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The Calibration at Transonic Speeds of a Mk.9A Pitot Static Head with and without Flow through the Static Slots

By

D. G. Mabey, M.Sc.(Eng.), A.C.G.I., D.I.C.

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SUMMARY

The static pressure error of a standard Mark 9A pitot static head at transonic speeds has been measured in the R.A.E. (Bedford) 3 ft tunnel. The static error may be reduced slightly by sealing the drain hole.

The effects of both flow through the drain hole and rate of altitude change were simulated and for a typical aircraft system the static error corresponding with a high rate of descent was found to be small.

Some tunnel interference effects have been observed.

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1 Introduction

The Mark 9A Pitot Static Head, as illustrated in Figs.1(a) and 2, is a standard fitting on British high speed aircraft. It has a drain hole between the pitot and static chambers: the airflow through this hole is intended to blow any moisture in the pitot lead through the static slots and thus prevent ice formation in the pitot lead. In flight there is thus a continuous flow of air through the static slots.

This report describes tests made in the R.A.E. (Bedford) 3 ft tunnel to determine the static error of a standard Mk.9A head at transonic speeds and the variation of this error with simulated rate of climb or descent.

Two heads were tested to obtain these results. The first was a standard head with which both static and pitot pressures were measured (Fig.1(a)). The second was a standard head with the pitot entry blocked and the drain hole enlarged (Fig.1(b)). This is referred to subsequently as the modified head. The static error of the modified head was measured with various flow rates through the static slots corresponding to climbing or descending flight.

The results of these tests have been compared with some measurements made in free flight using ground launched rocket models.

The ratio of the area of the static tube to the area of the working section was only 4.7×10^{-4}, but some tunnel interference effects were observed.

2 Description of the Heads

The heads tested are shown in Fig.1. The modified head had the same external shape as the standard head, but the pitot entry was blocked 1 inch from the nose. It has been shown[1] that the internal flow within a pitot tube does not measurably persist beyond one diameter from the nose. With the pitot entry blocked five diameters from the nose it was reasonable to assume that the flow round the nose of the modified head would be the same as that round the nose of the standard head with the drain hole sealed.

The drain hole of the modified head was enlarged from 0.031 inches to 0.062 inches diameter so that it was possible to pass up to four times the choking mass flow of the standard drain hole.

The mounting of the head is shown in Fig.2. The Mk.9 head was unaltered as far as the end of the tapered portion, where it usually enters the wing leading edge.

3 Equipment and Technique

A description of the 3 ft tunnel and its calibration at transonic speeds has already been given by Morris[2] and Sutton[3]. The working section was partially recalibrated with the 3° cone used in the earlier calibration to eliminate any changes with time and to cover additional stagnation pressure values.

In Fig.3 a static head is shown mounted in the transonic working section. The mid point of the static slots coincided with the position of the static holes on the calibration probe and the head was aligned accurately with the tunnel centre line. At about 10 inches from the static slots the flow was inclined at an angle of 0.1° to the tunnel centre line[4]. The uniformity of the Mach number in this region is such that it is reasonable to assume the same deviation in the flow direction at the static slots.

A previous low speed tunnel calibration of a Mk. 9A head[5] indicated that this deviation would not produce a significant error in either the pitot or static pressures.

The pitot lead of the modified head could be connected via a needle valve to the atmosphere or to a suction pump. The pressure in the working section of the tunnel, and hence in the static chamber, was always below atmospheric and air from the atmosphere could therefore pass through the needle valve into the static chamber and out through the static slots into the mainstream. Alternatively the suction pump could draw air from the mainstream through the static slots into the static chamber. The static lead transmitted the static chamber pressure.

The mass flows required for this experiment were small (up to 2.10^{-5} slugs/sec) and an orifice of 0.082 inches diameter was used to measure the flow. The maximum Reynolds number R_D (based on the orifice pipe diameter) was only 2500 so that the orifice was made to the design recommended by the German Standard for low Reynolds numbers[6]. The standard does not quote discharge coefficients below $R_D = 4000$ and recommends that every installation should be calibrated. Accordingly the orifice was calibrated with water over the required Reynolds number range. This calibration was checked by the direct displacement of air from a measuring vessel over the same Reynolds number range. The discharge coefficients obtained from these calibrations agreed within 5% but as the water calibration was considered the more reliable this was used.

The drain hole of the standard head was calibrated by sealing the pitot nose and the static slots and blowing from the pitot lead to the static lead: the mass flow was measured with the orifice. This calibration provided a check on the size of the drain hole and gave the following relation for the choking mass flow

$$m_c = 2.05 \times 10^{-7} H \text{ slugs/sec} \qquad (1)$$

where H = the mainstream stagnation pressure in inches of mercury.

4 The Calibration of the Working Section

In the recalibration of the working section the true Mach number was obtained from that given by the calibration probe by the addition of a correction obtained from the results of reference 3 (Appendix 1 and Fig.24(b)). The values of this correction are given in the following table

Indicated Mach Number M	Correction to be added dM
0.70 - 0.98	0
0.98 - 1.02	Linear variation from 0 to 0.004
1.02 - 1.20	0.004

The reference static hole was in the plenum chamber 67 inches downstream of the throat: it had been used in the earlier calibration and was also used in these subsequent tests.

5 The Accuracy of the C_p Measurements

Every pressure coefficient C_p is based on two pressure differences (conical probe pressure - reference pressure; head pressure - reference pressure) each of which may be in error by 0.03 inches of mercury, the maximum error of the manometric balances. Hence when $M_0 = 1.0$ we have:

Stagnation Pressure inches of mercury	Possible Error in C_p
20	±0.008
40	±0.004

These limits indicate the errors which may occur in C_p and they have been indicated in the figures giving the results. Although in all cases the scatter was well within these limits consistent errors of the above magnitude are not excluded.

6 Tests

All tests were made at stagnation pressures of 40 and 20 inches of mercury and a stagnation temperature of 30°C over a Mach number range from 0.85 to 1.18. these stagnation pressures correspond with flight at $M_0 = 1.0$ and 9,000 and 26,000 feet. Between $M_0 = 0.85$ and 1.18 the Reynolds number varied from 4.8×10^5 to 5.2×10^5 and from 2.4×10^5 to 2.6×10^5 at these respective stagnation pressures.

The static pressure of the standard head was measured as a difference from the tunnel reference pressure and the pitot pressure was measured as a difference from the tunnel stagnation pressure.

The variation of the indicated static pressure with Mach number was measured first for the mass flow ratios $m/m_c = -1, 0$ and $+1$. These readings showed the variation of indicated static pressure both with mass flow and Mach number.

The static pressure error at varying rates of discharge or inflow through the static slots was measured in detail for Mach numbers of 0.915 and 1.125. These Mach numbers were chosen so that in the expression;

$$\delta C_p = \frac{\partial C_p}{\partial m/m_c} \cdot \delta\left(m/m_c\right) + \frac{\partial C_p}{\partial M} \cdot \delta M,$$

$\frac{\partial C_p}{\partial M}$ was so small that with the likely errors in tunnel Mach number δM, the second term was negligible. Hence the law relating the static error with the mass flow could be determined accurately.

The pitot entry of the modified head was then filled and rounded, as shown in Fig.1(b), to determine the effect of this change of nose shape on the static error.

7 Results

7.1 The Pitot Pressure Error of the Standard Head

The dimensionless pitot pressure error $\left(H_s - H\right)/H$ is plotted as a function of Mach number in Fig.4, where H is the tunnel stagnation pressure and H_s the pitot pressure of the standard head.

In this figure the corresponding theoretical curve is also given for the normal pitot relation in supersonic flow.

Agreement between theory and experiment, within the indicated accuracy of measurement, is apparent over the whole Mach number range. Hence there appears to be no significant error in the pitot pressure due to the presence of the drain hole.

7.2 The Static Error of the Standard Head

Fig.5 shows the static error of the standard head in coefficient form, as C_p, against the true Mach number. As M_o increases above 0.95 the static error increases. This increase in error may be caused by the approach of the shock wave terminating the supersonic region on the nose of the head, or by the growth of the positive pressure region before the support, or by a combination of these effects. C_p attains a maximum at $M_o = 1.01$.

There is a sharp fall in C_p at both stagnation pressures, of about 0.09 between $M_o = 1.01$ and 1.025. The steepness of the curve indicates that this does not represent the passage of a wave reflected from the side walls. In the free flight tests described by Hamilton[7] the corresponding fall in C_p is only 0.016 and occurs at $M_o = 1.005$. The fall in C_p caused by a normal shock at $M_o = 1.005$ is 0.016 so that in the free flight test the fall in C_p may be attributed to the passage of the rocket bow wave and is not influenced by the flow round the nose of the head.

