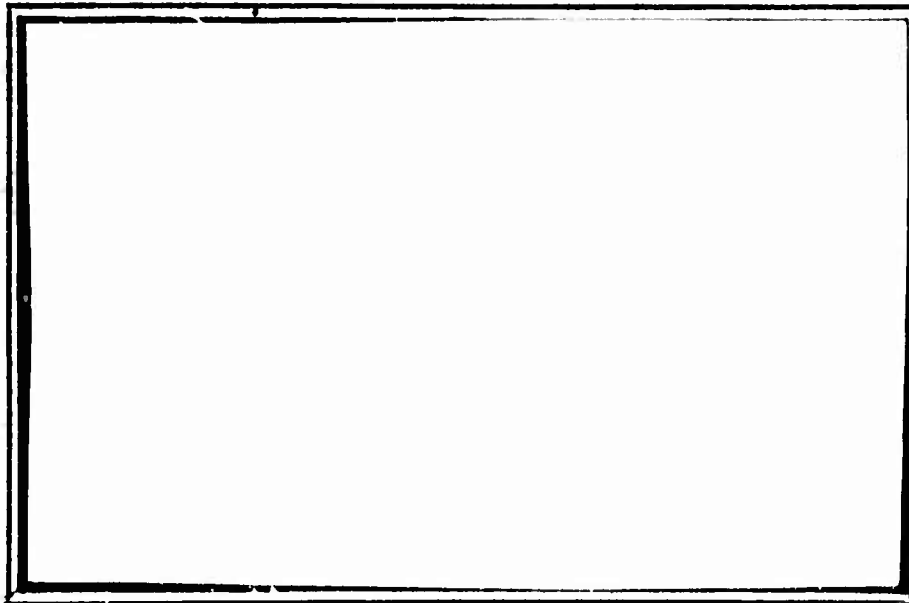


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SMALL SHIELDED THERMOCOUPLE TOTAL TEMPERATURE PROBES

by

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ABSTRACT

The design and the calibration of 2 mm and 3 mm O.D. shielded thermocouple total temperature probes are described.

The 3 mm O.D. probe recovery factor is 0.985 ± 0.005 and the 2 mm O.D. one is 0.975 ± 0.005 up to flow Mach number of 3.5. The probe response is only slightly dependent of Reynolds number. By positioning of the thermocouple junction at the vent holes position its output becomes sensitive to disturbances, such as shock waves in the flow. This characteristic of the probe can be useful in mapping of discontinuities in complicated flow fields.

TABLE OF CONTENTS

	<u>PAGE No.</u>
ABSTRACT	I
TABLE OF CONTENTS	II
LIST OF SYMBOLS	III
LIST OF FIGURES	IV
1. INTRODUCTION	I
2. THE 2 mm AND 3 mm O.D. SHIELDED THERMOCOUPLE PROBE DESIGN	2
3. THE SHIELDED THERMOCOUPLE PROBES CHARACTERISTICS	2 - 5
REFERENCES	6

LIST OF SYMBOLS

M	Mach number
r	Recovery factor
Re	Reynolds Number
T	Static temperature
T _T	Stagnation Temperature
T _{T,r}	Recovery Temperature

LIST OF FIGURES

Figure No.

1. The 2 mm O.D. shielded thermocouple probe.
2. Errors due to conduction and radiation losses as a function of heat transfer rate to the airstream.
3. Recovery factor as a function of Mach number for the 2 mm and 3 mm O.D. probes.
4. Recovery factor as a function of Reynolds number for the 2 mm and 3 mm O.D. probes.
5. Recovery factor dependence on the ratio of vent holes area to frontal hole area.
6. Typical response of the 2 mm O.D. probe to the flow structure in the supersonic wake behind a blunt base.
7. Sensitivity of the probe to flow disturbances as a function of thermocouple position in relation to the vent holes position.

