Contract No. Nonr 839(38)

SOME PRELIMINARY EXPERIMENTS ON PROBE INTERFERENCE — IN HYPERSONIC NEAR WAKES

by

Pasquale M. Sforza

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The research has been conducted under Contract Nonr 839(38) for PROJECT DEFENDER, and was made possible by the support of the Advanced Research Projects Agency under Order No. 529 through the Office of Naval Research.

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SOME PRELIMINARY EXPERIMENTS ON PROBE INTERFERENCE IN HYPERSONIC NEAR WAKES[†]

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Pasquale M. Sforza[‡]

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SUMMARY

Preliminary results concerning the effects of probing the recirculation region of a slender cone in hypersonic flow with conventional diagnostic techniques are presented. Experiments were performed at a free stream Mach number of 11.8 and unit Reynolds number of 0.6×10^6 per foot on a 5° half-angle cone with a base diameter of 10 in. The centerline axis of the recirculation region was investigated with various probes extended from the base (probe diameters were roughly one-hundredth of the base diameter) while base pressure at the base centerline and centerline pitot pressure at a station in the

[†]The research has been conducted under Contract Nonr 839(38) for PROJECT DEFENDER, and was made possible by the support of the Advanced Research Projects Agency under Order No. 529 through the Office of Naval Research. The author extends his appreciation to Professor R. J. Cresci for many stimulating discussions concerning this research.

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supersonic near wake were monitored. Similar studies were made while monitoring only the stagnation temperature profile in the supersonic near wake. It was found, for the above experimental conditions at least, that probes placed along the axis distorted downstream pitot pressures while off-axis curved probes did not appreciably alter either base pressure or downstream pitot pressure. In addition, it was found that extending even the off-axis probe too far from the base into the recirculation region (into the vicinity of the rear stagnation point) greatly disturbs the stagnation temperature profile at a station in the supersonic near wake.

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LIST OF ILLUSTRATIONS

LIST OF SYMBOLS

D	Base diameter
ℓ	Characteristic length
M	Mach number
p	Pressure
R	Base radius
R_e	Reynolds number
T_T	Stagnation temperature
X	Streamwise distance measured from base
Y	Normal distance measured from centerline
μ	Viscosity coefficient
θ	Cone half-angle

<u>Subscripts</u>

b	Denotes base centerline conditions
c	Denotes conditions in recirculation region
s	Denotes inviscid conditions at cone surface
T	Denotes pitot pressure
w	Denotes model wall conditions
∞	Denotes free stream conditions

I. INTRODUCTION

The study of the hypersonic near wake is quite complex, from both the theoretical and experimental point of view. In this region of the flow field of a hypersonic vehicle the flow and state properties vary widely, necessitating different experimental, as well as theoretical, approaches in various regions. In particular, the range of subsonic to transonic to supersonic to hypersonic flow generally occurs within a region one base diameter high by four base diameters long. Some preliminary observations concerning the sensitivity of this near wake region to probing of the recirculating flow is the basis for this report.

The present experimental program was carried out in the $M_\infty=12$ blowdown tunnel of the Polytechnic Institute of Brooklyn Aerospace Laboratories (PIBAL) hypersonic facility. The model was a cone of 10° total included angle and 10 in. base diameter and was wire supported (for a discussion of the support system see Zakkay and Cresci[1]). A sketch of the model and instrumentation in the test section appears in Fig. 1. The experiments were carried out at a free stream Mach number of 11.8 and free stream unit Reynolds number of 0.6×10^{6} per foot. The ratio of model wall temperature to free stream stagnation temperature was around

0.33 (uncooled) for the pitot pressure experiments and both 0.10 and 0.33 for the stagnation temperature experiments. The boundary layer was laminar along the entire cone surface for the above conditions. The free stream stagnation pressure was nominally 490 psia and both pitot and base pressures were measured with Hastings Type DV-13 gauges. The free stream stagnation temperature was nominally 1800°R and stagnation temperatures were measured with 40 gauge (.0035 in.) chromel-alumel thermocouples.

The base mounted probes utilized in this investigation are shown in Fig. 2a. They were constructed of heavy wall 1/8 in. O.D. stainless steel tubing and secured at the base interior by Swagelok fittings which enabled the probes to be displaced axially. The "axial" probe was mounted at the base centerline while the "offset" probes were mounted 7/8 in. off-axis. The sensing portion of all probes was therefore coincident with the axis of the base. A typical installation of an offset probe and the downstream pitot probe is shown in Fig. 2b; for clarity it is emphasized that each base-mounted probe was tested independently as shown, for example, in the figure.

II. EXPERIMENTAL INVESTIGATION

A. Pitot Pressures

The centerline base pressure was monitored for a "clean" base configuration (i.e., no rear-mounted probes) while a centerline pitot pressure survey of the supersonic near wake was conducted. The result of this investigation was considered the norm for the subsequent studies. Next an axially mounted pitot probe extending from the base centerline was utilized to measure total pressure at several stations on the axis of the recirculation region. The centerline pitot pressure at a downstream station in the supersonic region (X/D = 1.875) was monitored simultaneously. Finally, an offset probe was extended from the base into the recirculation region while both centerline base pressure and downstream centerline pitot pressure were monitored; the total pressure at several stations in the recirculation region was also measured with the offset total head probe.

