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by

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SOME MEASUREMENTS OF BASE PRESSURE FLUCTUATIONS AT SUBSONIC AND SUPERSONIC SPEEDS

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SUMMARY

Base pressure fluctuations were measured on three bodies. They were expressed in terms of a non-dimensional spectrum function and a frequency parameter.

The pressure fluctuation spectra for a body with a hemispherical nose and a 15° flare were independent of Mach number M from $M = 0.15$ to 0.85 and corresponded fairly well with those measured previously on a cylindrical body which covered the limited Mach number range from $M = 0.06$ to 0.32.

The base pressure fluctuations for a body with a flat nose and a plain 15° flare were considerably higher than those for the body with the hemispherical nose at subsonic speeds.

The base pressure fluctuations for a body with a divided 15° flare were much higher than for the undivided flare, and displayed a distinct shedding frequency at subsonic speeds.

At supersonic speeds, the base pressure fluctuations were smaller than at subsonic speeds and decreased as the Mach number increased.

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* Replaces RAE Technical Report 70148 - ARC 32702.

CONTENTS

1 INTRODUCTION

Base pressure fluctuations are a source of buffet excitation on missiles at low speeds[1]. This Report describes a repeat of the measurements at low speeds of the base pressure fluctuations of Ref.1 and extends them to high subsonic and supersonic speeds.

The measurements suggest that base pressure fluctuations could cause moderate to severe buffeting at subsonic speeds, and light to moderate buffeting at supersonic speeds.

2 EXPERIMENTAL DETAILS

2.1 Models

Fig.1 shows the sting supported models used for these tests which had a 15° flare. The plain flare was tested with a hemispherical nose and an almost flat nose. An alternative body was provided with a 15° flare divided into six castellated segments by slots of constant width. This arrangement, called the divided flare, provides additional drag at high Mach numbers[2]. (This body was tested, because it was believed to create higher pressure fluctuations than the plain flare and to introduce a discrete frequency.) This body was only tested with the hemispherical nose.

The body used in the previous low speed tests[1] was strut-supported; this body is also shown in Fig.1.

2.2 Instrumentation

Two capacitance pressure transducers[3] were mounted in the base at $r/R = 0.30$ and 0.65. (The previous measurements were made at $r/R = 0$ and 0.65.) The reference side of each transducer was connected through 7 m (20 ft) of 2 mm PVC tubing to a reference static hole in the base at the appropriate value of r/R. Thus the dc level of the signal measured by the transducers was 0 at 0° angle of incidence, the condition for most of the measurements. The mean base pressures were also taken from the reference static pressure holes to capsule manometers and recorded automatically. The fluctuating signal from each transducer was passed through a low pass filter (set at 12 kHz to eliminate the transducer resonance at about 18 kHz from the total rms signal) and then recorded on a Brüel and Kjäer 2107 spectrum analyser and level recorder. The results were made non-dimensional as suggested by T. B. Owen[4];

i.e.

$$\sqrt{n\ F(n)} = \frac{p}{q\ \sqrt{\varepsilon}} \qquad (1)$$

where $n = \frac{f\ d}{V}$

d = base diameter

V = freestream velocity

q = $\frac{1}{2}\rho\ v^2$ kinetic pressure

p = pressure fluctuation in a band Δf at frequency f

= voltage × calibration factor

ε = analyser bandwidth ratio $\frac{\Delta f}{f}$

so that the total power of the pressure fluctuations was

$$\frac{\overline{p^2}}{q^2} = \int_0^\infty n\ F(n)\ d\ (\log n)\ . \qquad (2)$$

Equation (2) was used to derive the rms pressure fluctuations from the spectra of $\sqrt{n\ F(n)}$. Good agreement was obtained between the values of $\bar{p}/q$ integrated from the spectra and that measured directly.

The measured base pressure fluctuations were not corrected for the pressure fluctuations in the tunnel. These are probably small and should only influence the base pressure fluctuations at low levels of $\sqrt{n\ F(n)}$.

2.3 Test conditions

The models were tested in the R.A.E. 3ft × 3ft tunnel. The slotted 0.96 m × 0.66 m working section was used for the subsonic and transonic tests. No fluctuating base pressure measurements are presented from $M = 0.93$ to 1.20 because they are subject to interference from the tunnel side walls over this Mach number range. The side walls first inhibit the movement of the terminal shock across the wake (from $M = 0.93$ to 0.99) and then produce strong shock reflections from $M = 1.02$ to 1.20 (Fig.2). The closed 0.96 m × 0.96 m working section was used for the supersonic tests at $M = 1.4$ and 2.0.

Roughness bands were applied to fix boundary layer transition as shown in Fig.1. The roughness selected (glass spheres 0.05 mm in diameter) was intended to ensure boundary layer transition close to the roughness at subsonic speeds, and may have been inadequate at supersonic speeds, particularly at the lower Reynolds numbers. However, there was no significant change of mean or fluctuating base pressure coefficient with the Reynolds number even at $M = 2.0$, so that the boundary layer was probably always turbulent at the base[5].

3 RESULTS

The spectra measured by both pressure transducers were almost identical at subsonic speeds so that the pressure fluctuations measured at $r/R = 0.65$ are typical of those over a large proportion of the base area. There was no variation of pressure fluctuations from 0° to 6° angle of incidence. At higher angles of incidence there were some variations in the base pressure fluctuations but here the wake development may have been influenced by the presence of the sting.