I. INTRODUCTION

In principle the temperature inside a pitot tube, where the flow is brought to rest at equilibrium, should be the stagnation temperature, and could be measured by a temperature transducer placed inside the tube. The difficulty is that in practice equilibrium does not exist, since heat is lost by conduction, convection and by radiation from the transducer and the probe walls. Thus the transducer responds to a temperature T_r (recovery temperature) which is lower than the stagnation temperature. This recovery temperature depends on the probe configuration, conductivity and reflectivity of the probe walls, flow conditions about the probe walls, construction materials etc. It will be shown that such a probe, can be specially designed to respond as well to various disturbances in the flow field such as shock waves, shear or entropy discontinuities etc. In the present investigation total temperature probes are developed for studies of the flow field in the supersonic near wake. These probes should have recovery factor, r close to unity which is also almost independent of Mach and Reynolds number variation. The probes must be of small dimensions so that a good resolution can be obtained with minimum disturbance to the wake flow. A successful total temperature-shielded thermocouple probe was designed and built at NOL by E. Winkeler (Ref. 1). This probe had good characteristics but its dimensions, 6 mm O.D., are large for most near wake measurements. In the present investigation probes of 3 mm and 2 mm O.D. were built and studied. It will be shown that those 2 mm and 3 mm O.D. probes have almost comparable characteristics to the 6 mm one of Ref. 1. The smaller probes can be made sensitive to flow discontinuities, so that these can be also used for flow field mapping (Ref. 2).

2. THE 2 mm AND 3mm O.D. SHIELDED THERMOCOUPLE PROBE DESIGN

The drawing and a photograph of the 2 mm O.D. probe are shown in Figures 1a and 1b respectively. The dimensions of the probes are given in Table 1.

TABLE 1.

TOTAL TEMPERATURE PROBE'S DIMENSIONS

Probe	D mm	d mm	x ₁ mm	x ₂ mm	$\frac{\text{Vent Hole Area}}{\pi d^2/4}$	x ₃ mm	x ₄ mm
2 mm	2.0	1.3	3	3	.60	5.3	10
3 mm	3.0	2.0	4	4	.40	8	10

The glass shield is coated with shining platinum paint (Hanovia paint type XX) baked at 760° C. The thermocouple is made of 33 gage iron-constant thermocouple wires packed in a stainless steel tube filled with inserted through a teflon plug. The thermocouple junction is obtained by spot welding in a mercury bath. The junction diameter is about 1.1 times larger than the wire diameters. The probe's head is glued by epoxy resin to the stainless steel probe holder. The stainless steel tube on which the probe head is mounted is bent, knee shape (see Fig. 1), so that the probe holder and support are kept outside the wake region.

3. THE SHIELDED THERMOCOUPLE PROBE'S CHARACTERISTICS

The recovery factor of the shielded thermocouple probe is defined as

$$r = \frac{T_f - T}{T_r - T}$$

where T_{Tr} - Recovery Temperature Inside the Probe

T_T - Stagnation Temperature

T - Static Temperature

The recovery factor is determined by the balance of the losses due to conduction and radiation and the rate of heat addition from the free stream to the probe. The losses can be evaluated approximately from the known properties of the probes' materials and rate of heating as shown in Fig. 2. It is seen that for moderate heat transfer rates to the probe external surfaces total temperature deficiencies of the order $\left(\frac{\Delta T}{T}\right)_{\text{convection}} + \left(\frac{\Delta T}{T}\right)_{\text{radiation}} = 2\% \text{ to } 5\%$ can be expected. The recovery factor values depend in general on the Mach number and Reynolds number. For convenience in use particularly in non-uniform flow regions (such as in the wake region) it is desirable to have a probe with a calibrated recovery factor which will be insensitive to the variation of these flow parameters. The present probes were designed to minimize the effects of Reynolds number variation on the recovery factor and only a small effect of Mach and Reynolds numbers is detected. The measured recovery factors are 0.985 ± 0.005 and 0.975 ± 0.005 for the 3 mm O.D. and 2 mm O.D. probes respectively. The variation of the probes output is shown in Figs. 3 and 4 as a function of Mach number and Reynolds numbers. The recovery factor dependence on the ratio of the vent holes area and frontal hole area is shown in Fig. 5. It can be seen that vent holes area of 35% to 50% are desired for the 3 mm probe while 50% to 80% are needed for the 2 mm probe, while the 6 mm probe required only 20% open vent area (Ref. 1).

The response time of the probe is important for transient measurements and also for measurements of temperature distribution using a traversing mechanism. The time response constant τ for the 3 mm probe is estimated to be about 0.27 sec, while for the 2 mm one, the value is about 0.2 sec. These response times are reasonable and enable recording of large number of temperature points during a traverse of few minutes during the wind tunnel test.

