

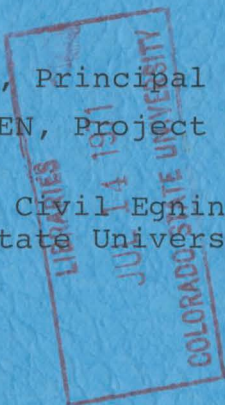
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FINAL TECHNICAL REPORT
FOR
"EQUIPMENT FOR BASIC RESEARCH ON TRUBULENCE
MECHANICS OF SHEAR FLOW"

TO
NATIONAL SCIENCE FOUNDATION
PROJECT GK-10875

LIONEL V. BALDWIN, Principal Investigator
KEMAL M. ATESMEN, Project Engineer

Department of Civil Egnineering
Colorado State University



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ABSTRACT

The experimental apparatus which is described in this report to study the mechanics of turbulent shear flow is described. The preliminary calibration experiments have been performed; the results are reported.

FINAL TECHNICAL REPORT

FOR

"EQUIPMENT FOR BASIC RESEARCH ON TURBULENCE

MECHANICS OF SHEAR FLOW"

INTRODUCTION

This annual report presents the description of the pipe flume that has been constructed to do research on turbulence mechanics. The starting and ending dates of the contract are 3-27-1969 and 9-27-1970 respectively. The details of the experimental equipment, along with photographs are included. The results of the preliminary calibration experiments are reported. The flow in the pipe is assured to be fully developed. The trouble shooting of the experimental equipment has been nearly completed. The problems that were confronted and their solutions are discussed.

NATIONAL SCIENCE FOUNDATION

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DEPARTMENT OF CIVIL ENGINEERING

COLORADO STATE UNIVERSITY

AUGUST, 1970

EXPERIMENTAL EQUIPMENT

The experimental equipment which has been constructed by the Machine Shop of the Engineering Research Center at CSU is shown in Figures 1 - 5 and in detail in the Appendix.

ABSTRACT

The experimental apparatus which has been constructed to study the mechanics of turbulent shear flow is described. The preliminary calibration experiments have been performed; the results are discussed.

The apparatus meets all the specifications over the entire experimental range which was described in the original proposal for this grant.

INTRODUCTION

This annual report presents the description of the pipe flume that has been constructed to do research on turbulence mechanics of shear flow under NSF contract GK-10875. The starting and the ending dates of the contract are 3-27-1969 and 9-27-1970 respectively. The details of the experimental equipment, along with photographs are included. The results of the preliminary calibration experiments are reported. The flow in the pipe is assured to be fully developed. The trouble shooting of the experimental equipment has been nearly completed. The problems that were confronted and their solutions are discussed.

A separate fiscal report is being prepared by the CSU Business Office to complete the required reports on Grant GK-10875. The project funds will be expended prior to the 10-1-1970 termination date of this grant.

EXPERIMENTAL EQUIPMENT

The experimental equipment which has been constructed by the Machine Shop of the Engineering Research Center at CSU is shown in Figures 1 - 5 and in detail in the Appendix.

Basically the system consists of a fifty foot long recirculating pipe flume, designed to utilize the hot-film anemometer for measurements of turbulence quantities. A description of the individual components with a discussion of design considerations is given below.

The circular tube in which the measurements are being made consists of a fifty foot long plexiglass tube, six inch inside diameter and a quarter inch thick. The tubes are commercially available in five foot sections; these sections are machined and glued together, then thoroughly polished to assure a smooth inner wall. The fifty foot length was chosen so that fully developed flow would be attained in the test section at the downstream end of the pipe. To assure that the flow is fully established, honeycomb vanes are used in the entrance to the plexiglass pipe, the head tank is constructed to be three foot above the entrance level, and the test section is located sixty-eight pipe diameters downstream from the entrance. Measurements of turbulent intensities are also being made upstream from the test section to determine if the flow in the test section is fully developed. The pressure gradient is indicated by a series of piezometers located at five foot intervals and connected to a manometer board.