3.1 Subsonic speeds

On the body with the hemispherical nose the tunnel schlieren apparatus shows that the boundary layer separates just downstream of the junction between the hemisphere and the circular cylinder and then reattaches to the surface of the 15° flare before separating again from the base as a single, well-defined shear layer. On the body with the flat nose, the boundary layer separates at an acute angle and forms a wide shear layer. This appears to reattach towards the end of the flare, and then separates giving a wake slightly narrower and less well defined than the wake from the hemispherical nose (Fig.2). These differences in the mean wake structure are associated with different pressure fluctuation spectra.

Fig.3 shows the base pressure fluctuation spectra for the body with the hemispherical nose and the plain flare. The spectra of the pressure fluctuations are independent of Mach number from $M = 0.30$ to 0.85, with an rms level $\bar{p}/q = 0.026$. At $M = 0.90$ there are large shock waves visible in the tunnel schlieren, the pressure fluctuation spectrum is rather different and the rms level $\bar{p}/q$ rises to 0.029. Fig.3 also shows that Eldred's base pressure fluctuations have rather similar spectra from $n = 0.01$ to 0.50 to the present results, though with a lower rms level of $\bar{p}/q = 0.015$. The difference between the spectra is most noticeable at the lower frequencies ($n < 0.07$) and might be caused by the large differences between the shape of the models and the supports. (The present measurements were on sting supported models; Eldred's measurements were on a strut supported model.)

The similarity of the spectra at the higher frequencies suggest that the smaller-scale disturbances in the base region are similar for both series of tests despite the large differences between the models.

The question of what the structural and dynamic response of these bodies to these pressure fluctuations might be has not been investigated. Although there is at present no justification for the assumption that the buffeting characteristics of these bodies are in any way related to those of wings, the buffet categories suggested for wings[6] are marked on the right hand side of Figs.3 to 6. These limits are:

Buffet intensity	$\sqrt{n \, F(n)}$
Light	0.004
Moderate	0.008
Heavy	0.016

Fig.3 shows that the base pressure fluctuations from $n = 0.02$ to 3.0 would fall within the limits for moderate to heavy buffet.

Fig.4 shows the base pressure fluctuations for the body with the flat nose and the plain flare. The spectra of the pressure fluctuations are independent of Mach number from $M = 0.15$ to 0.90, with rms levels of $\bar{p}/q = 0.038$. The higher pressure fluctuations on this body are caused partly by the large scale separation between the flat nose and the flare which is not present with the hemispherical nose (Fig.2). The pressure fluctuations from $n = 0.02$ to 0.3 are above the heavy buffet limit of $\sqrt{n \, F(n)} = 0.016$.

The base pressure fluctuations associated with the high drag, divided flare, are much higher than had been anticipated. (Note the change of scale between Fig.5 and Figs.3 and 4.) Fig.5 shows that the spectra are independent of Mach number from $M = 0.30$ to 0.60 and that there is a large peak at $n = 0.15$; the rms level is $\bar{p}/q = 0.055$. It is interesting to note that the frequency parameter n_w based on the slot width w is $n_w = 0.015$. This is of the same order as the frequency parameter found[7] in slotted wind tunnels with diffuser suction, $0.03 < n_w < 0.04$. Between $M = 0.60$ and 0.80 this peak in the pressure fluctuation spectrum disappears, probably because sonic flow is achieved at the edge of the flare. (The base pressure coefficient at $M = 0.80$ is $Cp_b = -0.40$, close to the critical value.) The pressure fluctuation spectra are independent of Mach number from $M = 0.80$ to 0.90 and the rms level drops to $\bar{p}/q = 0.044$, which is still considerably higher than that for the plain flare. The heavy buffeting limit $\sqrt{n\,F(n)} = 0.016$ is exceeded from $n = 0.08$ to 0.5 for all Mach numbers, and this, together with the high peak at the lower Mach numbers, might restrict the use of divided flares.

3.2 Supersonic speeds

For the two configurations tested, the pressure fluctuations at supersonic speeds are smaller than at subsonic speeds, but they were still significant.

Fig.6 shows that for the plain flare the spectra were different at $M = 1.4$ and 2.0 and that the rms levels were $\bar{p}/q = 0.012$ and 0.0065 respectively at $r/R = 0.65$. At $M = 1.4$ with the transducer at $r/R = 0.3$ the rms levels were about 50% higher, with $\bar{p}/q = 0.019$. This pressure transducer failed at the end of the run so that it was not possible to verify if this discrepancy existed at $M = 2.0$.

Fig.6 also shows that the pressure fluctuations with the divided flare at $M = 1.4$ were higher than those for the plain flare from $n = 0.04$ to 2.0, although the rms pressure fluctuations were identical, $\bar{p}/q = 0.012$. There is more energy at low frequencies ($n < 0.05$) and less at medium frequencies ($0.1 < n < 5$) with the plain flare than with the divided flare. The pressure fluctuations at $M = 1.4$ correspond with light to moderate buffet for both configurations.

3.3 Mean base pressure

Fig.7 shows the mean base pressure coefficients measured during these tests. The mean base pressure measured by Eldred at Reynolds number $Rd = 0.3 \times 10^6$ (−0.26) agrees well with that measured in the present test (−0.28) at about the same Reynolds number for the body with the hemispherical nose and the plain flare. The change from a hemispherical nose to a flat nose does not change the base pressure coefficient significantly. However, replacing the plain flare by the divided flare decreases the base pressure coefficient from −0.28 to −0.38 and this must account for a large proportion of the extra drag of the divided flare at subsonic and low supersonic speeds. The base pressure variation with Mach number in the transonic region was subject to considerable interference from $M = 0.96$ to 1.20 and should be disregarded.