In tunnel tests, wall interference is believed to influence both the magnitude of this fall in C_p and the Mach number at which it occurs. In tests on static tubes in the slotted wall tunnel of the English Electric Company[8] it was found that as the blockage increased, the fall in C_p, and the Mach number at which it occurred increased.

It is interesting to compare the sharp fall of C_p in Fig.5 with the corresponding fall in C_p obtained from the English Electric results.

Test	R.A.E.	English Electric	Free Flight
Blockage	0.047%	0.047%	-
Fall in C_p	0.090	0.095	0.016
Mach number at fall	$1.01 < M_o < 1.025$	1.02	1.005
Fall in C_p due to normal shock	0.060 ($M_o = 1.018$)	0.067	0.016

It will be seen that the R.A.E. and English Electric results are in good agreement but that the experimental fall in C_p is greater than that for the corresponding normal shock. This illustrates a possible effect of wall interference.

In the R.A.E. tests, as the Mach number increases from 1.020 to 1.065 C_p increases from -0.02 to 0.05 at the higher stagnation pressure. The overshoot does not appear in the free flight tests and hence is attributed to tunnel interference. In the English Electric tests on an 0.25 inch diameter probe (blockage 0.034%) the corresponding rise in C_p was 0.06 and Schlieren photographs showed that the reflected wave passed the static slots at $M_o = 1.05$. This reflected compression wave increased C_p to a maximum at $M_o = 1.06$ and was followed by an expansion wave which reduced C_p by 0.025 between $M_o = 1.06$ and 1.10. A similar explanation can be applied to the results shown in Fig.5, where C_p falls from 0.052 at $M_o = 1.065$ to 0.026 at $M_o = 1.105$.

Thus when M_o was greater than 1.10 the reflected bow wave would be downstream of the static slots and the head then free from tunnel interference. The curve of Fig.5 for the higher stagnation pressure is seen to agree well with the free flight results from $M_o = 0.85$ to 0.95 and from $M_o = 1.10$ to 1.18.

It should be noted that Fig.5 indicates that there may be a small Reynolds number effect on the Standard head. In Appendix I it is suggested that this may be caused by a Reynolds number effect on the flow through the drain hole.

7.3 The Static Error of the Modified Head

Fig.6 shows the pressure coefficient C_p, for the modified head with zero mass flow through the static slots. The curves of Fig.6 closely resemble those of Fig.5, so that the main features of the flow are unchanged, but they are displaced downwards by about 0.01 at subsonic to 0.02 at supersonic speeds. A similar displacement was observed in the free flight test of a head with the pitot entry blocked[7]. This displacement is of the same order as that obtained by sealing the drain hole of a Mark 8 head[9] in the range from $M_o = 0.2$ to $M = 0.9$.

It will be seen by comparing Fig.5 with Fig.6 that any Reynolds number effect that may exist on the standard head is eliminated at subsonic speeds and considerably reduced at supersonic speeds.

Fig.7 shows the C_p of the modified head with the rounded nose for zero mass flow through the static slots. Compared with Fig.6 the static pressure is little changed. Hence the static error is insensitive to this change of nose shape. This provides further support for the assumption of Section 2 that the external flow is the same with the pitot entry blocked five diameters from the nose, as it is with the drain hole sealed.

7.4 The Effect of Flow through the Static Slots

The static pressure was measured for approximately constant discharge or inflow over the complete Mach number range (Fig.8). When air was blown from the pitot chamber to the tunnel the static pressure increased and when air was drawn from the tunnel to the pitot chamber the static pressure decreased. The position and magnitude of the rapid variations in C_p are unchanged so that these mass flows have not altered the main features of the flow.

The detailed variation of C_p with the dimensionless mass flow $^m/m_c$* at $M_o = 0.915$ and 1.125, is shown in Fig.9: some points at $M_o = 1.130$ and 1.153 have also been included. The shape of the graphs near the origin could not be determined because the measured values were within the experimental errors.

This non-dimensional representation indicates that within the experimental accuracy the variation of the static error with mass flow through the enlarged drain hole is independent of Reynolds number.

Fig.9 shows that the points given lie on straight lines which, it may be noted, cut the $^m/m_c$ axis at approximately 0.15 and -0.15. The slopes of these lines are 0.008 and 0.015 at $M_o = 0.915$ and 1.125 respectively, so that the order of magnitude of $\dfrac{d\,C_p}{d\,^m/m_c}$ is 10^{-2}.

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* If the small loss caused by the bow wave is neglected, $^m/m_c$ will be 1 in level flight for the standard head when M_o lies between 1.00 and 1.18.

Two possible causes of this error are:

(1) the pressure drop across the slots due to the mass flow, or

(2) the pressure change in the external flow near the slots due to the mass flow. These possibilities are now considered.

The pressure, dp, required to drive the choking mass flow through the static slots of the modified head into air at rest was measured. It was found that:

$$dp = 6.23 \times 10^{-5} \times H \times \text{inches of mercury.}$$

The corresponding error in C_p when $M_o = 1.0$ would be

$$\frac{dp}{q} = 1.7 \times 10^{-4}$$

and as $$\frac{m}{m_c} = 1.0,\ \frac{d}{d}\frac{C_p}{m/m_c} = \frac{dp}{q} = \underline{1.7 \times 10^{-4}}\ .$$

This is much smaller than the experimental order of magnitude of $\frac{d}{d}\frac{C_p}{m/m_c} = 1.10^{-2}$.

Hence the measured static error with the free stream in motion cannot be attributed to the pressure drop across the slots.

Assuming that the principal effect of the mass flow from the static slots is to deflect the external flow, the order of magnitude of this deflection may be used to calculate the corresponding value of $\frac{d}{d}\frac{C_p}{m/m_c}$.

If the mainstream is supersonic $\frac{m}{m_c} = 1.0$. If the mass flow is divided evenly between the front and rear slots (both of which extend half way round the tube) the velocity normal to the slots is:

$$u = \frac{m_c}{\rho_o \pi d t}$$

where d = the head diameter = 0.75 inches

and t = the slot width = 0.030 inches.

The order of magnitude of the deflection θ, on the outside of the boundary layer is then:

$$\theta = O\left(\frac{u}{V_o}\right) = O\left(\frac{m_c}{\pi d t} \cdot \frac{1}{M_o\ a_o\ \rho_o}\right)$$

where a_o = the free stream velocity of sound.

Hence $$\theta = O\left(\frac{m_c}{\pi d t} \cdot \frac{1}{a_s \rho_s} \cdot \frac{1}{M_o} \cdot \frac{\rho_s}{\rho_o}\ \frac{a_s}{a_o}\right)$$

where a_s and ρ_s are the stagnation velocity of sound and the density. If the appropriate values are substituted in this equation it is found that:

$$\theta = O(0.5^o).$$

At $M_o = 1.10$ it is found from tables that the shock wave giving a deflection of 0.8° gives an increase in C_p of 0.04. Hence we have

$$C_p = O(0.04)$$

or since $\frac{m}{m_c} = 1.0$

$$\frac{d\, C_p}{d\, {}^m/_{m_c}} = O(0.04).$$

The assumption of a simple flow deflection thus predicts the order of magnitude of the measured pressure error. The real flow will, of course, be more complex. The shock wave will be followed by an expansion wave which will influence the static pressure at the rear slots, apart from any pressures transmitted through the boundary layer.

The correlation in Fig.9 between the points at different stagnation pressures indicates that there is no Reynolds number effect on the enlarged drain hole.

In Figs. 10, 11, 12 and 13 the slopes $\frac{d\, C_p}{d\, {}^m/_{m_c}}$ for discharge and inflow at the two stagnation pressures, are plotted against the true Mach number. (C_p origins are assumed at ${}^m/_{m_c} = 0.15$ and -0.15 so that the slopes are consistent with those of Fig.9). At most Mach numbers only three mass flows were measured, hence the considerable scatter of the points. C_p varied widely from $M_o = 0.97$ to 1.05 so that the scatter increased in this range. However, the other points show that the drain hole error increases with Mach number. No significant Reynolds number effect can be affirmed from Figs.10-13 because the Reynolds number effect is small compared with the scatter.

The present results can be used to determine the effect of diving or climbing upon the static error if the mass flow into the aircraft static system is known. An example and further discussion is given in Appendix II. In this Appendix the mass flow into an aircraft static system with a volume of 100 cubic inches has been estimated for a rate of descent of 1000 ft/second at an altitude of 27,000 ft. This mass flow produces an error in indicated height of about 40 ft at a Mach number of 0.915 and of 90 ft at a Mach number of 1.125. Thus the error in this example is small.

8 Conclusions

Tests made on the standard Mk.9A pitot static head show that the drain hole does not produce a measurable error in the pitot pressure of the standard head.

The drain hole does however introduce a positive error in the indicated static pressure which is nearly doubled between Mach numbers of 0.915 and 1.125 and has possibly a small variation with Reynolds number.

