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CURRENT PAPERS

Free-Flight Experiments on the Measurement of Free-Stream Static Pressure at Transonic Speeds with Particular Reference to the Mk.9 Pitot-Static Head

by

C. Kell

LONDON: HER MAJESTY'S STATIONERY OFFICE

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ADDENDA

1 Insert at end of para. 3.0 on page 4 the following paragraphs:-

Based on the known accuracy of the transducers and telemetering equipment and on the experience gained from tests on a wide variety of free-flight models an uncertainty of ±3% of the telemetering sub-carrier band width is considered to be representative for the present tests. An illustration of the corresponding uncertainty in pressure coefficient is given in each of the relevant figures. Although this uncertainty is appropriate for results obtained from different test vehicles the relative errors for measurements made by the same instrument at different times throughout the flight are expected to be much smaller.

Mach number was obtained from sources external to the test vehicle and for this an uncertainty of ±0.004 is considered representative.

2 Page 5, Section 3.2, first paragraph.

Insert full stop after the word 'forward' and delete the remaining words of this paragraph.

3 Page 5, Section 3.2, second paragraph.

Insert asterisk after the word 'identical' in order to indicate reference to footnote.

4 Insert footnote on page 5 as follows:

*Footnote:- When the normal shock is moving along the probe the pressure at a measuring hole behind the shock will be the sum of the pressure rise through the shock and the subsequent subsonic compression between the shock and the hole. Although the shock pressure rise for any hole is a maximum when the shock-wave is at the hole, the total measured pressure might be greater when the shock-wave is ahead, if the subsonic compression has more than offset the difference in shock strengths.

5 Page 6. End of first paragraph insert following sentence:

This reasoning does not apply to hole number one whose behaviour is discussed later in para. 6.3.

6 Page 10, Conclusions, second paragraph last line, insert the word 'about' so as to read:- corresponded to a C_p of about 0.01.

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FREE-FLIGHT EXPERIMENTS ON THE MEASUREMENT OF FREE-STREAM STATIC PRESSURE AT TRANSONIC SPEEDS WITH PARTICULAR REFERENCE TO THE MK 9 PITOT-STATIC HEAD

by

C. Kell

RAE Ref: Aero/Sup/CK

SUMMARY

This note deals with the problem of measuring ambient static pressure at Mach numbers between 0.8 and 1.4; it is in two parts, the first dealing with free-flight measurements of the pressures ahead of bodies of revolution with noses of various shapes. The results indicate the minimum distances ahead of blunt-nosed bodies at which the errors in static pressure measurements are small enough to be acceptable.

The second part of the note deals with errors introduced by the static-pressure measuring heads themselves; tests on the standard Mk 9 pitot-static head are described and the results from this and other types of head are presented.

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PART I THE PRESSURE FIELD AHEAD OF SOME AXI-SYMMETRIC BODIES

1 INTRODUCTION

The usual method of obtaining Mach number, airspeed and altitude in flight is to measure the pitot and ambient-static pressures and feed these into suitably calibrated pressure-sensing instruments. The measurement of pitot pressure usually presents no great difficulty because the value of this quantity is not greatly dependent upon the siting of the sensing head relative to the aircraft. On the other hand, the static pressure is very greatly dependent upon the relative positions of sensing head and aircraft and for supersonic aircraft particularly, it is difficult to find a position for the sensing head which will produce acceptably small errors throughout the Mach number range.

At transonic speeds the problem of static-pressure measurement is additionally complicated by the presence of shock waves moving rapidly over the aircraft and its sensing head giving rise to sudden variations in pressure which result in errors not only in the recorded velocity but in rate of change of velocity i.e. in sensitivity.

This note is concerned primarily with the measurement of static pressure in the transonic region. The first part describes some free-flight experiments to investigate the variation of static pressure ahead of bodies of revolution having different nose shapes. The second part is concerned with the influence of the geometry of the sensing head upon the static pressure errors, and includes results from measurements on the Mk 9 pitot-static head which is standard equipment on British high-speed aircraft

2 DESCRIPTION OF TEST-VEHICLES

Fig.1 shows three of the test vehicles used for the experiments and Fig.2 their dimensions. Each vehicle consisted of a plain cylindrical body 5 inches diameter and 100 inches long with four rectangular stabilising fins mounted at the rear end of the body; these fins had a chord and exposed semi-span of 6.5 inches.

At the front of the vehicle the appropriate nose shape was attached with the profile at the maximum diameter tangential to the cylindrical body at the junction. The nose of Test vehicle A was hemispherical, that of vehicle B was ellipsoidal with its semi-major axis equal to one body diameter and vehicle C had a tangent-ogival nose three body diameters long.

To the front of each vehicle a cylindrical probe with a hemispherical end was fitted; on A and B the probe was 0.375 inches diameter and 14 inches long. On vehicle C the length of the probe was increased to 36 inches and the diameter increased to 0.75 inches to maintain adequate stiffness. At a series of stations along the probes, pressure-measuring holes were drilled at right-angles to the surface and these were connected to separate tubes running along the inside of the probe. The method of manufacture of the probe was such that the pressure hole at each station was at a different circumferential position from the others so that the surface of the probe was uninterrupted forward of each hole. The position of the measuring holes relative to the nose is shown in Fig.2.

The internal pressure tubes were all kept the same length, in order to minimise discrepancies due to pressure lag, and fed separate pressure transducers carried within the body of the test vehicle. The pressure transducers were effectively differential-pressure gauges and the datum side of each instrument was connected to a common reference chamber which was sealed before flight at ground-level ambient pressure.

The information from the pressure transducers was fed to a 465 Mc/s telemetering transmitter located within the body of the test vehicle and this radiated a signal through a pair of spike aerials mounted on the body well aft of the nose.

The test vehicles which were launched from the ground, were boosted to a maximum Mach number between 1.3 and 1.4, by means of a 5 inch diameter L.A.P. solid-fuel rocket motor which formed the final 63 inches of the body. After the rocket had finished burning the vehicle was allowed to coast down through the Mach number range to about $M = 0.8$ before finally striking the ground. It was from this coasting part of the flight, when the effects of acceleration and vibration were at a minimum, that the telemetered results were taken.

Based on the maximum body diameter the Reynolds numbers for these tests varied from 2.4 millions at $M = 0.8$ to 4.1 millions at $M = 1.4$.

3 RESULTS

The methods of obtaining trajectory and velocity from kine-theodolites and radio-Doppler have been described elsewhere[1]; the ambient atmospheric conditions at altitude were obtained from meteorological observations made at the firing range at the time of the test.

3.1 Tests on a vehicle with a hemispherical nose

The telemetered results from the vehicle with a hemispherical nose are shown in Fig.3 as plots of pressure coefficient, C_p, against Mach number, for the appropriate measuring stations ahead of the nose. The curves for the front four points show the characteristic shape for this type of measurement, i.e. an increasing pressure coefficient, owing to compressibility effects, from $M = 0.8$ to about $M = 1.0$, followed by a sharp drop as the bow shock-wave passes the measuring point, with the value finally settling near to zero. The fact that this final value is not zero, as might be expected since it represents conditions ahead of the bow-shock, is in all probability a combination of experimental errors and interference due to the probe itself; this will be discussed in the second part of this note.

The position of the shock ahead of the nose will be determined by the Mach number and as we see in Fig.3, the Mach number of the sharp pressure drop varies according to the station at which the measurement is made.

The peaks of the pressure coefficient curves in Fig.3 become less sharply defined as the measuring station moves back along the probe and this may be caused by an increasing amount of diffusion of the pressure at the foot of the shock due to the progressive thickening of the boundary layer.

The most marked anomaly in the results shown in Fig.3 occurs in the pressure measurements from the two measuring points nearest to the nose of the body, and these results serve to illustrate one of the difficulties which may accompany attempts to measure free-stream static pressure by means of a probe. The behaviour of the pressure plot of these two rear-most points on the probe is much the same as for the other stations up to about $M = 1.0$; after this the shape of the curves no longer follows the earlier pattern. The pressure coefficient does fall away after reaching a peak but the fall is fairly gentle and for both these points it finally settles down at a positive value of $C_p \approx 0.34$. Seddon[2] has suggested that this is the value one would expect behind shock-separated flow and Mair[3] and other workers have shown that the effects we have measured are to be expected when a probe is mounted on a blunt-nosed body. As the bow shock approaches the body and the pressure increases so conditions finally occur where the flow separates from the nose probe and a conical dead-air region is formed in which the pressure is substantially constant at a given Mach number. It is clear from Fig.3 that such a condition is well established at $M = 1.3$ and the conical dead-air region extends for at least 0.8 body diameters ahead of the nose.

3.2 Tests on a vehicle with an ellipsoidal nose

Turning now to Fig.4 we see that the results for the test vehicle with the ellipsoidal nose (vehicle B) are generally of the same form as those for vehicle A but the pressures are lower at all stations ahead of the nose. It is evident from this figure that a dead-air region has again formed ahead of the nose but this time the affected region does not extend so far forward, a result which might be expected from the lower pressures which have been measured at each station.