4 CONCLUSIONS

Base pressure fluctuations were measured on three bodies and expressed in terms of a non-dimensional spectrum function and a frequency parameter.

The pressure fluctuation spectra for a body with a hemispherical nose and a 15° flare were independent of Mach number from $M = 0.15$ to 0.85 and corresponded fairly well with those measured previously on a cylindrical body which covered the limited Mach number range from $M = 0.06$ to 0.32.

The base pressure fluctuations for a body with a flat nose and a plain 15° flare were considerably higher than those for the body with the hemispherical nose at subsonic speeds.

The base pressure fluctuations for a body with a divided 15° flare were much higher than for the undivided flare, and displayed a distinct shedding frequency at subsonic speeds.

At supersonic speeds, the base pressure fluctuations were smaller than at subsonic speeds and decreased as the Mach number increased.

TEST CONDITIONS

Table 1

PLAIN FLARE

Nose	M	$Rd \times 10^{-6}$	Remarks	Fig.
Hemispherical	0.30	0.34	Sting supported model	3
	0.45	0.66		
	0.60	0.95		
	0.80	1.41		
	0.85	1.46		
	0.90	1.48		
	1.40	0.42 to 1.25	No change of roughness	6
	2.00	0.46 to 0.85		
Ogival (K. M. Eldred Ref.1)	0.06 to 0.32	0.2 to 1.0	Strut supported model	3
Flat	0.15	0.27	Sting supported model	4
	0.30	0.58		
	0.45	1.10		
	0.60	0.47 to 1.90		
	0.80	1.41		
	0.85	1.46		
	0.90	0.74 to 1.48		

Table 2

DIVIDED FLARE

Nose	M	$Rd \times 10^{-6}$	Remarks	Fig.
Hemispherical	0.30	0.34	Sting supported model	5
	0.45	0.66		
	0.60	0.95		
	0.80	1.41		
	0.85	1.46		
	0.90	1.48		
	1.41	0.42 to 1.25	No change of roughness Transducer T1 broken at end of this run	6

SYMBOLS

d	body diameter $= 2R$
f	frequency (Hz)
$F(n)$	contribution to $\frac{\overline{p^2}}{q^2}$ in frequency band Δf
$\sqrt{n F(n)}$	$= \frac{p}{q \sqrt{\varepsilon}}$
M	Mach number
n	$\frac{f\,d}{V}$ frequency parameter
Q	pressure fluctuation in a band Δf at frequency f
$\frac{\overline{p^2}}{q^2}$	$= \int_0^\infty n\, F(n)\, d\, (\log n)$
q	$= \frac{1}{2}\rho\, V^2$ kinetic pressure
r	radial position of pressure transducers
Rd	Reynolds number based on diameter d
V	freestream velocity
ε	analyser bandwidth ratio $\frac{\Delta f}{f}$
ρ	freestream density

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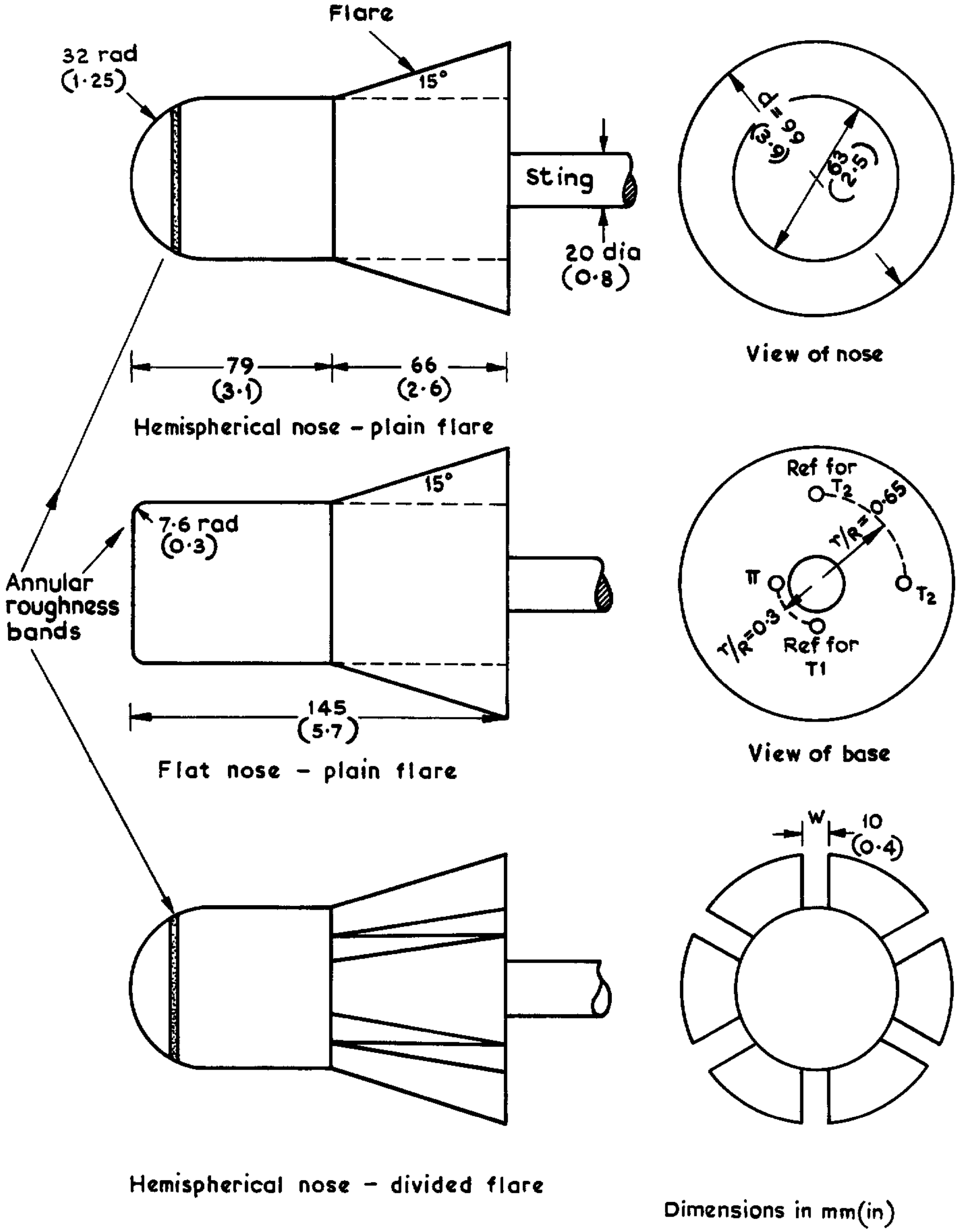
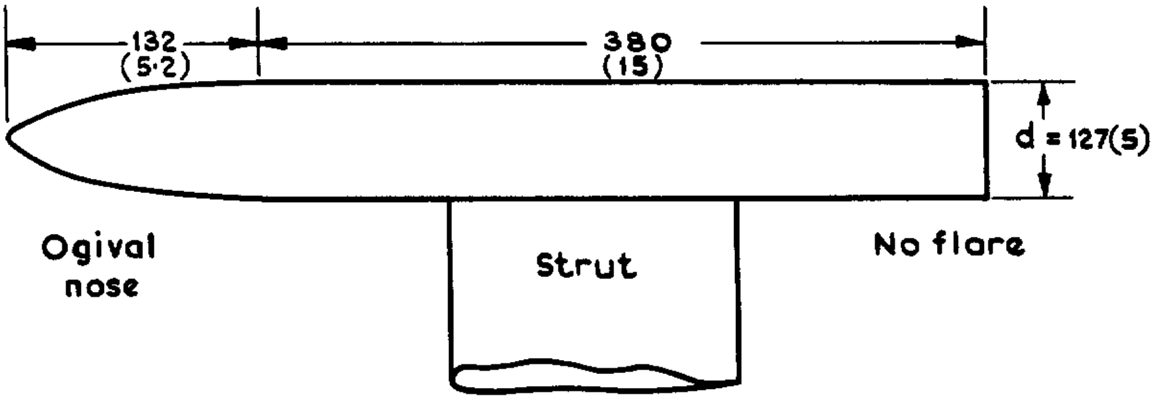