An additional feature of the shielded thermocouple probe is its sensitivity to disturbances in the flow. When the probe crosses a disturbance (such as a shock wave or a thin shear layer) its recovery factor changes abruptly by the severe changes in the heat transfer rates due to the disturbed flow configuration in and about the probe. This characteristic of the probe can be used for detection of disturbances in a flow field. It was found that the change in the recovery factor may be made positive (indicating "higher" temperature) or negative ("lower" temperature) or even neutral depending on the position of the thermocouple junction in relation to the vent holes position. The magnitude of the response of the probe to the disturbances is determined in the present investigation at the jump of the probe's response as it traverses the trailing shock and entropy layer at a fixed station in the wake of a wedge-flat plate model. A typical probe's response at this position is shown in Fig. 6. Probes with varying thermocouple junction position are tested at the same wake station and the probe sensitivity to the wake disturbances is measured. The results of this measurement for the 3 mm probe is shown in Fig. 7. It is seen that when the junction is positioned near the probe's entrance the probe's output is reduced as the probe crosses the disturbance while beyond about 1/3 distance towards the vent holes this output becomes neutral and then becomes positive as the thermocouple junction is moved towards

the vent holes. The maximum sensitivity is obtained when the junction is at the vent hole position. Similar results are obtained also in the case of the 2mm O.D. probe. The use of these probes for wake flow mapping is shown in Reference 2.

Further miniaturization of the probe design can be obtained by using new technique for manufacturing such as by use of new tools for drilling holes in glass etc. These miniature probes can be used for boundary layer studies and can be useful as additional tools to the generally used hot wire techniques.

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2. Rom J., Kronzon, Y. and Seginer A., : "The Velocity, Pressure and Temperature Distribution in the Turbulent Supersonic Near Wake Behind a Two-Dimensional Wedge-Flat Plate Model", Contract AF 61 052 67 C 0033, Interim Scientific Report No. 4, TAE Report No. 80 Dec. 1967.

