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A NEW TECHNIQUE FOR INDUCING A TURBULENT BOUNDARY LAYER IN A SUPERSONIC FLOW*

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by

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FORWARD

This report was prepared by Masafumi Miyazawa, Assistant Research Scientist, Department of Aeronautics and Astronautics, New York University.

The original idea of this experimental work was proposed by Professor Antonio Ferri. The author wishes to thank Professor Antonio Ferri for his suggestions and invaluable discussions, and Professor Victor Zakkay for his supervising the whole experimental work. Thanks are also extended to Dr. Anthony M. Agnone for his assistance in the presentation of this paper.

ABSTRACT

The feasibility of using slot injection to establish a turbulent boundary layer corresponding to a known Reynolds number is investigated here experimentally. The basic concept proposed by Professor A. Ferri consists of injecting secondary air through a slot. The air is injected at the same local static pressure and at a selected stagnation temperature to simulate a given upstream heat conduction condition. The mass of the injected air can be controlled to match a desired Reynolds number. In the present experiment, secondary air was injected through a supersonic nozzle over a flat plate model. The outer stream Mach number at the slot location (1 inch behind the leading edge) was in the range of 5.43 - 5.83, and the Reynolds number R_{ex} based on the streamwise distance was varied between 4×10^5 to 2×10^5 per inch. Tests were conducted with different injection air conditions, with values of $R_{e\theta}$ and $\lambda\left(= \frac{\rho_i u_i}{\rho_e u_e}\right)$ in the range of 0 - 1500 and 0 - 0.172 respectively.

Heat transfer rates were measured at about 4 to 8 inches (54 ~ 108 slot heights) behind the slot and the results were compared with theoretical estimates. Static pressure measurements were made over the surface in the streamwise direction. Velocity and Mach number profiles were determined at a position 7 inches (95 slot heights) downstream of the slot. Laminar and turbulent profiles were calculated from the Crocco method and 1/7 power law respectively to compare with the results of measurements. The experimental results obtained indicate that this method is effective in establishing a turbulent boundary layer having a prescribed value of $R_{e\theta}$.

TABLE OF CONTENTS

LIST OF FIGURES

FIGURE

FIGURE

NOMENCLATURE

c	Specific heat of wall material
C_p	Specific heat at constant pressure
d	Wall thickness of the model
h_j	Injection nozzle height
M	Mach number
p	Pressure
Pr	Prandtl number
q	Heat transfer rate $[\frac{BTU}{ft^2 sec}]$
R_{ex}	$\frac{\rho_e u_e x}{\mu_e}$, Reynolds number based on the streamwise coordinate x
$R_{e\theta}$	$\frac{\rho_e u_e \theta}{\mu_e}$, Reynolds number based on the momentum thickness θ
T	Temperature
t	Time
u	Flow velocity in the streamwise direction
x	Streamwise coordinate
y	Coordinate normal to the model surface
δ	Boundary layer thickness
θ	Momentum thickness
λ	$\frac{\rho_j u_j}{\rho_e u_e}$, Mass flow rate parameter
μ	Viscosity
ρ	Density

χ $\quad \dfrac{M_\infty^3}{\sqrt{(R_{ex})_\infty}}\sqrt{\dfrac{\rho\mu}{\rho_\infty\mu_\infty}}$, Viscous interaction parameter

Subscripts

aw Adiabatic wall conditions

e Outer flow conditions, edge of the boundary layer

j Injection air

t Local stagnation conditions

w Conditions at the wall

∞ Free stream conditions

oj Stagnation conditions of injection air

$o\infty$ Stagnation conditions of free stream

Superscripts

* Conditions at reference enthalpy (or temperature)

I. INTRODUCTION

One of the most difficult experimental problems to be solved in transonic, supersonic and hypersonic aerodynamics is the correct simulation of the boundary layer and inviscid flow interaction. Specially in transonic and hypersonic tests the available Reynolds number is much smaller than in full scale. Therefore, the correct simulation is not possible. Usually the transition from laminar to turbulent flow is induced by tripping the boundary layer by means of local roughness. However, this approach is somewhat arbitrary, because it does not permit the determination of the actual Reynolds number of the boundary layer. This effectiveness changes with local conditions and is different at different angles of attack, and this roughness often affects the flow outside the boundary layer.

A different method for boundary layer tripping that gives better controlled simulation has been proposed by Professor A. Ferri. The scheme consists of injecting secondary air flow tangentially through a backward facing slot near a leading edge. Experiments with slot injection (Refs. 1, 2, 3, 4, and 5) indicate that the mixing between the injected air and the boundary layer is rapid and even at sufficiently low Reynolds number the flow is turbulent; at a small distance downstream of the slot the profile becomes a classical turbulent boundary layer profile. Because the mass injected through a slot can be controlled, the value of $R_{e\theta}$ of the boundary layer can be changed without changing the wind tunnel Reynolds number. In addition, $R_{e\theta}$ can be correctly evaluated from available information on slot cooling. The basic idea of this method is shown schematically in Fig. 1.

To investigate experimentally the above concept, experiments have been conducted at Mach 6 on a flat plate model having slot injection near the leading edge. The investigation has been directed to give specific informations that could be used in a study of a hypersonic inlet to be tested at Mach 6. Heat transfer rates, static pressure distributions over the surface and profiles have been obtained for several values of $R_{e\theta}$ ranging from 0 (the nominal $R_{e\theta}$ at the injection slot corresponds to the case of zero injection) to 1500.

The experiments indicate that a turbulent boundary layer can be induced at low free stream Reynolds number with this method and that $R_{e\theta}$ can be controlled by adjusting the mass flow injected through the slot.

II. APPARATUS AND TEST CONDITIONS

1. Wind Tunnel

The present experiments were conducted in a Mach 6 blowdown type axisymmetric wind tunnel (12 inches in diameter) at the New York University Aerospace Laboratory. A more complete description of this facility is presented in Ref. 5.

2. Model

The model used in the present experiments is a flat plate having sharp leading edge and a span of 6 inches, and the plate was supported horizontally from the downstream side of the tunnel. The model configuration is shown in Fig. 2, and the details of the injection nozzle are shown in Fig. 3. The splitter plate thickness is 0.02 inches. In the present experiments a supersonic nozzle has been used, because a supersonic injection flow requires a smaller slot height for the conditions required. A subsonic injection flow is preferable when local small pressure perturbations due to injection must be avoided. All the dimensions of the nozzle are determined so as to give sufficient large range of $R_{e\theta}$ (1500 ~ 2000, for injection cases) to establish the required turbulent flow. The design Mach number of the slot nozzle, M_j, has been selected equal to 2.06. The Reynolds number based on the momentum thickness, $R_{e\theta}$, ranged from 730 to 1500 (for injection cases), whereas the Mach number (M_j) varied from 1.60 to 1.94. An air supply pipe was heated by a 3-kw heater outside the tunnel to obtain hot injection air having approximately the same total temperature as the total temperature of free stream, since it was desired in this test to produce only the momentum defect while keeping the total enthalpy profile unchanged. The spanwise uniformity of the injected air distribution was measured at the beginning of the test series.

3. Instrumentations

Two types of measurements were performed. Heat transfer and static pressure distributions along the surface were determined. The boundary layer profiles were measured at a station 7 inches downstream of the slot by means of a traversing probe.

The model was instrumented with pressure taps and chromel-alumel thermocouples welded on a stainless steel shimstock of 0.01 inch thickness. All the thermocouples were calibrated beforehand to ensure accurate temperature readings. A scani-valve was used to obtain the static pressure distribution over the model surface. The locations of these pressure taps and thermocouples are shown in Fig. 2 and Fig. 3. A probe that determines the stagnation temperature, the total and static pressure was used for the measurement of profiles.

4. Test Conditions

The tests were performed at two different free stream conditions, with several values of injection mass flow. Actual test conditions covered in this experimental work are summarized in Table 1.

III. EXPERIMENTS AND RESULTS

One of the important parameters which determines the state of a boundary layer is the Reynolds number based on the momentum thickness, $R_{e\theta}$, defined as:

$$\left.\begin{aligned} R_{e\theta} &= \frac{\rho_e u_e \theta}{\mu_e} \\ \text{where } \theta &= \int_0^\delta \frac{\rho u}{\rho_e u_e} \left(1 - \frac{u}{u_e}\right) dy \end{aligned}\right\} \tag{1}$$

When the slot flow is uniform, the expression for the momentum thickness at the slot location can be simplified as (See Fig. 1):

$$\theta = \frac{\rho_j u_j}{\rho_e u_e} \left(1 - \frac{u_j}{u_e}\right) h_j \tag{2}$$

where h_j is the slot height. From Eqs. (1) and (2), the Reynolds number based on the momentum thickness, $R_{e\theta}$, at the slot location can be expressed as follows:

$$R_{e\theta} = \frac{\rho_j u_j h_j}{\mu_e} \left(1 - \frac{u_j}{u_e}\right) \tag{3}$$

where u_e and μ_e refer to the outer stream conditions at the slot location. In the present tests the slot is located 1 inch downstream of the leading edge. The flat plate model has been designed corresponding to values of $R_{e\theta}$ of about 1500-2000. Such values of $R_{e\theta}$ are considered sufficient to induce locally a turbulent boundary layer, and correspond to the following conditions.

Design conditions:

$$\left.\begin{array}{llll} M_\infty = 6.0 & & M_j = 2.06 \\ T_{o\infty} = 900^\circ R & & p_j = p_e \\ p_{o\infty} = 200 \text{ psi} & & T_{oj} = T_{o\infty} \end{array}\right\} \qquad (4)$$

The actual Mach number of the injected air measured during the tests varied from 1.60 to 1.94. These values are lower than the design value and show some scattering. This is probably due to the small dimension of the passage upstream of the slot, and also due to the difficulty in reading very small values of pressures (p_j, p_{oj}) accurately from which M_j was computed. The injected air was heated by means of an electrical heater to a stagnation temperature approximately equal to the free stream stagnation temperature.

Cold air could be injected to change independently the total enthalpy profile of the boundary layer and to simulate the effect of wall cooling.

It has been shown (Refs. 1-5) that the mixing between slot injected air and an external flow is controlled by a parameter λ, defined as:

$$\lambda = \frac{\rho_j u_j}{\rho_e u_e} \qquad (5)$$

In the present experiments, the mass flow rate parameter λ was in the range of 0 to 0.172 as shown in Table 1.

The two-dimensionality of the main flow (no tip effects) at the model centerline was checked experimentally up to $x \simeq 9$ in. ($x/h_j \simeq 122$). The flat plate was oriented at zero angle of attack; for these conditions the Mach number M_e of the outer stream at the position of the slot was in the range of 5.43 to 5.83 which is slightly lower than the free stream Mach number due to viscous interactions ($\chi \simeq 0.32 \sim 0.45$, at the slot location). Reynolds numbers obtained in the Test No. 1-4 were about 4×10^5 1/in. at the slot location, whereas those of Test No. 5-7 were about 2×10^5 1/in.

Velocity and Mach number profiles were measured at $x = 8$ in. ($x/h_j \simeq 108$) from the leading edge (i.e. 7 in. from the slot).

To determine the state of the boundary layers, laminar and turbulent boundary layer velocity and Mach number profiles were calculated for comparison with the measured profiles. The Crocco method (Pr = 0.75, Ref. 6) determines the laminar profile and the boundary layer thickness, δ, completely for the given conditions. For estimating typical turbulent boundary layer profiles, the 1/7 power law and the Crocco relation for the temperature field have been employed, following the next expression.

$$\left.\begin{aligned} \frac{u}{u_e} &= \left(\frac{y}{\delta}\right)^{1/7} \\ \frac{T_t - T_w}{T_{t\infty} - T_w} &= \frac{u}{u_e} \; ; \; Pr = 1 \end{aligned}\right\} \qquad (6)$$

where the boundary layer thickness, δ, was taken from the measured profile as the point where $u/u_e \simeq 0.98$ for convenience. In the above simple calculations, the effect of the slot step was not taken into account.

The heat transfer rate was determined using the transient technique, and is derived from the slope of the temperature as a function of time by means of the following expression.

$$q = (\rho\ c\ d)_w \ \left(\frac{dT}{dt} \right)_{t=0} \tag{7}$$

All the heat transfer data were reduced and expressed in terms of $q/(T_{O\infty}-T_w)$, were measured values of local wall temperature, T_w, were used at each thermocouple location. The heat transfer rates to be expected for laminar and turbulent boundary layer over the flat plate were calculated, using the flat plate reference enthalpy method (FPREM, Ref. 7). The heat transfer rates are given by the following expressions: (x = 0 was taken at the model leading edge.)

$$q_w = 0.322\ C_p\ Pr^{*^{-\frac{2}{3}}}\ \rho^*\ u_e\ R_e^{*^{-\frac{1}{2}}}\ (T_{aw} - T_w);\ \text{for laminar flow} \tag{8}$$

$$q_w = 0.0296\ C_p\ Pr^{*^{-\frac{2}{3}}}\ \rho^*\ u_e\ R_e^{*^{-\frac{1}{5}}}\ (T_{aw} - T_w);$$

$$\text{for turbulent flow and } 5 \times 10^5 < Re^* < 10^7 \tag{9}$$

where

$$\left.\begin{aligned} Re^* &= \frac{\rho^* u_e x}{\mu^*} \\ T^* &= 0.5\ (T_e + T_w) + 0.22\ (T_{aw} - T_e) \end{aligned}\right\} \tag{10}$$

The laminar heat transfer rates were also calculated, following the theoretical work by Cohen and Reshotko (Pr = 1 , Ref. 8). These estimates were compared with the experimental results.

The static pressure distributions along the x-axis over the entire plate surface were measured and shown in the figures along with the static pressures of the injection air and the wind tunnel.

Schlieren photographs were taken during the tests and Fig. 4 shows two examples of them. All the experimental results obtained are shown in Fig. 5 through 20 (Test No. 1-4, $R_{ex} \simeq 4 \times 10^5$ 1/in.) and in Figs. 21 through 28 (Test No. 5-7, $R_{ex} \simeq 2 \times 10^5$ 1/in.), including velocity and Mach number profiles, heat transfer rates and static pressure distributions.

Test No. 1 corresponds to the case of zero injection. The results (Figs. 5-8) clearly indicate that a laminar boundary layer exists at least up to x = 8 in. ($x/h_j \simeq 108$) from the leading edge. The static pressure is almost constant all over the surface along the x-axis (Fig. 8).

The results of small injection air flow (Test No. 2, $p_j \simeq 0.61\ p_e$) are shown in Figs. 9 through 12. A comparison of heat transfer measurements with estimated results shows that transition takes place near $x = 6 \sim 8$ in. ($x/h_j \simeq 82 \sim 108$). The value of $R_{e\theta}$ was 940 in this case.

Figures 13 through 16 show the results of Test No. 3, corresponding to an increased rate of injection mass flow with $R_{e\theta} = 1100$. In this case, the static pressure of injection air was slightly lower than the outer stream pressure ($p_j \simeq 0.83\ p_e$), and the boundary layer at $x = 7 \sim 8$ in. ($x/h_j \simeq 95 \sim 108$) was turbulent.

The results of higher injection mass flow which corresponds to Test No. 4 ($p_j \simeq 1.05\ p_e$) are shown in Figs. 17 through 20. This test corresponds to $R_{e\theta}$=1500. For these conditions, the boundary layer at x = 8 in. ($x/h_j \simeq 108$) was found to be also turbulent and similar to Test No. 3.

Additional tests were conducted at lower wind tunnel total pressures, with resulting Reynolds number R_{ex} of about 2×10^5 1/in.