In previous experiments on static-pressure measurement[4] attempts have been made to relate the peak pressure coefficient with the pressure behind a normal shock wave and although there is no a priori reason why these two pressures should be identical it is instructive to compare them. (Fig.3 and 4). The peak pressures recorded on vehicle A (Fig.3) are consistently higher than the normal-shock values although for vehicle B - allowing for the difficulty in defining peak pressure - there is better agreement (Fig.4).

In Ref. 4 the results of static pressure measurements ahead of sharp nosed bodies gave similar results to those recorded for vehicle A, i.e. the pressure rise was greater than normal shock theory predicted or alternatively the Mach number at which the pressure rise occurred could be considered to be some 0.02 in Mach number lower than would have been predicted.

3.3 Tests on a vehicle with a tangent-ogival nose

The results from vehicle C, which had a tangent-ogive nose, are presented in Fig.5. The pressure coefficients for this vehicle were expected to be substantially lower than for the other two vehicles and this, together with the introduction of new instruments, allowed a lower range pressure transducer (±1 p.s.i.) to be used instead of the ±6 p.s.i. instrument used on the earlier vehicles. Since the general level of accuracy of the telemetering equipment is fixed by the frequency band-width available and since the instrument range is tied to this band-width, the accuracy in terms of pressure for the smaller range of instrument was correspondingly increased. Thus the increased scale of Fig.5 compared with the earlier figures is justified by the improvement in accuracy.

As was expected, the recorded pressures are lower than for the earlier vehicles and there is now no evidence of any separation leading to a dead-air region near the nose of the body. The results from the points near the nose of the body follow the same pattern as before but working forward along the probe we see that by the time we reach a point some three body diameters ahead of the nose the pressure increment producing the peak has settled down to a more or less constant value, except for the most forward point where the pressure pattern again changes considerably. This difference in the shape of the pressure curves near the front of the probe is probably due to the pressure field from the nose of the probe and similar results were obtained from a probe mounted much further ahead of the nose of the body where the influence of the body would be expected to be even further reduced. (See Part II and Fig.10).

It is clear from Fig.5 that the Mach number at which the peak occurs on the forward points of the probe is slightly less than unity and yet we should normally not expect any bow shock to exist at subsonic speeds. In Ref. 5 Prandtl deduced that for decelerating flight along a straight line a bow wave could be expected to exist some distance ahead of the nose of a body at Mach numbers slightly less than unity and in Ref. 6 Cope demonstrates the presence of such a shock wave on a decelerating projectile. The test vehicles on which the present measurements were made were decelerating at about 70 ft/sec^2 and it seems probable that in spite of the Mach number being less than unity the peaks themselves are nevertheless due to the presence of the bow shock.

Considering all the results from the three test vehicles it is clear that at subsonic and transonic speeds large errors in the measurement of free-stream static pressure must be expected if this measurement is made in the region immediately ahead of a body. How far ahead of the body it is necessary to go to reduce the errors to an acceptable level will largely depend on the shape of the nose and the dimensions of the body. It is also clear from the results for vehicle C that after moving forward a certain distance the errors will be reduced to values where the existence of the measuring probe itself will set the limit to any further reduction in measuring error. This is illustrated in Fig.6 where the maximum recorded value of C_p is plotted against the distance from the nose. For the ogival nose there is clearly little to be gained by placing the sensing holes more than two body diameters ahead of the nose and even for the ellipsoidal nose the $C_{p_{max}}$ is less than 0.1 at this distance. The question of what errors are acceptable is beyond the scope of this note but some unpublished work suggests that if $C_{p_{max}}$ is not greater than 0.1 the subsonic and supersonic errors will be acceptable and the loss of sensitivity in the indication of Mach number at high subsonic speeds will not exceed 50%*.

PART II STATIC-PRESSURE ERRORS OF MK 9 AND OTHER MEASURING HEADS

4 INTRODUCTION

In the earlier part of this note we saw that a careful choice of site for the location of the static-pressure measuring head in relation to the major components of the aircraft or missile was of the first importance if large errors were not to be introduced. We also saw that even when this site was well chosen and the pressure-sensing holes were well ahead of the body bow shock wave, there were still errors which we deduced were due to the probes themselves. To learn something about the errors introduced by the probes and to try to find some way of reducing these errors, free-flight tests were made on a number of test vehicles with probes having differing measuring heads, particular attention being given to the Mk 9 pitot-static head which is standard equipment on British high-speed aircraft.

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* Sensitivity here is defined as $\dfrac{dM_i}{dM} = \left(1 - \dfrac{d(\Delta M)}{dM}\right)$

where M is true Mach number

M_i is indicated Mach number

ΔM is correction due to C_p error.

5 DESCRIPTION OF TEST VEHICLES

The vehicles carrying the measuring heads to be tested were substantially the same as vehicle C described in Part I, i.e. they all had tangent-ogive noses three diameters long. Extending from the nose of each was a tapered support carrying at its end a parallel tube, and except for vehicle J, this parallel portion was terminated by a hemispherical front end. The tapered support extended some five body diameters ahead of the nose of the body and its dimensions corresponded to those of the tapered support which forms part of the standard Mk 9 pitot-static head. Dimensioned sketches of the heads discussed in this part of the note are shown in Fig.7.

Although the general arrangement of the support for vehicle J was the same as for the other models there were dimensional differences as Fig.7 shows. The body of revolution which was tested on this vehicle was 12.5 inches long with its base 7.5 inches forward of the junction of the tapered and parallel sections of the support. Unlike the other measuring heads which were manufactured from metallic materials this one was made from hard-wood with the surface smoothed and polished to wind-tunnel model standards and in this case the nose, instead of being hemispherical was in the form of a tangent-ogive 4.5 inches (3.6 diameters) long.

The experiments covered the range $M = 0.87$ to $M = 1.4$ (with the exception of vehicle J where the maximum was $M = 1.17$) and the maximum height of the trajectory of any vehicle did not exceed 1700 ft.

6 RESULTS

6.1 Tests on Mk 9 heads

Vehicle D, carrying a standard Mk 9 pitot-static head, was the first to be tested in this series. Ahead of the tapered portion, the head was 14 inches long and 0.75 inches diameter, with the hemispherical front end pierced along its axis by a 0.24 inches diameter hole. For these tests this hole, which normally picked up pitot pressure was sealed at the pipe connection inside the body of the test vehicle so that the inside of the pitot tube was maintained at pitot pressure with conditions at the open end unchanged from those normally applying in practice.

The static-pressure sensing slots were located at two stations 6 inches and 6.5 inches from the nose of the head and were arranged in two groups of three slots, each slot extending around 1/6th of the tube circumference. The six slots connected with an annular chamber which surrounded the central pitot tube and from this chamber the static-pressure was fed to a ±1 p.s.i. pressure transducer contained within the body of the model and incorporated in the telemetering system.

A plot of the measured pressure coefficient against free-stream Mach number is shown in Fig.8. From a fairly low subsonic value a sharp rise and fall occurs with the peak at a Mach number slightly below unity and this peak is followed by a progressive rise as the Mach number increases in the supersonic region. This progressively increasing error did not appear in the results from the earlier tests on vehicle C in Part I but there is a probable explanation which is related to the construction of the standard Mk 9 head. A 1/32 inch diameter hole connects the pitot tube with the static chamber on this head, allowing any excess water which may collect in the pitot tube to drain away through the static slots at the bottom of the assembly. It appears that with the rapidly increasing pitot pressure at supersonic speeds the effect of this drain hole is becoming too great to ignore.

In order to investigate quickly the effect of removing this drain hole without the delay of breaking down a standard head, a further free-flight test was made with a standard head but this time with the pitot tube blocked at the entry. In this way there could be no large air-flow between the pitot and static sides and the only external difference was that the end of the probe was now truly hemispherical instead of being pierced by the pitot entry.

The results from these tests are also shown in Fig.8 and it will be observed that the values of the pressure coefficient are lower throughout the whole range of Mach numbers and although there is still a rise in C_p as the supersonic Mach number increases, this rise is not so rapid and the rate of increase is less at the higher Mach numbers. At $M = 1.4$, the highest Mach number of the tests, the value of the pressure coefficient is only one quarter of the value recorded for the standard Mk 9 head.

These results from vehicle E were sufficiently encouraging for a further test to be made, this time on a head which was manufactured without a drain hole, vehicle F. This allowed the experiment to be done with the pitot entry unblocked and the external conditions exactly the same as they would be in service.

The pressure coefficients recorded for this test, see Fig.8, are somewhat surprising. Within the limits of experimental accuracy the sub-sonic and 'peak' pressures have returned to the values obtained on the standard head but the supersonic values instead of rising, now remain fairly constant. In other words the progressive supersonic rise has been eliminated but none of the earlier improvements has been repeated. This difference in the two results may be due to one of two things; either it is a reflection of the experimental errors or it is due to the alteration in the external flow when the pitot entry is blocked. A study of the results from other models covered by this note suggests that there is some evidence that smaller pressure errors <u>are</u> recorded when the end of the probe has no pitot entry, but these recorded differences approach the limit of experimental accuracy.