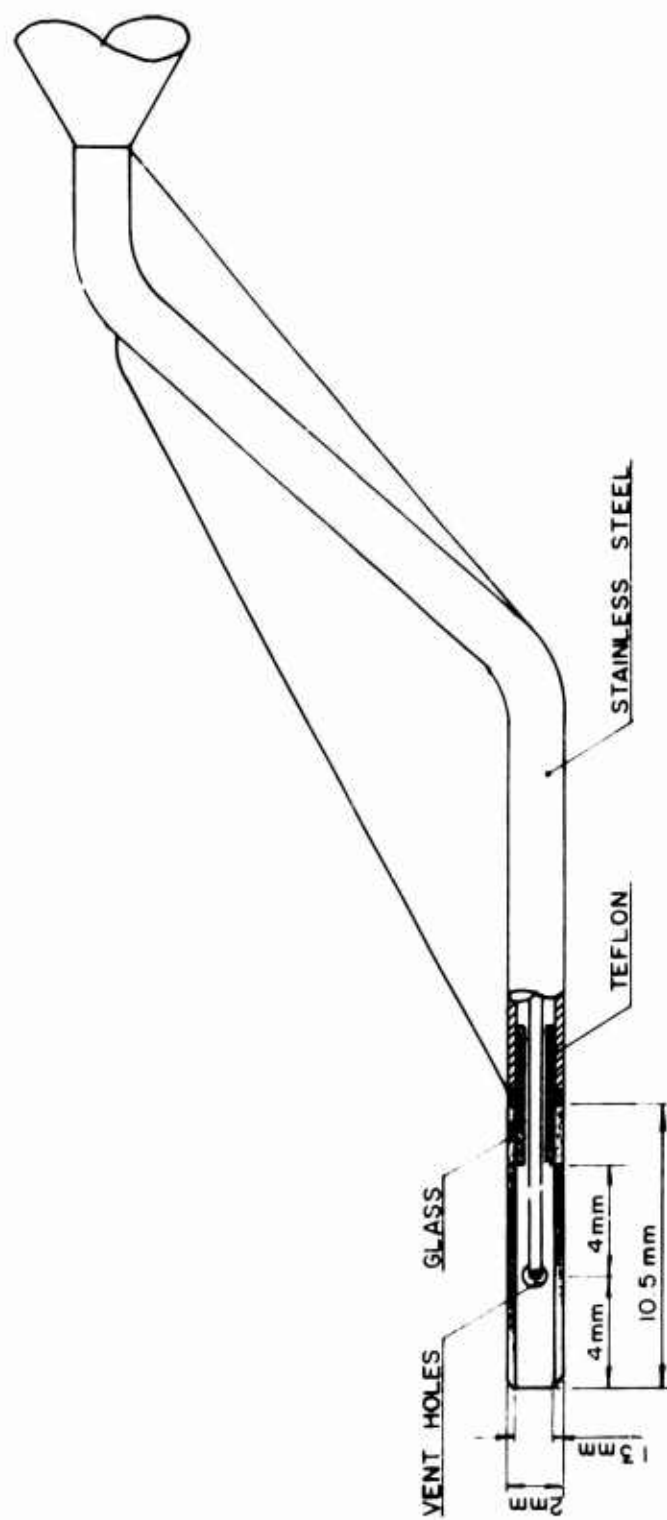


FIG. 1 DIAGRAM OF THE 2mm TOTAL TEMPERATURE PROBE

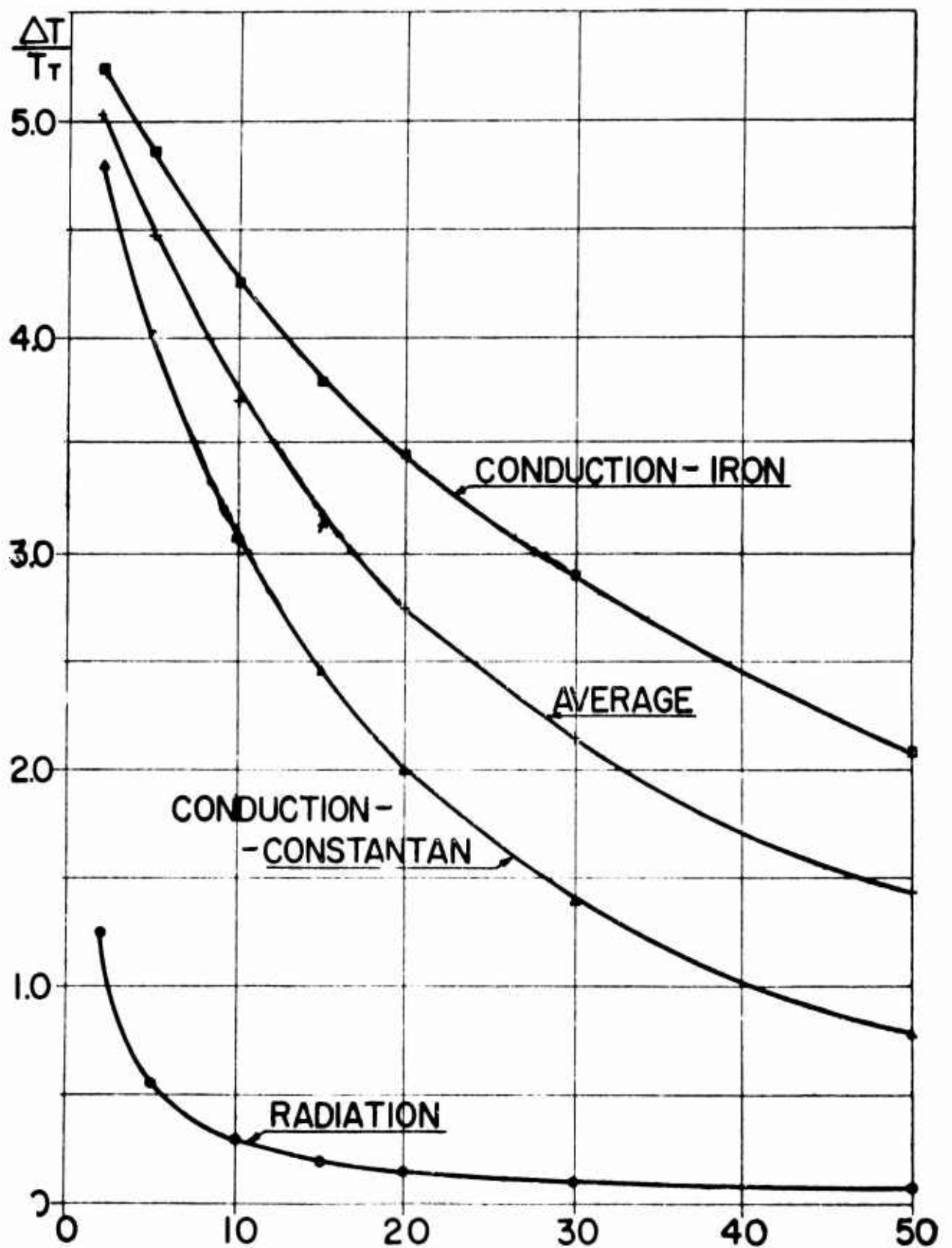


FIG. 2 ESTIMATES OF TOTAL TEMPERATURE ERROR DUE TO CONDUCTION AND RADIATION LOSSES