The results of this series of experiments is presented in Fig. 3. It is clear that the utilization of axially mounted recirculation region probes distorts the centerline pitot pressure in the supersonic region while the offset probes do not appreciably alter either the centerline base pressure or the downstream centerline pitot pressure. It seems reasonable to assume then, that under the present conditions, i.e., probes completely within the subsonic region, axially mounted probes alter the flow field to such an extent that the downstream behavior is adversely affected. It must be pointed out that, for the present test conditions, no measurements of pressure on the base near the axially mounted probe were performed. Further experiments conducted subsequently in the M_∞=8.0 tunnel of the PIBAL hypersonic facility indicate that no significant departures from the clean base configuration results were observed. The results of this test series are shown in Fig. 4. In these M_∞=8 experiments (on a 10° half-angle cone) the probe-to-base diameter ratio (1.5%) was roughly equal to that in the M_∞=11.8 results reported herein. The major difference was that the length of the probe was 2.2 diameters, i.e., it extended well into the supersonic region. Thus it appears that, although the base pressure in the vicinity of the centerline is unaffected by a axially mounted probe (Fig. 4), the flow field in the supersonic region downstream may be disturbed (Fig. 3).

B. Stagnation Temperature Profiles

Similar investigations were carried out while the profile of stagnation temperature in the downstream supersonic region (in particular, at a station X/D=1.875) was monitored. In addition, two different ratios of wall to free stream stagnation temperature were utilized. The results of this study appear in

Fig. 5. It is evident that for offset probes at stations $X_p/D < 0.5$, the data for both wall temperature ratios are in agreement with each other and with the clean base results. However, when the offset probe is moved out from the base to greater distances, i.e., $X_p/D = 0.7$ and 0.9, the stagnation temperature profile at $X/D = 1.875$ is badly distorted. It had been estimated[1] that for these flow conditions, the rear stagnation point is located at approximately $X/D = 0.8$. It is apparent that the placement of a probe in the vicinity of this point should, and indeed does, greatly influence the downstream behavior of the flow field.

III. DISCUSSION

The experimental results indicate that axially mounted probes adversely affect the flow field in the supersonic near wake region, while offset probes, if not placed in close proximity to the rear stagnation point, do not appreciably alter the flow field. It is felt that this is a consequence of the range of influence of disturbances caused by different probes in this region. The parameter which describes this influence for subsonic viscous flows is the Reynolds number. Hence with an axially mounted probe in this region, one has a body of revolution of small transverse radius of curvature in a rapidly decelerating (stagnating) axisymmetric flow field. This is enough to cause large boundary layer buildup. In addition, however, the Reynolds number in this region may be extremely low, thus extending further the range of influence of the disturbance caused by the axially mounted probe. This displacement effect may be manifested in an alteration of the initial portion of the dividing streamline, thus affecting the downstream flow properties. The base pressure near the rim of the cone would thus appear to be the most pertinent parameter in this connection. This possibility is currently under investigation.

With the offset probe, however, there is no appreciable length of axisymmetric body along the axis; the major portion of the body of the probe is normal to the flow which proceeds along the base away from the base stagnation point.

One may make some crude estimates of the ratio of Reynolds number on the axis of the recirculation region to that on the surface of the cone and arrive at curves similar to those shown in Fig. 6. It is apparent from these figures that the Reynolds number ratio for a fixed cone angle and centerline base pressure ratio (here $p_b/p_c \simeq 1$ has been assumed) varies appreciably with free stream Mach number (i.e., $Re_c/Re_s \sim M_\infty^{-0.7}$) and with the assumed value for the characteristic Mach number on the axis of recirculation region, M_c. These Reynolds number estimates are based on (1) $\mu_c/\mu_s = (T_c/T_s)^{3/4}$, (2) $\gamma=1.4$, (3) $p_c \simeq p_b$, and

(4) the ratio of characteristic lengths $\ell_c/\ell_s \cong \tan\beta$; the curves are meant only for illustration of the wide variation in the Reynolds number ratio that may occur. It is suggested that more accurate numerical values be calculated in specific cases.

It is important to note that the Reynolds number in the recirculation region may reach into the Stokes flow range, particularly at high Mach numbers ($M_\infty > 10$). It is clear though that an effort must be made to determine as accurately as possible the Mach number in the recirculation region since this quantity is important for calculating an accurate recirculation region Reynolds number. Furthermore, from perusal of Fig. 6, it may be noted that, for relatively low Mach number - high Reynolds number experiments, these flow interference effects, as described herein, may not be as important as indicated in the present experimental program.