No injection case (Test No. 5, Figs. 21-24) shows a laminar boundary layer up to x = 8 in. ($x/h_j \simeq 108$). In Test No. 6, only profiles were measured under the condition of $p_j \simeq p_e$ and $R_{e\theta} = 730$. The results (Figs. 25 and 26) show also a laminar boundary layer. Heat transfer rates were measured for Test No. 7, whose results are shown in Figs. 27 and 28. The boundary layer type is transitional over the surface at $x = 6 \sim 9$ in. ($x/h_j \simeq 82 \sim 122$). The value of $R_{e\theta}$ was about 1000.

It can be concluded from these experimental results that the boundary layer remains laminar behind the slot for the values of $R_{e\theta}$ approximately less than 1000, and above this value it is changed from transitional to turbulent within 100 slot heights under the conditions tested here.

IV. CONCLUSIONS

An experimental investigation of boundary layer tripping by means of slot injection in a supersonic flow has been performed. The secondary air was injected through a supersonic nozzle over the flat plate model at nearly the same stagnation temperature as free stream. The outer stream Mach number at the slot location (1 in. behind the leading edge) was in the range of 5.43 to 5.83, and Reynolds numbers based on the streamwise distance were about 4×10^5 1/in. and 2×10^5 1/in. depending on the free stream (wind tunnel) total pressures. Tests were conducted with different conditions of injection air, resulting in varied values of $R_{e\theta}$ and λ. Heat transfer rates were measured at about 4 to 8 inches (54 ~ 108 slot heights) behind the slot, and the results were compared with estimates of laminar and turbulent heat transfer on a flat plate by cited references. Static pressure distributions were obtained over the surface along the x-axis. Velocity and Mach number profiles were measured at x = 8 in. (108 slot heights) from the leading edge (7 in. behind the slot). Laminar and turbulent profiles for the flat plate were estimated by the theoretical and semi-empirical methods available and compared with experimental results.

From the experimental data obtained here, the following conclusions can be made.

1. The proposed technique permits us to create a turbulent boundary layer having a selected value of $R_{e\theta}$ at low wind tunnel Reynolds number without disturbing the outer stream. Therefore, it permits us to simulate a high Reynolds number test in a low Reynolds number wind tunnel.
2. The boundary layer with injection remains laminar downstream of the slot for values of $R_{e\theta}$ less than 1000. The same result is obtained for the case of zero injection ($R_{e\theta} = 0$). The boundary layer changes rapidly from transitional to turbulent over the flat plate when $R_{e\theta}$ passes from 1000 to 1500.

REFERENCES

1. Wieghardt, K., "Hot-Air Discharge for De-icing," AAF Translation Report No. F-TS-919-RE, 1946. (Original in Deutsche Luftfahrt Forschung, Forschungsbericht Nr. 1900, 1943).

2. Hartnett, J.P., Birkebak, R.C., and Eckert, E.R.G., "Velocity Distributions, Temperature Distributions, Effectiveness and Heat Transfer for Air Injected Through a Tangential Slot into a Turbulent Boundary Layer," J. Heat Transfer, Trans. ASME, Vol. 83, pp. 293-306, 1961.

3. Samuel, A.E. and Joubert, P.N., "Film Cooling of an Adiabatic Flat Plate in Zero Pressure Gradient in the Presence of a Hot Mainstream and Cold Tangential Secondary Injection," ASME Publication, 64-WA/HT-48, 1964.

4. Goldstein, R.J., Eckert, E.R.G., Tsou, F.K., and Haji-Sheikh, A., "Film Cooling with Air and Helium Injection Through a Rearward-Facing Slot into a Supersonic Air Flow," HTL TR No. 60, University of Minnesota, 1965.

5. Parthasarathy, K. and Zakkay, V., "Turbulent Slot Injection Studies at Mach 6," ARL 69-0066, 1969.

6. Van Driest, E.R., "Investigation of Laminar Boundary Layer in Compressible Fluids Using the Crocco Method," NACA TN 2597, 1952.

7. Eckert, E.R.G., "Engineering Relations for Friction and Heat Transfer to Surfaces in High Velocity Flow," J. Aero. Science, Vol. 22, No. 8, pp. 585-587, 1955.

8. Cohen, C.B. and Reshotko, E., "Similar Solutions for the Compressible Laminar Boundary Layer with Heat Transfer and Pressure Gradient ," NACA Report No. 1293, 1956.

TABLE I — TEST CONDITIONS

Test No.	Outer Stream at the Slot	Injection Air	$R_{e\theta}$	λ	Fig. No. of Results: Profiles	Fig. No. of Results: Heat Transfer & Pressure
1) $P_{0\infty}$ = 167 - 200 psi, R_{ex} = 3.9 - 4.3 x 10^5 $\frac{1}{in.}$ at the slot location						
1	p_e= 8.1 mm Hg $T_{0\infty}$= 770°R	No Injection	0	0	5, 6	7,8
2	p_e= 7.9 mm Hg $T_{0\infty}$= 745°R	p_j= 4.8 mm Hg T_{oj}= 650°R	940	0.076	9,10	11, 12
3	p_e= 7.1 mm Hg $T_{0\infty}$= 732°R	p_j= 5.9 mm Hg T_{oj}= 742°R	1100	0.134	13, 14	15, 16
4	p_e= 7.8 mm Hg $T_{0\infty}$= 768°R	p_j= 8.7 mm Hg T_{oj}= 778°R	1500	0.172	17, 18	19, 20
2) $P_{0\infty}$ = 74 - 83 psi, R_{ex} = 1.9 - 2.1 x 10^5 $\frac{1}{in.}$ at the slot location						
5	p_e= 5.0 mm Hg $T_{0\infty}$ = 735°R	No Injection	0	0	21, 22	23, 24
6	p_e= 4.1 mm Hg $T_{0\infty}$= 744°R	p_j= 4.8 mm Hg T_{oj}= 782°R	730	0.167	25, 26	——
7	p_e= 4.3 mm Hg $T_{0\infty}$ = 736°R	p_j= 4.3 mm Hg T_{oj}= 566°R	1000	0.162	——	27, 28

Wind Tunnel : M_∞ = 5.77 - 5.87, $T_{0\infty}$ = 730 - 770°R

Outer Stream at Slot : M_e = 5.43 - 5.83

Injection Air: M_j = 1.60 - 1.94

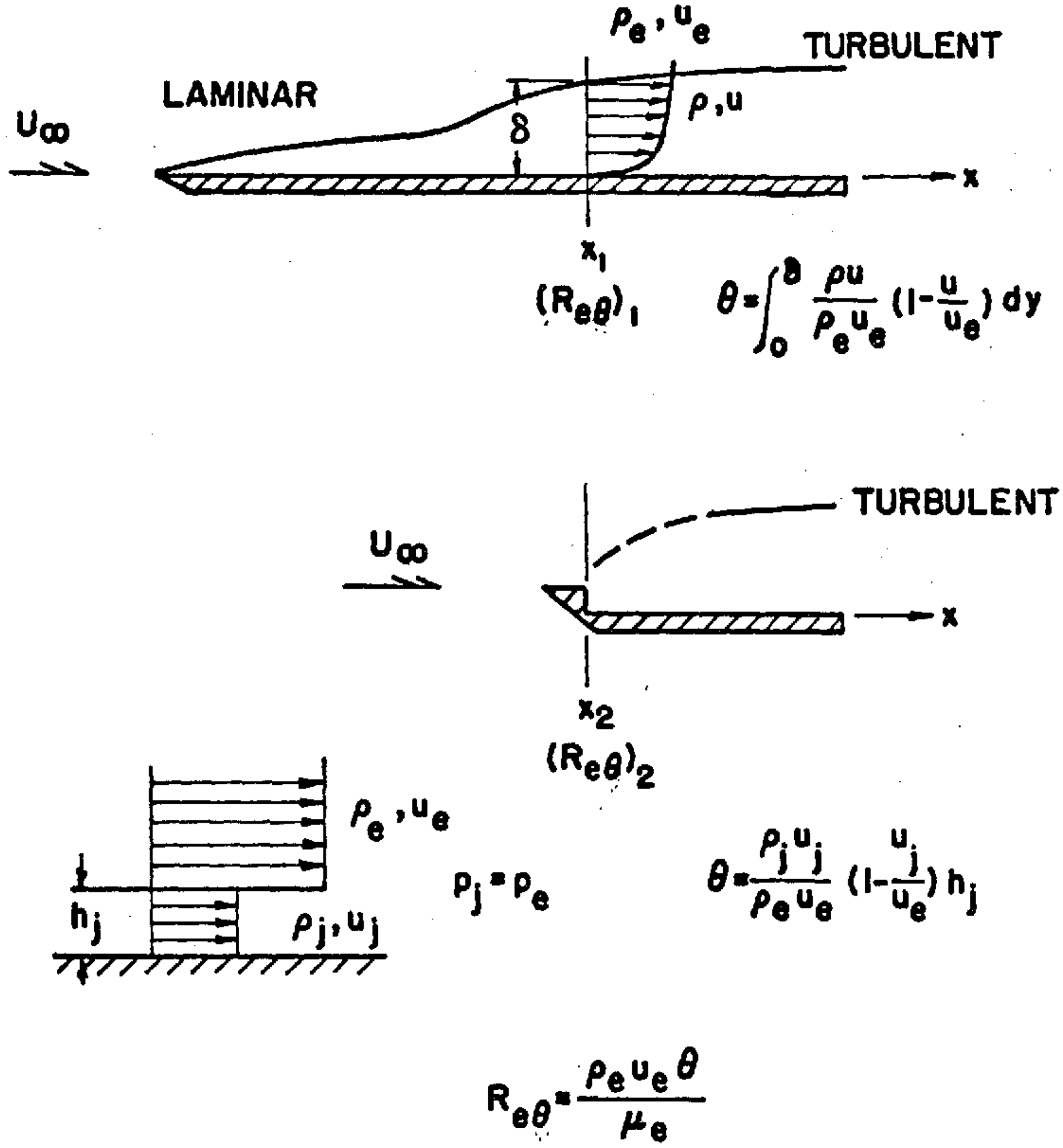


Fig. 1 Schematic Explanation of the Basic Idea of this Experiment

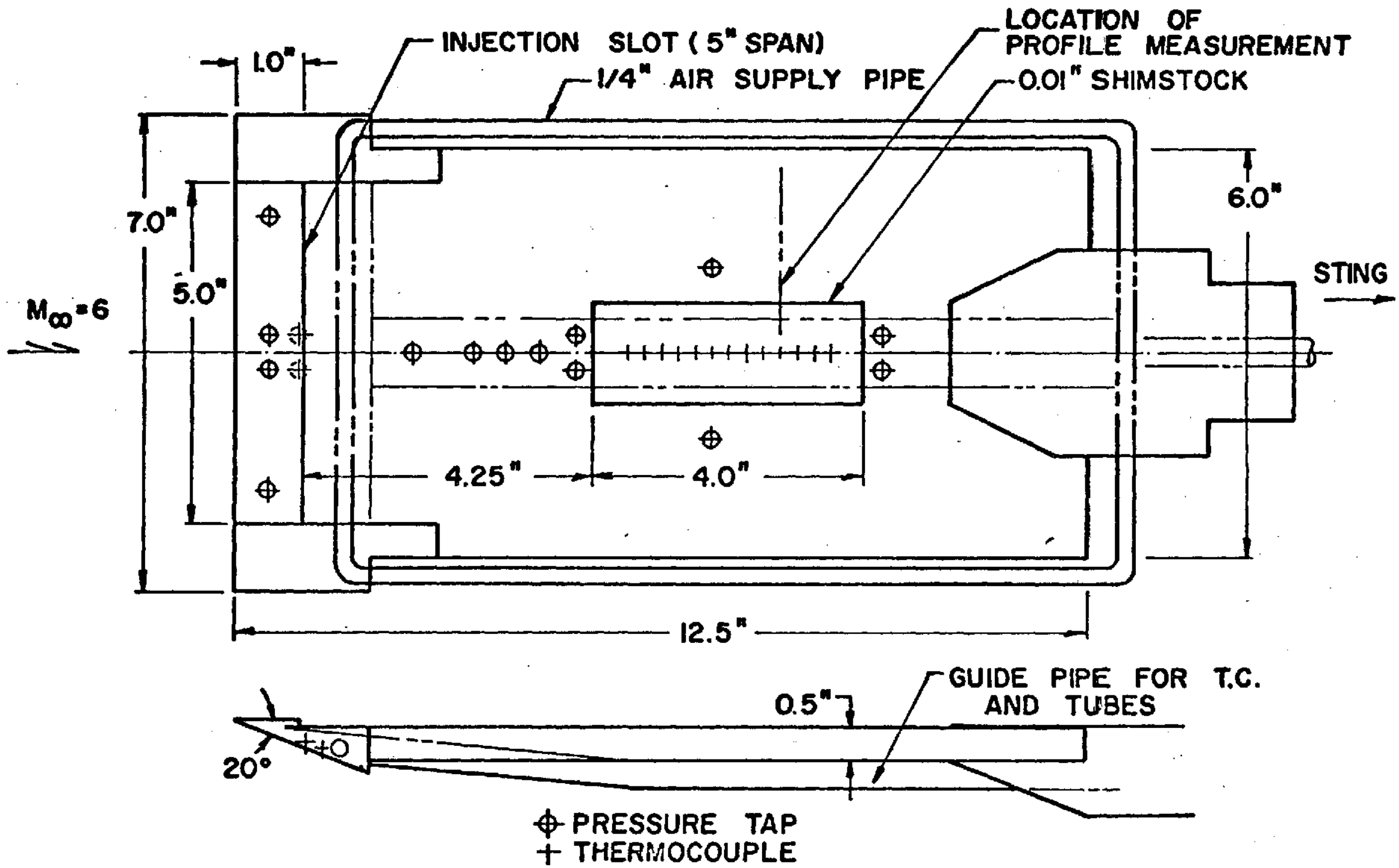


Fig. 2 Model Configuration

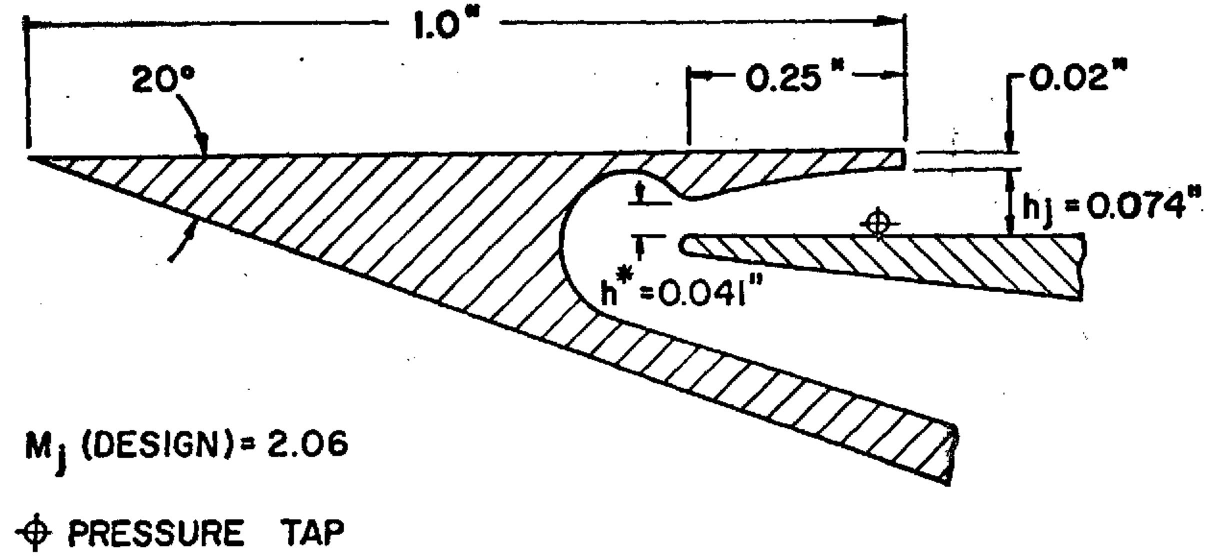
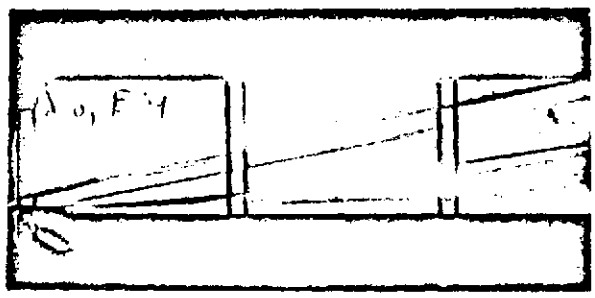
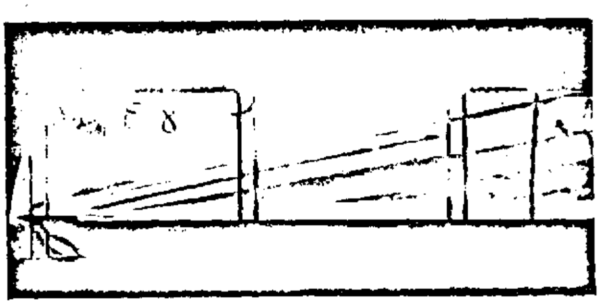