6.2 Tests on Mk 9 head with variations in static slot position

From the tests on vehicle F it was clear that even when the drain hole connecting pitot and static was sealed there was still a residual error at supersonic speeds despite the fact that, as we know from the earlier tests, the measurements were made at a position well ahead of the bow-shock. The most likely cause seemed to be due to effects from that part of the probe forward of the measuring slot, although there might have been some influence due to the proximity of the junction with the tapered support. To get some idea of just how significant the position of the slots was in relation to the front end of the head and to the junction with the support, two further tests were made.

In the first of these tests (vehicle G) the length of the parallel portion of the probe was increased to 15 inches and the mean distance of the slots from the front end reduced to 6.0 inches. Thus for this model the slots were 0.25 inches nearer to the front end but 1.25 inches further away from the support junction compared with the standard head.

On the second test (vehicle H), the length of the parallel portion was increased to 18.0 inches and the slots were cut at a mean distance of 9.0 inches from the front end. Compared with the standard head the slots had therefore moved back 3.0 inches but like vehicle G they were 1.25 inches further forward of the support junction. On both vehicles G and H there was no connecting drain hole between the pitot and static sides of the head.

The results from the tests on these two vehicles are presented in Fig.9 together with those from vehicle F which was the one fitted with the standard head but with the drain hole sealed. There were some small improvements with the extended heads, that with the measuring slots moved from 6 inches to 9 inches aft of the front end giving the better result. But these improvements were small and only just significant when related to the experimental accuracies. At a free-stream Mach number of 1.4 the best improvement (between vehicles F and H) would correspond to a reduction in the error of the pilot's Machmeter from 0.012M to 0.009M and considering the limitations of the present experiments one would hardly be justified in changing the design of the standard head to achieve this limited improvement.

6.3 Tests to measure the pressure along an extended static head

The results from vehicles G and H suggested that it might be worth investigating the way in which the pressure varied along a parallel probe to see whether there might be some measuring position superior to that already tested. For this purpose a much extended head was built and the pressures measured at eleven points along its length, (vehicle I Fig.7). The parallel head portion along which these measurements were made was 36 inches long and was mounted ahead of the body by means of a tapered support similar to that used for the Mk 9 heads. Unlike all but one of the earlier tests described in this part of the note there was no pitot entry and the front end was completely hemispherical; a dimensioned sketch of the probe is shown in Fig.7. The construction of the measuring head itself was similar to that described for vehicle C in Part I.

Equally spaced along the head were eleven holes, each hole being displaced 1/11th of the circumference relative to its neighbour. A series of pipes, all of which were kept the same length, connected the measuring holes with ±1 p.s.i. pressure transducers located inside the body of the test vehicle.

The results of the test on this model are shown in Fig.10 and like all the earlier tests where the measuring points were well ahead of the nose of the body the small peaks in the pressure curves occur at Mach numbers slightly less than one. There appears to be no significant trend to suggest that any one position is better than another and apart from random scatter the results, at M = 1.2 for example, suggest that the pressure coefficient is fairly constant along the full length of the head.

If we consider the results from the measuring point nearest to the nose of the head we see that the pattern and magnitude of the pressure discontinuity near M = 1 is substantially different from that measured at the other stations. This same effect was found on vehicle C in Part I where a similar probe was used; in that case however, the front hole in the head was only 33 inches ahead of the body nose compared with 58 inches for the present vehicle. This similarity in the pattern of the pressure curves coupled with the wide differences in distance ahead of the body nose suggests that the different pressure pattern at the most forward station is due to the proximity of the nose of the probe and not due to the bow-shock from the body.

6.4 Tests on a head with ogival nose

The tests so far reported suggest that having moved far enough ahead of the body to eliminate effects due to the body, there remain residual errors which can only be removed by modification to the probe itself. We have seen that although at all stations a small pressure peak occurs just below M = 1 the effects are more pronounced near the front end. All these results refer to probes with hemispherical heads but an earlier free-flight test, not designed specifically for the general investigation of static-pressure measuring heads, gave some results for the pressures behind an ogival nose. These results have been included in the present note.

The test was made on a small body of revolution of fineness ratio 10 having a diameter of 1.25 inches and an ogival nose 3.6 diameters long; this body was mounted ahead of the main body of the test vehicle in much the same way as were the static-pressure measuring heads already discussed. The general arrangement of this model and its mounting together with dimensions is shown in Fig.7, Model J. At the time of these tests it was necessary to use a pressure transducer having a range of ±3 p.s.i. and consequently the accuracy, in terms of absolute values of C_p, is correspondingly reduced when compared with the tests reported earlier in this part.

The model head was manufactured from wood with the surface highly polished; wrapped around the ogival nose at a station 1.75 inches from the nose was a nylon thread designed to fix transition and to ensure that the flow over the body was turbulent.

The results are plotted in Fig.11 which shows the pressure coefficient variation with Mach number at six positions along the body, the first position corresponding to a station 0.5 inches aft of the junction of the ogive and parallel section. These curves show the way in which the supersonic region which develops over the nose affects firstly the most forward point and then moves rapidly back as a free-stream Mach number of one is approached.

At Mach numbers greater than one, quite large negative pressure coefficients were recorded at the most forward stations but these changed progressively to small positive values as the measuring station moved back. We therefore deduce that there is some station between these points where at supersonic speeds the pressure coefficient is substantially zero. No attempt has been made to interpolate between the results from these stations to determine where the value of C_p is zero because the pressure differences recorded in this region were small enough to be approaching the limits of the accuracy to be expected from the experiment. Nevertheless, it does seem that the pressure changes its sign at a station somewhere between 7.5 inches and 10 inches aft of the nose.

The few pressure measurements made at stations behind that at which the pressure coefficient is assumed to change sign suggest that like the earlier tests on heads with a hemispherical nose, the pressure coefficient is settling down to a small positive value of the same order as recorded on the earlier tests.

7 CONCLUSIONS

Measurements of the pressure field ahead of bodies of revolution with various nose shapes suggest that for nose fineness ratios likely to be used on transonic or supersonic aircraft there is little to be gained by having static-pressure sensing holes more than two body diameters forward of the aircraft nose.

For positions further forward than two diameters the transonic and supersonic errors are dictated largely by the shape of the sensing head itself. At zero incidence with a hemispherical nose on the sensing head the minimum supersonic error achieved corresponded to a C_p of 0.01.

Any connection between the pitot or static circuits on a pitot-static head increases the static-pressure error at supersonic speeds. There is some evidence that the presence of the pitot-pressure entry may also increase the static-pressure errors.