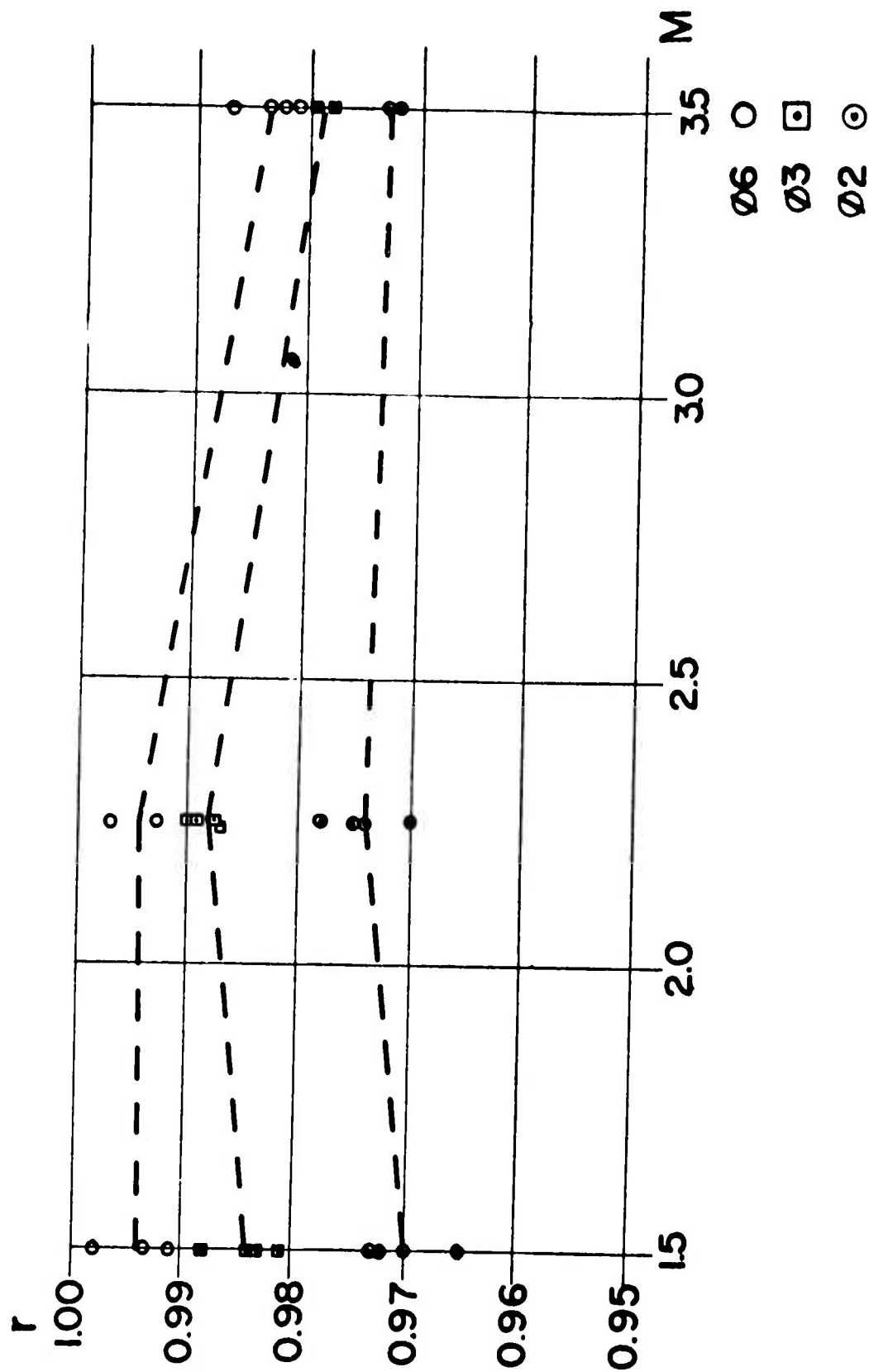


FIG.3 TOTAL TEMPERATURE PROBES RECOVERY FACTOR
AS A FUNCTION OF FLOW MACH NUMBER

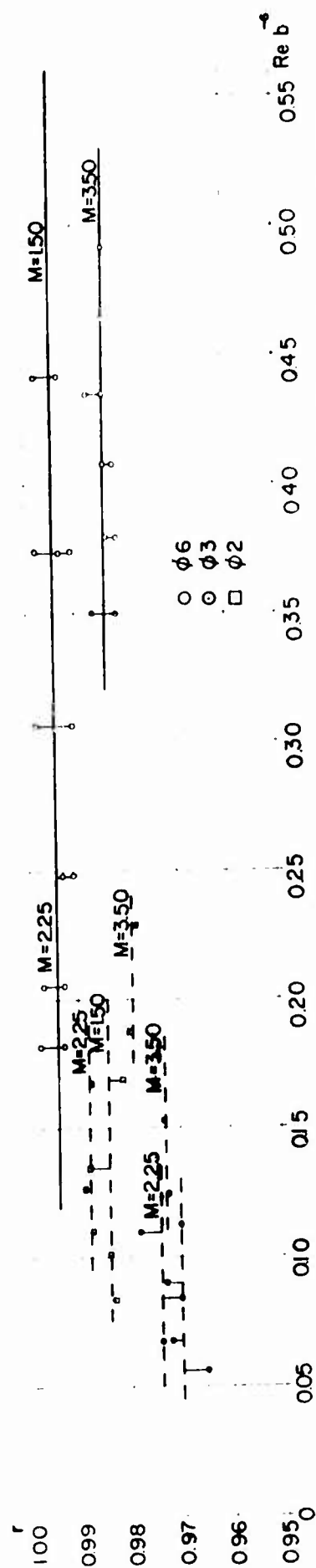


FIG. 4 TOTAL TEMPERATURE PROBES RECOVERY FACTOR AS A FUNCTION OF REYNOLDS NUMBER