a Present tests – sting supported bodies

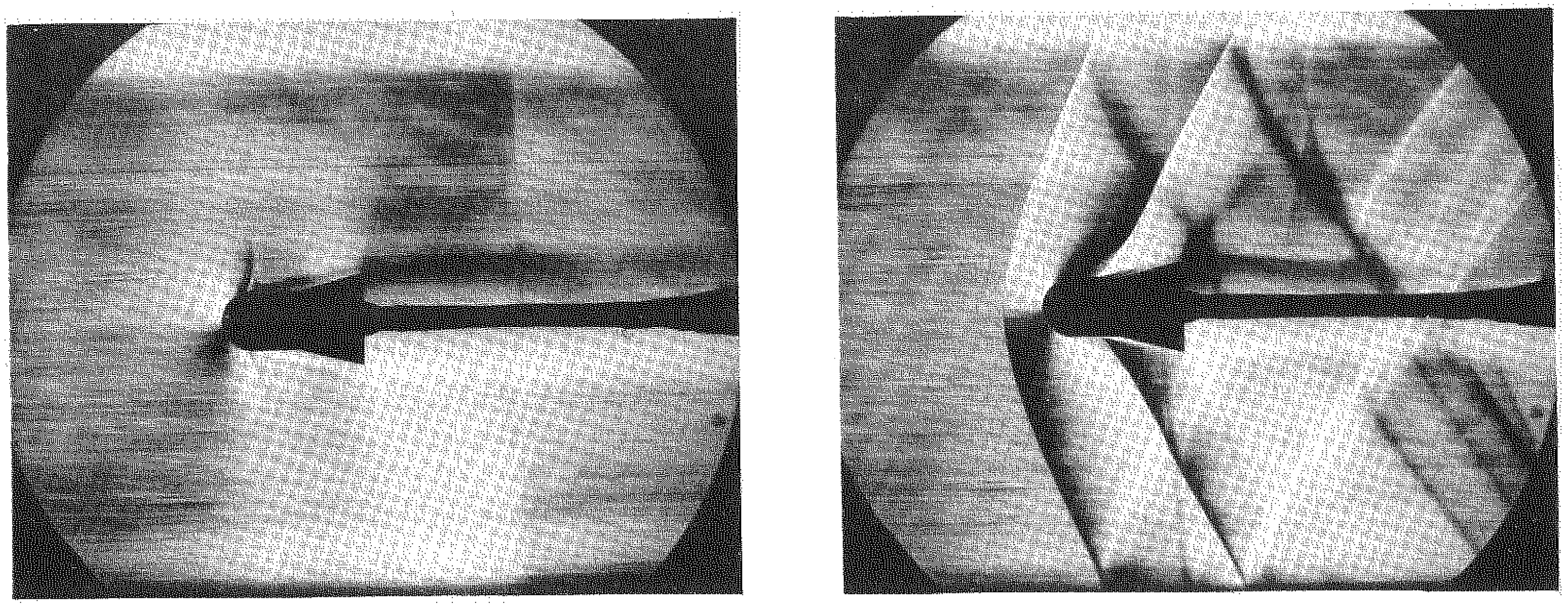
Fig.1 Bodies used for pressure fluctuation measurements