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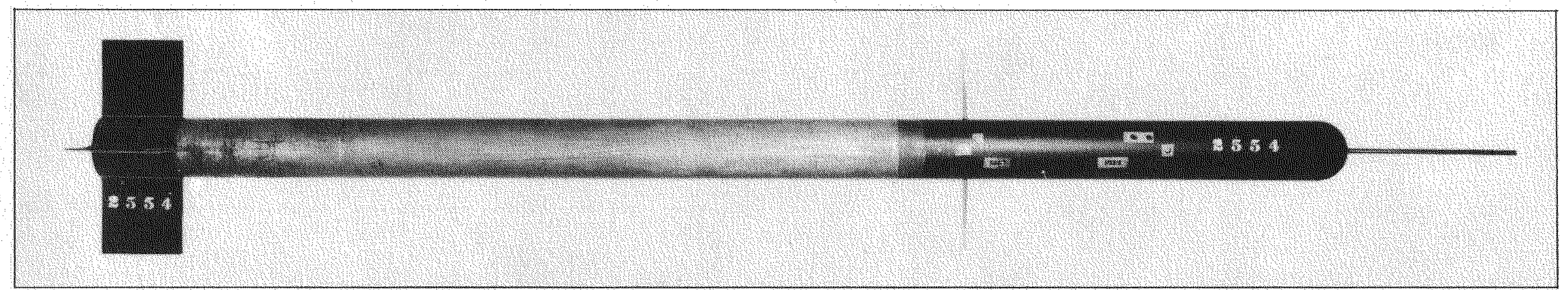
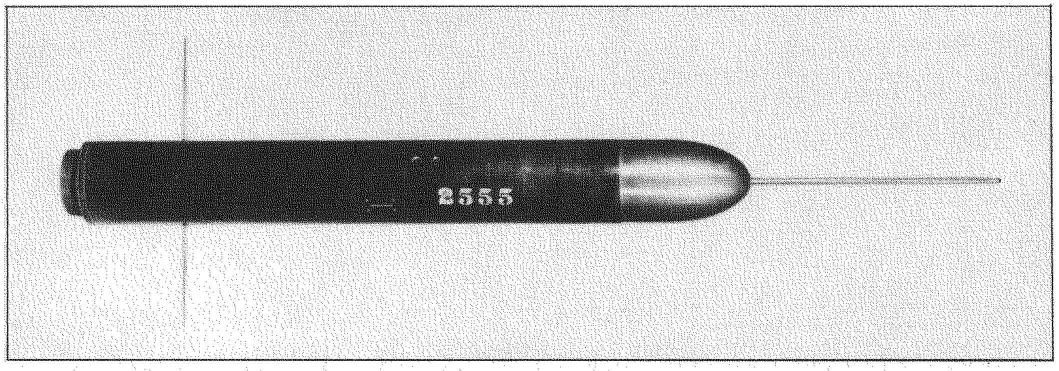
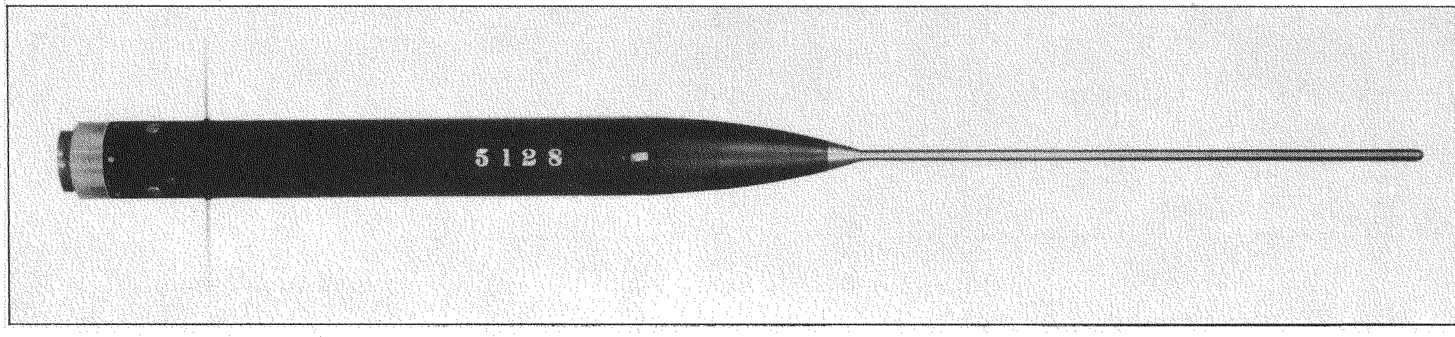


TEST VEHICLE FOR MEASUREMENT OF PRESSURES AHEAD OF HEMISPHERE



FRONT PORTION OF TEST VEHICLE FOR MEASUREMENT OF PRESSURES AHEAD OF ELLIPSOID



FRONT PORTION OF TEST VEHICLE FOR MEASUREMENT OF PRESSURES AHEAD OF OGIVE

FIG.1. GENERAL LAYOUT OF TEST VEHICLES USED FOR STATIC-PRESSURE MEASUREMENTS

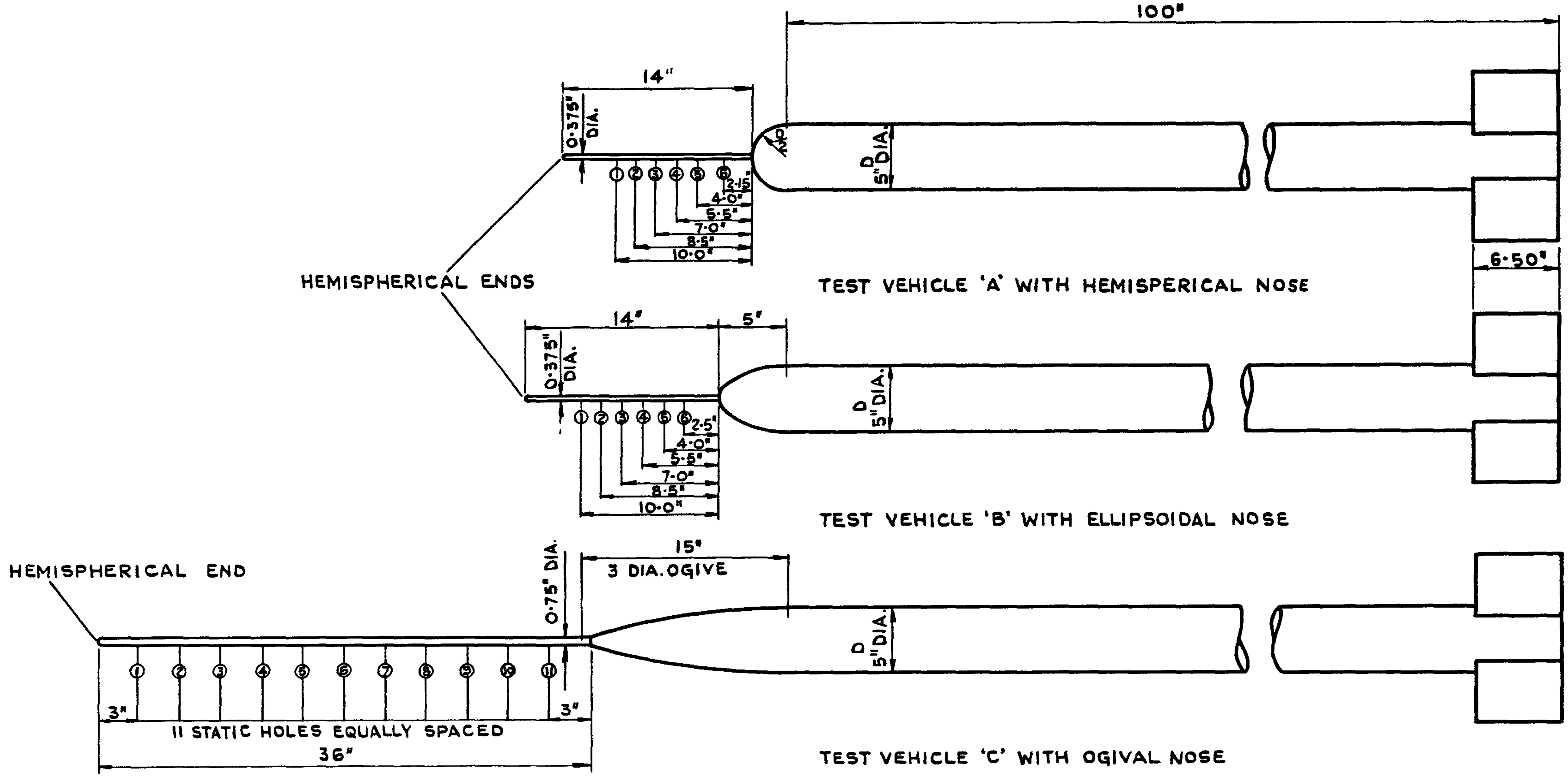


FIG.2. TEST VEHICLES FOR MEASUREMENT OF STATIC PRESSURE AHEAD OF VARIOUS NOSE SHAPES.