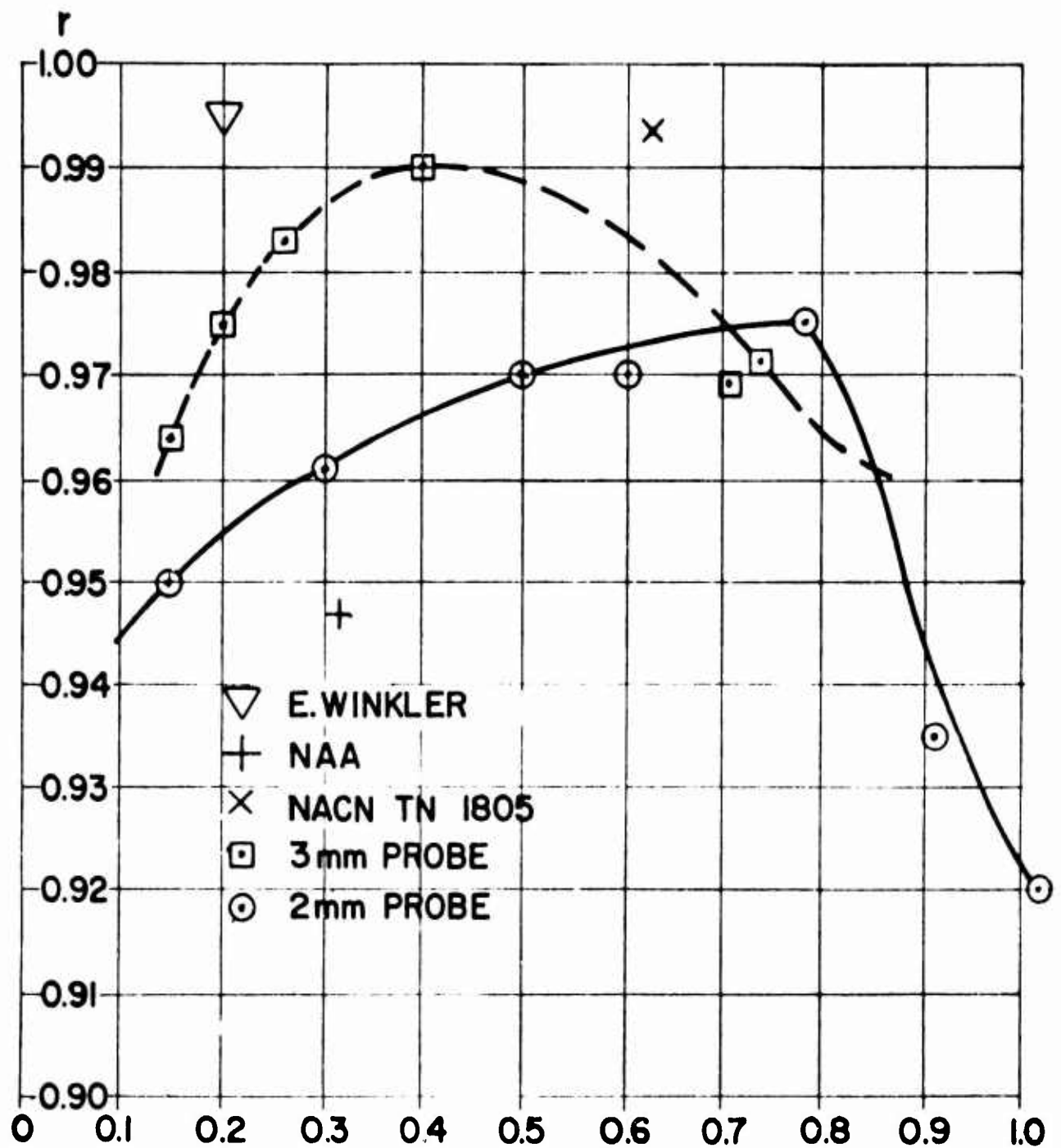


FIG.5 RECOVERY FACTOR DEPENDENCE ON
THE RATIO OF VENT HOLES AREA
TO FRONTAL HOLE AREA

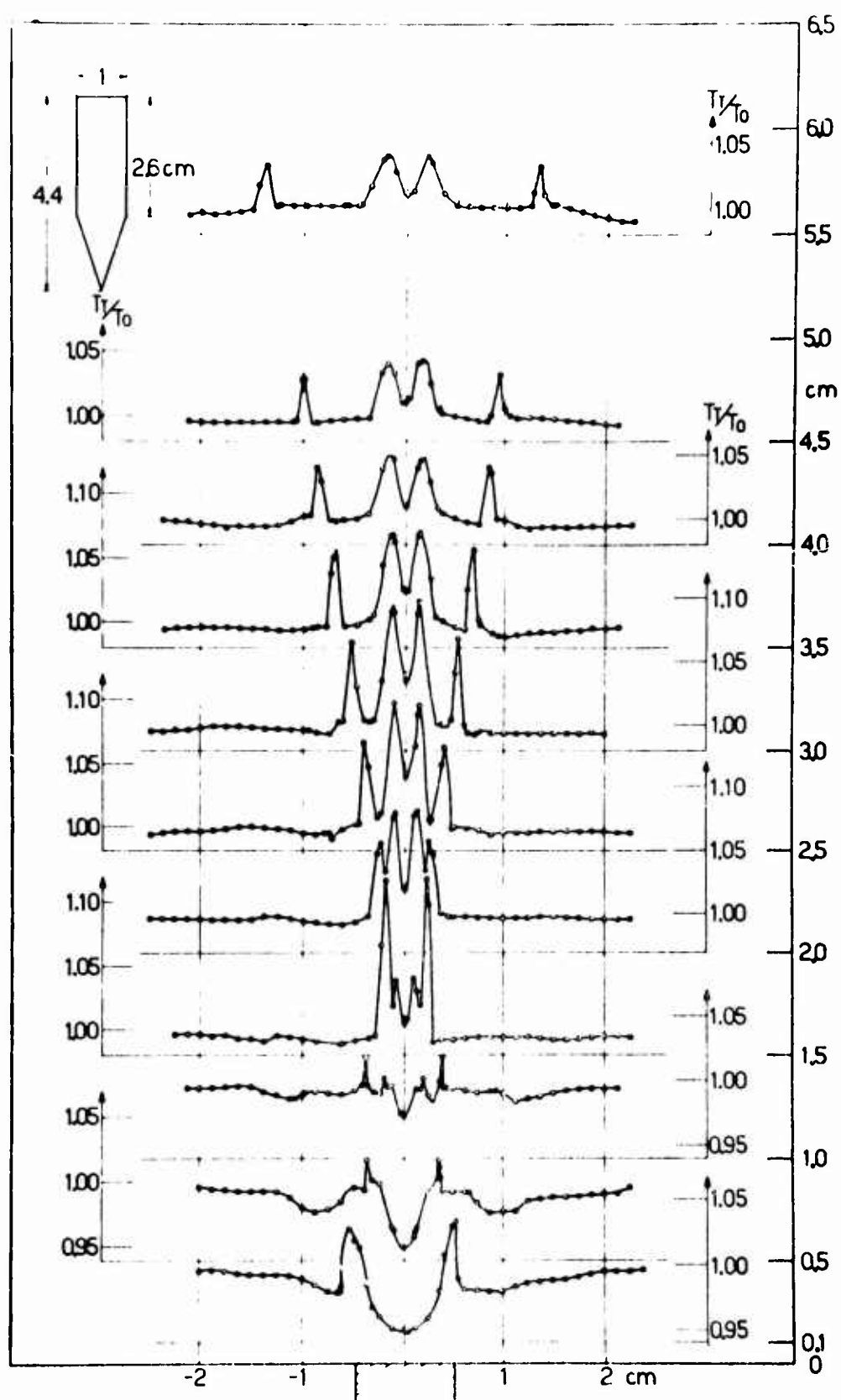


FIG.6 RECOVERY TEMPERATURE PROFILES IN THE TURBULENT