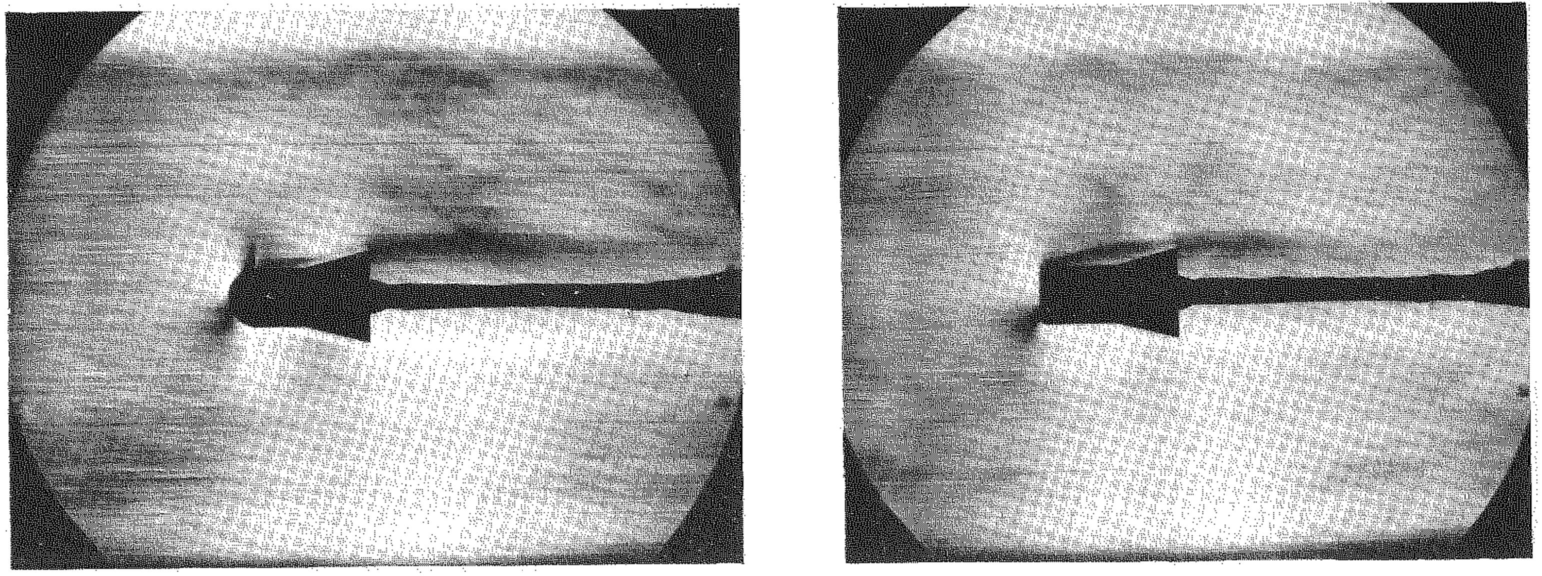
Transducers at $r/R = 0{\cdot}65$ and 0

b Eldred's tests — strut supported body

Fig. 1 contd



M=0.96 Transonic interference-hemispherical nose M=1.20



Hemispherical Nose Flat Nose

Development of shear layers-M=0.90

