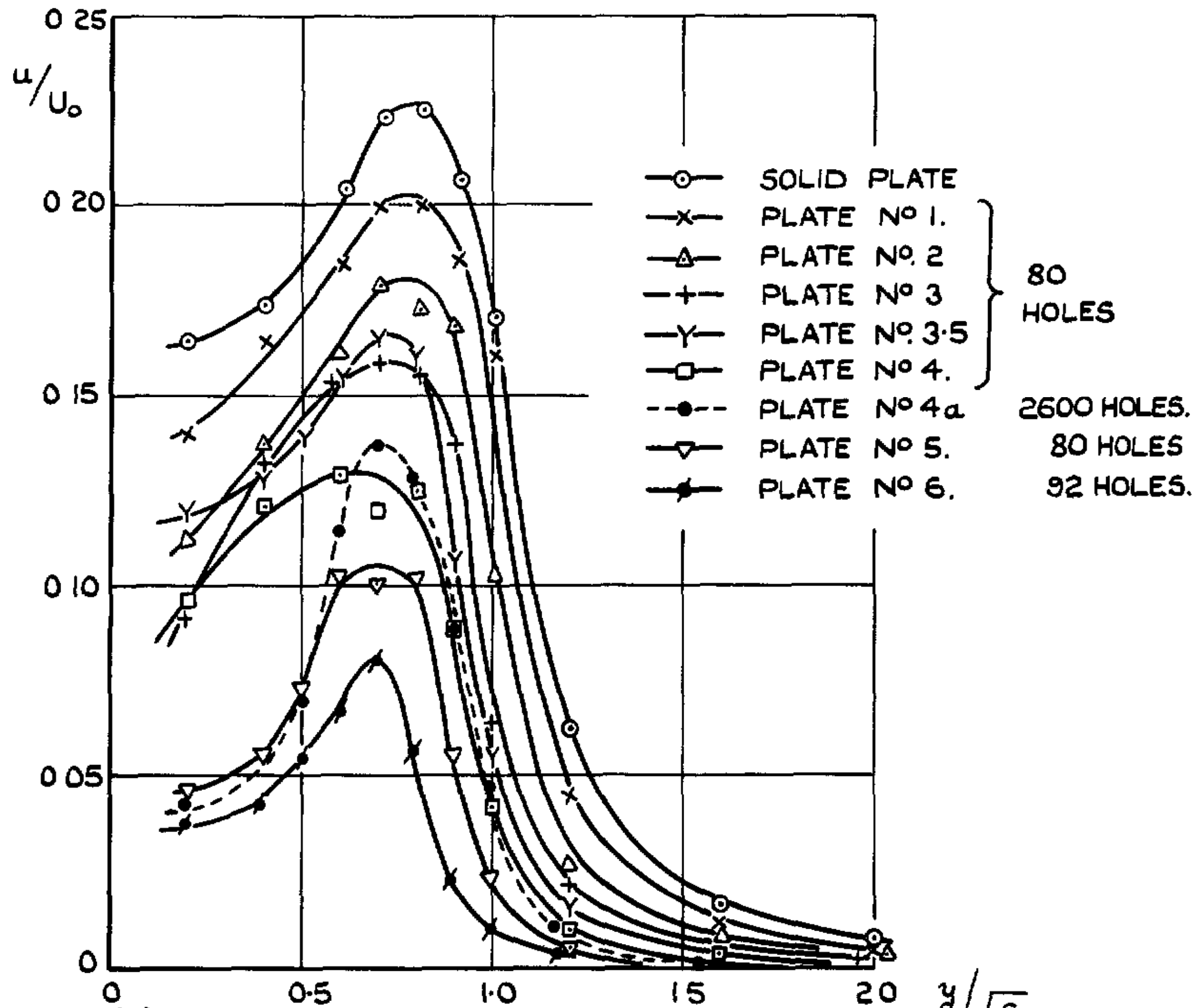