Fig. 3 Injection Nozzle Configuration



(i) No Injection Case

($P_{0\infty}$ = 210 psi; $R_{e\theta}$ = 0, λ = 0)



(ii) Injection Case

($P_{0\infty}$ = 250 psi; $R_{e\theta}$ = 2400, λ = 0.218)

Fig. 4 Examples of Schlieren Photographs

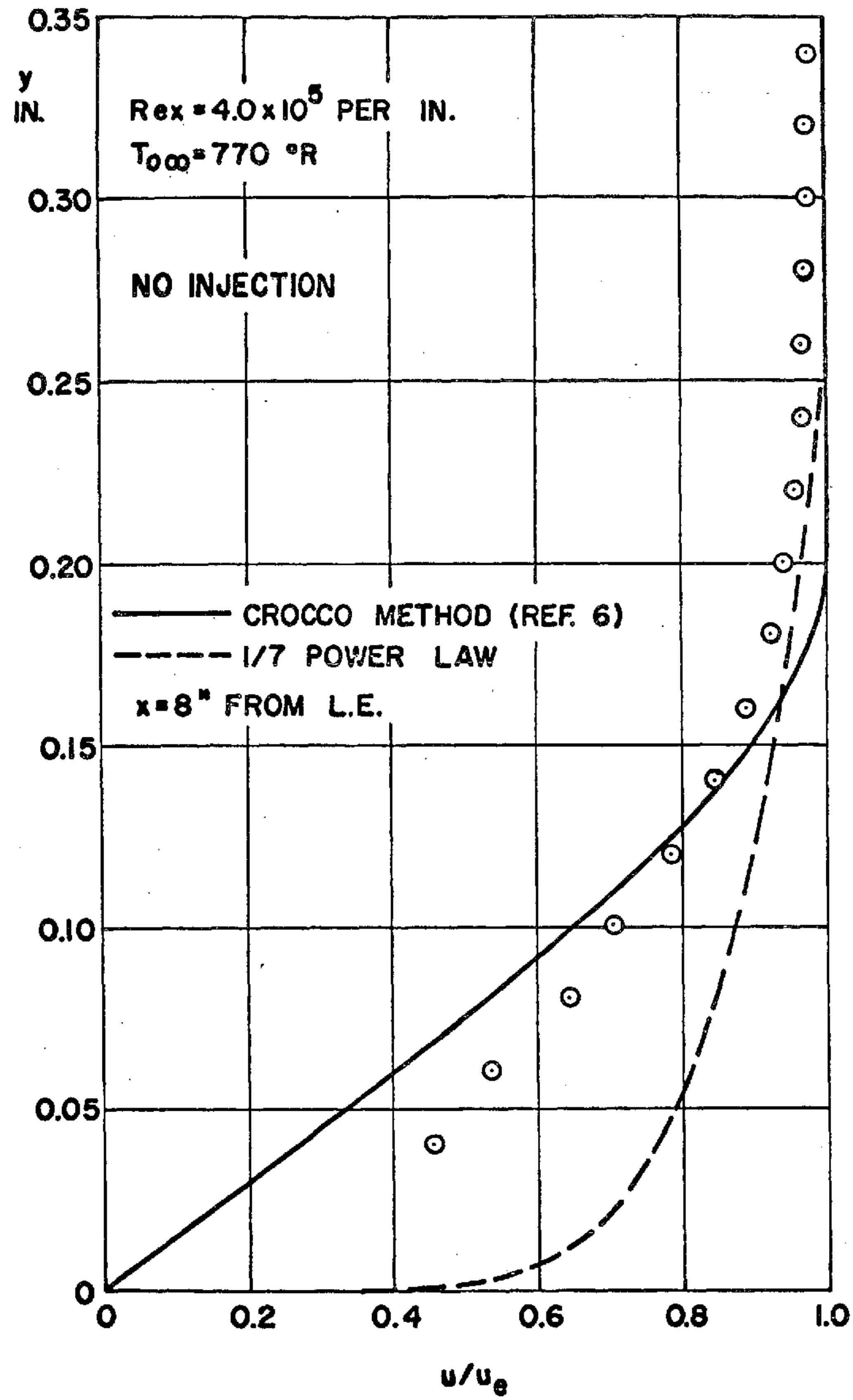


Fig. 5 Velocity Profile, Test No. 1

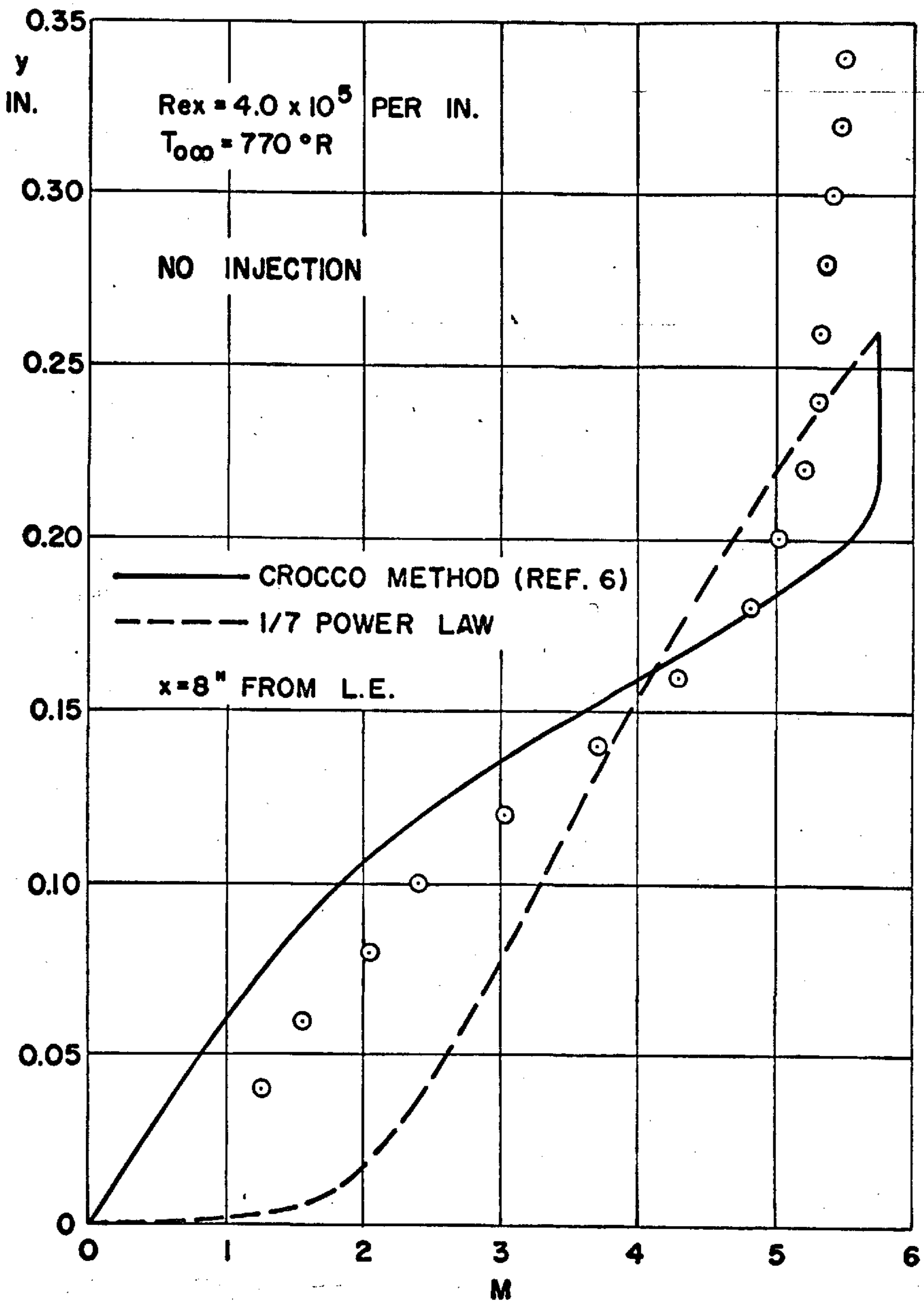


Fig. 6 Mach Number Profile, Test No. 1