Fig.2. Typical schlieren photographs-plain flare

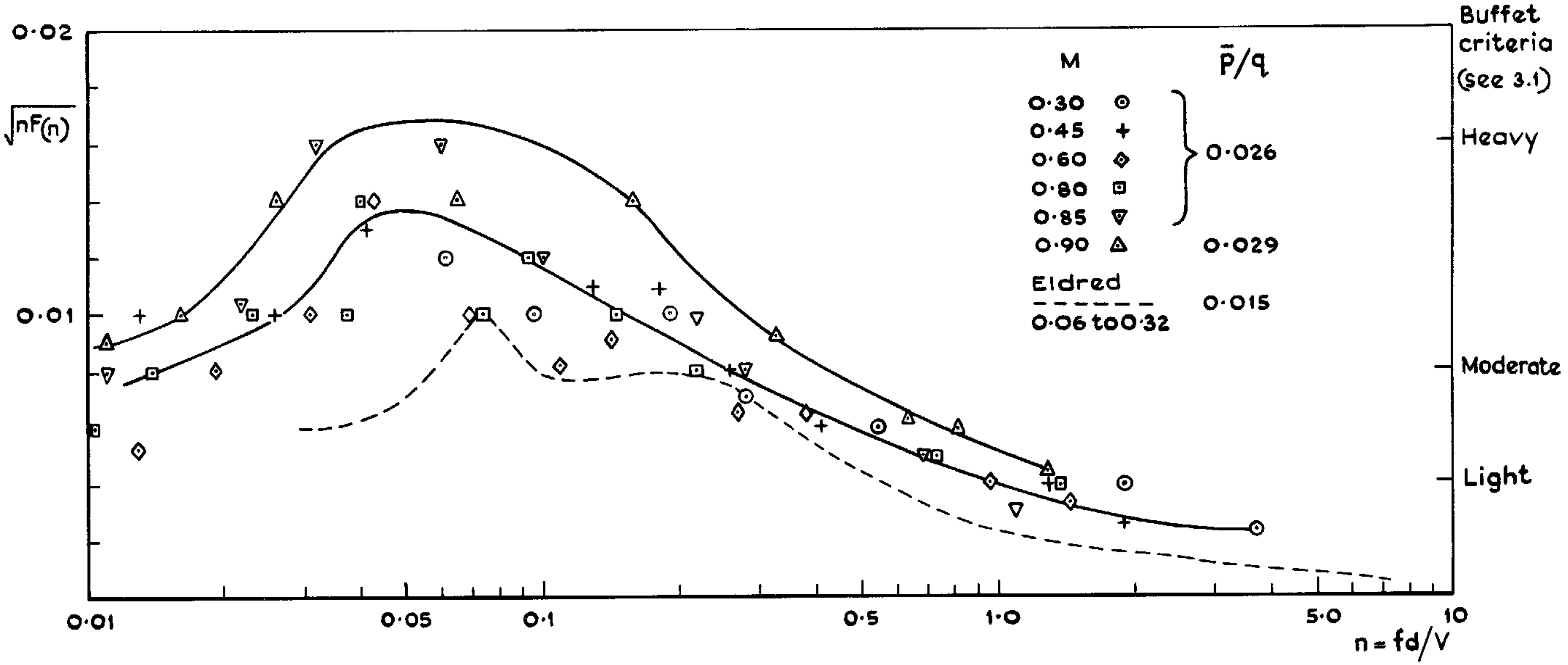


Fig.3 Spectra of base pressure fluctuations – hemispherical nose – plain flare – subsonic

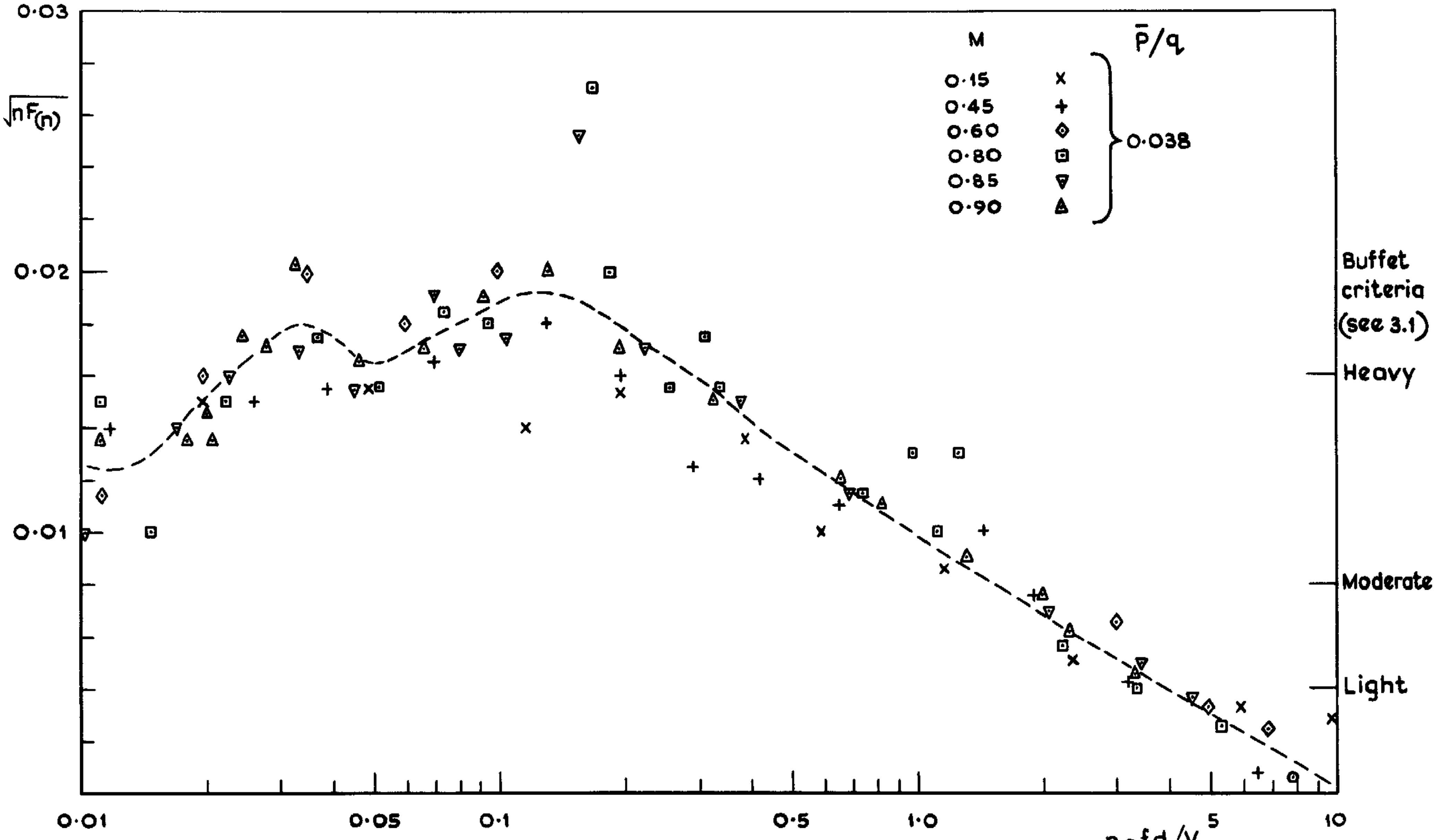


Fig. 4 Spectra of base pressure fluctuations - flat nose - plain flare - subsonic