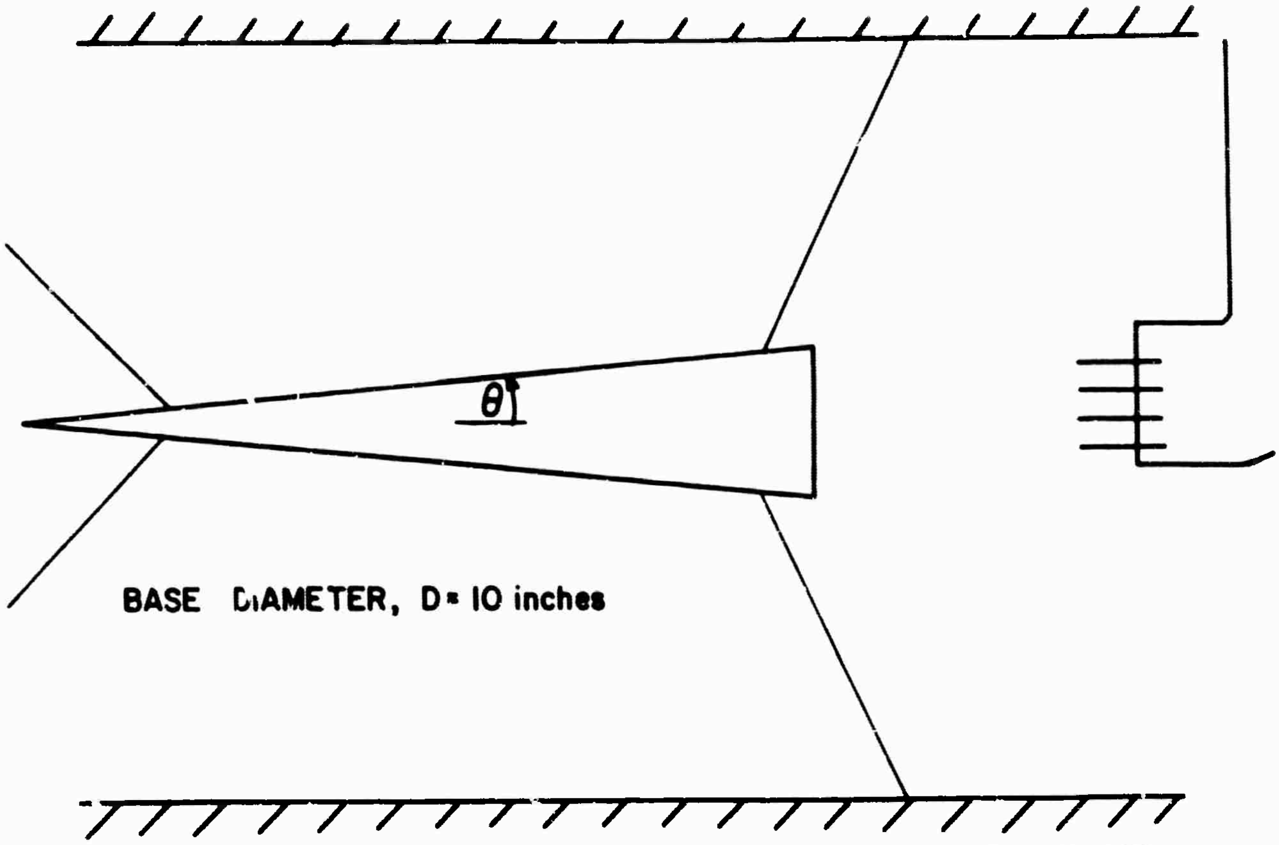
IV. CONCLUSIONS

It has been found, based on preliminary experiments, that probing of the recirculation region, if not carefully undertaken, may lead to disturbed downstream flow fields. It also appears that the centerline or near-centerline base pressure is not as sensitive a quantity as downstream pitot pressures or total temperatures for determining the extent of probe interference. It is suggested that the Reynolds number of the recirculation region is the critical parameter describing the extent of these effects and that the base pressure near the rim of the cone may be more pertinent a flow property than the centerline base pressure in this connection.

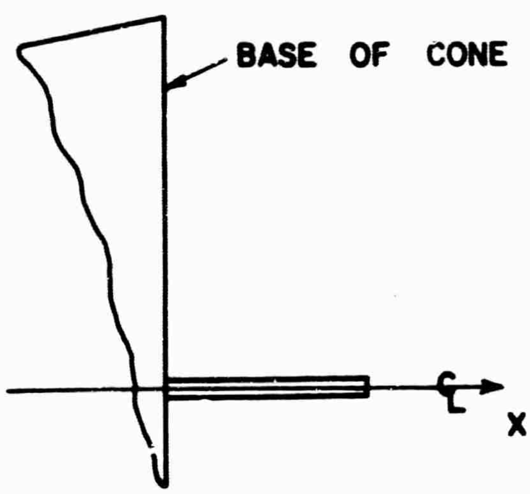
Further investigations conducted under various Mach number and Reynolds number conditions are necessary to aid in the more precise definition and understanding of these interference effects.

REFERENCES

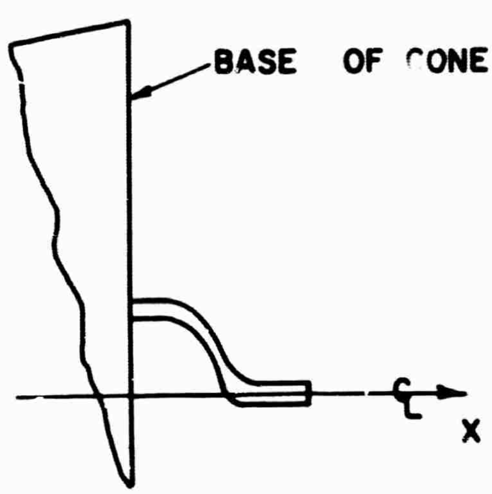
1. Zakkay, V. and Cresci, R.J.: An Experimental Investigation of the Near Wake of a Slender Cone at M_∞=8 and 12. AIAA J., 4, 1, pp. 41-46, January 1966.