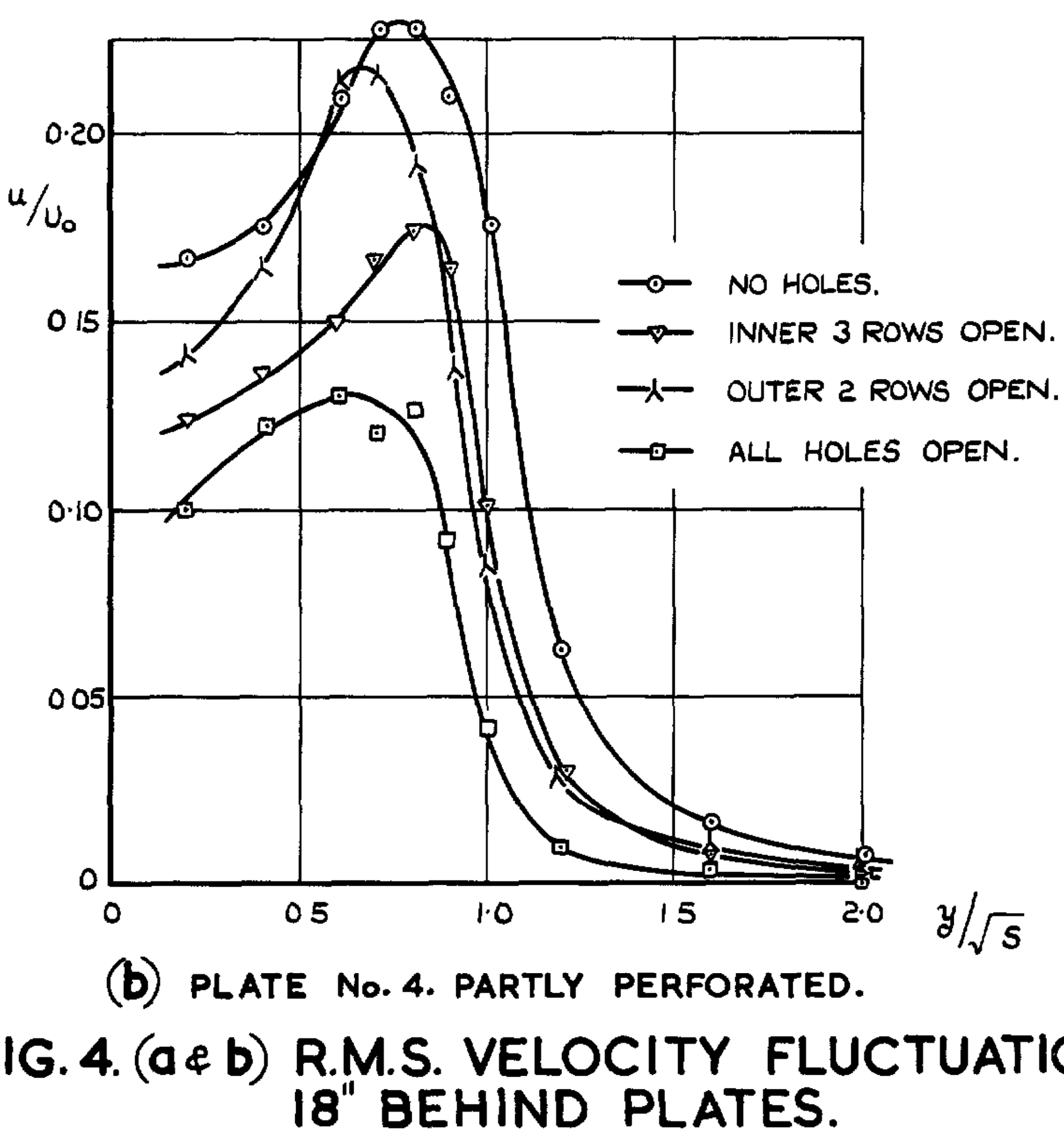