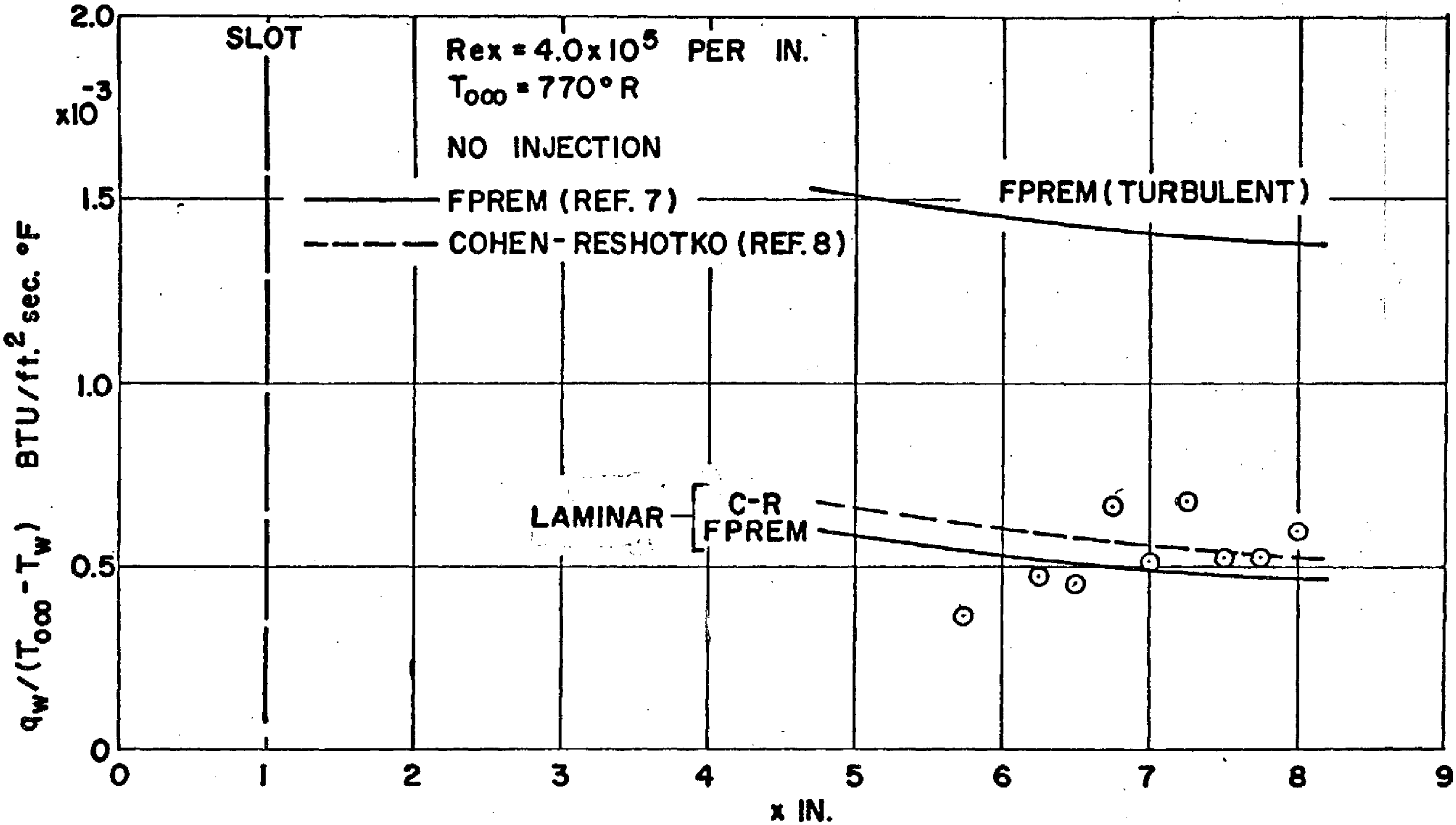


Fig. 7 Heat Transfer Distribution, Test No. 1

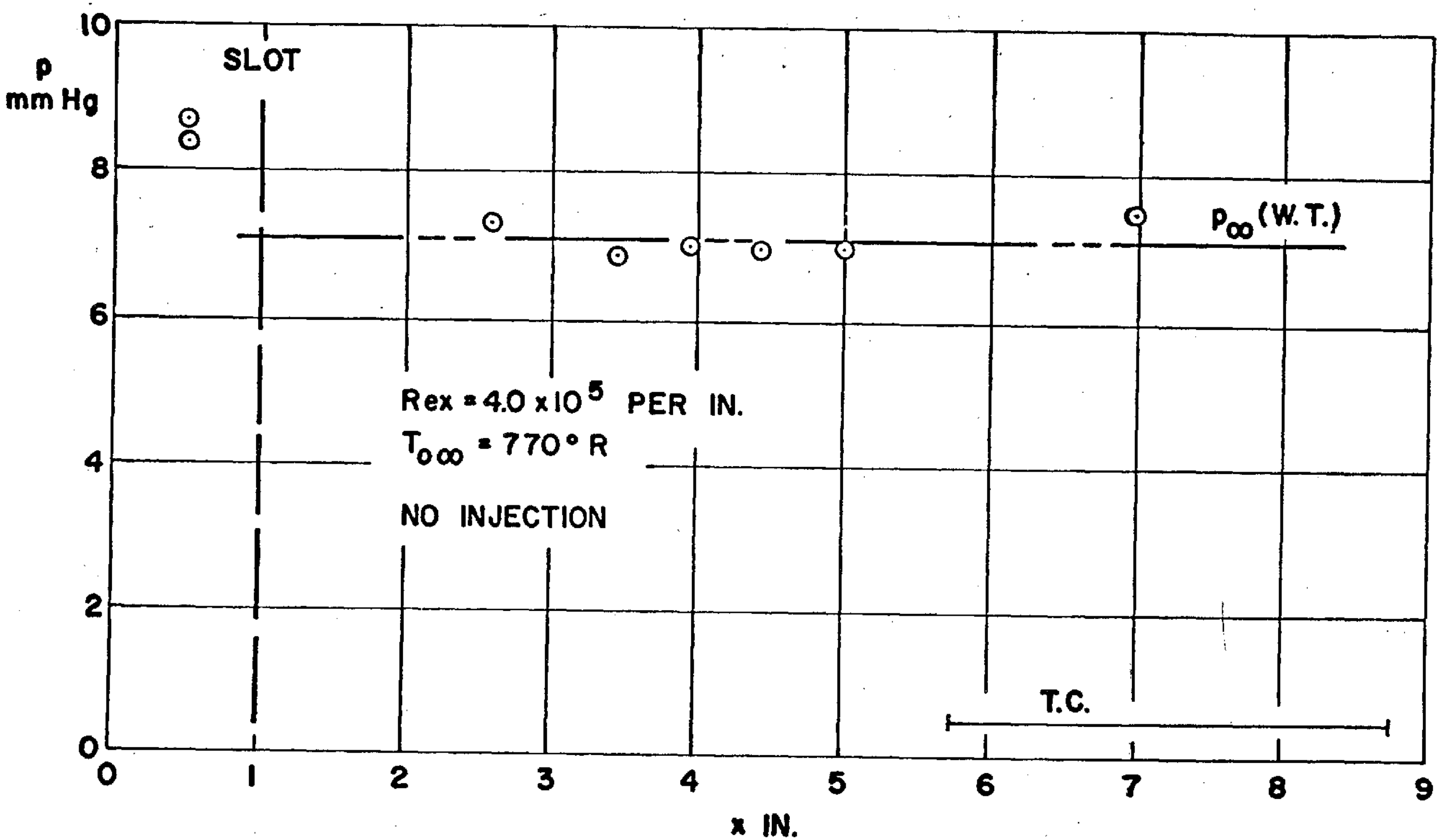


Fig. 8 Static Pressure Distribution, Test No. 1

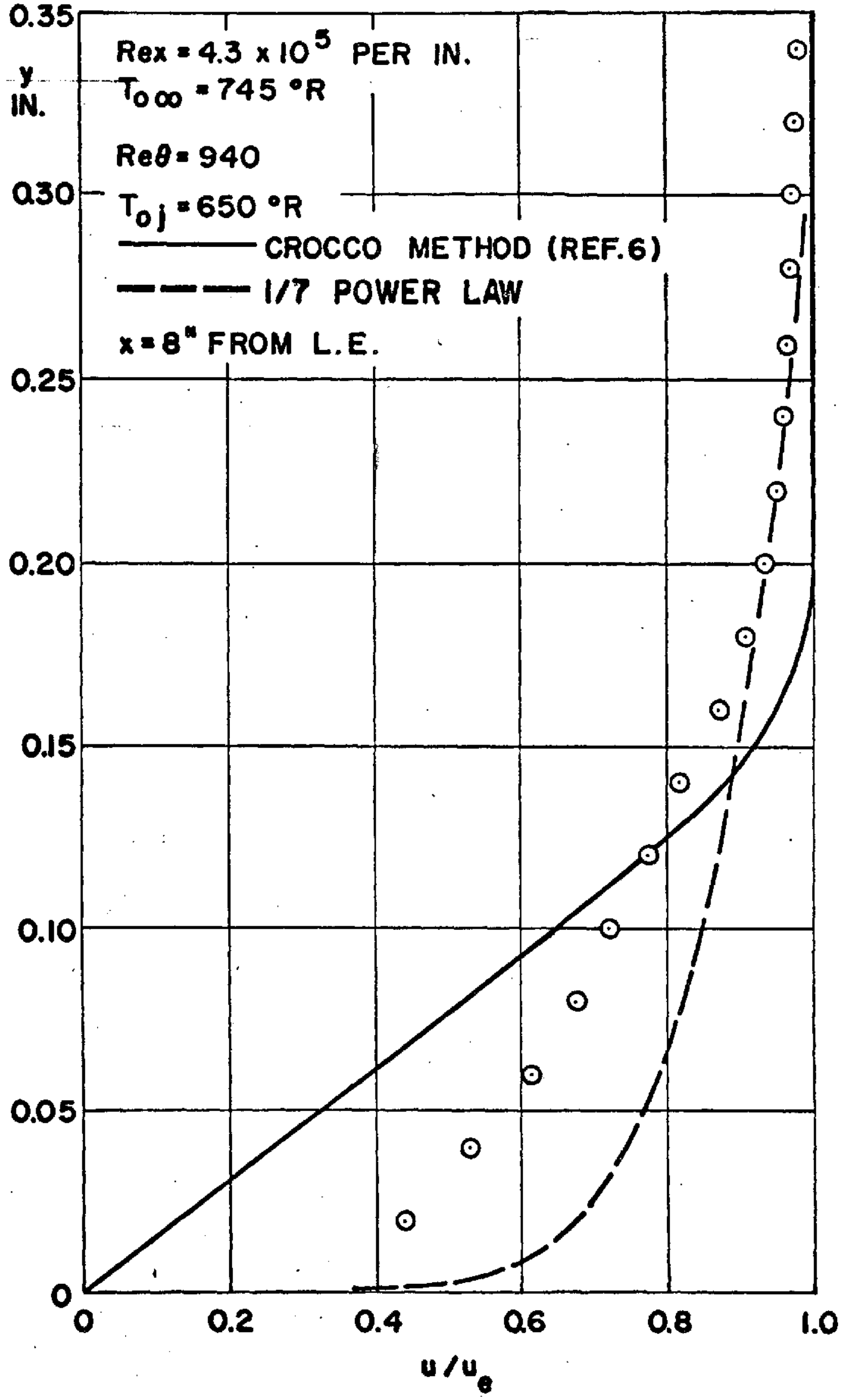


Fig. 9 Velocity Profile, Test No. 2

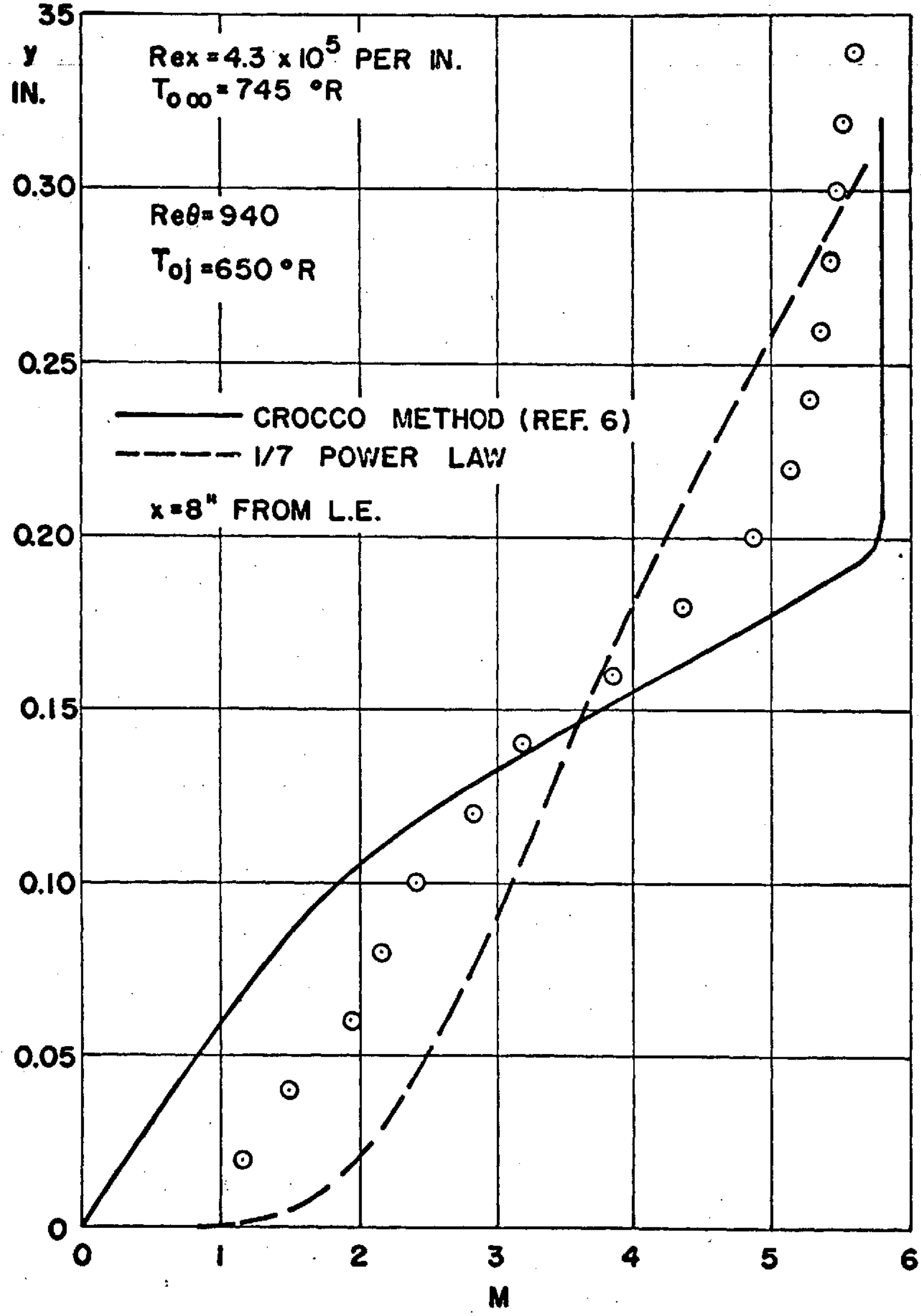


Fig. 10 Mach Number Profile, Test No. 2

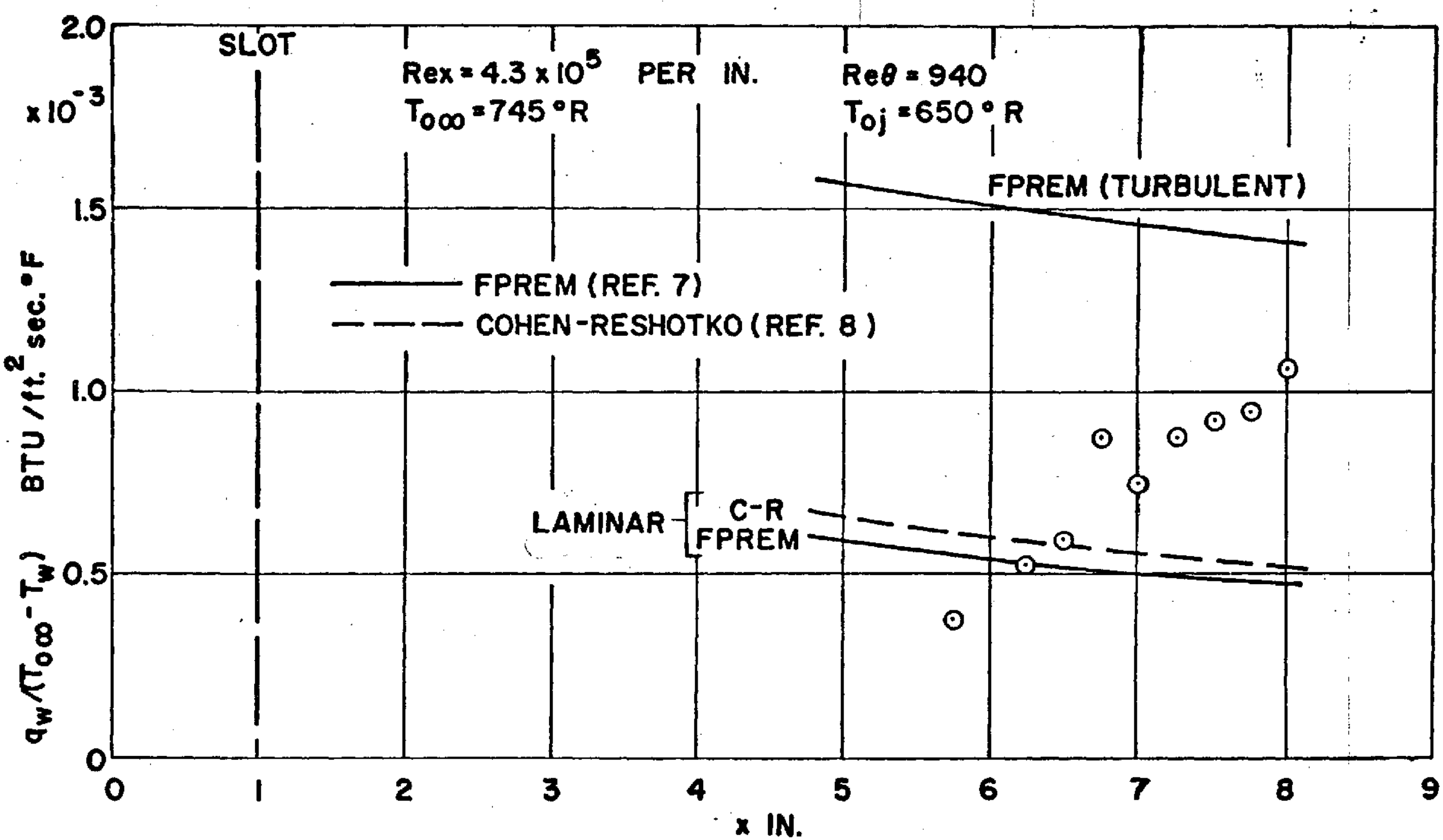