(a) SCHEMATIC OF MODEL AND DOWNSTREAM INSTRUMENTATION. SHOWN HERE IS THE "CLEAN" BASE CONFIGURATION



(b) DETAIL OF MODEL BASE WITH AXIALLY MOUNTED PROBE



(c) DETAIL OF MODEL BASE WITH OFFSET PROBE

FIG. 1 SCHEMATIC DIAGRAM OF MODEL CONFIGURATION

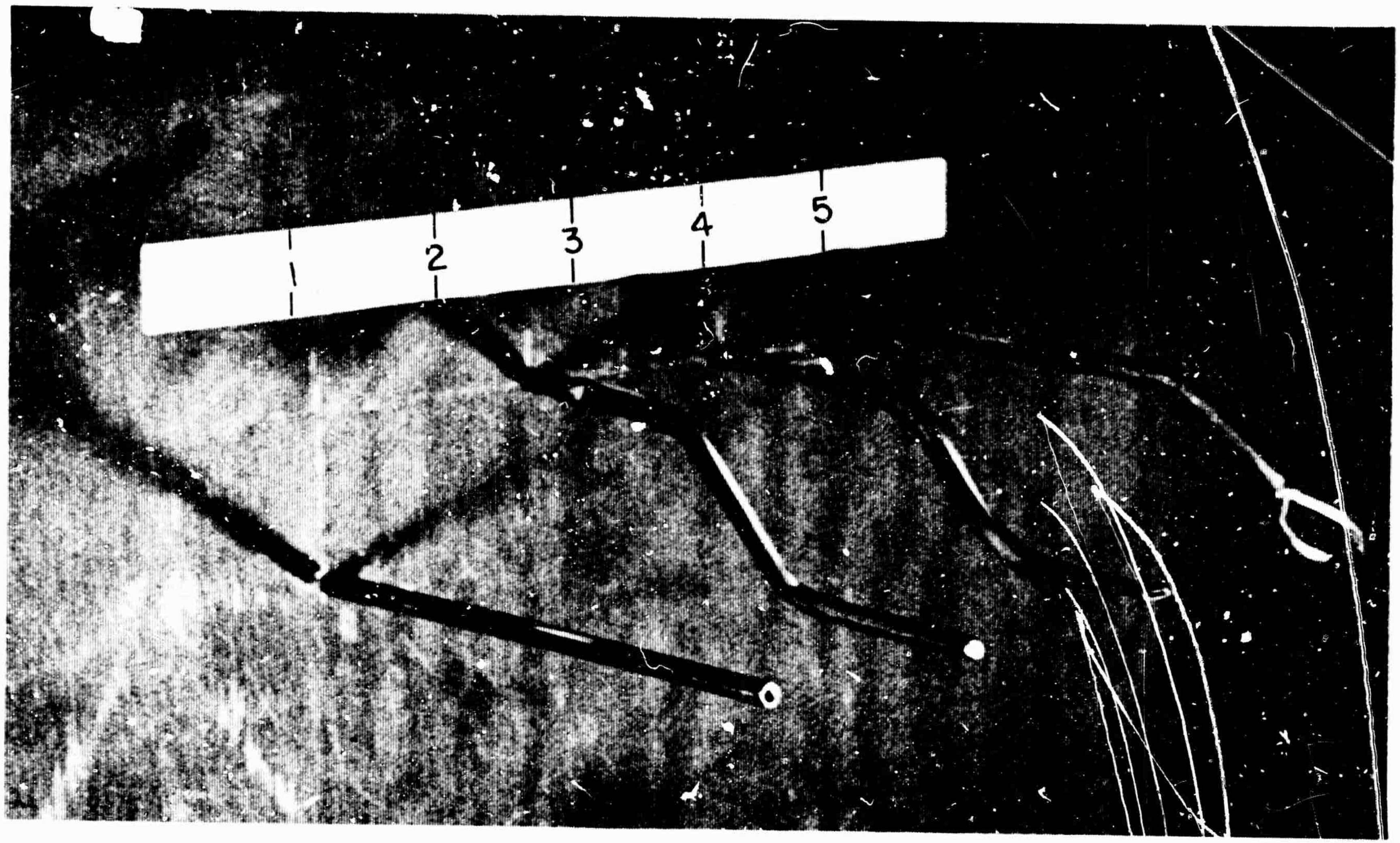


FIG.(2a) PHOTOGRAPH OF VARIOUS RECIRCULATION REGION PROBES UTILIZED. FROM LEFT: AXIAL PITOT PROBE, OFFSET STATIC PROBE, OFFSET PITOT PROBE, AND OFFSET THERMOCOUPLE PROBE.