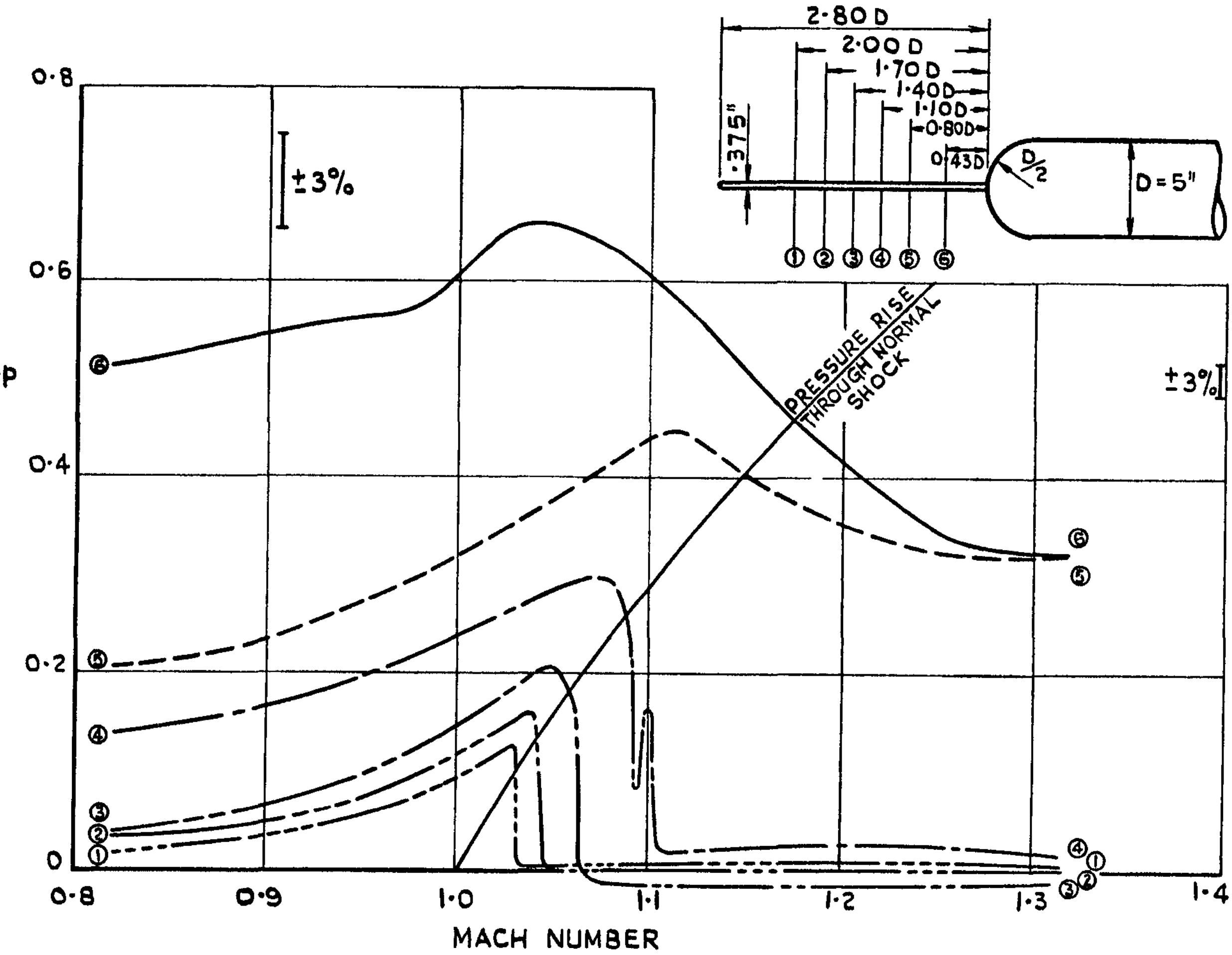


FIG.3. VARIATION OF PRESSURE COEFFICIENT ALONG PROBE AHEAD OF HEMISPHERICAL NOSE (TEST VEHICLE A).

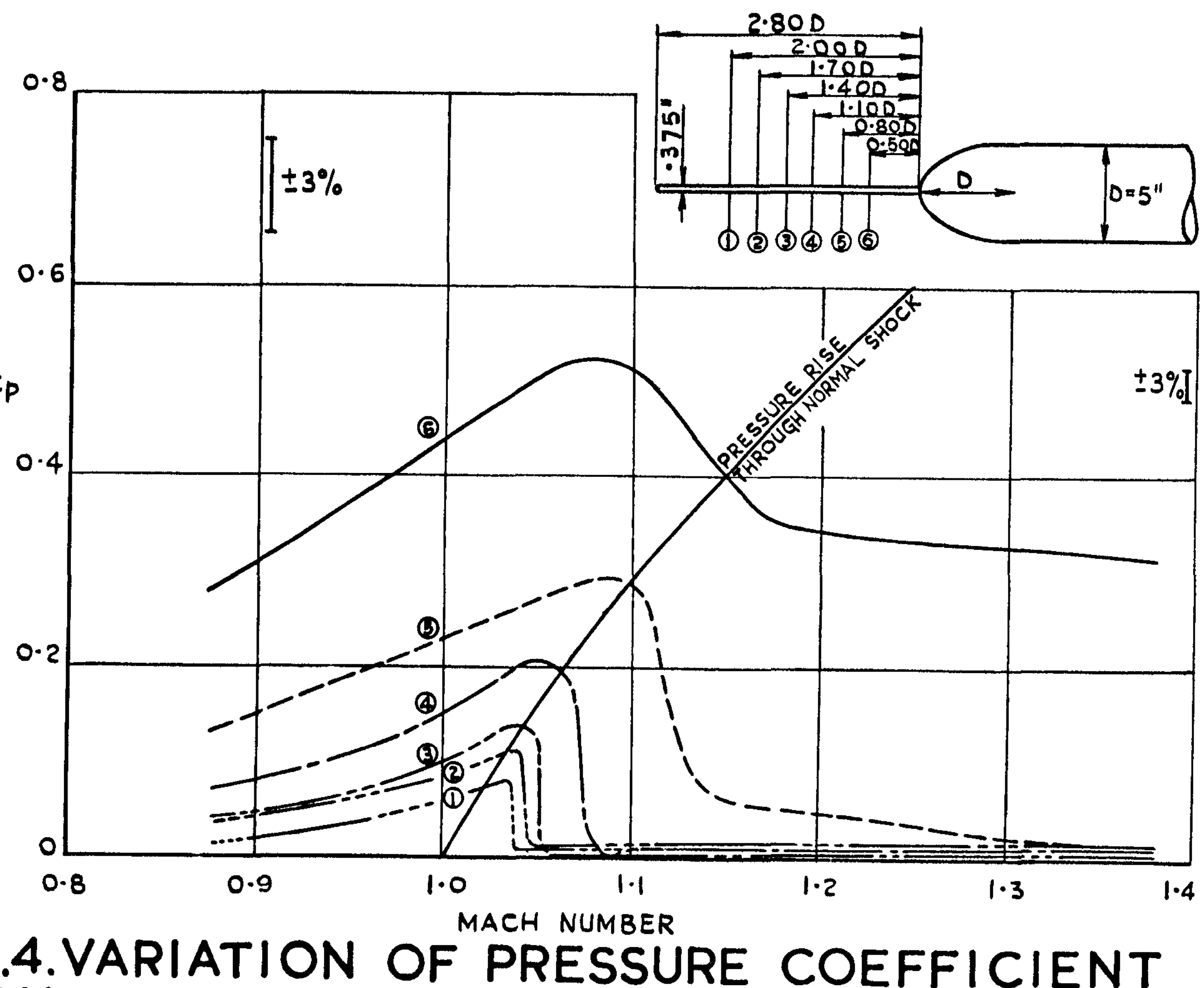


FIG.4. VARIATION OF PRESSURE COEFFICIENT ALONG PROBE AHEAD OF ELLIPSOIDAL NOSE (TEST VEHICLE B).

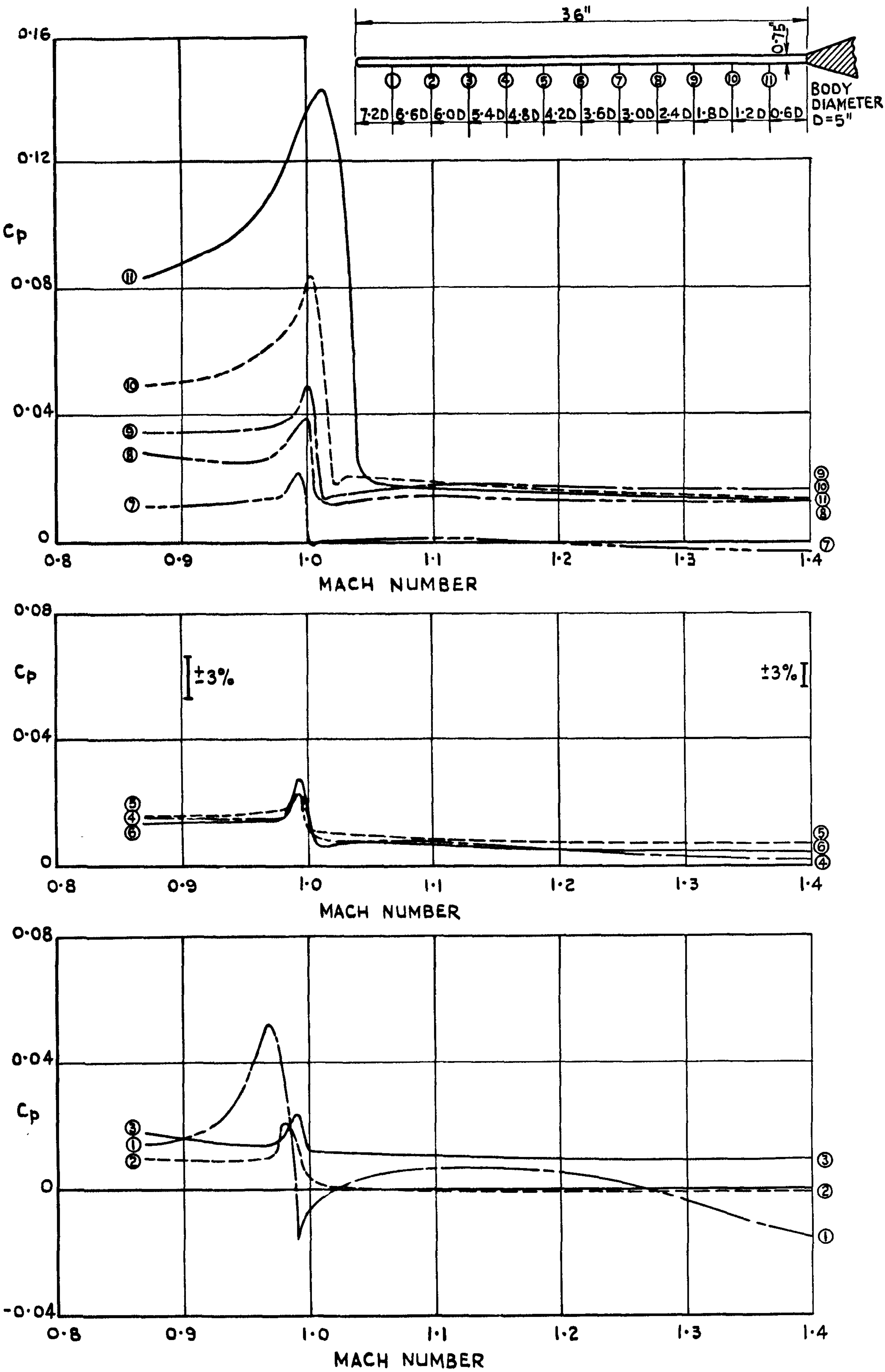


FIG.5. VARIATION OF PRESSURE COEFFICIENT ALONG PROBE AHEAD OF TANGENT-OGIVAL NOSE (TEST VEHICLE C).