The variation of the static pressure error from $M_o = 0.80$ to 1.18 is insensitive to the differences of nose shape tested.

The relation between the static error and the flow through the static slots has been measured. From these results the error corresponding with a high rate of descent for a typical aircraft system has been estimated and found to be small.

The indicated static pressure was subject to tunnel interference in the range from $M_o = 0.95$ to 1.10.

LIST OF SYMBOLS

a	velocity of sound
$C_p = \frac{p_s - p_o}{q}$	pressure coefficient
C_{p_o}	pressure coefficient with zero mass flow
C_{p_s}	pressure coefficient of standard head
C_{p_M}	pressure coefficient of modified head
d	diameter of head
dp	static pressure drop across slots
dM	Mach number correction
H	stagnation pressure - inches of mercury
H_s	pitot pressure of standard head
M	indicated Mach mumber
M_o	true Mach number
m	mass flow through the static slots
m_c	choking mass flow through standard drain hole
p_s	indicated static pressure
p_o	free stream static pressure
$q = \frac{1}{2} \rho_o V_o^2$	dynamic pressure
t	width of slots
u	velocity normal to slots
V_o	free stream velocity
V	volume of static system
θ	flow direction
ρ	density
δC_p	error in C_p due to rate of descent

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APPENDIX 1

The possible Reynolds number Effect of the Drain Hole

Table 1 furnishes a check on the possible Reynolds number effect of the drain hole.

C_{p_s} is the C_p of the standard head obtained from Fig.5. C_{p_M} is the C_p of the modified head with zero mass flow obtained from Fig.6.

The difference between $C_{p_s} - C_{p_M}$ is the error produced by the standard drain hole. $^m/m_c$ is the dimensionless mass flow through the drain hole at a given Mach number, taken from the drain hole calibration curve. $\frac{d\ C_p}{d\ ^m/m_c}$ is the appropriate slope taken from Figs. 10 and 11. This slope, when multiplied by the mass flow, should give the error produced by the drain hole

i.e.
$$C_p - C_{p_o} = \frac{d\ C_p}{d\ ^m/m_c}\left(^m/m_c - 0.15\right) .$$

The difference between the measured error and the calculated error is called $d\ C_p$ in Table 1.

It should be noted that the comparison made in Table 1 ignores possible static errors caused by differences in the external shape of the heads due to manufacturing tolerances. Tests in free flight on standard heads indicated that the difference in instrument error was likely to be ±0.002 in C_p at $M_o = 1.0$. Such a difference could alter the average value of $d\ C_p$ given in Table 1.

For a given mass flow the Reynolds number of the flow through the standard drain hole is twice that of the modified head. This increase in Reynolds number might be expected to increase the choking mass flow m_c and hence give a greater error in C_p for the standard head than for the modified head. Hence if there were no shape effects on the heads

$$C_{p_s} - C_{p_m} > C_p - C_{p_o}$$

∴ $d\ C_p > 0$ for both $H = 40 + 20$ inches of mercury.

The fact that $d\ C_p$ is negative for $H = 20$ inches of mercury suggests that a shape effect does exist. It may be eliminated by comparing $C_{p_s} - C_{p_m}$ for both stagnation pressures. If there is an increase in m_c due to the increase in Reynolds number

$(C_{p_s} - C_{p_m})\ H = 40$ should be greater than $(C_{p_s} - C_{p_m})\ H = 20$.

Table 1 shows that this condition is satisfied.

APPENDIX II

The Effect of Rate of Descent

In this appendix the order of magnitude of the static error caused by rate of descent at transonic speeds is calculated for a typical aircraft system.

The mass flow into a static chamber of volume V, due to the rate of change of density $\left(\frac{d\rho}{dt}\right)$ of the air enclosed, is,

$$m = V \frac{d\rho}{dt} .$$

At 26,000 ft (corresponding with the tunnel tests at 20" Hg stagnation pressure) the rate of change of atmospheric density for a rate of descent of 1000 ft/sec is

$$\frac{d\rho}{dt} = 3.65 \times 10^{-5} \text{ slugs/ft}^3\text{/sec.}$$

If this value of $\frac{d\rho}{dt}$ is used with an enclosed volume of 100 cubic inches the outflow from the static system is

$$m = -2.11 \times 10^{-6} \text{ slugs/sec.}$$

At 26,000 ft and a Mach number = 0.915 the stagnation pressure H = 18.3" Hg and from equation (1)

$$m_c = 3.74 \times 10^{-6} \text{ slugs/sec.}$$

The static error due to this mass flow is

$$\delta C_p = \left({}^m/m_c + 0.15\right) \frac{d}{d} \frac{C_p}{{}^m/m_c}$$

and from Fig.13 $\frac{d}{d} \frac{C_p}{{}^m/m_c}$ is 0.008 at $M_o = 0.915$

and 0.015 at $M_o = 1.125$. Hence at $M = 0.915$,

$$\delta C_p = \left(\frac{-2.11}{3.74} + 0.15\right)\left(0.008\right) = \underline{0.0033}$$

which corresponds to a height difference of 40 ft.

At 26,000 ft and a Mach number M = 1.125, H = 23.4" Hg so that $m_c = 4.81 \times 10^{-6}$ slugs/sec. The static error is then -0.0043 and the corresponding height difference is 90 ft.

It should be noted that this static error is a difference between the true static pressure and the static chamber pressure; it is not a difference between the true static and the instrument chamber pressure but it does give a qualitative value for the altitude error.

TABLE 1

Measured and Calculated Static Errors

H = 40 inches of mercury

M_o	C_{p_s} Fig.5	C_{p_M} No drain hole flow Fig.6	$C_{p_s} - C_{p_M}$ Standard drain hole	m/m_c	$\frac{d\ C_p}{d\ m/m_c}$	$C_p - C_{p_o}$ Enlarged drain hole	$d\ C_p$
0.95	0.018	0.009	0.009	0.86	0.0072	0.005	0.004
1.10	0.027	0.013	0.014	1.00	0.0136	0.012	0.002
1.15	0.029	0.012	0.017	1.00	0.016	0.014	0.003
1.18	0.032	0.014	0.018	1.00	0.0175	0.015	0.003

H = 20 inches of mercury

M_o	C_{p_s} Fig.5	C_{p_M} No drain hole flow Fig.6	$C_{p_s} - C_{p_M}$ Standard drain hole	m/m_c	$\frac{d\ C_p}{d\ m/m_c}$	$C_p - C_{p_o}$ Enlarged drain hole	$d\ C_p$
0.95	0.011	0.009	0.002	0.86	0.0072	0.005	-0.003
1.10	0.017	0.007	0.010	1.00	0.0125	0.011	-0.001
1.15	0.014	0.005	0.009	1.00	0.0152	0.013	-0.004
1.18	0.022	0.007	0.015	1.00	0.0162	0.014	0.001