Fig. 11 Heat Transfer Distribution, Test No. 2

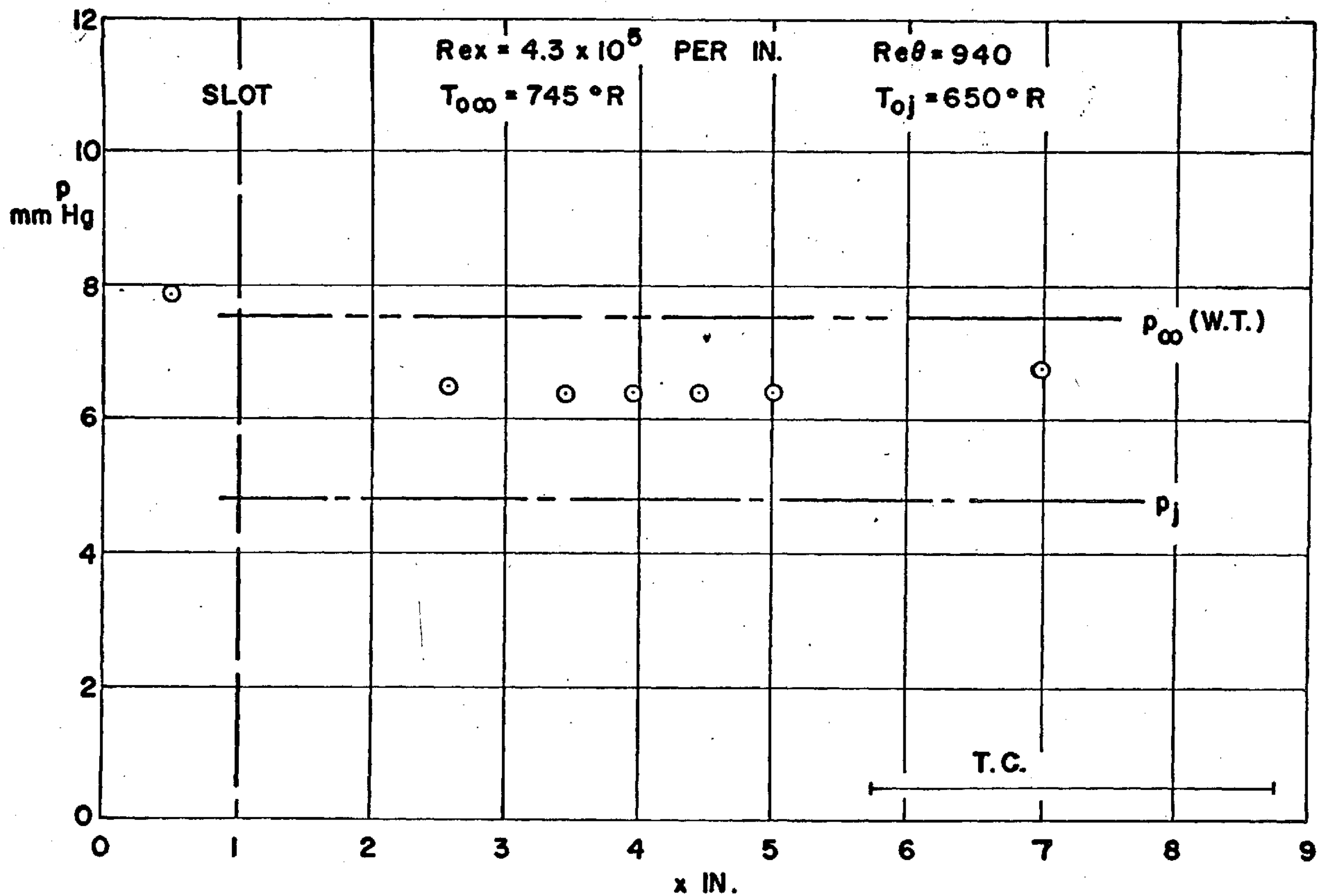


Fig. 12 Static Pressure Distribution, Test No. 2

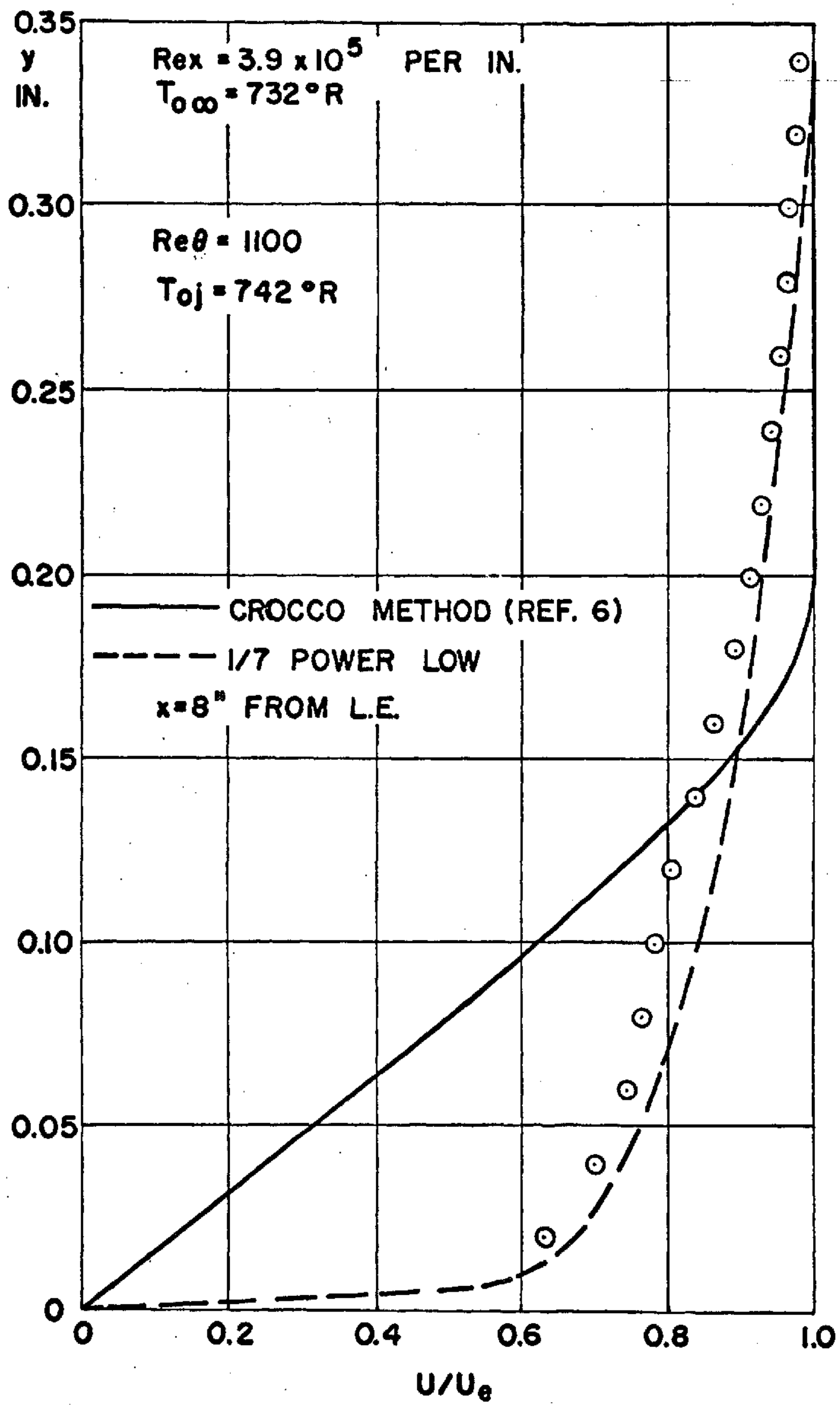


Fig. 13 Velocity Profile, Test No. 3

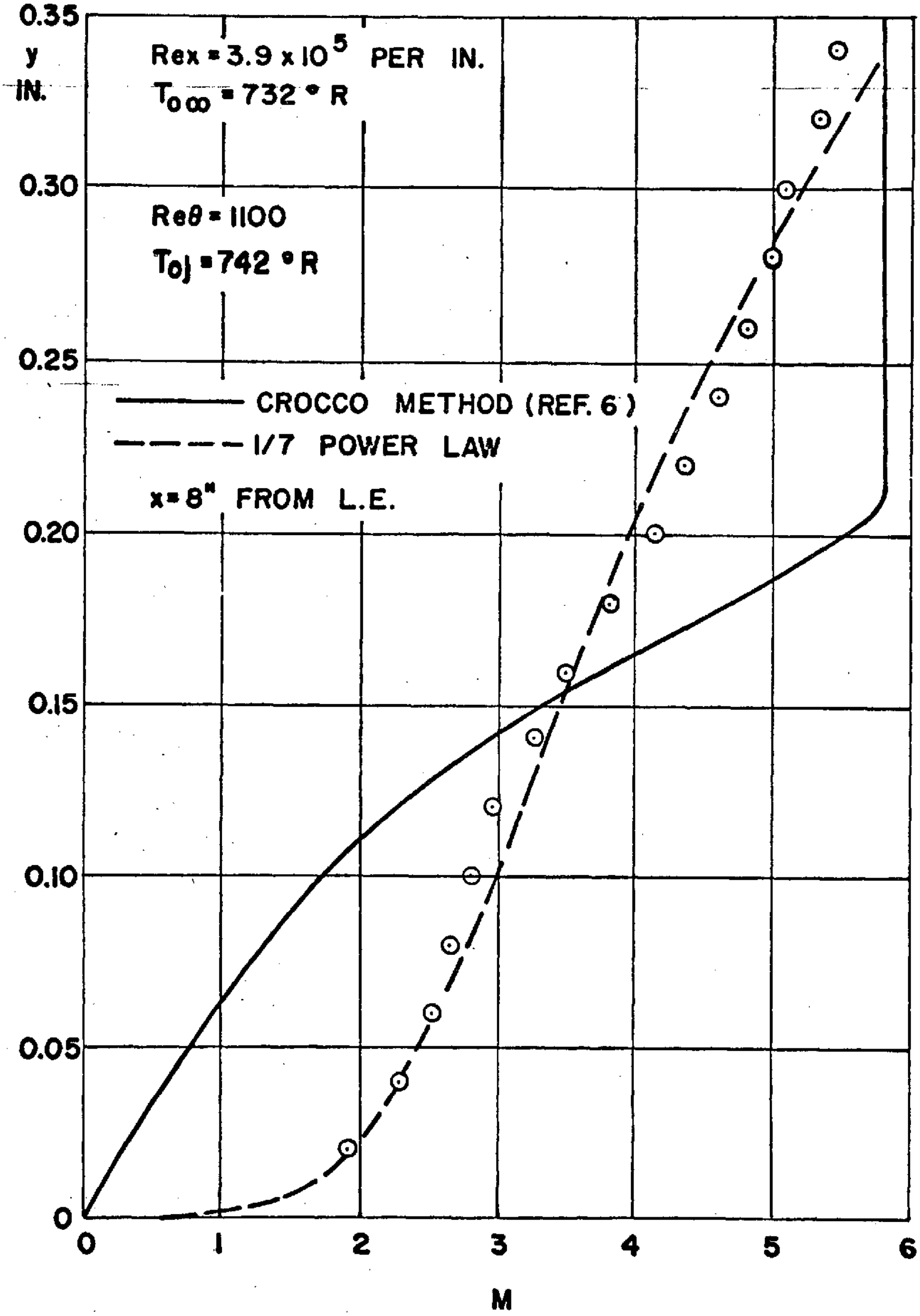


Fig. 14 Mach Number Profile, Test No. 3

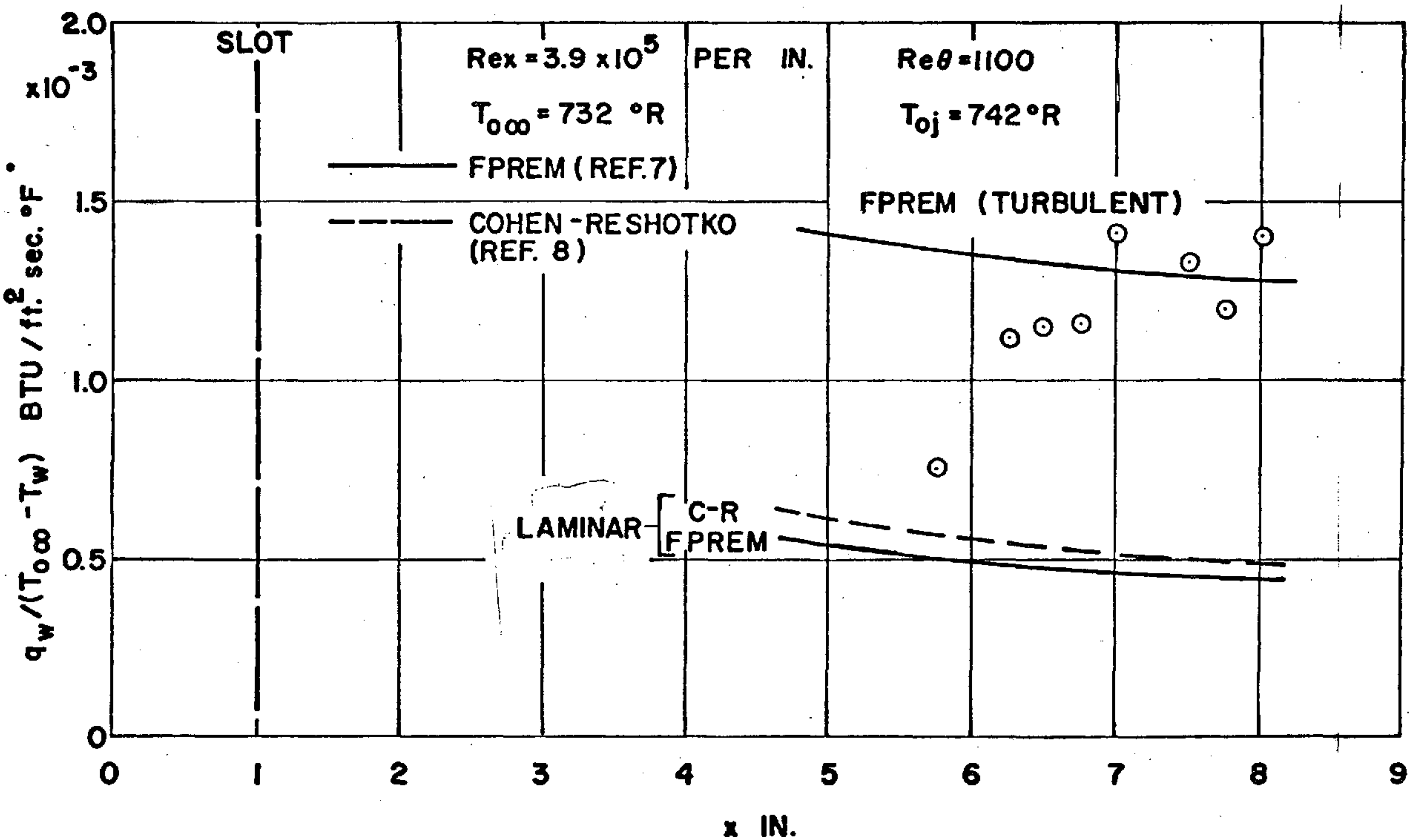