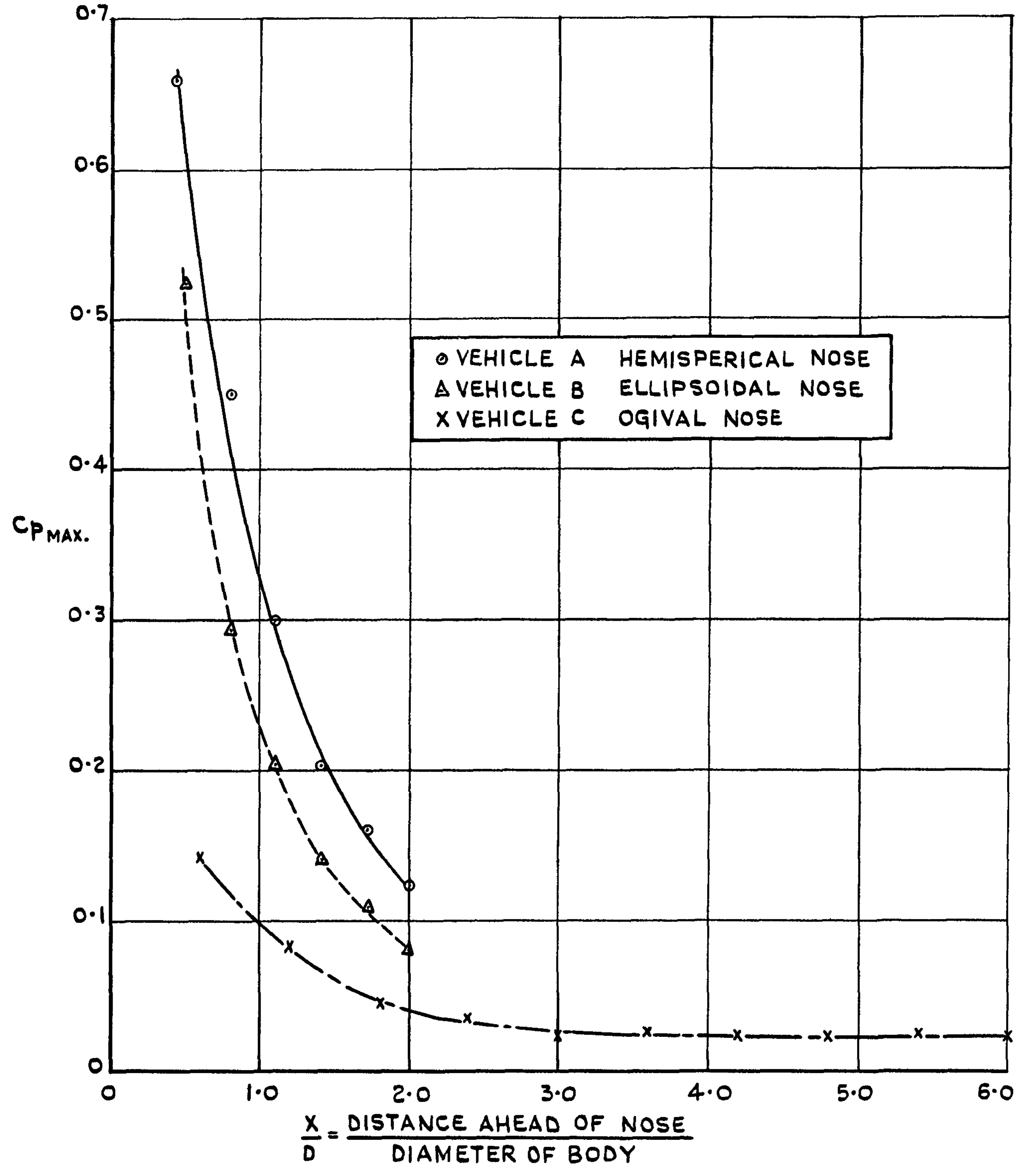
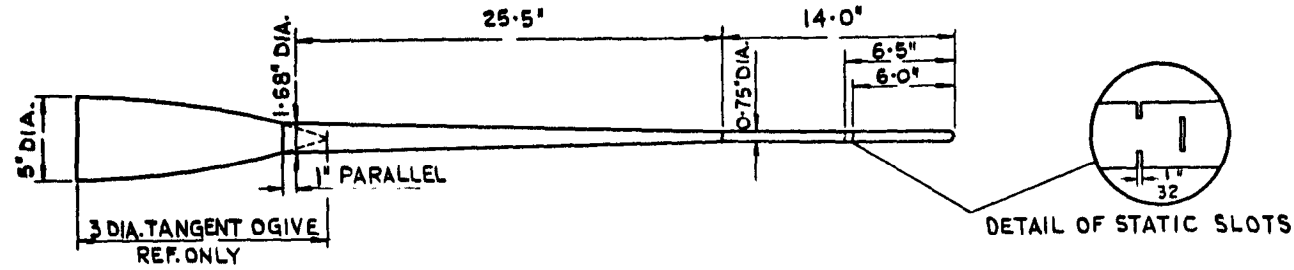
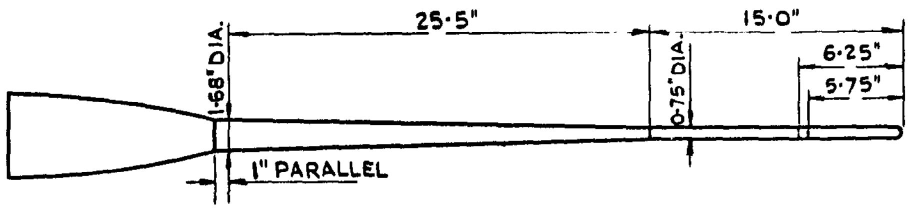


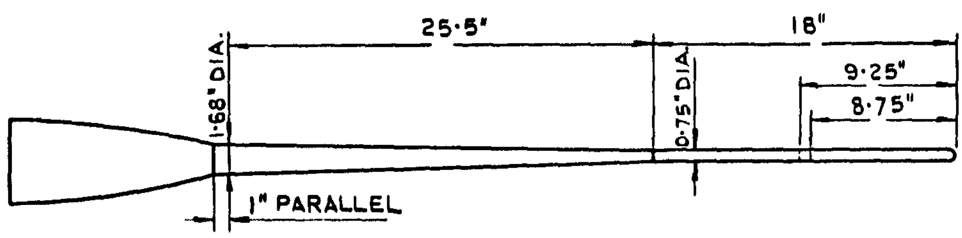
FIG.6. VARIATION OF PEAK PRESSURE COEFFICIENT WITH DISTANCE AHEAD OF NOSE.