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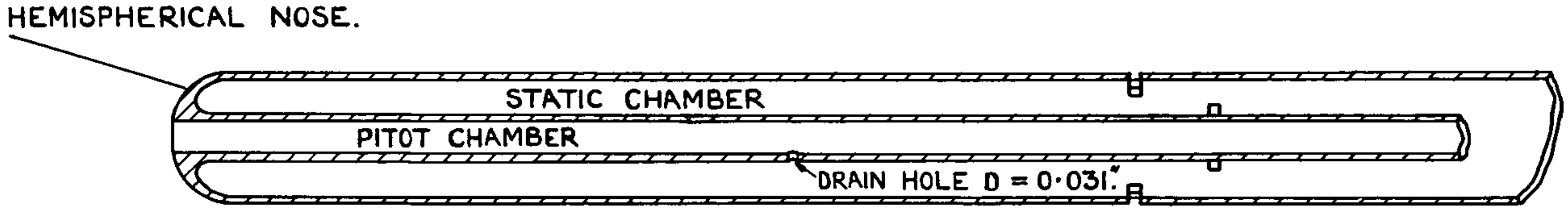
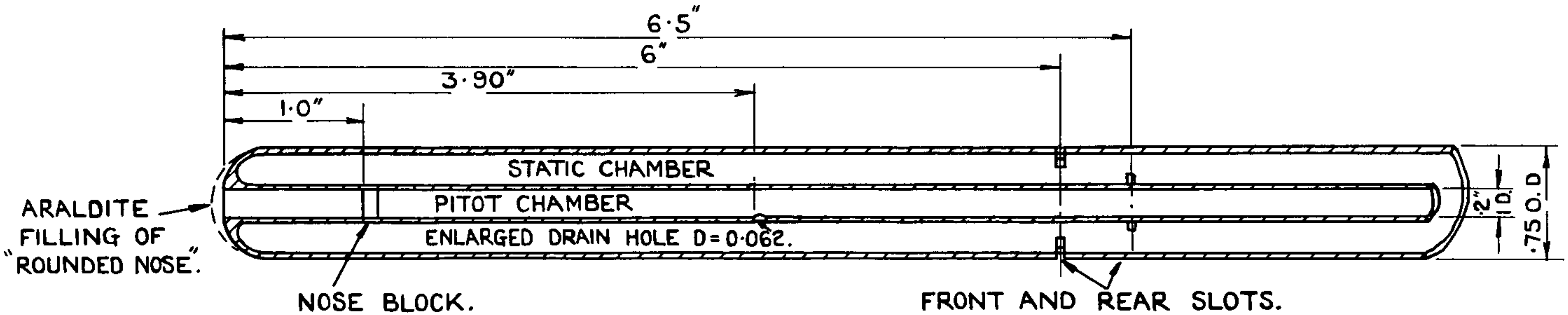
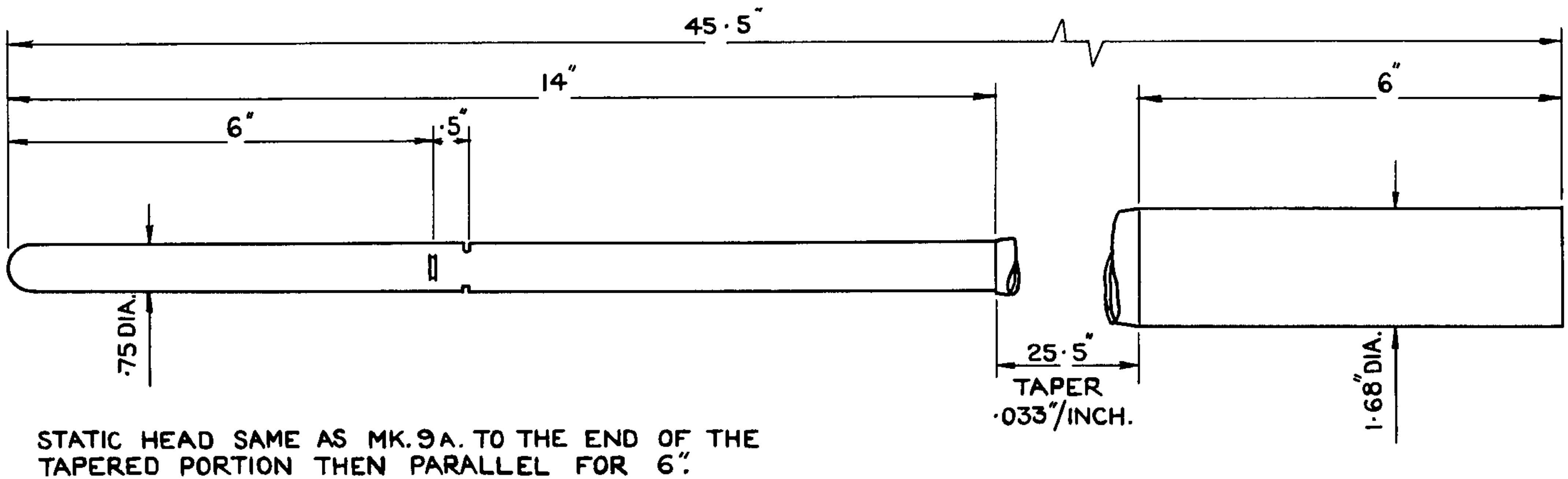


(a.) NOSE OF STANDARD MK.9A. PITOT STATIC HEAD.



(b.) NOSE OF MODIFIED MK.9A. PITOT STATIC HEAD.

FIG. 1. (a & b) HEADS TESTED.



SCALE :- 1/2

FIG.2. MOUNTING FOR MK. 9A. HEAD IN R.A.E. 3 FT. TUNNEL

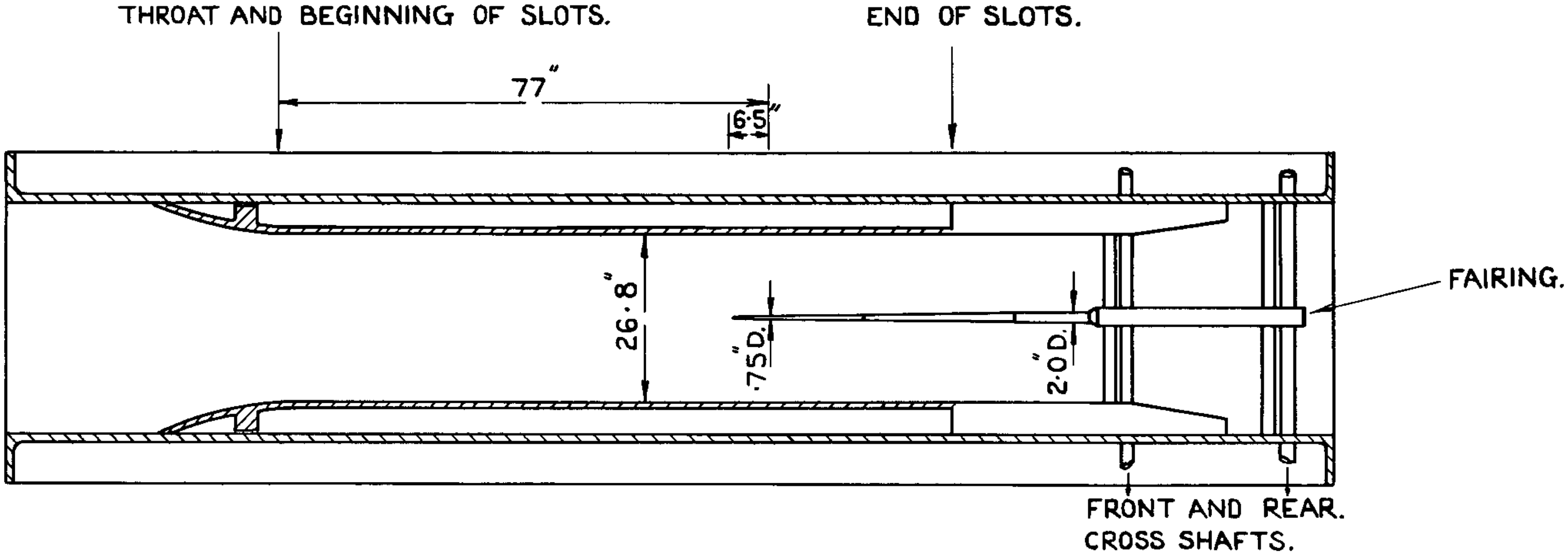


FIG. 3. GENERAL ARRANGEMENT OF MK. 9A. PITOT-STATIC HEAD IN R.A.E. 3 FT. TUNNEL.

SCALE :- 1/24 PLAN VIEW.

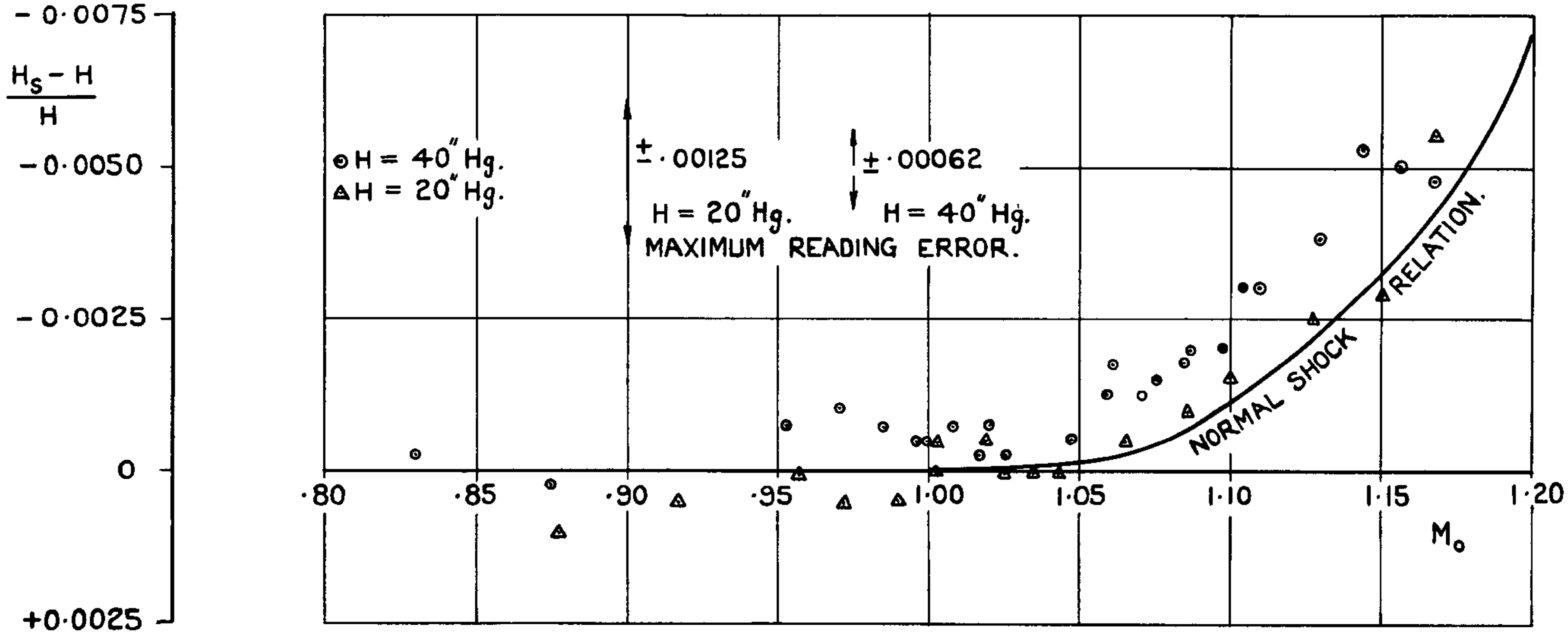


FIG. 4. PITOT PRESSURE ERROR OF STANDARD MK.9A. PITOT STATIC HEAD.