The details of the openings in the pipe and the construction of the probe holders are shown in Figure 5. The hole is bored into the wall of the pipe and a plug is machined for each station so that when a probe is not used at that particular station the plug is closely fitted to minimize flow disturbance. When a measurement is to be made at that station the plug is removed and the probe holder is inserted. The test section itself is designed

so that intensity measurements, both longitudinal and lateral, and space-time correlations may be made. Calculations indicate that the integral length scale of turbulence in the Reynolds number range desired is from 2.03 to 2.84 feet. The openings have thus been designed to best define the envelope of the space-time correlations.

The circulating system consists of the pump, the internally epoxy coated steel return pipe, globe valve, cooling section, blister meter, head tank, filter and the rubber connecting pipes.

An all brass pump with a three speed motor is being used, capable of pumping 2.67 cubic feet per second at 19.0 feet total dynamic head, and uniformly covering the desired flow range of 1.06 to 2.37 cubic feet per second. The brass pump was chosen so that salt water and certain polymers may be used as the test liquid in future experiments. The flow rate of each pump speed is controlled by eight inch gate valve on the eight inch steel return pipe downstream of the pump. The water bulk temperature is held constant by passing the steel return pipe through a circulating cold water reservoir. The heat addition to the water by the pump is thus be transferred through the pipe walls to the surrounding cold water.

A blister meter in the eight inch steel pipe is calibrated to measure the total flow rate and serves as a convenient method of calibrating the hot-film probes in place. The centerline velocities and the mean flow rates are calibrated with the blister meter pressure drop.

The head tank is constructed from a 24 inch steel pipe section. A commercial jet-fuel filter is attached to the system to filter and deaerate the water so that

more accurate hot-film measurements may be made. A small valve is placed on the water inlet plate on the head tank to remove the air in the system. Rubber pipe sections connect each end of the plexiglass pipe to reduce vibrations from the pump and any external vibrations.

The plexiglass pipe is supported by a fifty foot steel truss, triangular in cross section, and welded together from ten foot lengths. The pipe is attached at five foot intervals to the truss with leveling screw supports, that may be used to straighten the pipe and assure a uniform pipe flow with no secondary circulation. The truss is supported on three concrete piers with rubber bearings to minimize vibrations from the floor.

Suitable instruments and transducers have been purchased. A list is given in Table I. Also several instruments such as tape recorders, signal correlators, oscilloscopes, and filters which are available at the Engineering Research Center, are being utilized.

The special transducer problems associated with hot-film probes are reduced to a minimum by using filtered, deaerated, and constant bulk temperature water especially with the provisions for in-place probe calibration. The availability of this pipe flow facility enables the hot-film measurements to be made more readily than in a flume.

PRELIMINARY EXPERIMENTS

The velocity profiles are measured with a pitot tube at $X/D = 16, 67, \text{ and } 94$ locations at several Reynolds numbers as shown in Figure 6. The pitot tube is read

through a pressure transducer which is calibrated before and after each run, and the output signal is filtered to give smooth means. Square velocity profiles are observed at $X/D = 16$ location. The velocity profiles develop and do not change after $X/D = 67$. All the velocity profiles are symmetric, but small asymmetry that is caused by the entrance characteristics of the apparatus, is observed above $Re_D = 400,000$. This asymmetry at large Re_D is corrected by plugging several holes in the entrance honeycomb. The velocity profiles and the turbulent intensity measurements show that a fully developed turbulent pipe flow is attained in an inlet length of 67 diameters.

The velocity profiles are integrated graphically to obtain mean velocities and to be able to calibrate the blister meter. The mean velocities and the centerline velocities in the test section are shown as functions of the pressure drop, $\sqrt{\Delta H}$, in the blister meter in Figures 7 and 8. This calibration allows us to obtain mean and centerline velocities within ± 0.25 ft/sec accuracy by controlling the gate valve.