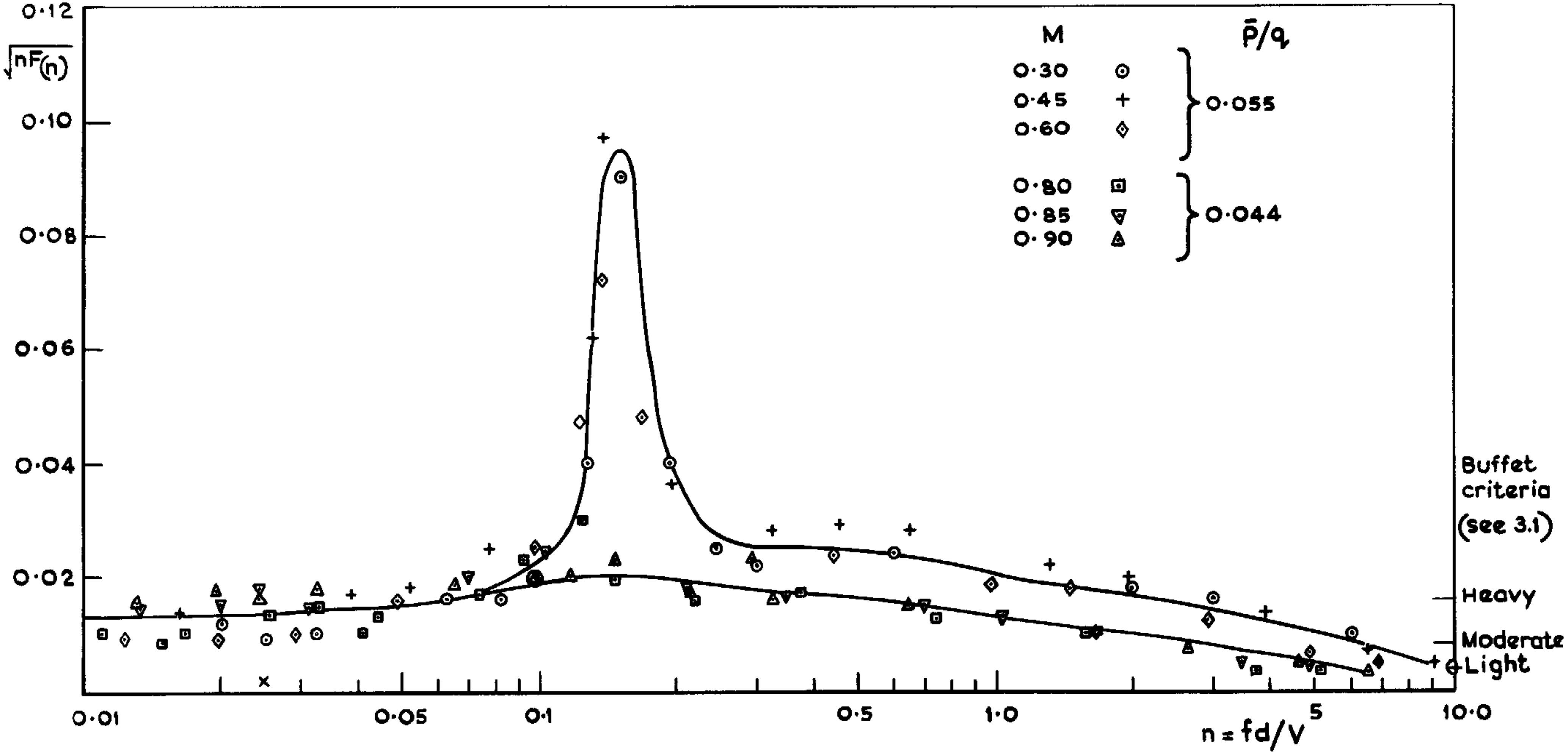
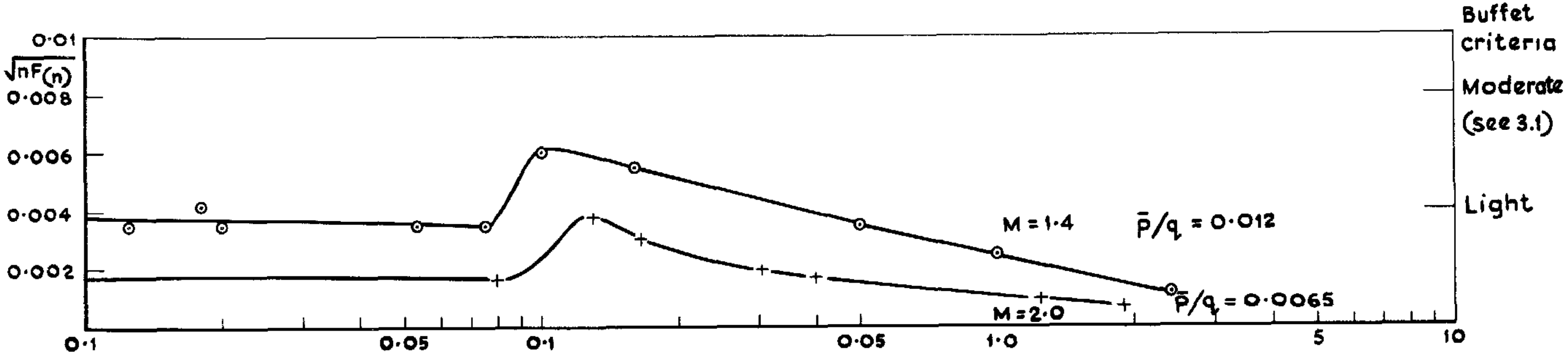
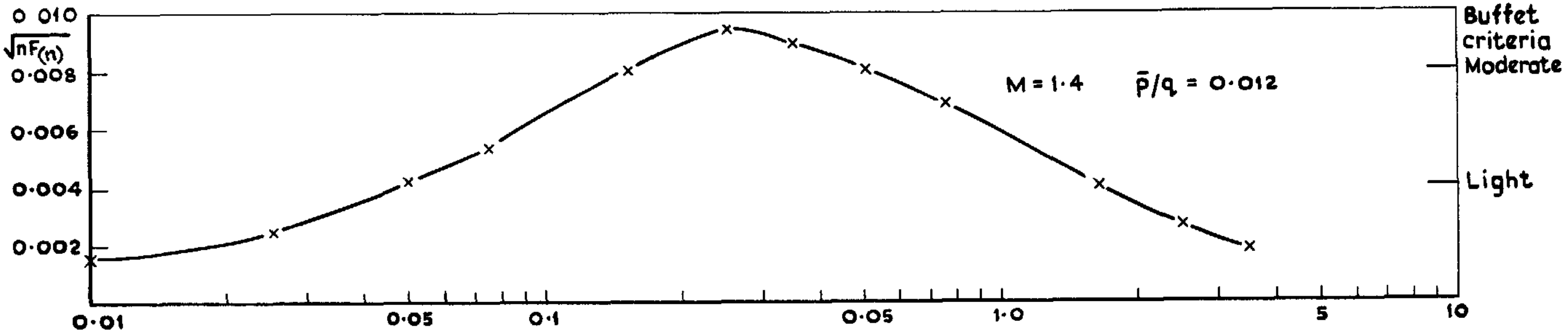