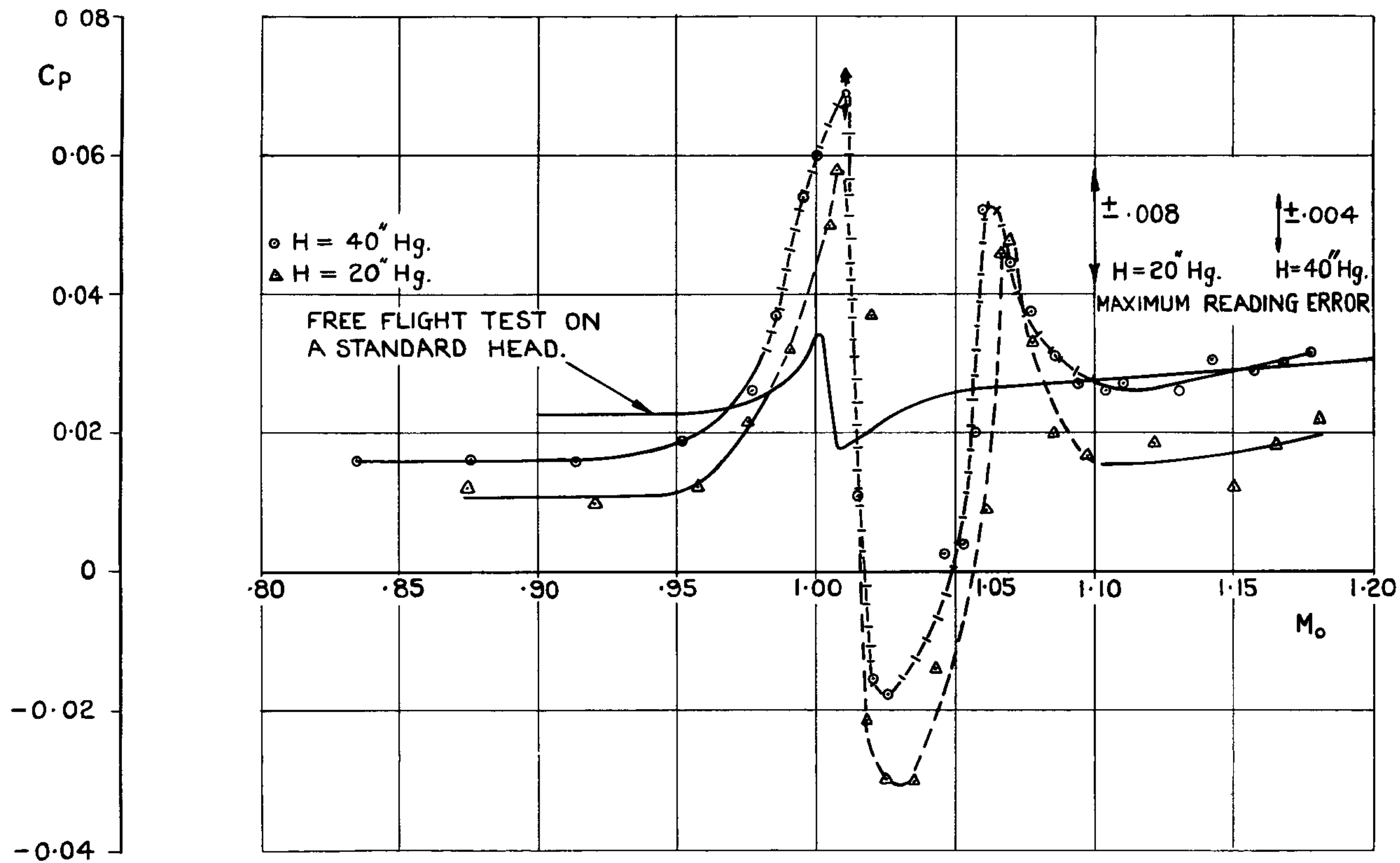


FIG. 5. STATIC PRESSURE ERROR OF STANDARD MK.9A. PITOT STATIC HEAD.

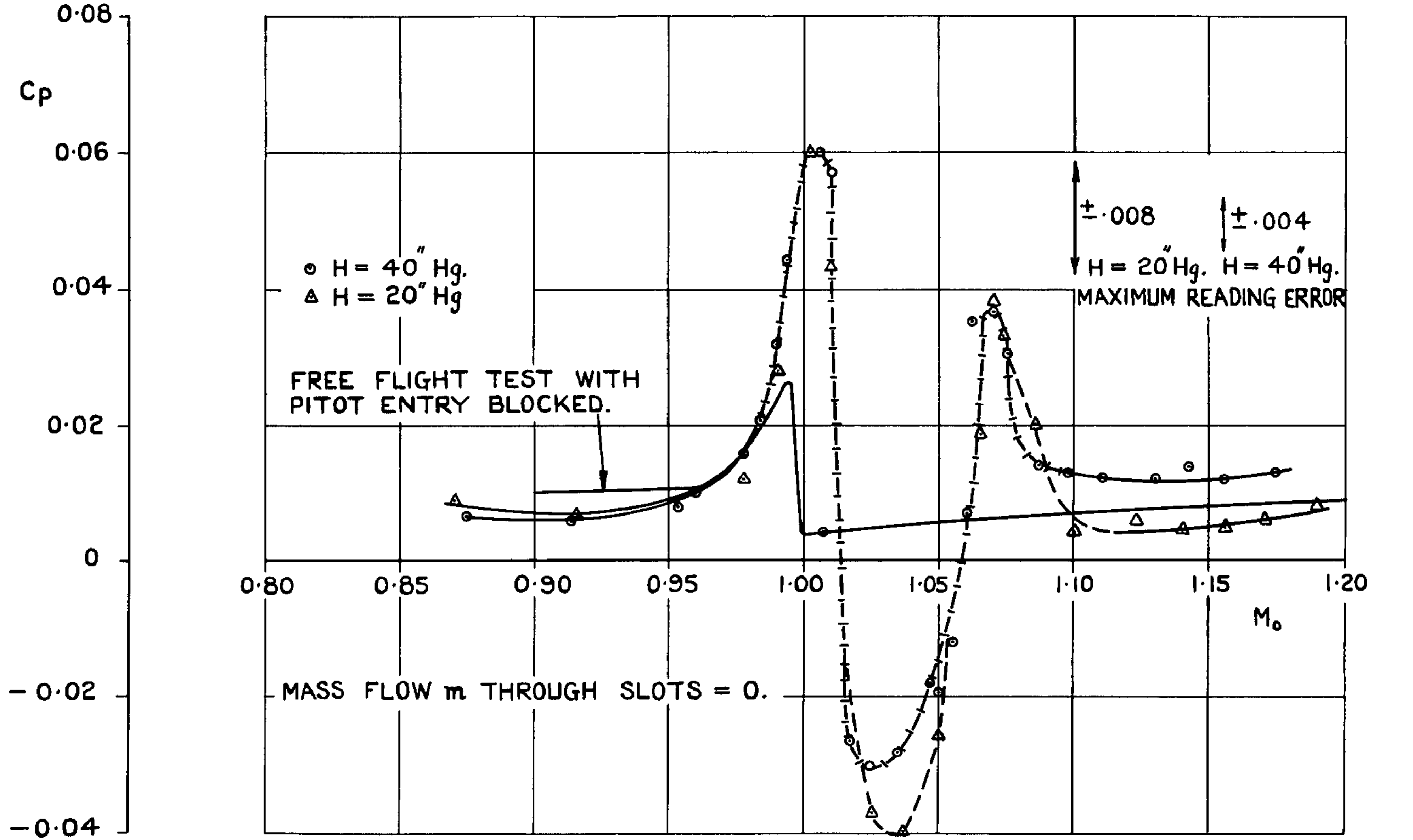


FIG.6. STATIC PRESSURE ERROR OF MODIFIED MK.9A. PITOT STATIC HEAD.