FIG. 3. DRAG OF PLATE No. 4. PARTLY PERFORATED.
(SIZE & SPACING OF HOLES AS FIG. I.)

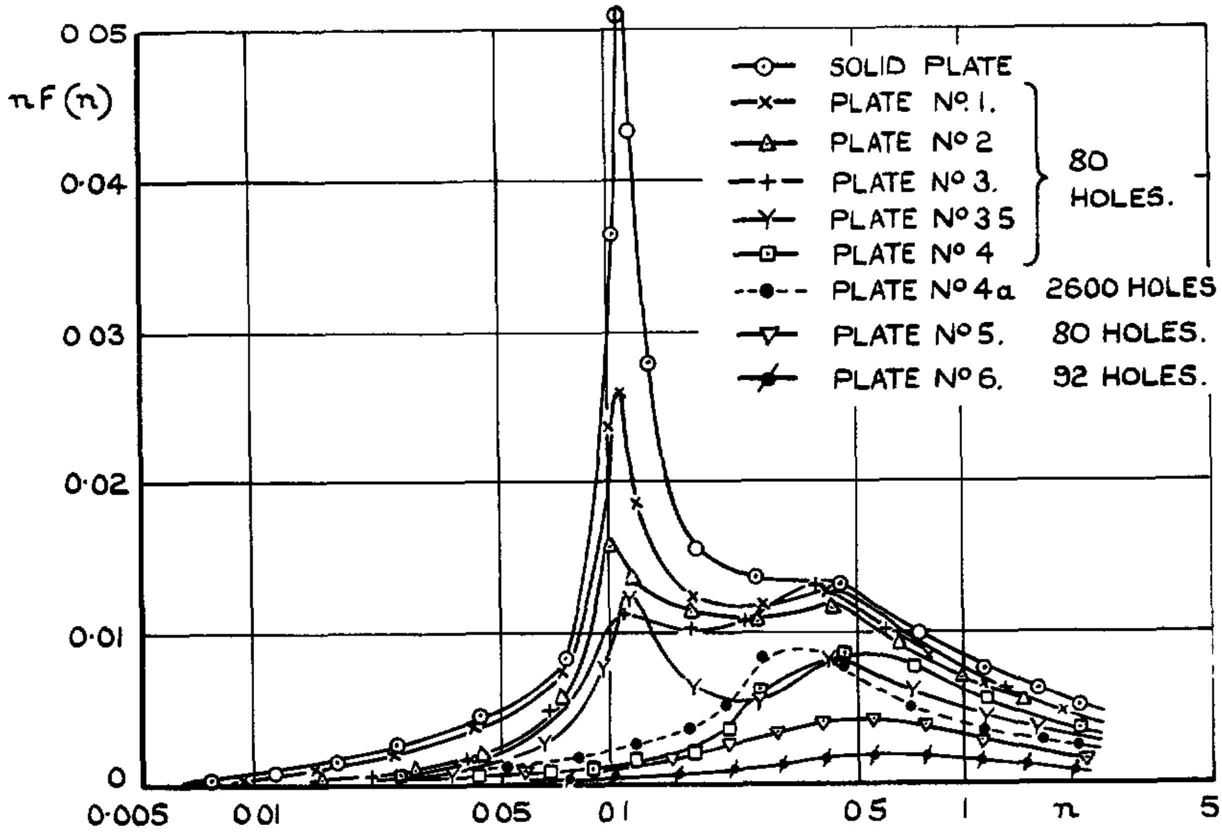


(a) UNIFORMLY PERFORATED PLATES.