The wall static pressure measurements are obtained by the series of piezometers located at five foot intervals and connected to a manometer board. The static pressure gradients along the longitudinal axis of the pipe are shown in Figure 9.

The longitudinal turbulent intensity measurements are made at $X/D = 67$ and 82 locations with 0.001 inch diameter, quartz-coated, cylindrical hot-films at the centerline of the pipe at different Re_D . First the water is filtered and deaerated. A weak solution of potassium

dichromate is added to water to prevent the growth of algae in the system and to keep the plexiglass clean. The hot-films are first annealed for twelve hours at 1.08 overheat ratio. Then they are calibrated in place while reading the rms fluctuations. Several time constants were tried on the true rms voltmeter, and ten seconds was found to be the most feasible one for the present measurements. During a run, the water is kept at a constant bulk temperature, namely the room temperature. Dirt free, constant temperature fluid along with in place calibration gave the results shown in Figure 10. At the present time, more turbulent intensity measurements are being made for repeatability purposes.

ACKNOWLEDGEMENTS

The investigators wish to express their special thanks to the machine shop of the Engineering Research Center at Colorado State University for their outstanding work, able guidance, and valuable counseling during the construction of the pipe flume.

Part of Kemal Atesmen's doctoral studies was made possible through the financial support of this project.

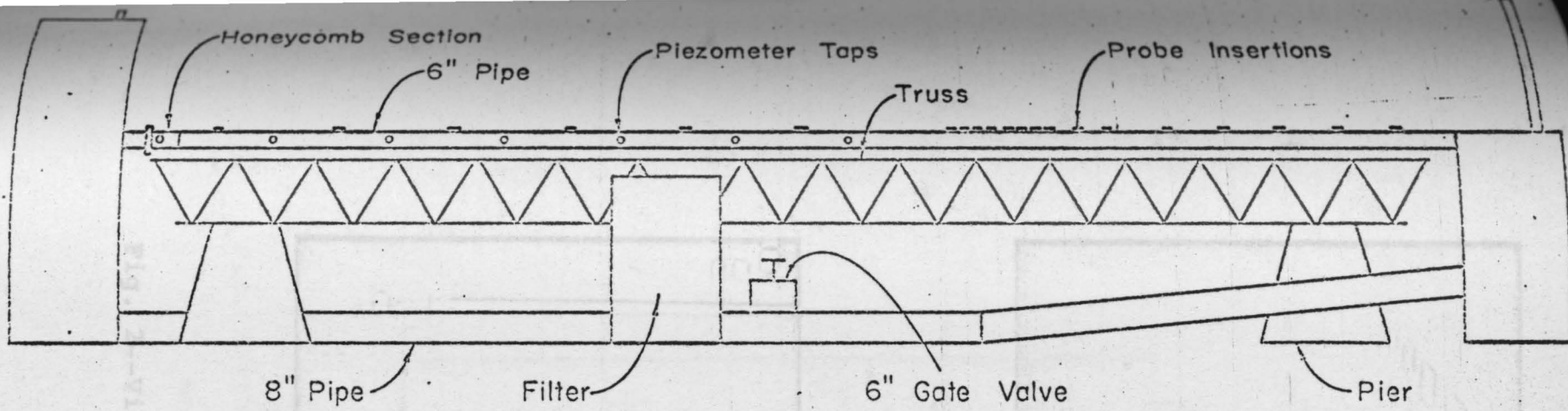
1. "Catalog and Prices Flow Instrumentation," Thermo-Systems Inc., St. Paul, Minnesota.
2. "Probes for Measuring Temperature, Total and Static Pressure, Velocity and Flow Direction of Fluids, Gases and Liquids," United Sensor and Control Corp., Watertown, Mass.