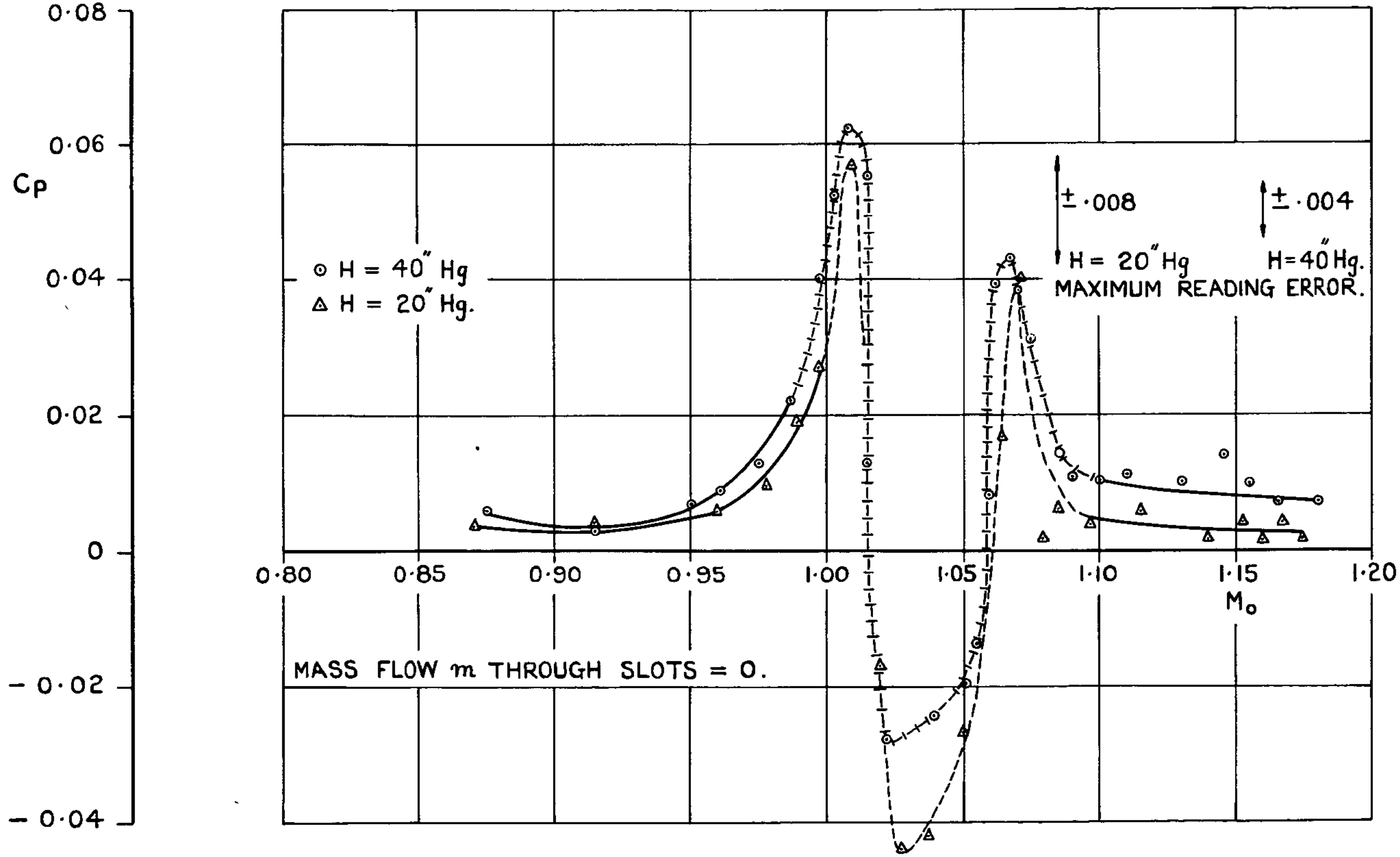


FIG.7. STATIC PRESSURE ERROR OF MODIFIED HEAD WITH ROUNDED NOSE.

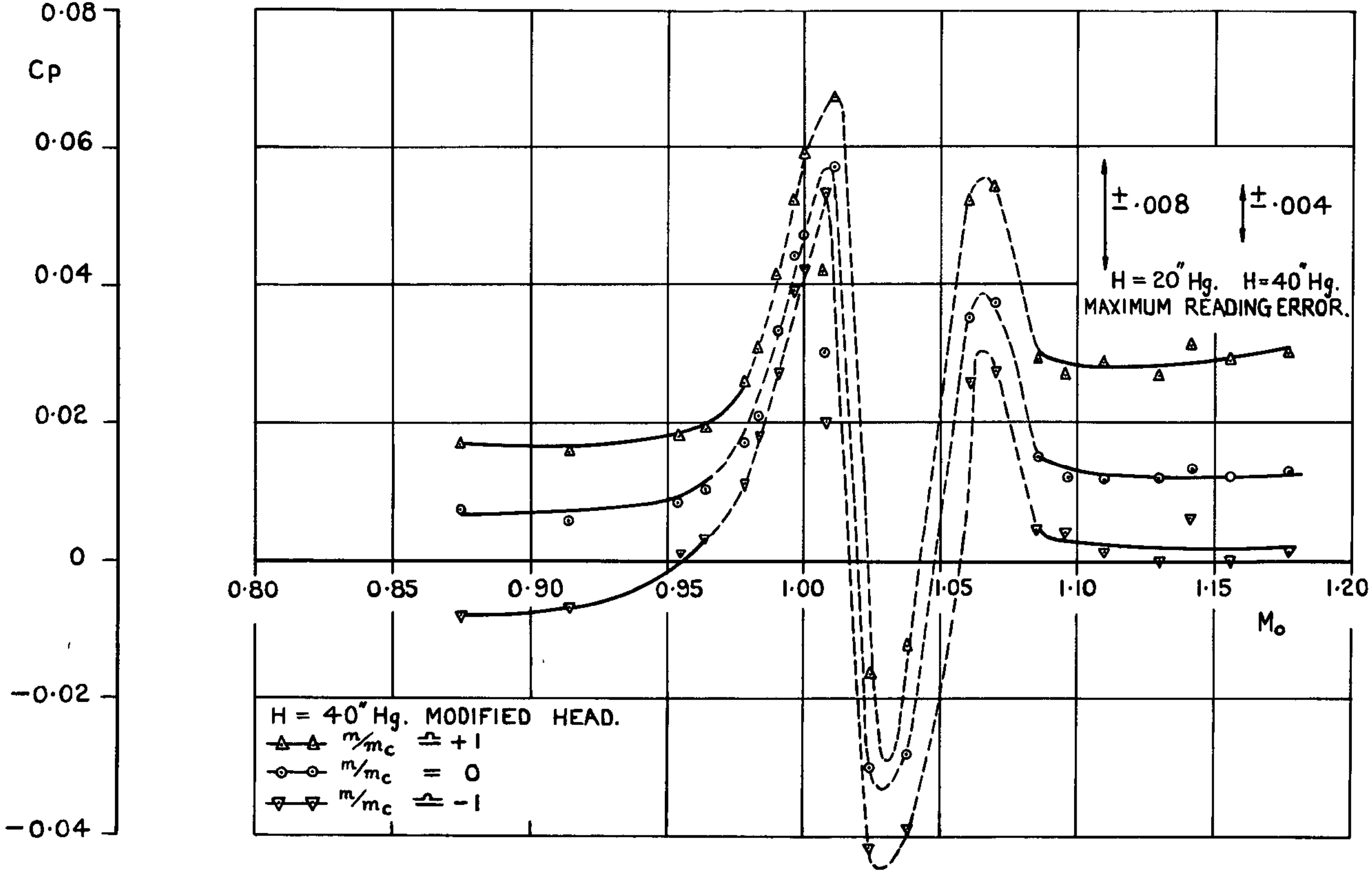


FIG. 8. EFFECT OF DISCHARGE AND INFLOW ON THE STATIC PRESSURE.