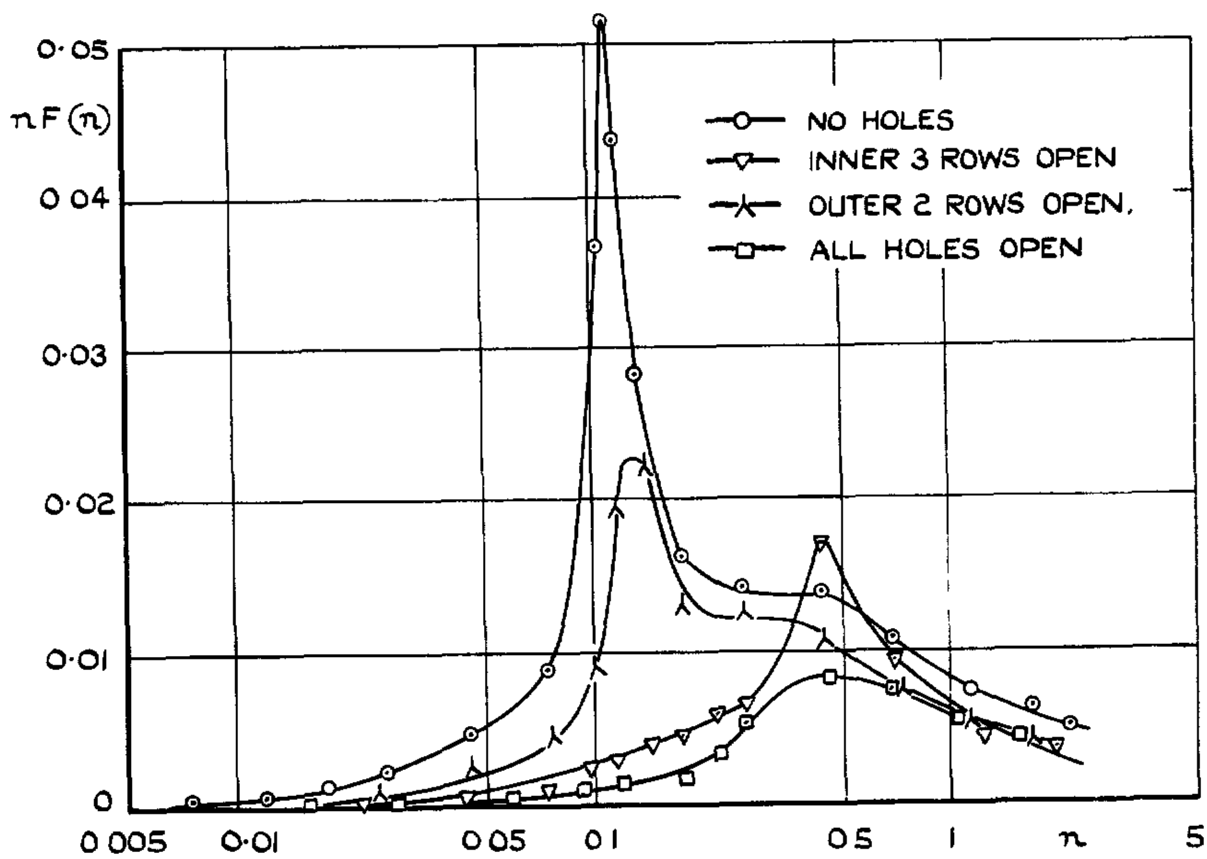


(b) PLATE No. 4. PARTLY PERFORATED.

FIG. 4. (a & b) R.M.S. VELOCITY FLUCTUATIONS.
18" BEHIND PLATES.



(a) UNIFORMLY PERFORATED PLATES.



(b) PLATE No. 4. PARTLY PERFORATED.

FIG. 5 (a & b) VELOCITY FLUCTUATION SPECTRA. 18" BEHIND PLATES $y/\sqrt{s} = 0{\cdot}8$.