TABLE I

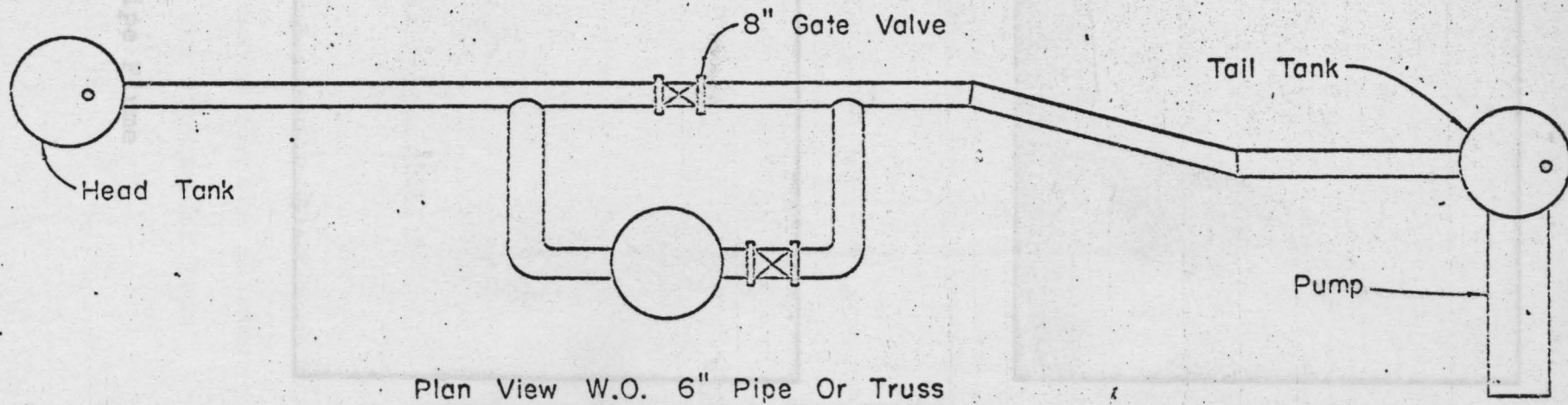
List of the purchased instruments and transducers

<u>Quantity</u>	<u>Model</u>	
2	TSI-1050	General purpose anemometer ¹
2	TSI-1057	Signal conditioner
1	TSI-1051-2	Monitor and power supply
1	TSI-1060	True RMS voltmeter
2	TSI-1241-10W	Hot-film probes "X" configuration for end flow
1	TSI-1157	Right angle adapter
1	TSI-1155-6	Probe support
2	TSI-1158-6	Locking and protecting sleeve
1	TSI-1138-1	Mounting block
4	TSI-1210-10W	Hot-film probes
2	TSI-1150-6	Probe support
2	TSI-1152	Right angle adapter
1	US-PDC-12-G-10-KL	Pitot tube with removable take-offs ²

1. "Catalog and Prices Flow Instrumentation," Thermo-Systems Inc., St. Paul, Minnesota.
2. "Probes for Measuring Temperature, Total and Static Pressure, Velocity and Flow Direction of Fluids, Gases and Liquids," United Sensor and Control Corp., Watertown Mass.