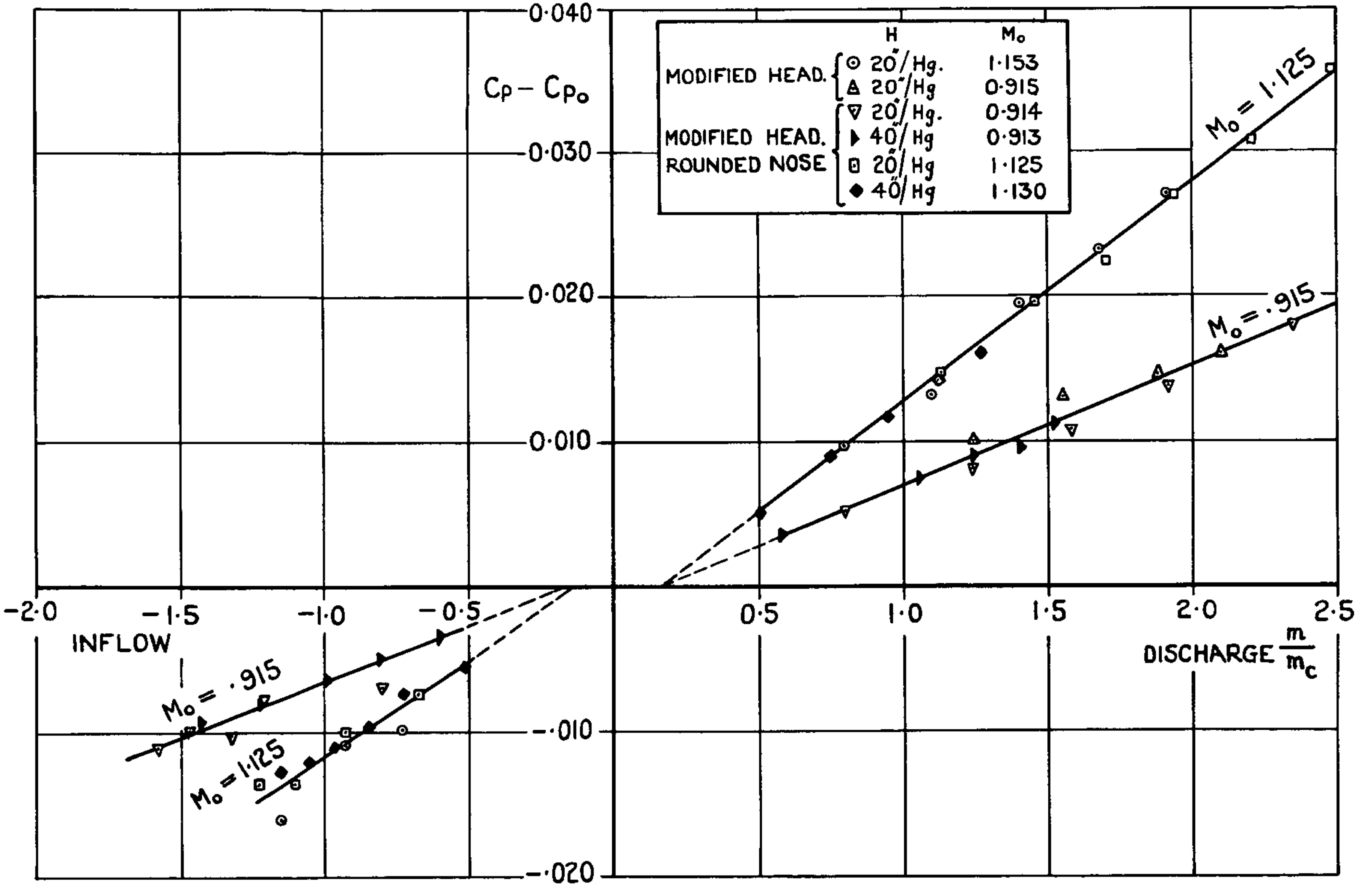


FIG. 9. EFFECT OF VARYING MASS FLOW.

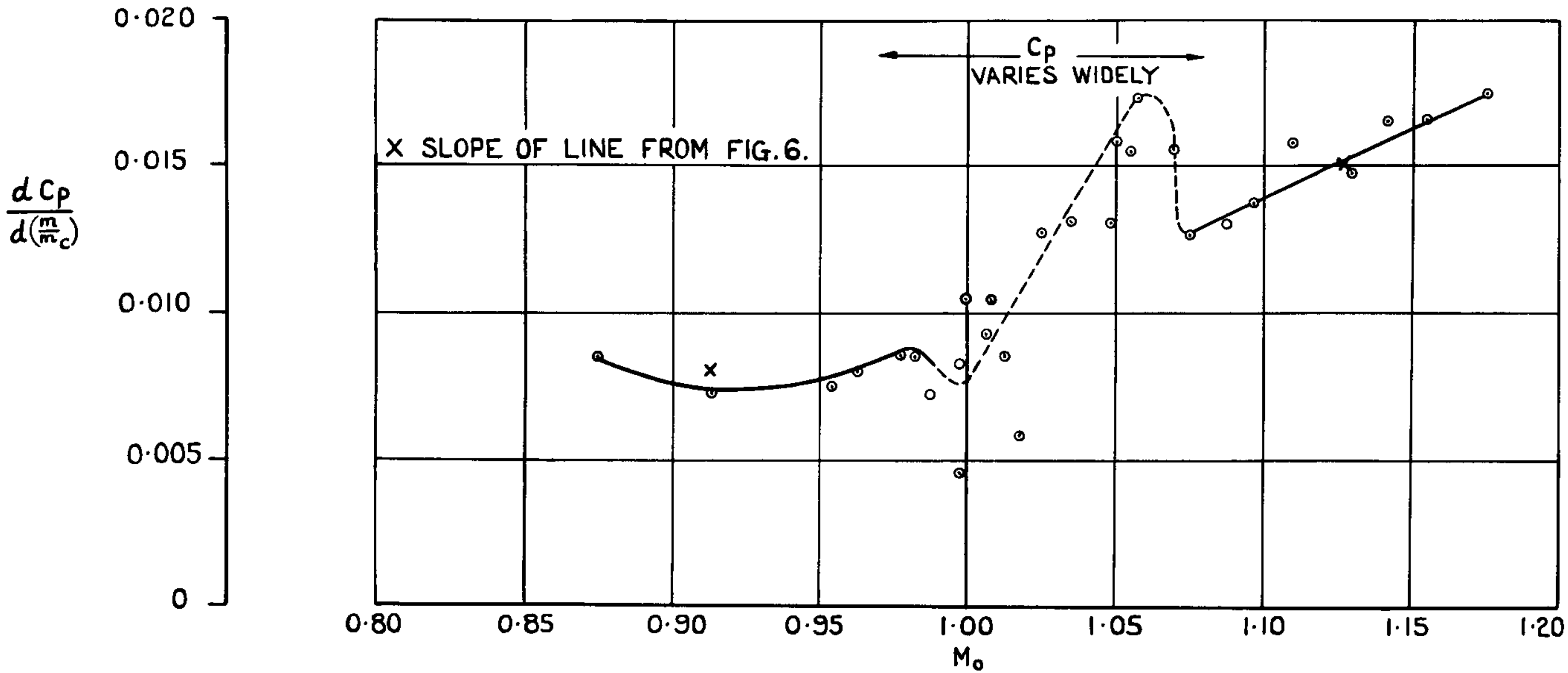


FIG. 10. MODIFIED HEAD H = 40" Hg. SLOPE OF C_p AGAINST DISCHARGE.