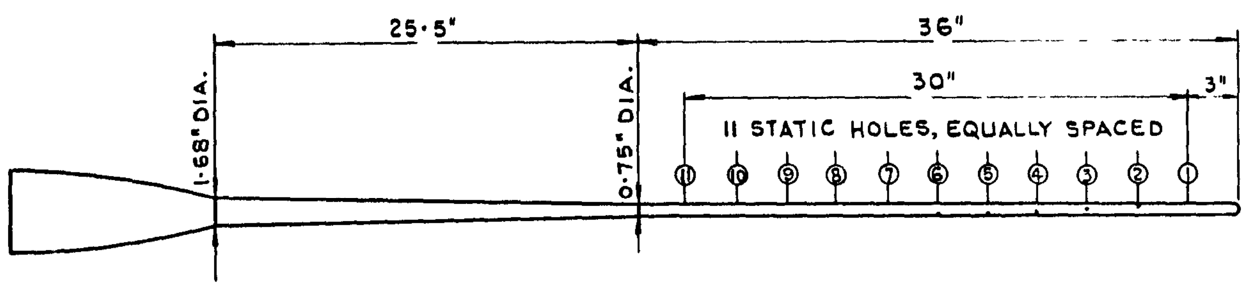
STANDARD MK.IX HEAD, TEST VEHICLES D, E & F



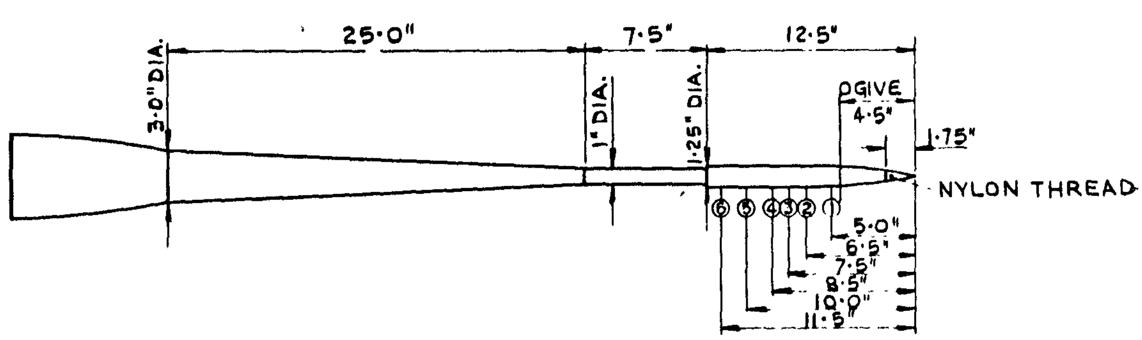
MODIFIED MK.IX HEAD, TEST VEHICLE G



MODIFIED MK.IX HEAD, TEST VEHICLE H



EXTENDED HEAD FOR MEASURING PRESSURE VARIATIONS ALONG PROBE, TEST VEHICLE I



HEAD USED FOR MEASURING PRESSURES BEHIND OGIVAL NOSE, TEST VEHICLE J

FIG.7. DIMENSIONS OF STATIC-PRESSURE MEASURING HEADS.

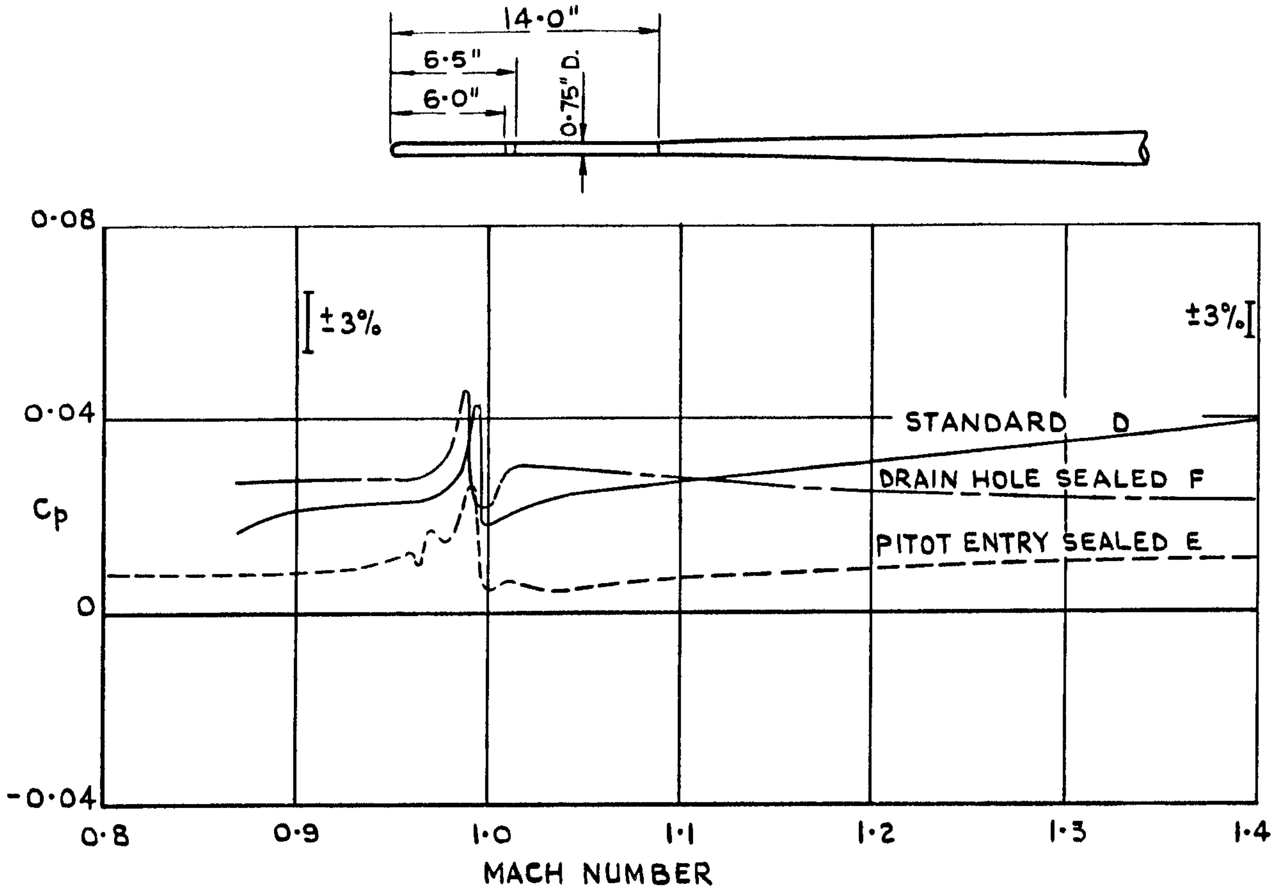
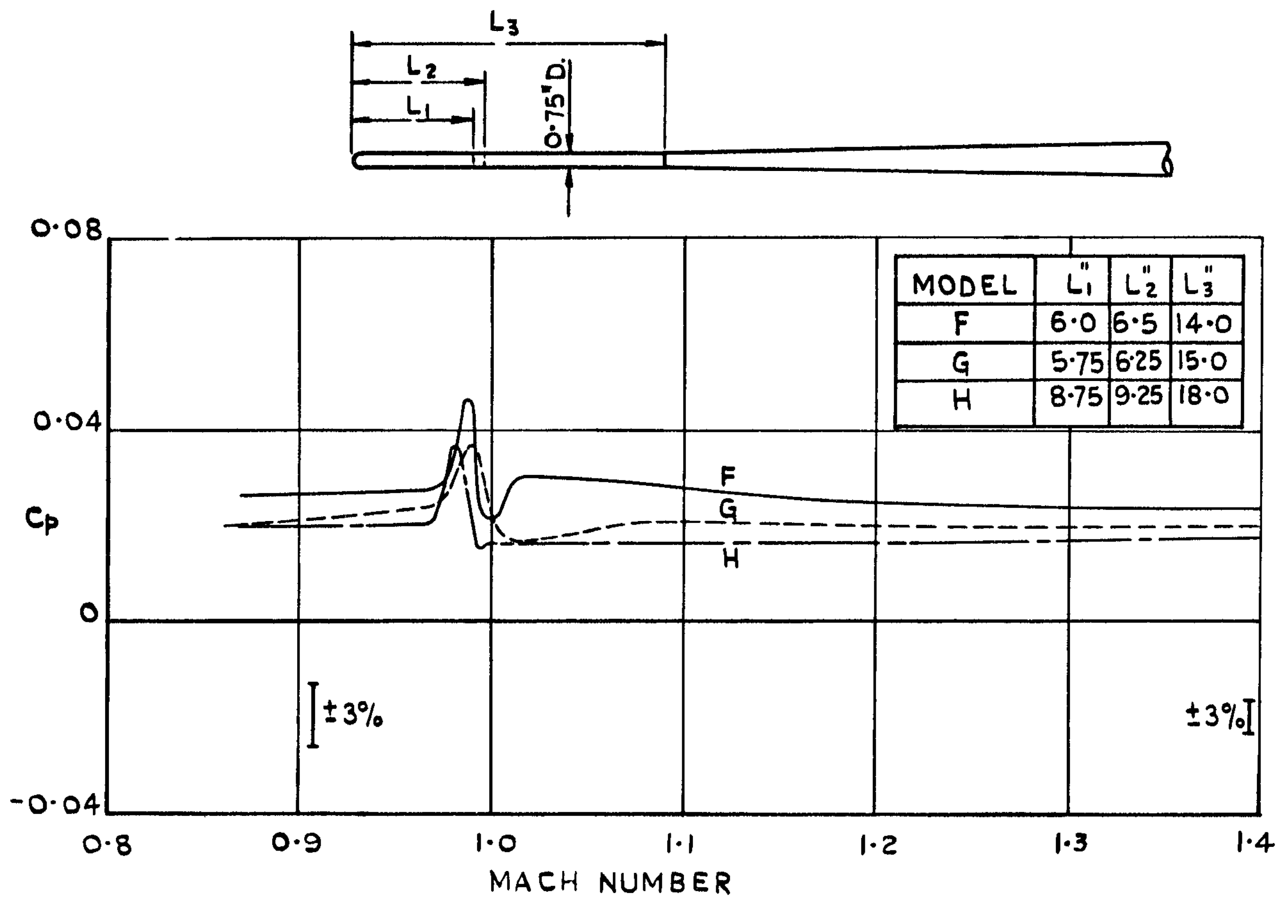


FIG.8. STATIC PRESSURE ERRORS OF MK-9 PRESSURE HEAD WITH & WITHOUT LEAK BETWEEN PITOT & STATIC SIDES.