Fig. 15 Heat Transfer Distribution, Test No. 3

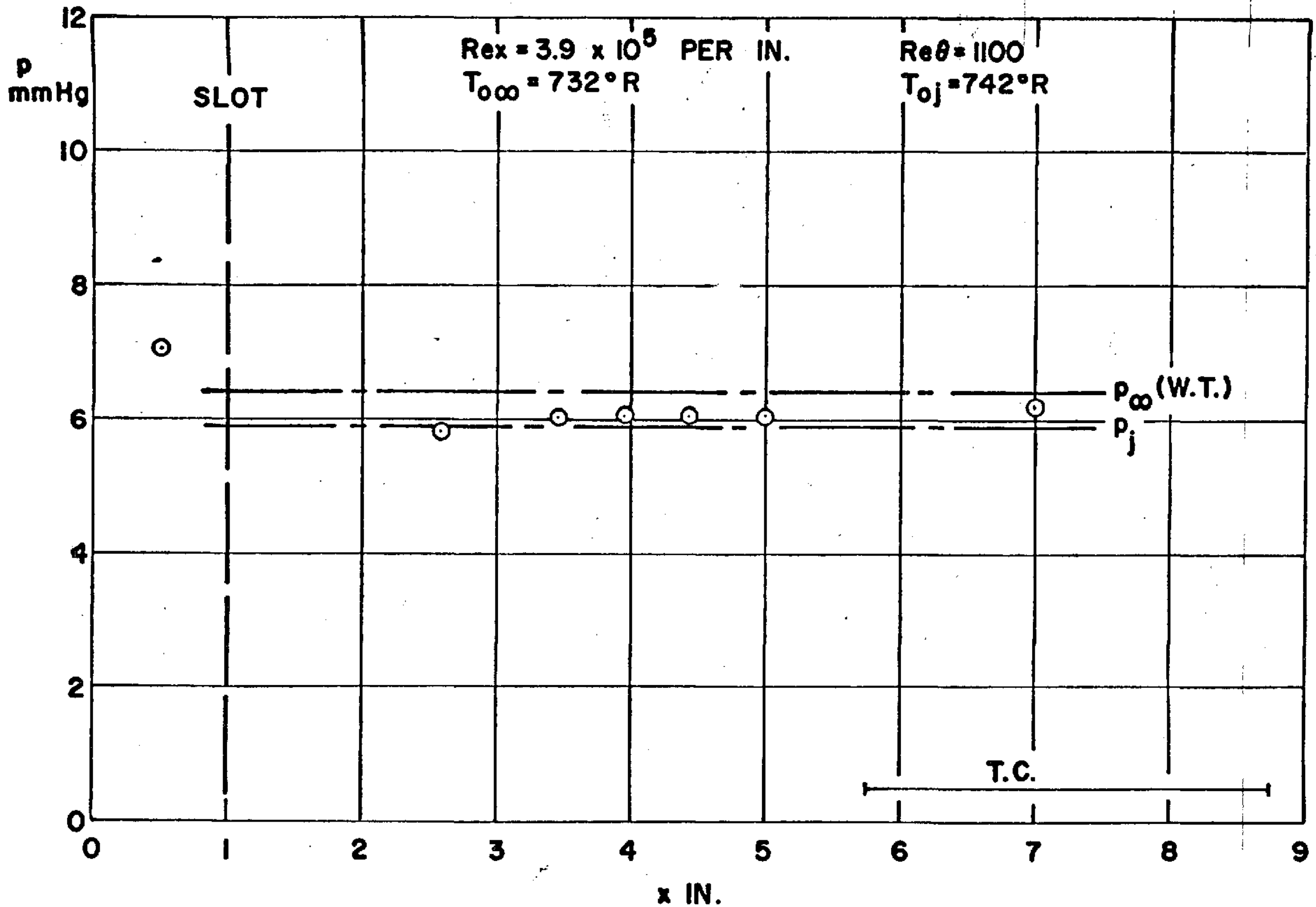


Fig. 16 Static Pressure Distribution, Test No. 3

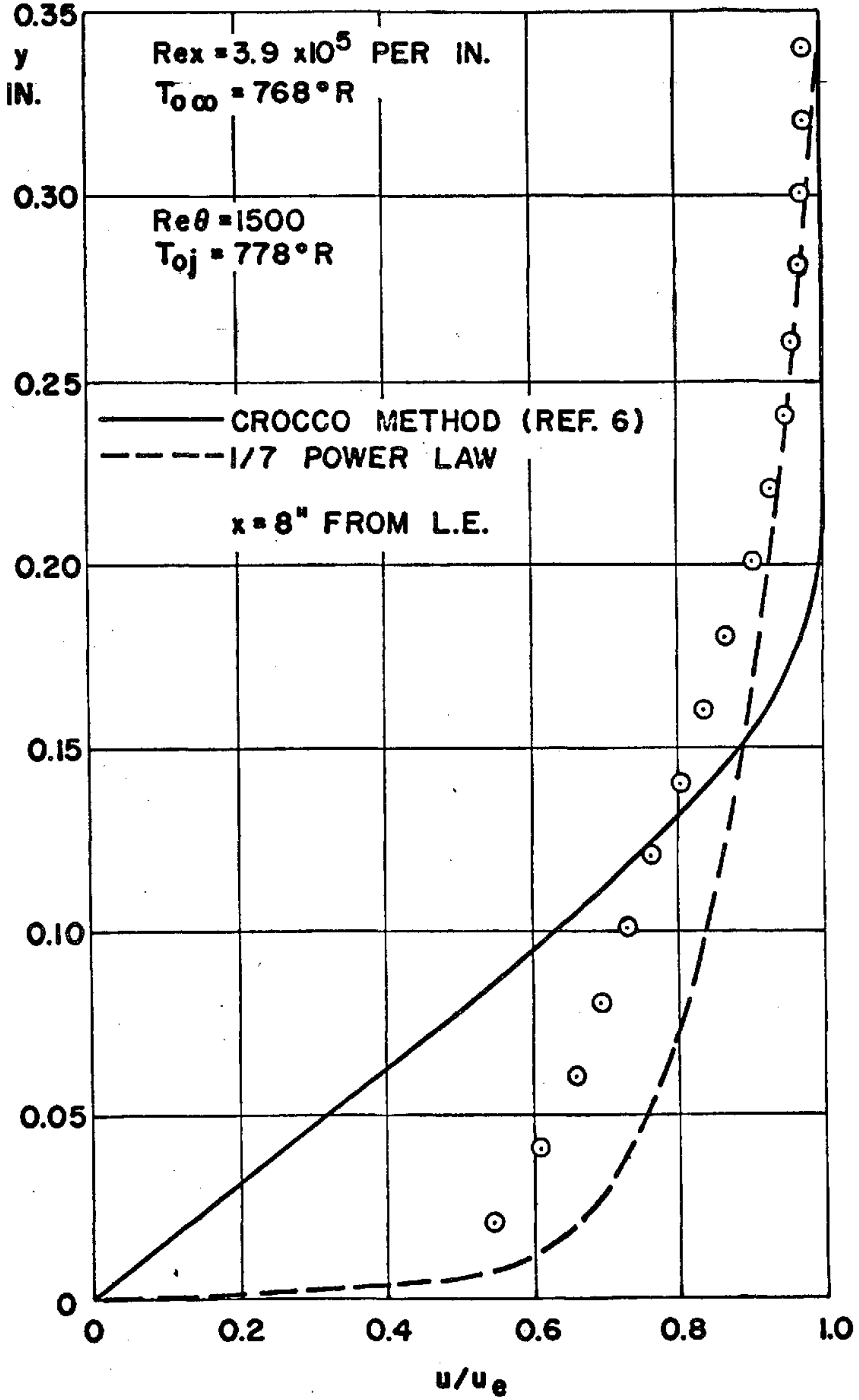


Fig. 17 Velocity Profile, Test No. 4

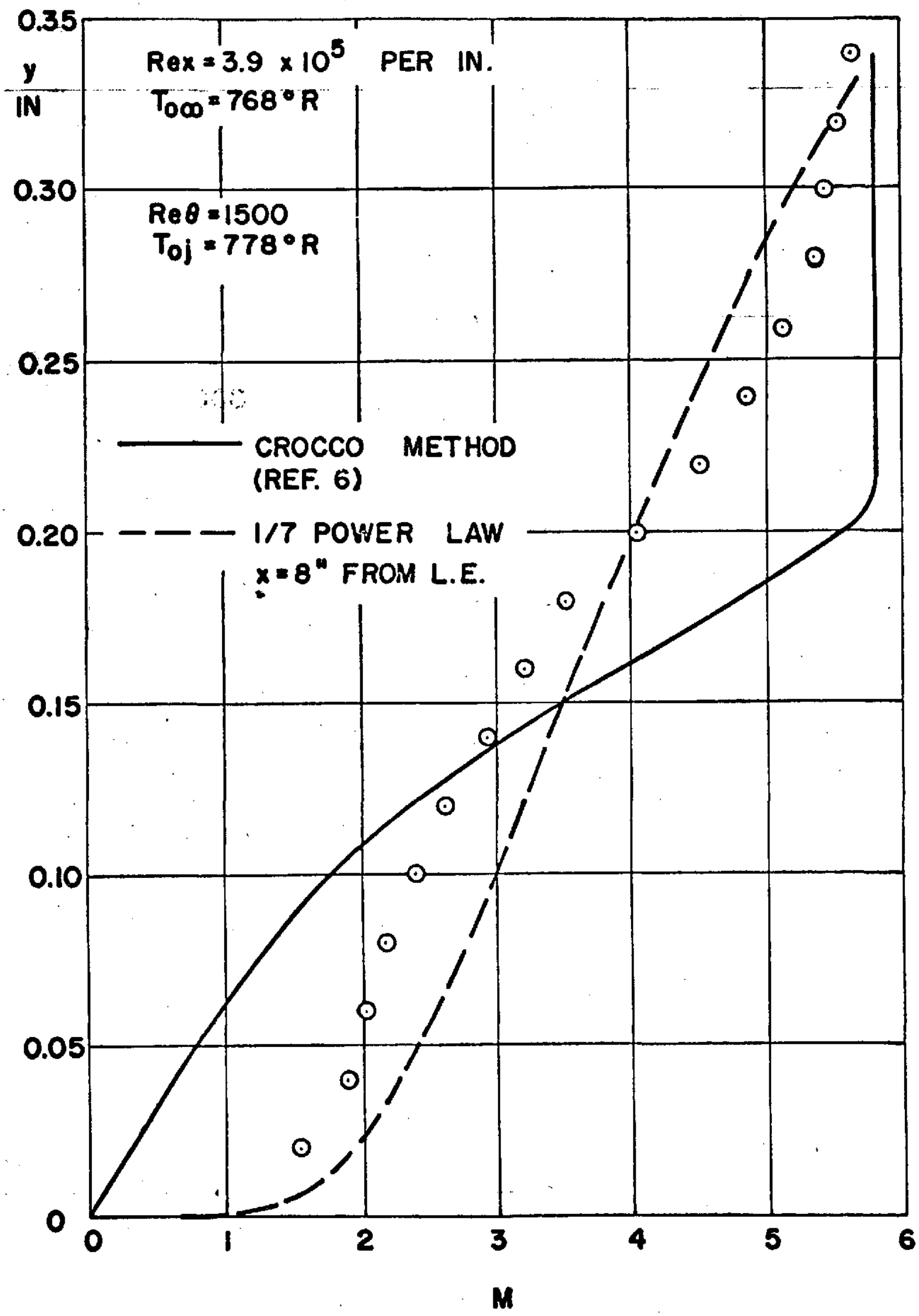


Fig. 18 Mach Number Profile, Test No. 4

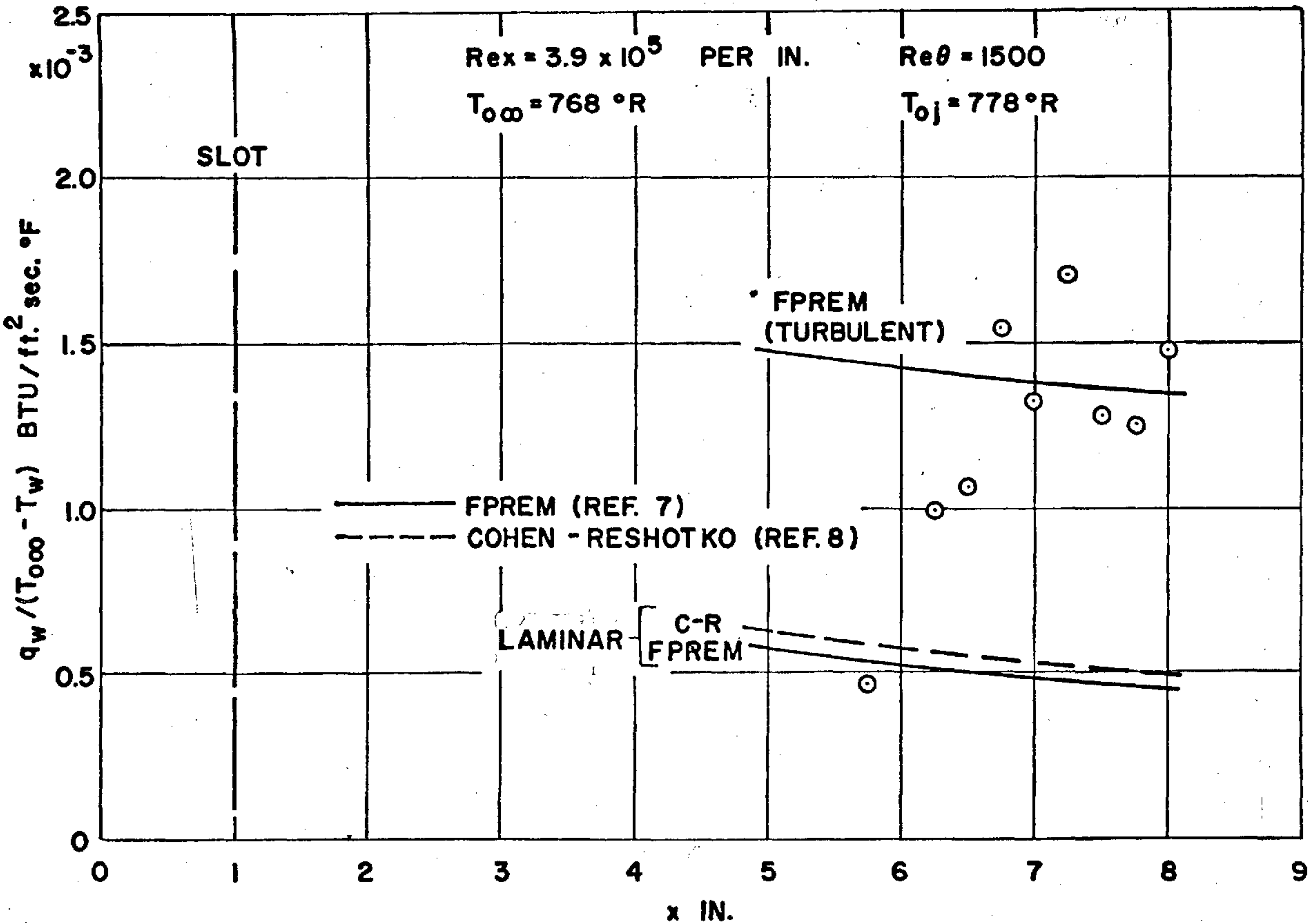


Fig. 19 Heat Transfer Distribution, Test No. 4