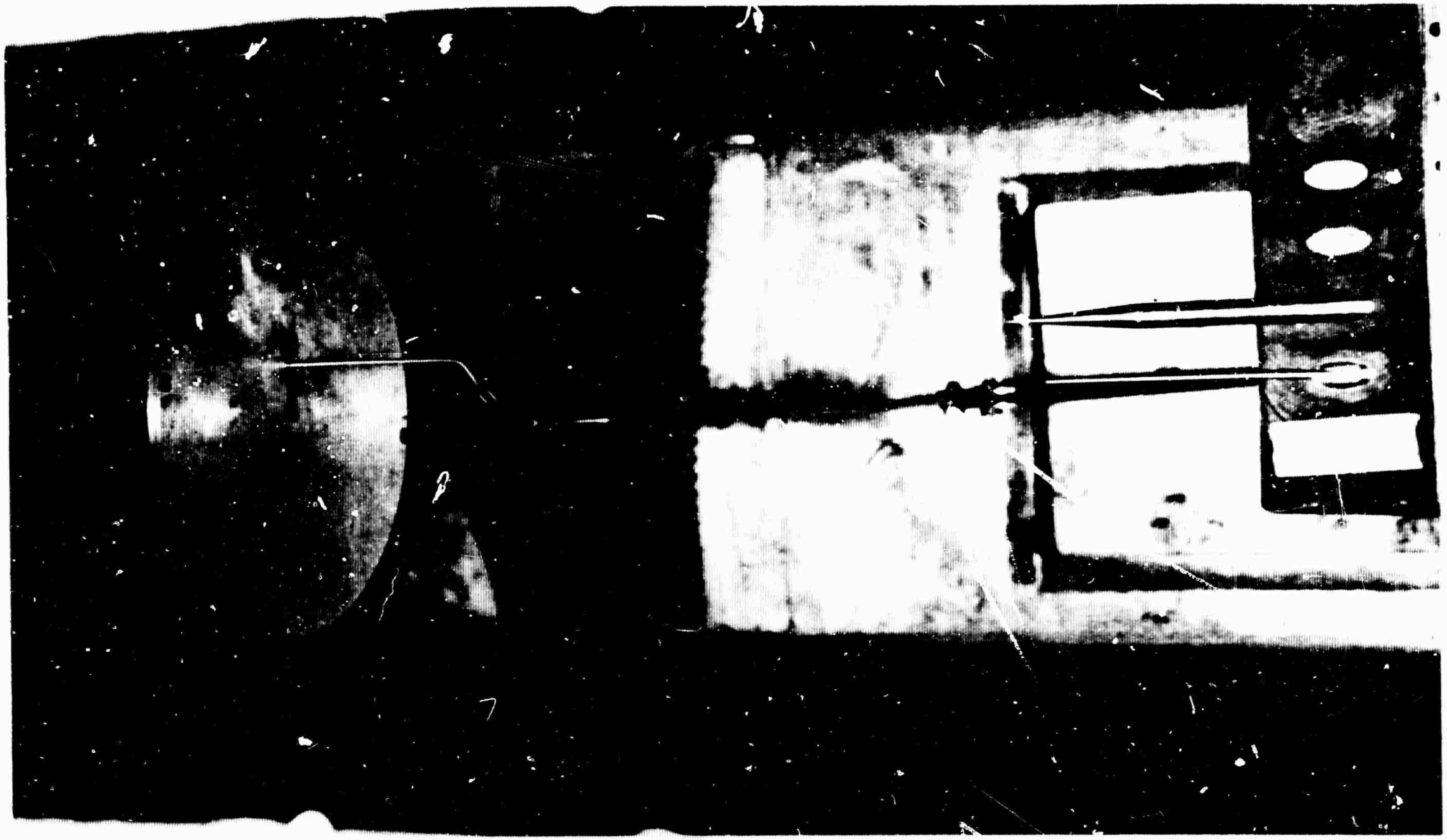


FIG. (2b) PHOTOGRAPH OF TYPICAL INSTALLATION OF OFFSET THERMOCOUPLE PROBE AND DOWNSTREAM CENTERLINE PITOT PROBE IN WIND TUNNEL.