Side View Of Pipe Flow Apparatus



Plan View W.O. 6" Pipe Or Truss

Fig. 1--Schematic Diagram of the Pipe Flume

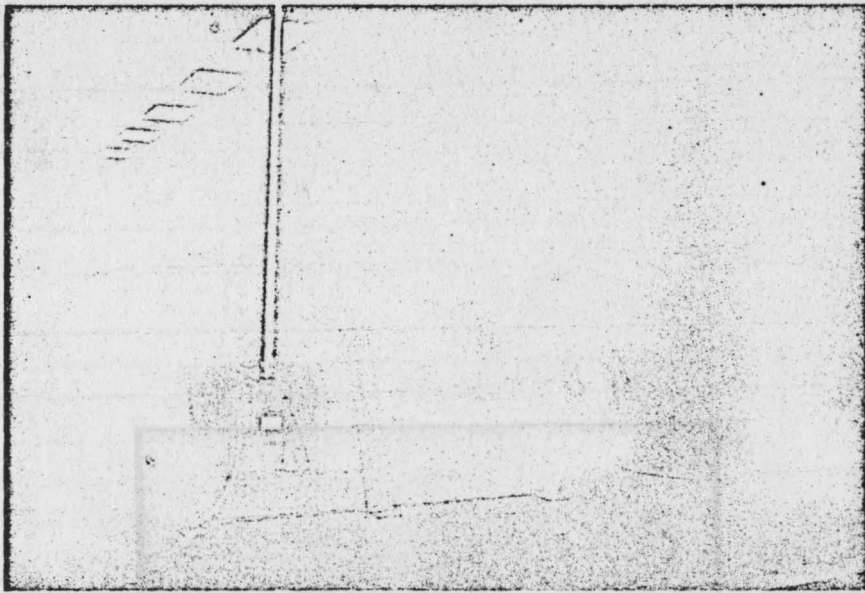


Fig. 3--The Nonmeter Board for the Blister
Meter and for the Piezometer Taps

Fig. 2--View of the Pipe Flume

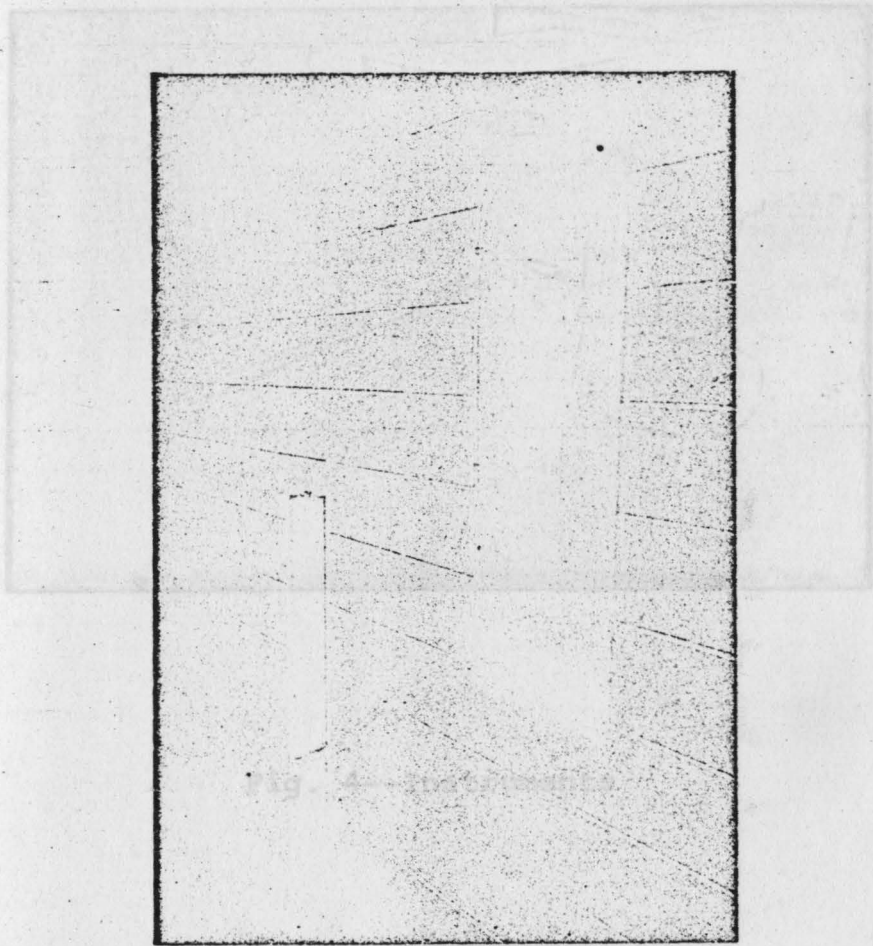


Fig. 3--The Monometer Board for the Blister
Meter and for the Piezometer Taps



Fig. 4--Instruments

Fig. 5--Hot-film Probe Inserted into the Flow.