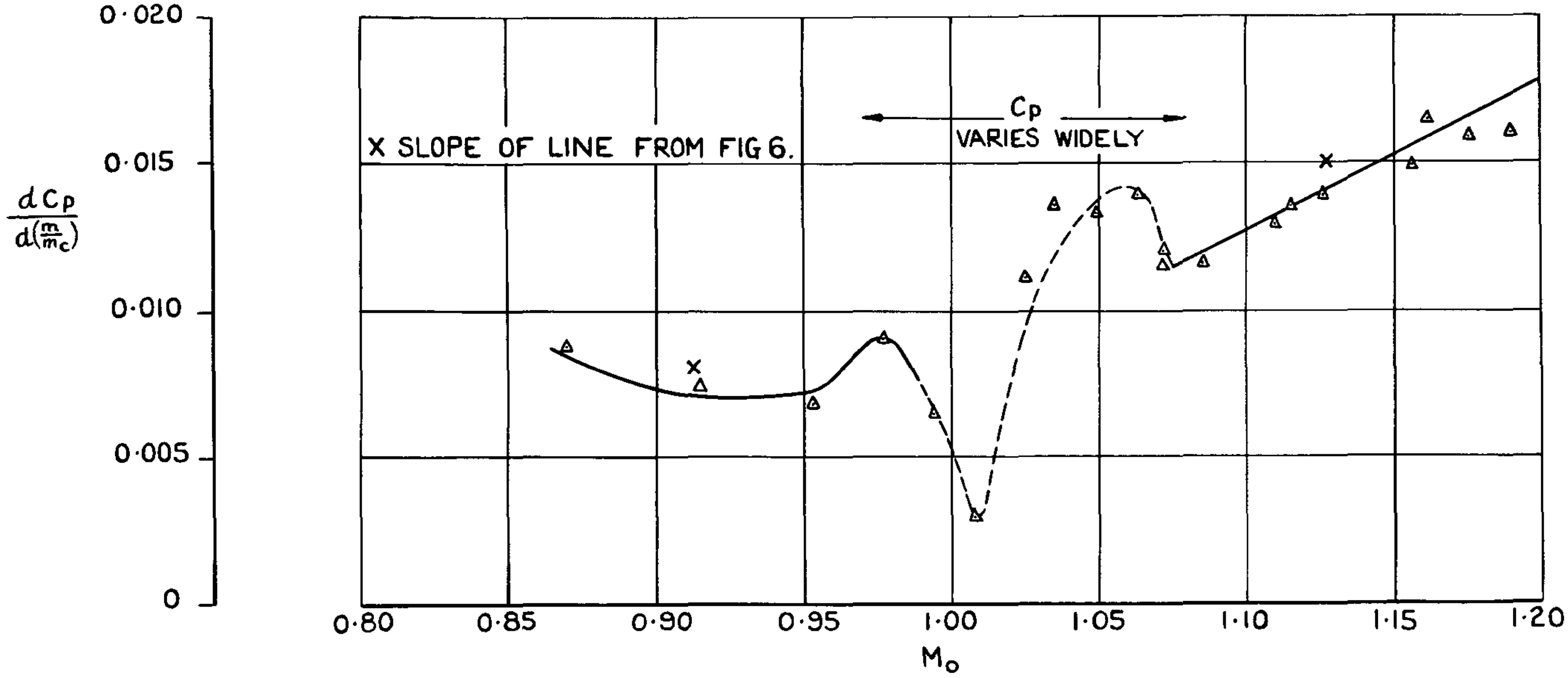


FIG. 11. MODIFIED HEAD $H = 20''$ Hg. SLOPE OF C_p AGAINST DISCHARGE.

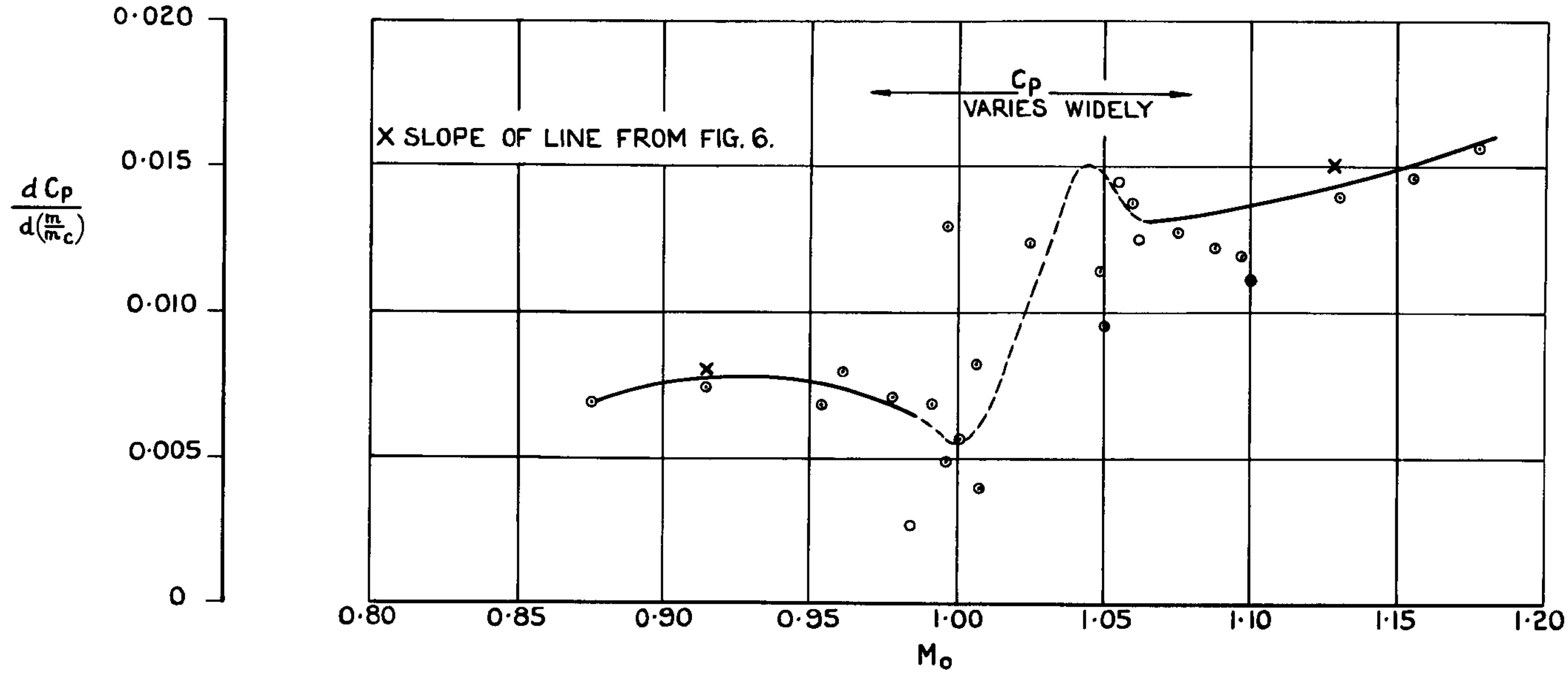


FIG. 12. MODIFIED HEAD H = 40" Hg. SLOPE OF C_p AGAINST INFLOW.

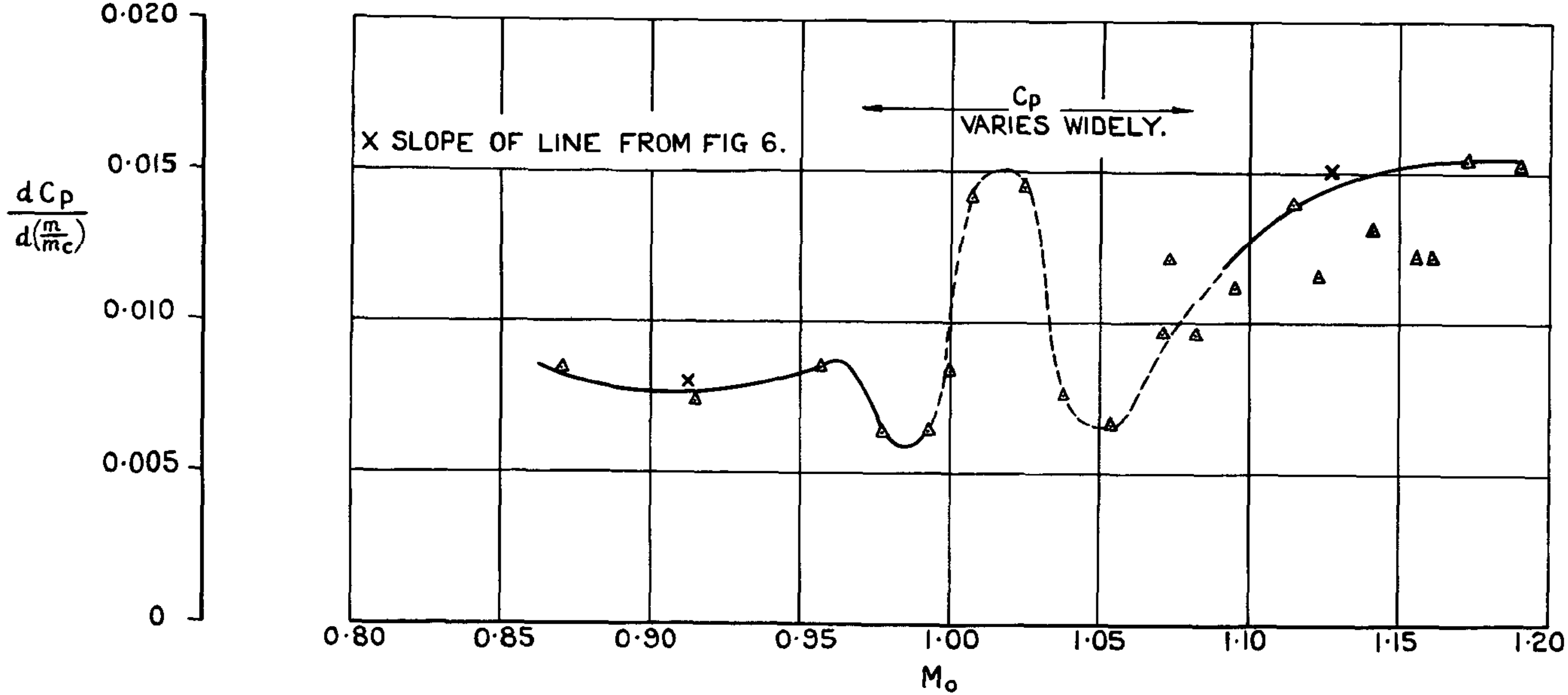


FIG. 13. MODIFIED HEAD H = 20" Hg. SLOPE OF Cp AGAINST INFLOW.

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