NEAR WAKE BEHIND A BLUNT TWO DIMENSIONAL BASE AT
 $M = 2.25$

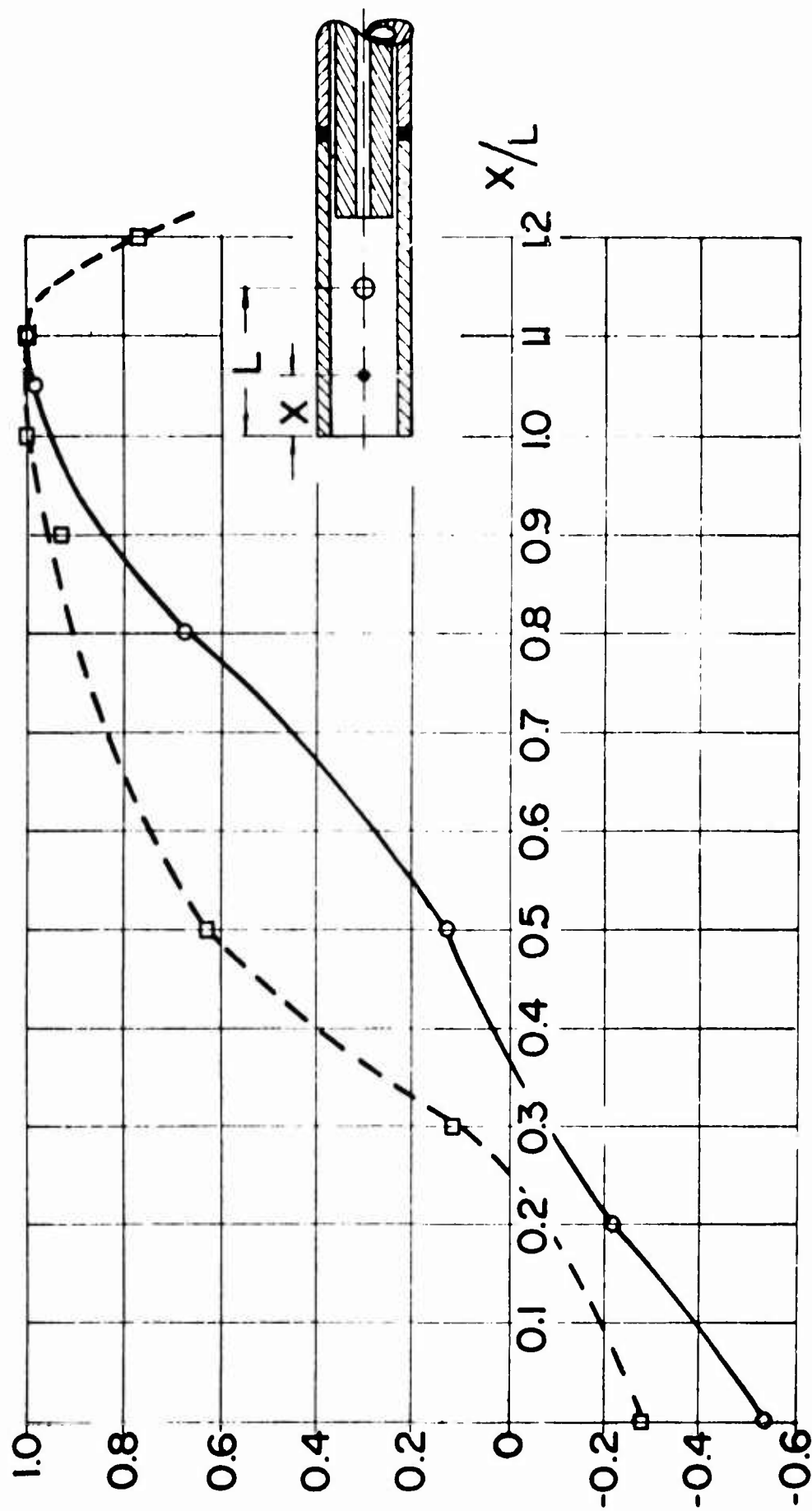


FIG. 7 TOTAL TEMPERATURE PROBE RESPONSE AT A SHOCK WAVE AS A FUNCTION OF THERMOCOUPLE JUNCTION POSITION

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KEY WORDS

Small Shielded Thermocouple Probes

Total Temperature Probes

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LINK B

LINK C

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