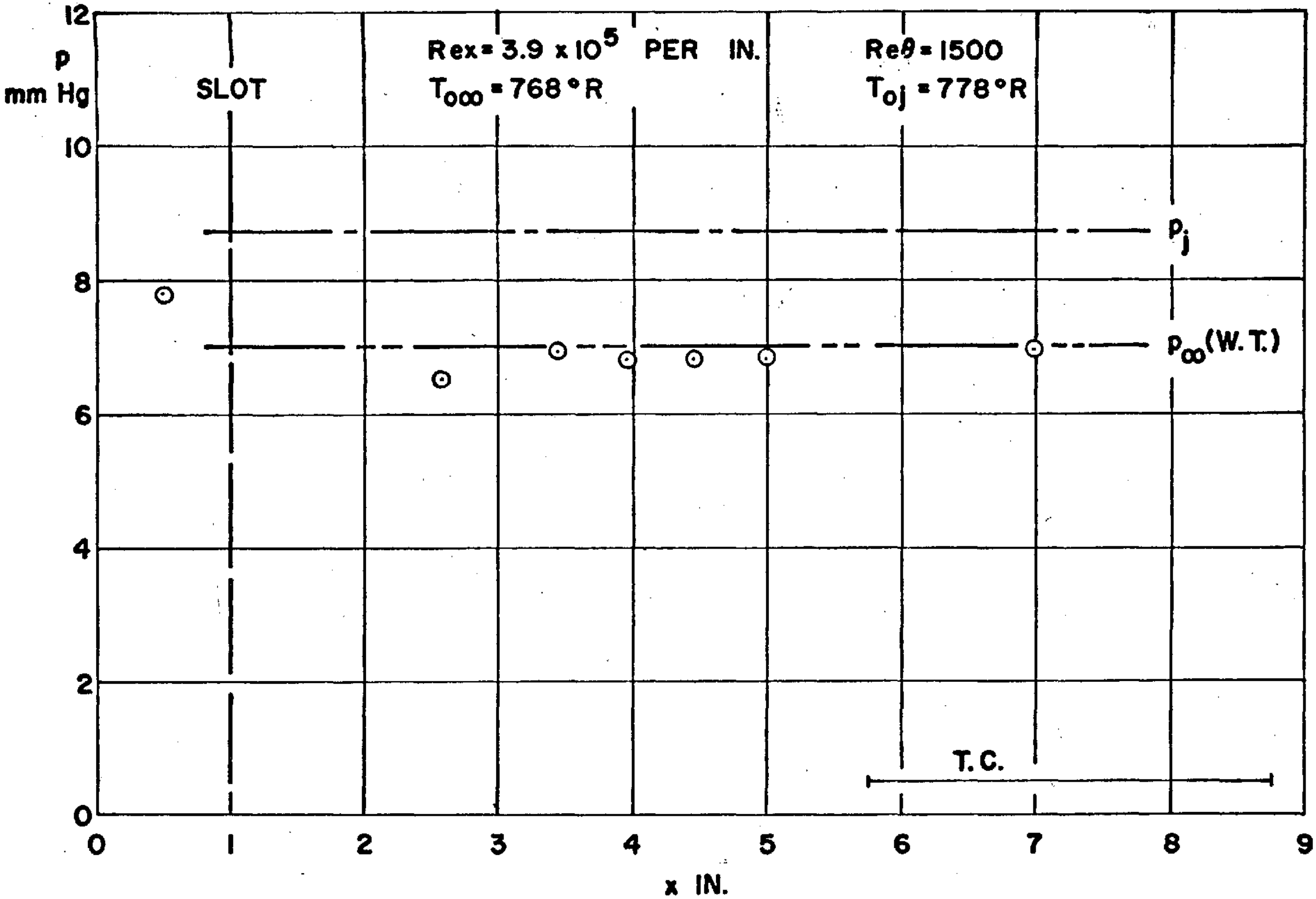


Fig. 20 Static Pressure Distribution, Test No. 4

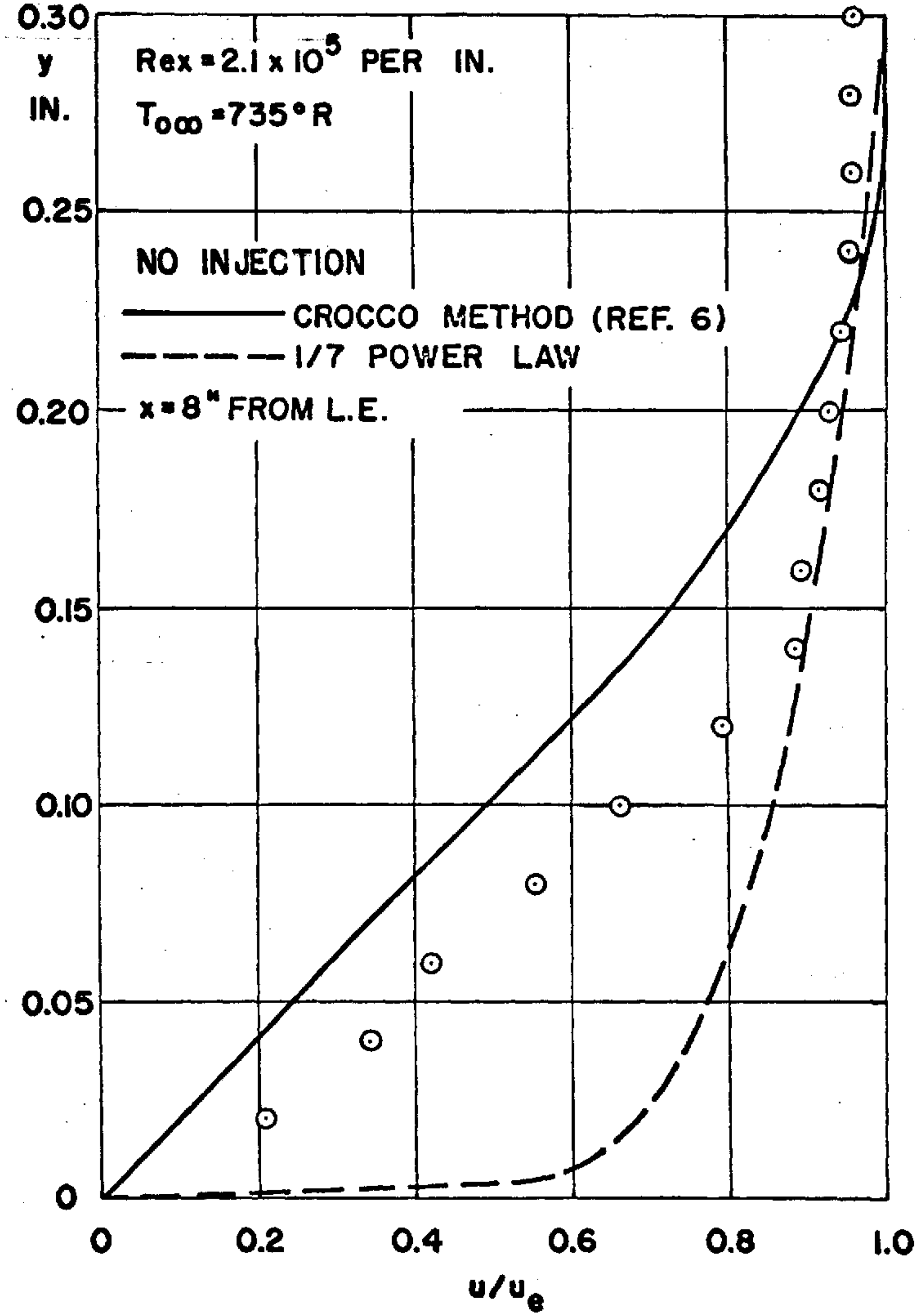


Fig. 21 Velocity Profile, Test No. 5

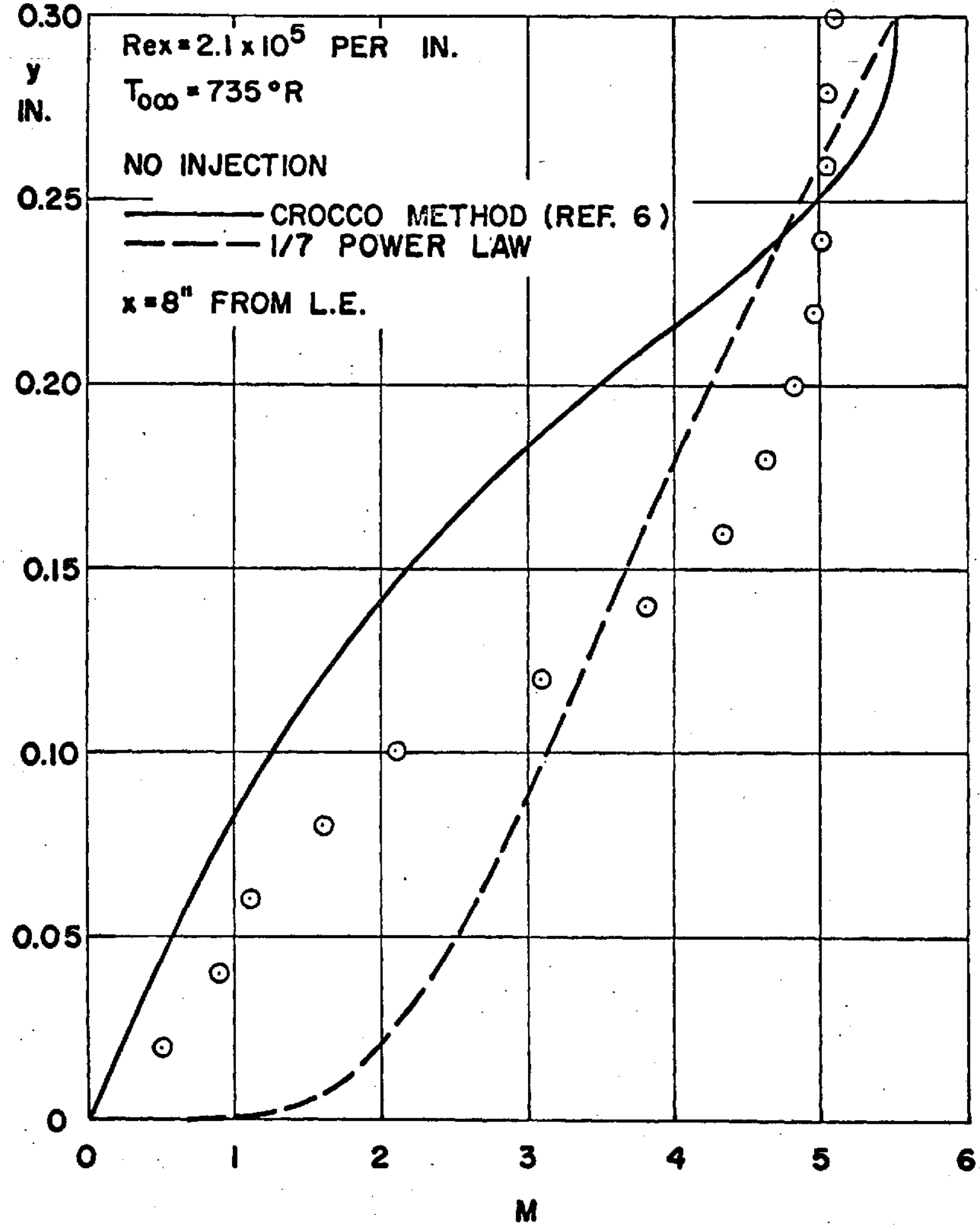


Fig. 22 Mach Number Profile, Test No. 5

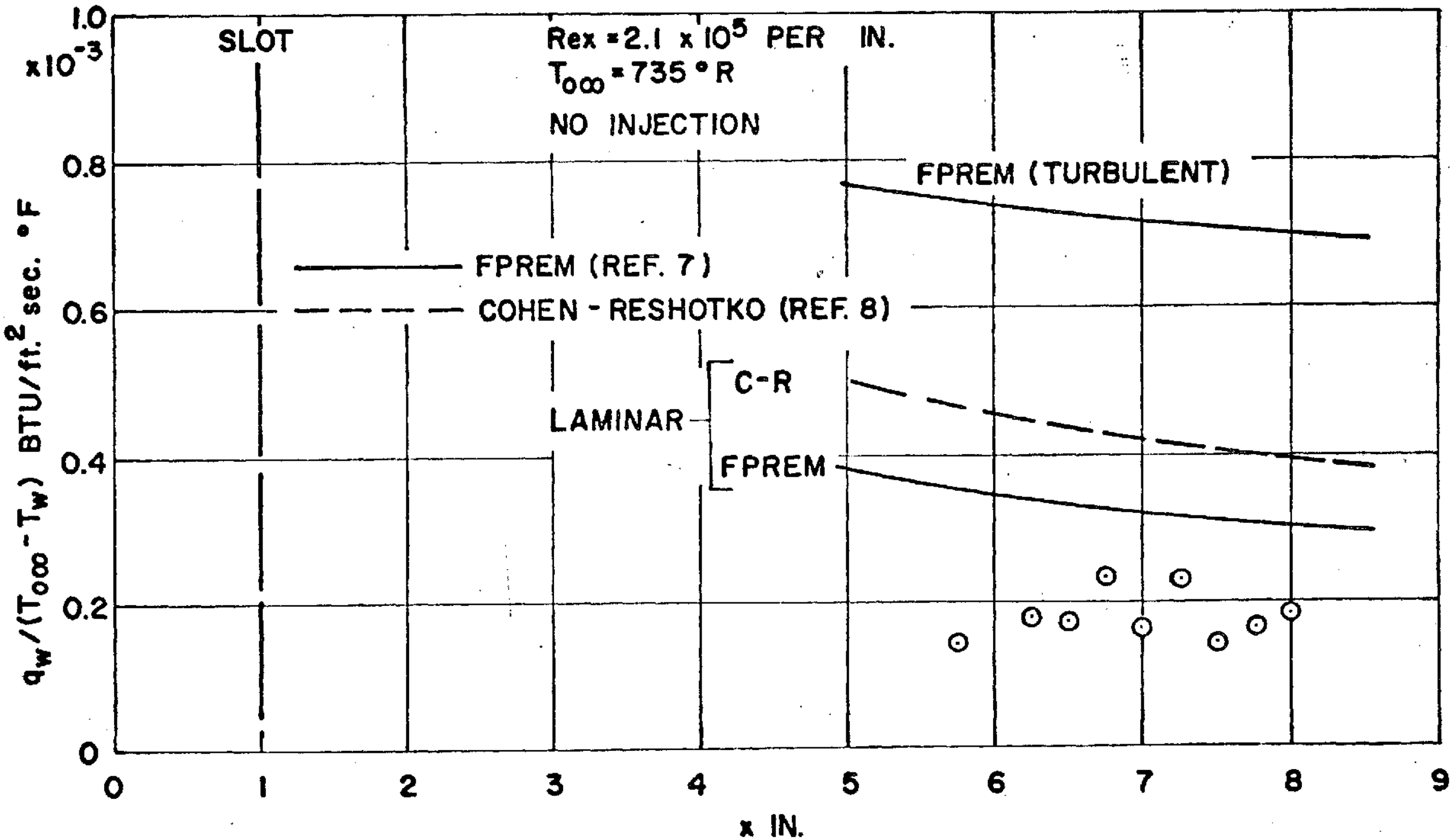


Fig. 23 Heat Transfer Distribution, Test No. 5

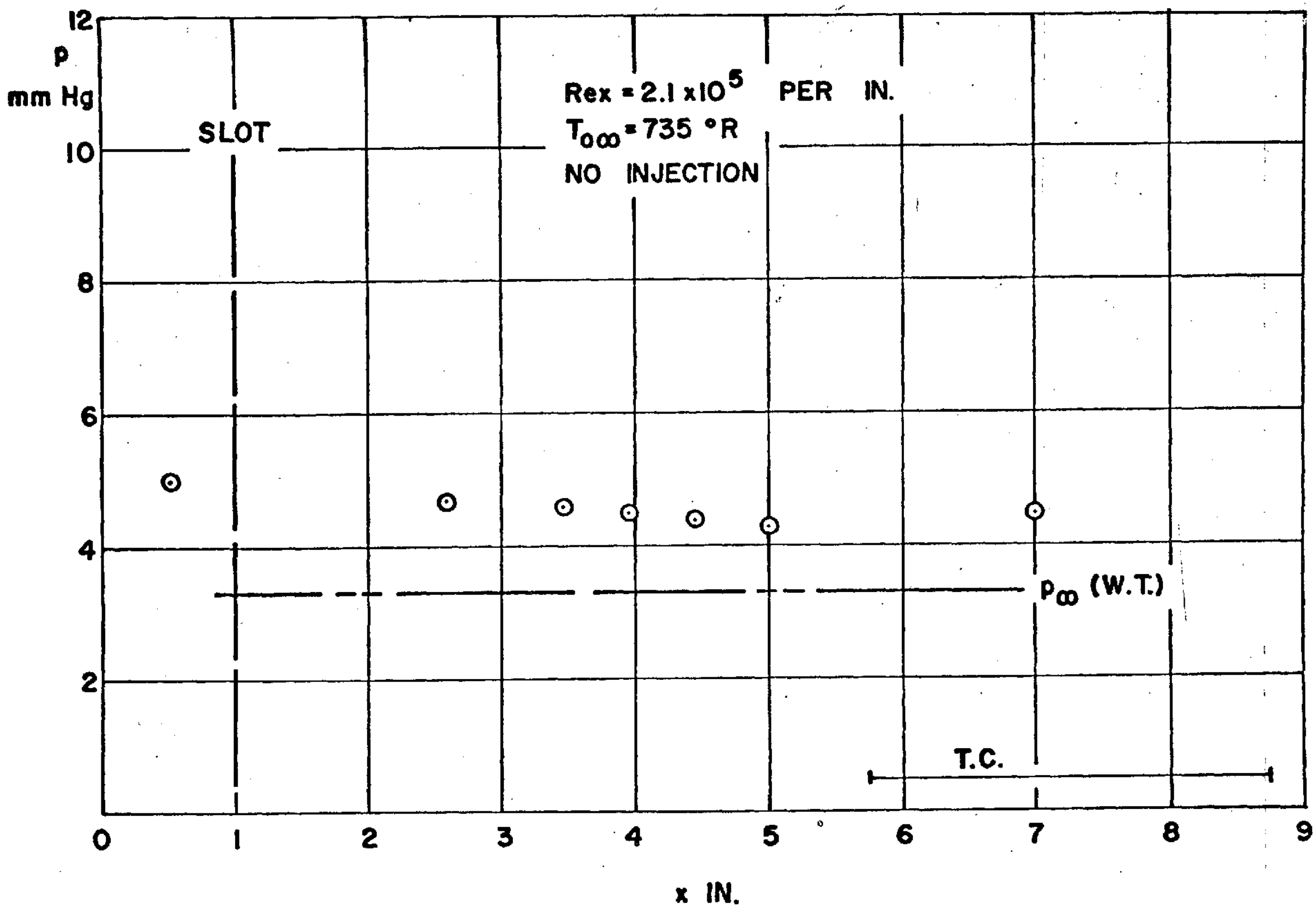