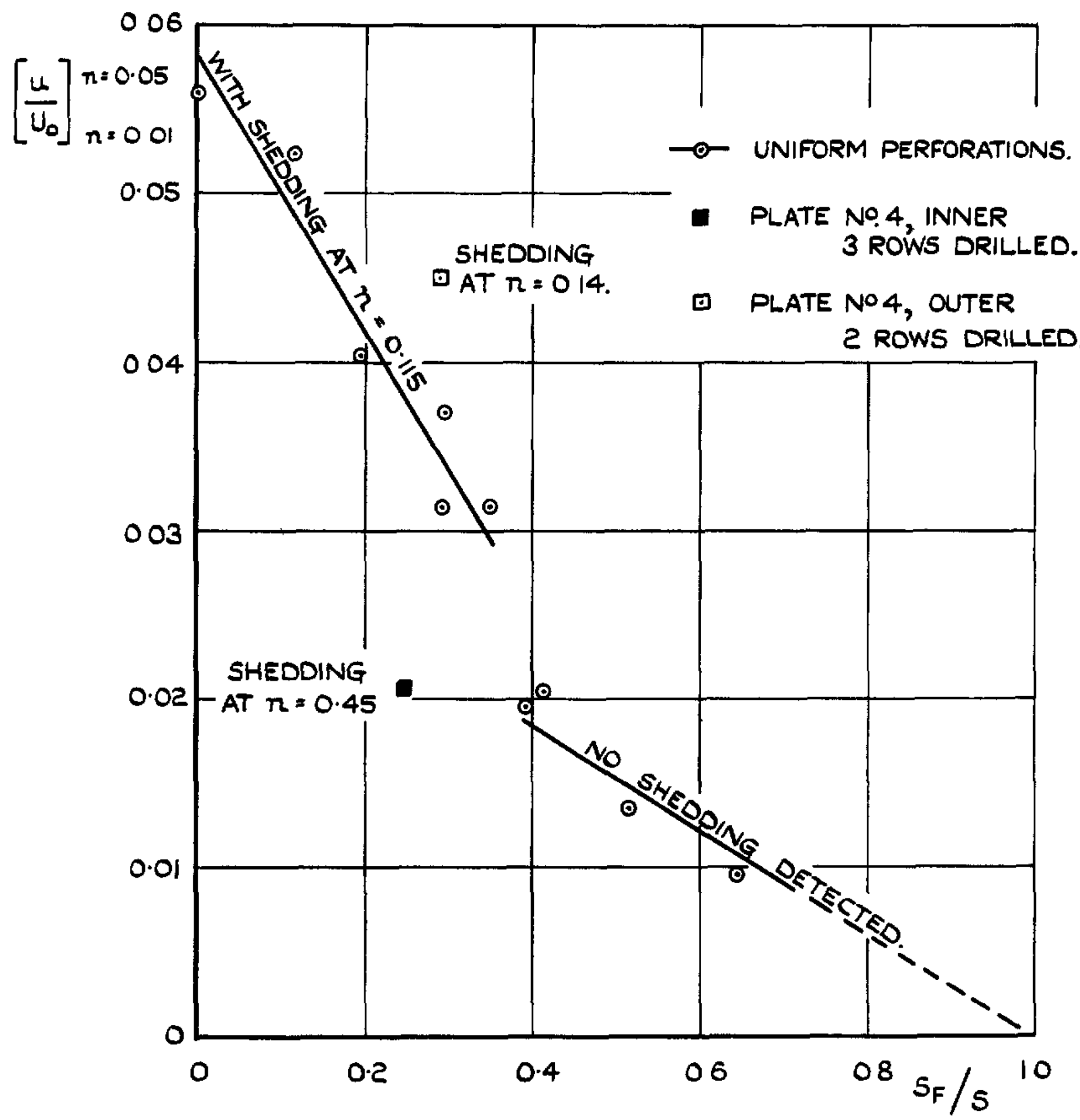


FIG. 6. LOW-FREQUENCY BAND OF VELOCITY FLUCTUATIONS 18" BEHIND PLATES.

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