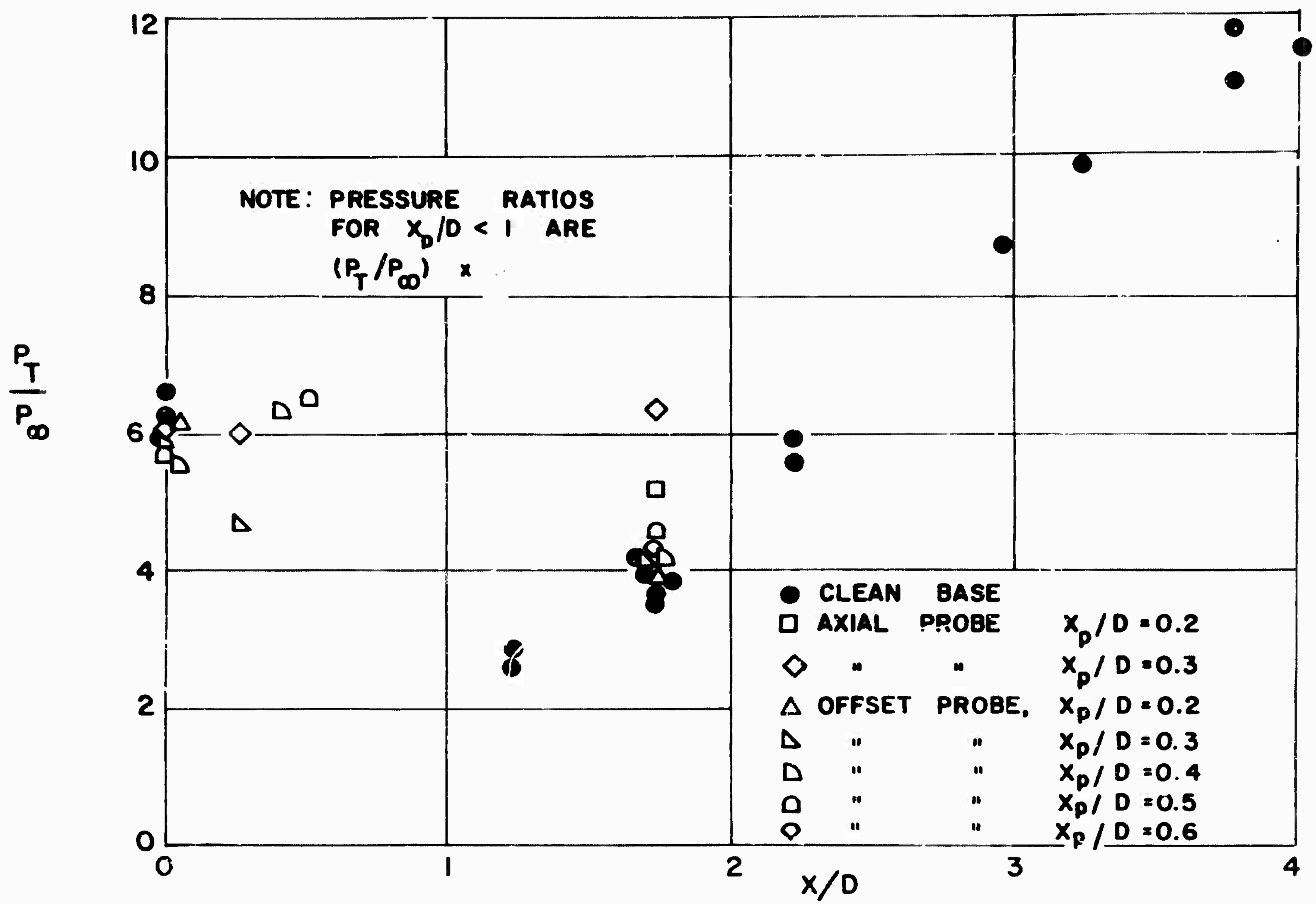


FIG. 3 CENTERLINE PITOT PRESSURES AND BASE PRESSURES FOR VARIOUS RECIRCULATION REGION PROBE SETTINGS. $M_\infty = 11.8$, $R_{e_\infty} = 0.6 \times 10^6$, $\theta = 5°$