MODEL	L1"	L2"	L3"
F	6·0	6·5	14·0
G	5·75	6·25	15·0
H	8·75	9·25	18·0

FIG.9. STATIC PRESSURE ERRORS OF MK-9 PRESSURE HEAD & THE EFFECT OF THE POSITION OF THE SENSING SLOTS.

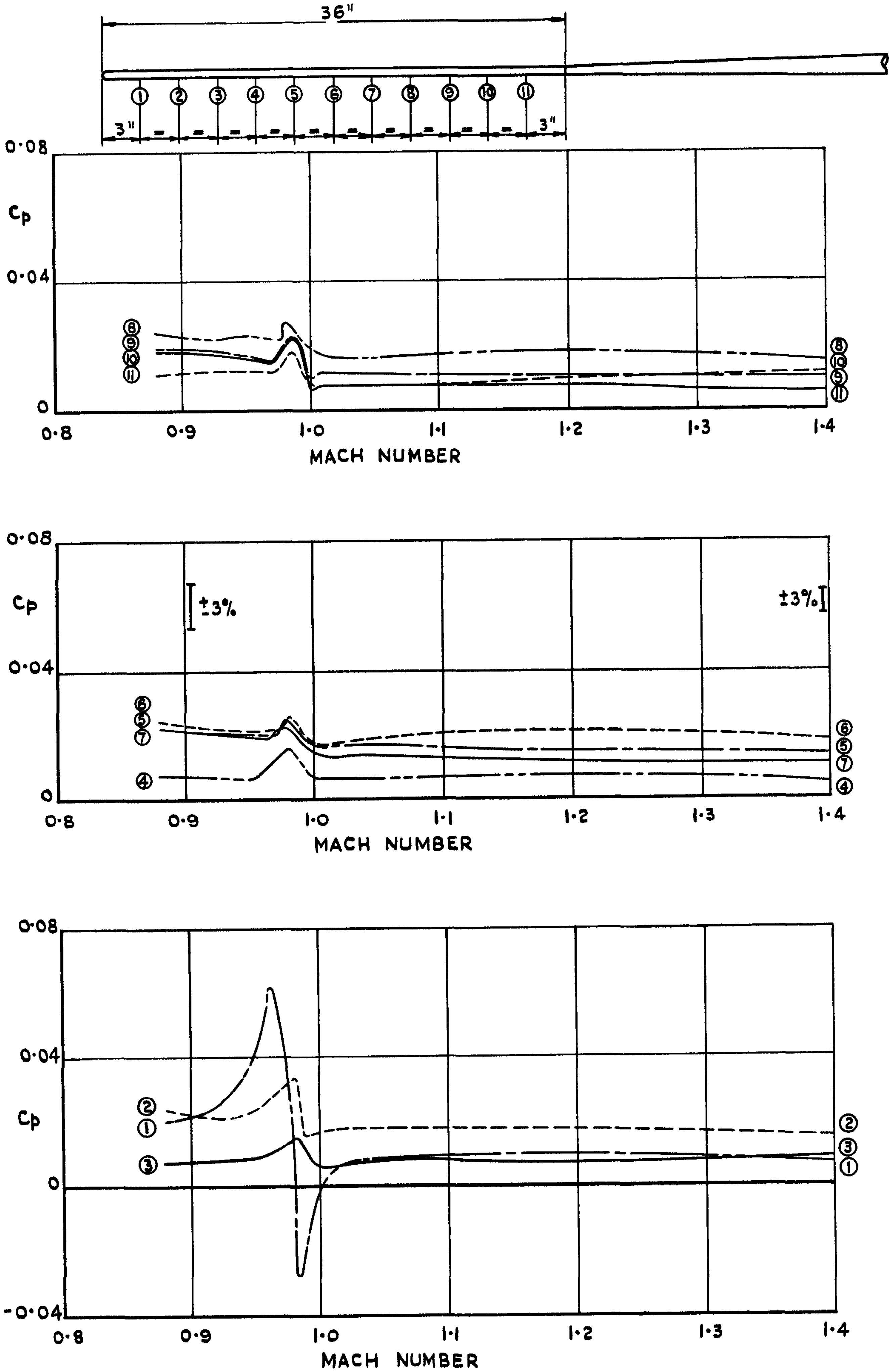


FIG.10. PRESSURE DISTRIBUTION ALONG AN EXTENDED STATIC HEAD.

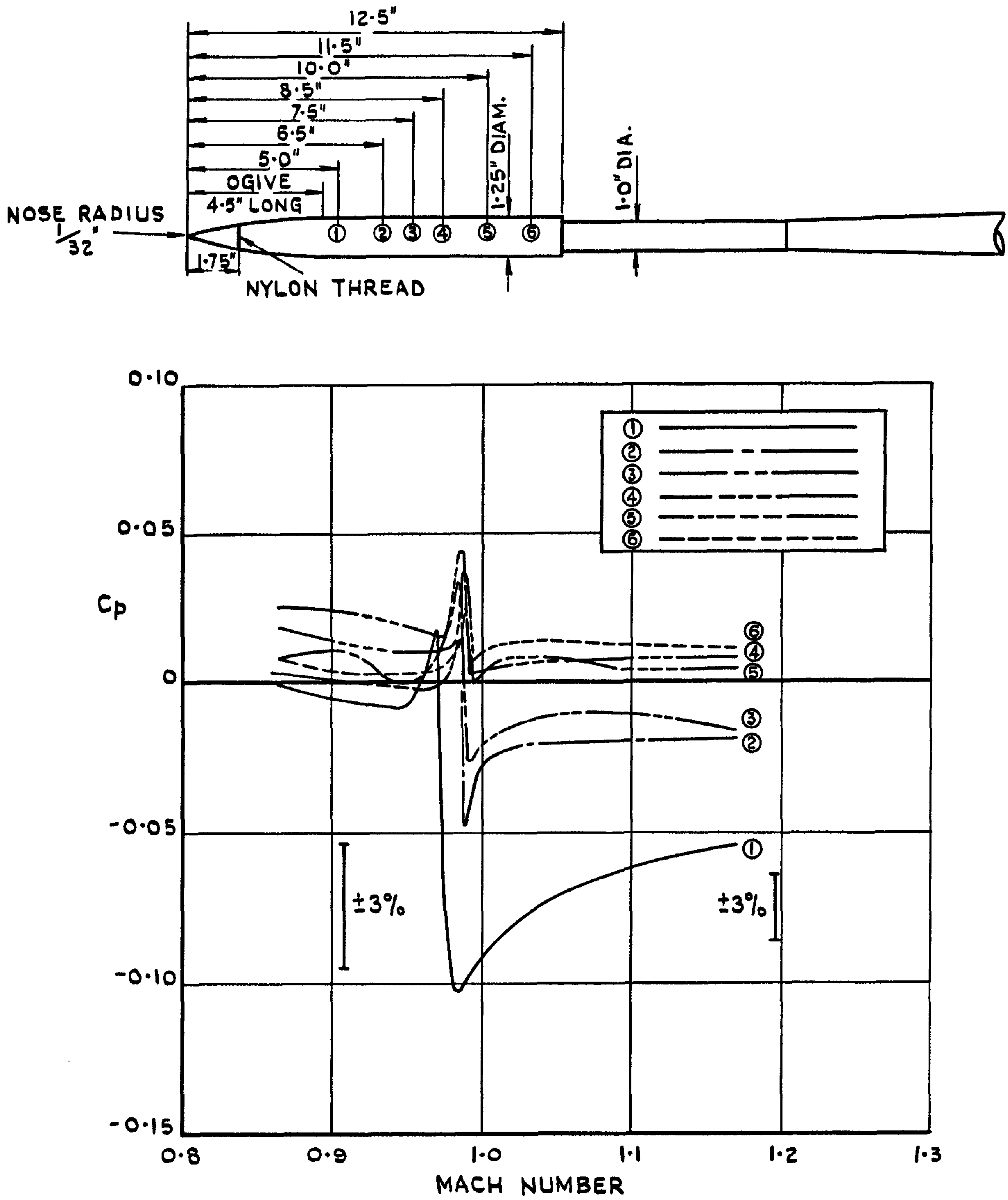


FIG.11. PRESSURE DISTRIBUTION ALONG A PARALLEL BODY WITH OGIVAL NOSE.

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