Fig.5 Spectra of base pressure fluctuations – hemispherical nose – divided flare – subsonic

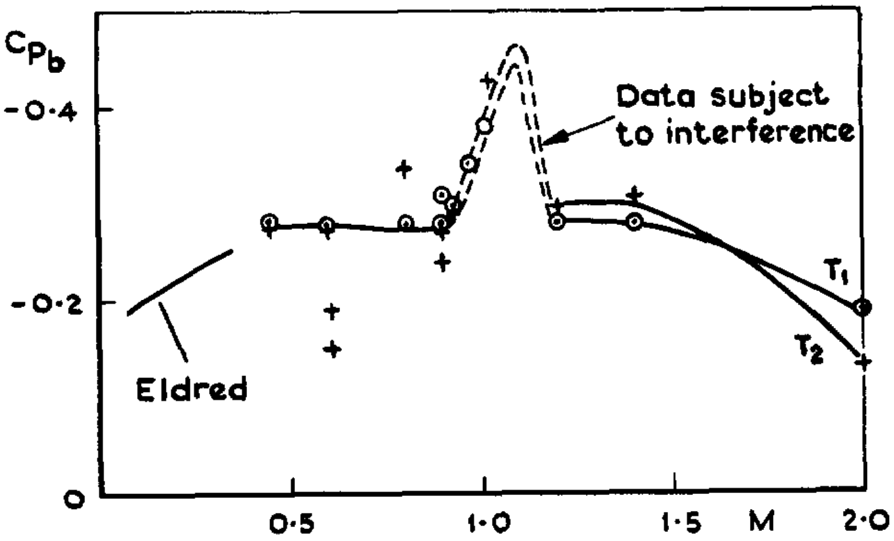


Plain flare

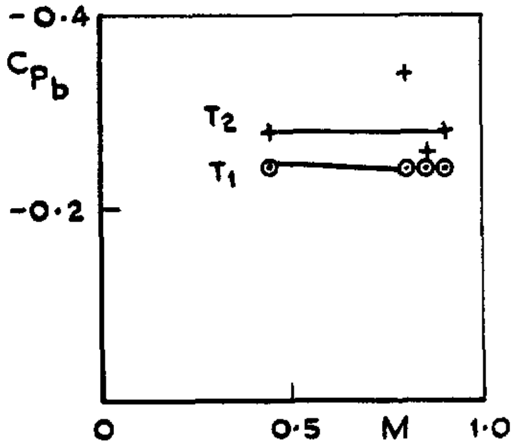


Divided flare

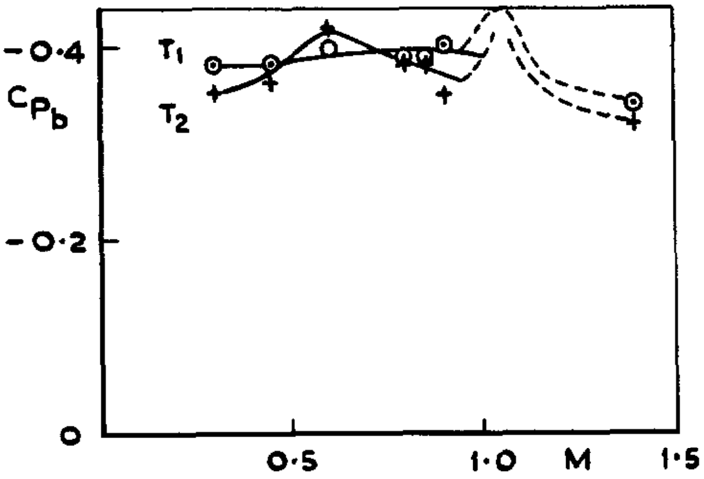
Fig 6 Spectra of base pressure fluctuations – hemispherical nose – supersonic



Hemispherical nose – plain flare



Flat nose – plain flare



Hemispherical nose – divided flare

Fig.7 Variation of base pressure coefficients with Mach number

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