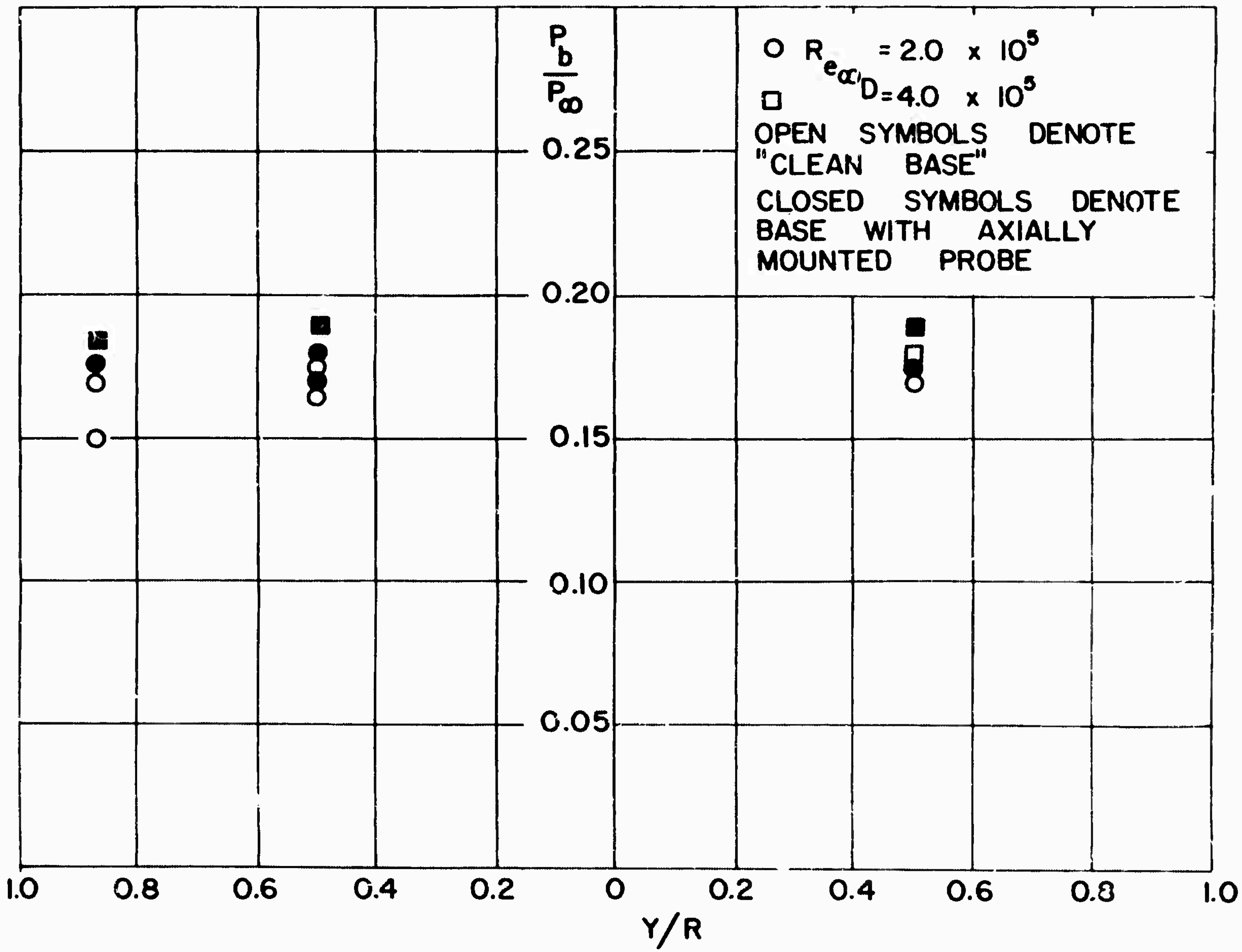


FIG. 4 EFFECT OF AXIALLY MOUNTED PROBE ON BASE PRESSURE AS A FUNCTION OF RADIAL DISTANCE FROM BASE CENTERLINE (M_∞ = 8.0, θ = 10°)

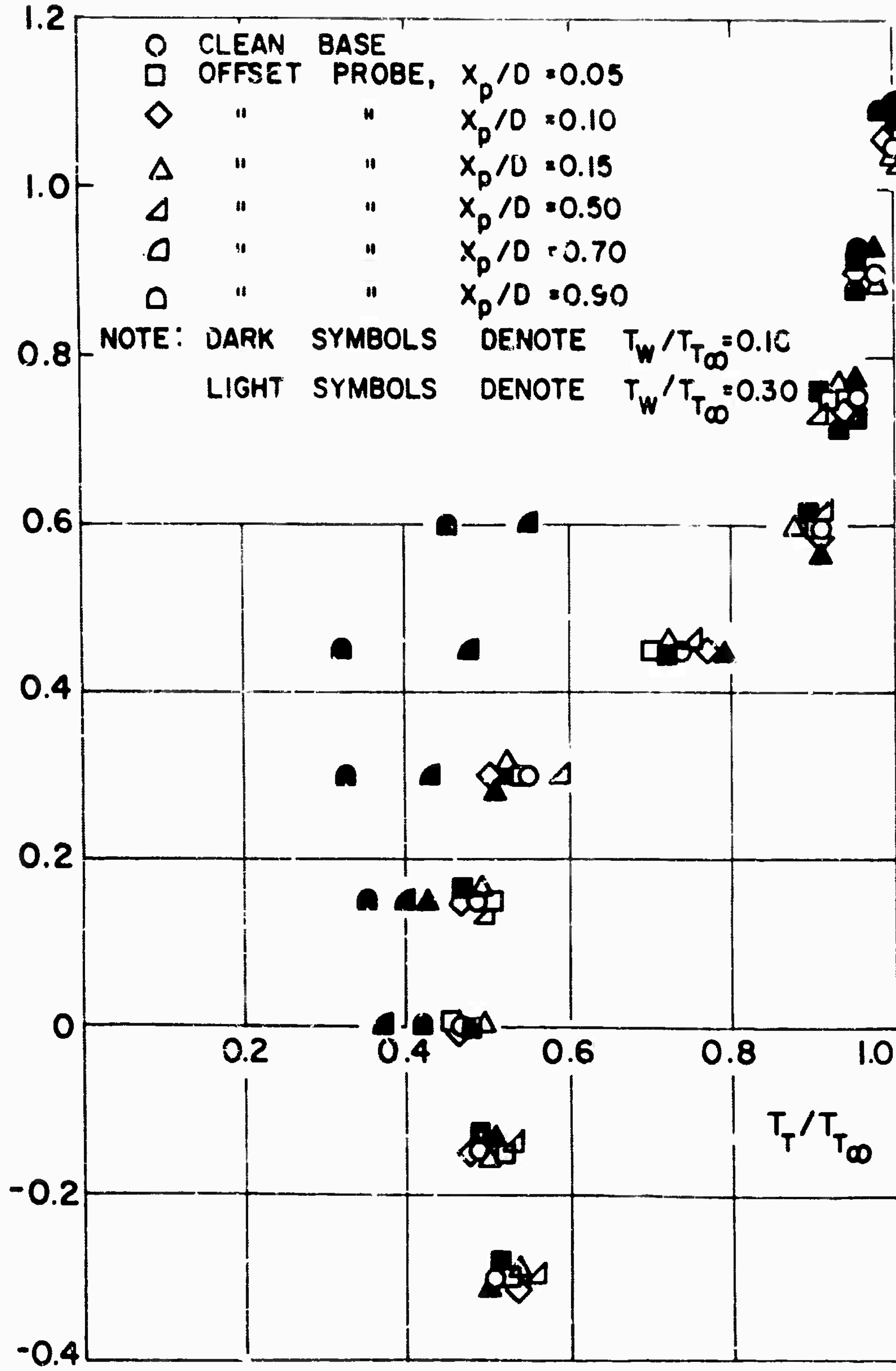


FIG. 5 STAGNATION TEMPERATURE PROFILES AT X/D = 1.875 FOR VARIOUS RECIRCULATION REGION PROBE SETTINGS.
$M_\infty = 11.8$, $R_{e_\infty} = 0.6 \times 10^6$ PER FOOT, $\theta = 5°$