Fig. 24 Static Pressure Distribution, Test No. 5

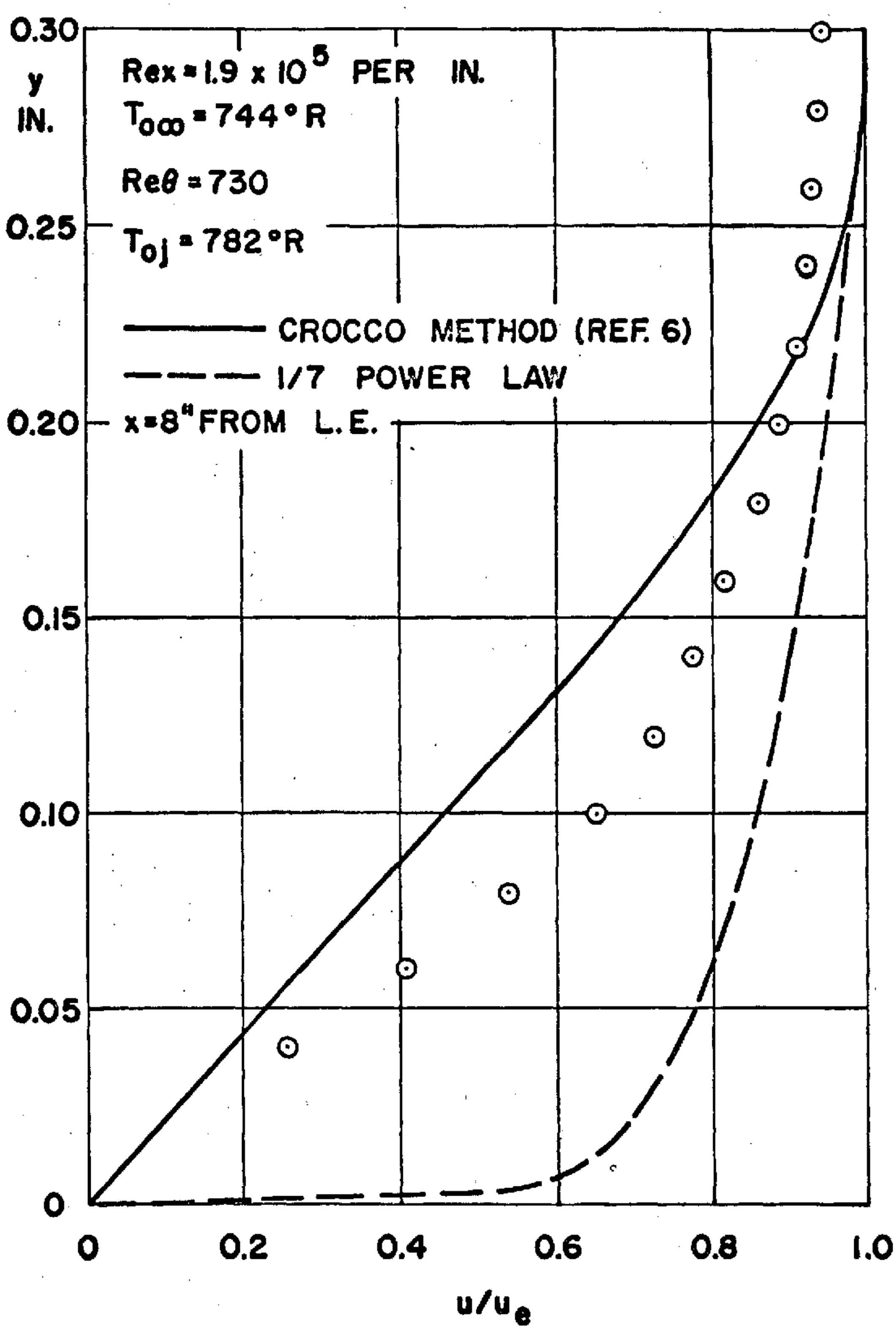


Fig. 25 Velocity Profile, Test No. 6

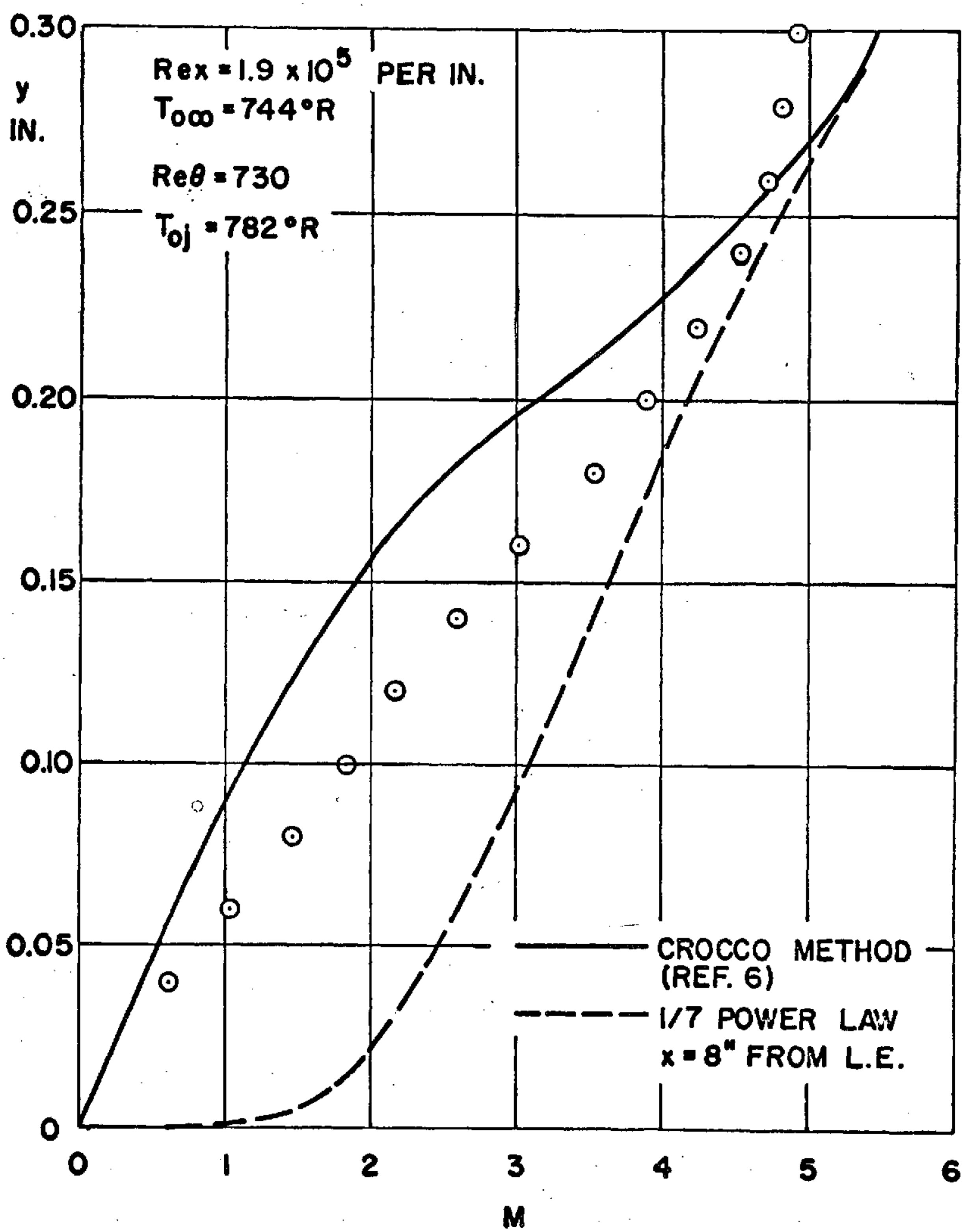


Fig. 26 Mach Number Profile, Test No. 6

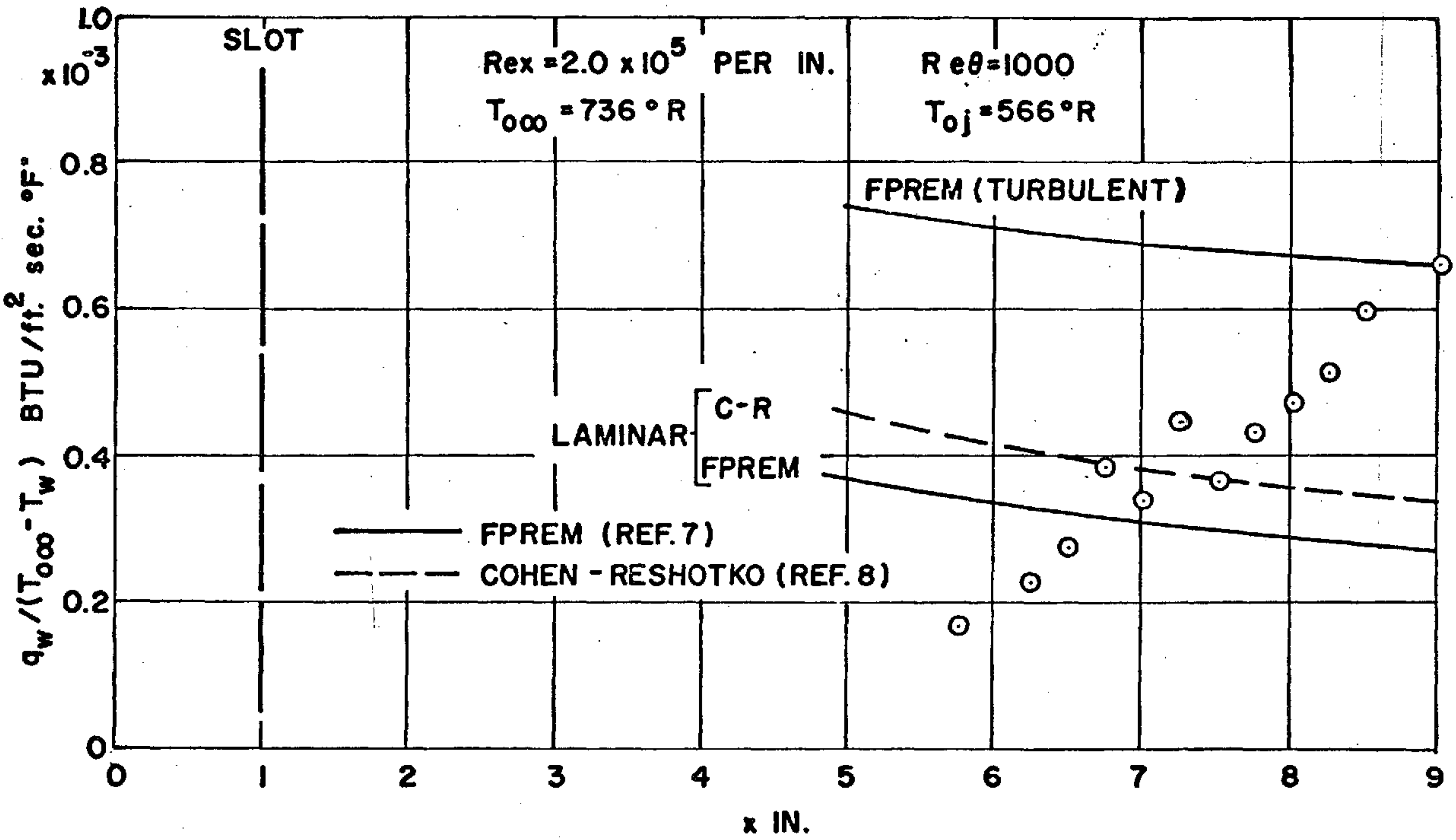


Fig. 27 Heat Transfer Distribution, Test No. 7

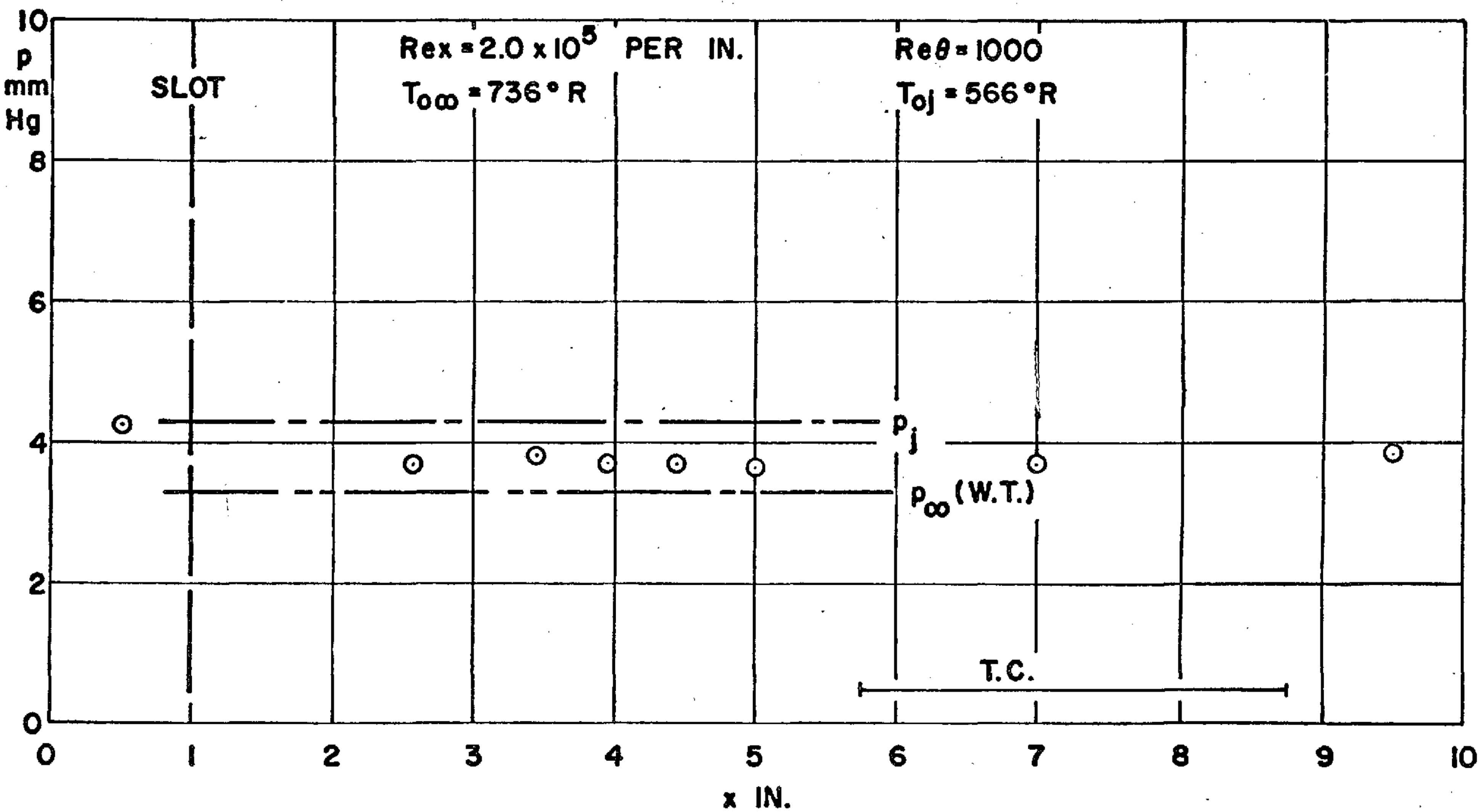


Fig.28 Static Pressure Distribution, Test No. 7