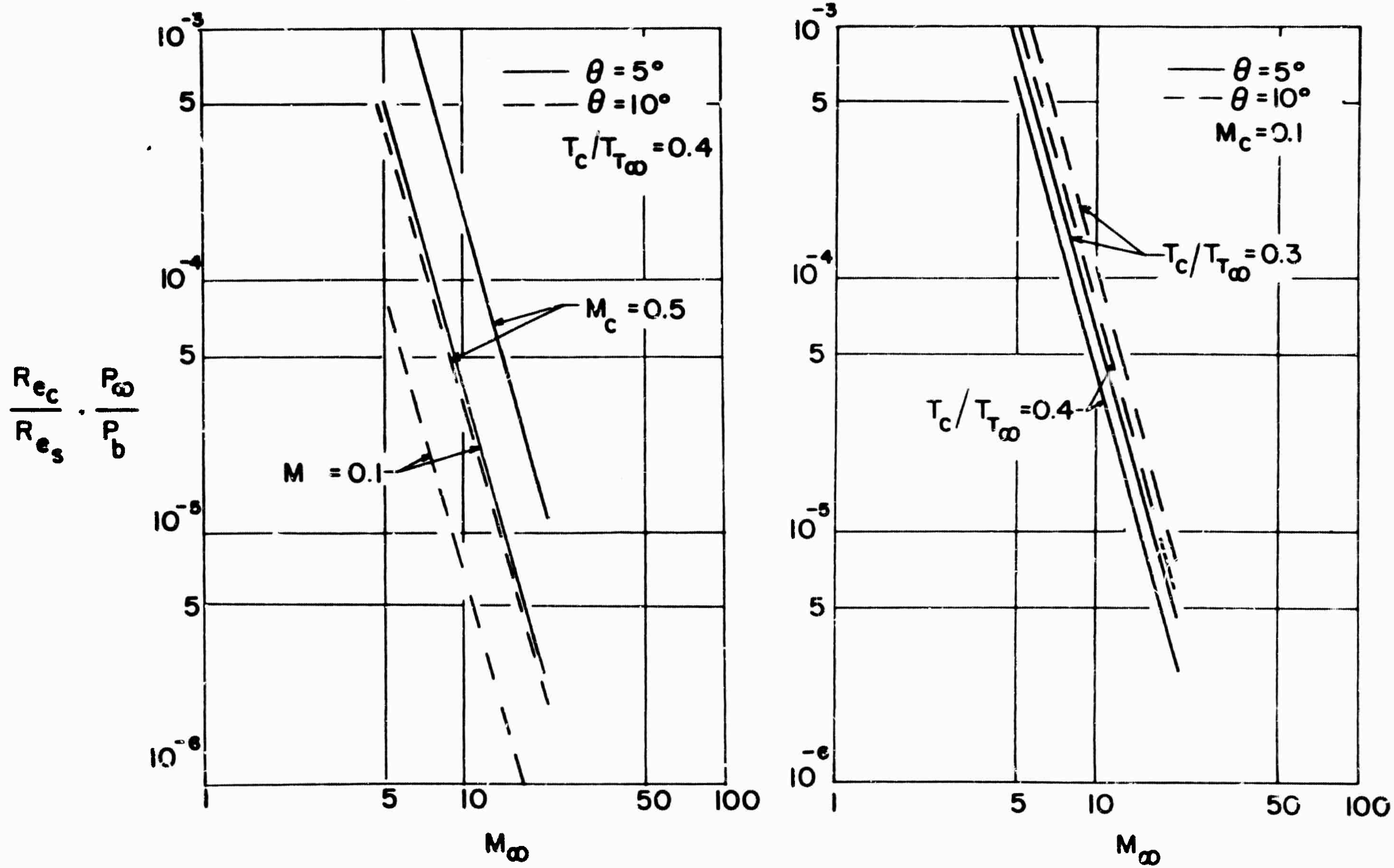


FIG. 6 APPROXIMATE VARIATION OF RATIO OF REYNOLDS NUMBER IN THE RECIRCULATION REGION TO THAT ON THE CONE SURFACE WITH FREESTREAM MACH NUMBER

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1 ORIGINATING ACTIVITY (Corporate author) Polytechnic Institute of Brooklyn Dept. of Aerospace Engrg. & Applied Mechanics Route 110 Farmingdale, New York 11735	2a REPORT SECURITY CLASSIFICATION Unclassified 2b GROUP

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SOME PRELIMINARY EXPERIMENTS ON PROBE INTERFERENCE IN HYPERSONIC NEAR WAKES

4 DESCRIPTIVE NOTES (Type of report and inclusive dates)

Research report

5 AUTHOR(S) (Last name, first name, initial)

Sforza, Pasquale M.

6 REPORT DATE	7a TOTAL NO. OF PAGES	7b NO. OF REFS
May 1967	15	1

8a CONTRACT OR GRANT NO. Nonr 839(38) b. PROJECT NO. c. ARPA Order No. 529 d.	9a ORIGINATOR'S REPORT NUMBER(S) PIBAL Report No. 1011 9b OTHER REPORT NO(S) (Any other numbers that may be assigned this report)

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13 ABSTRACT

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