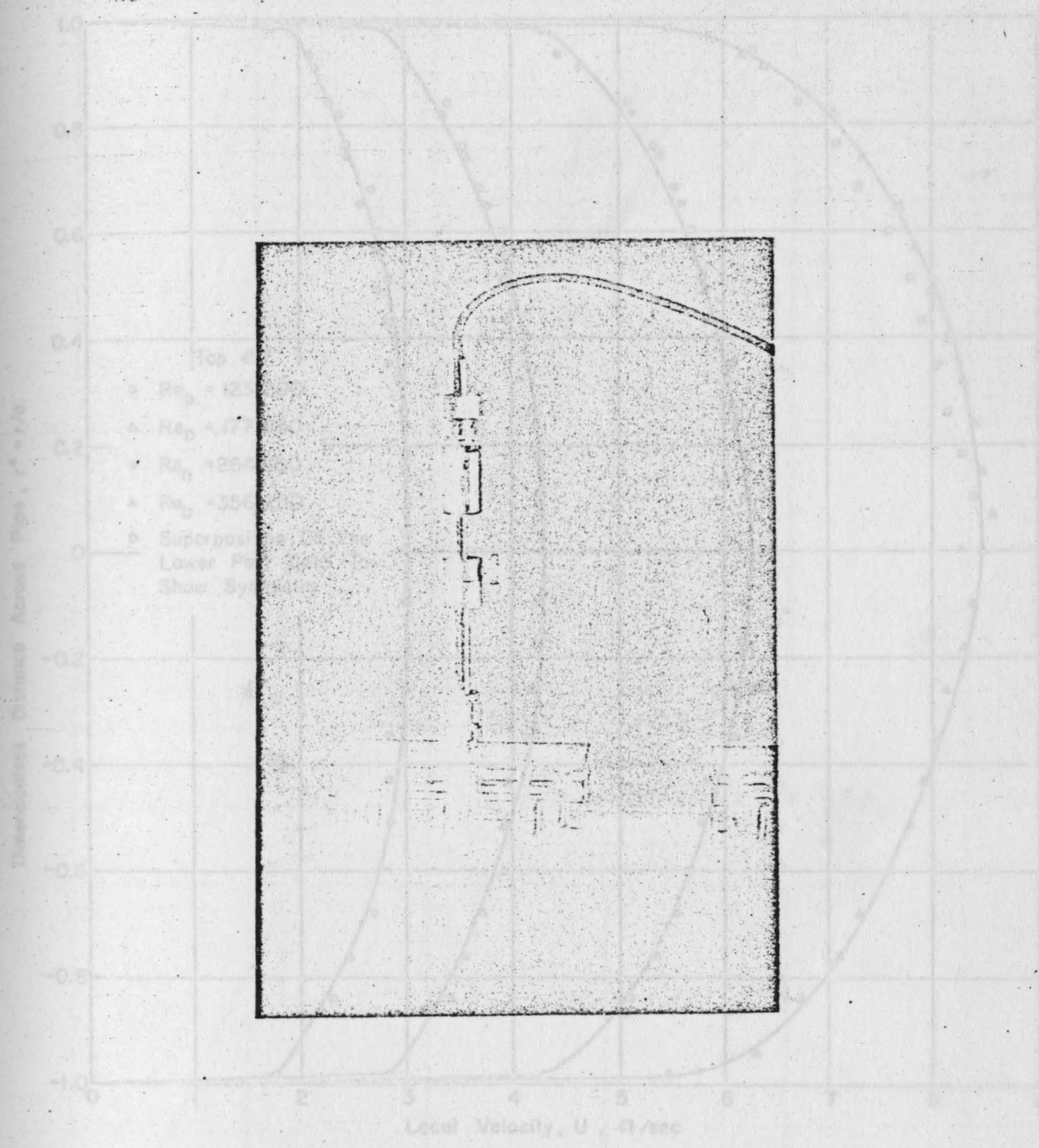


Fig. 5--Hot-film Probe Inserted into the Flow

Fig. 6--Mean Velocity Distribution Across Pipe

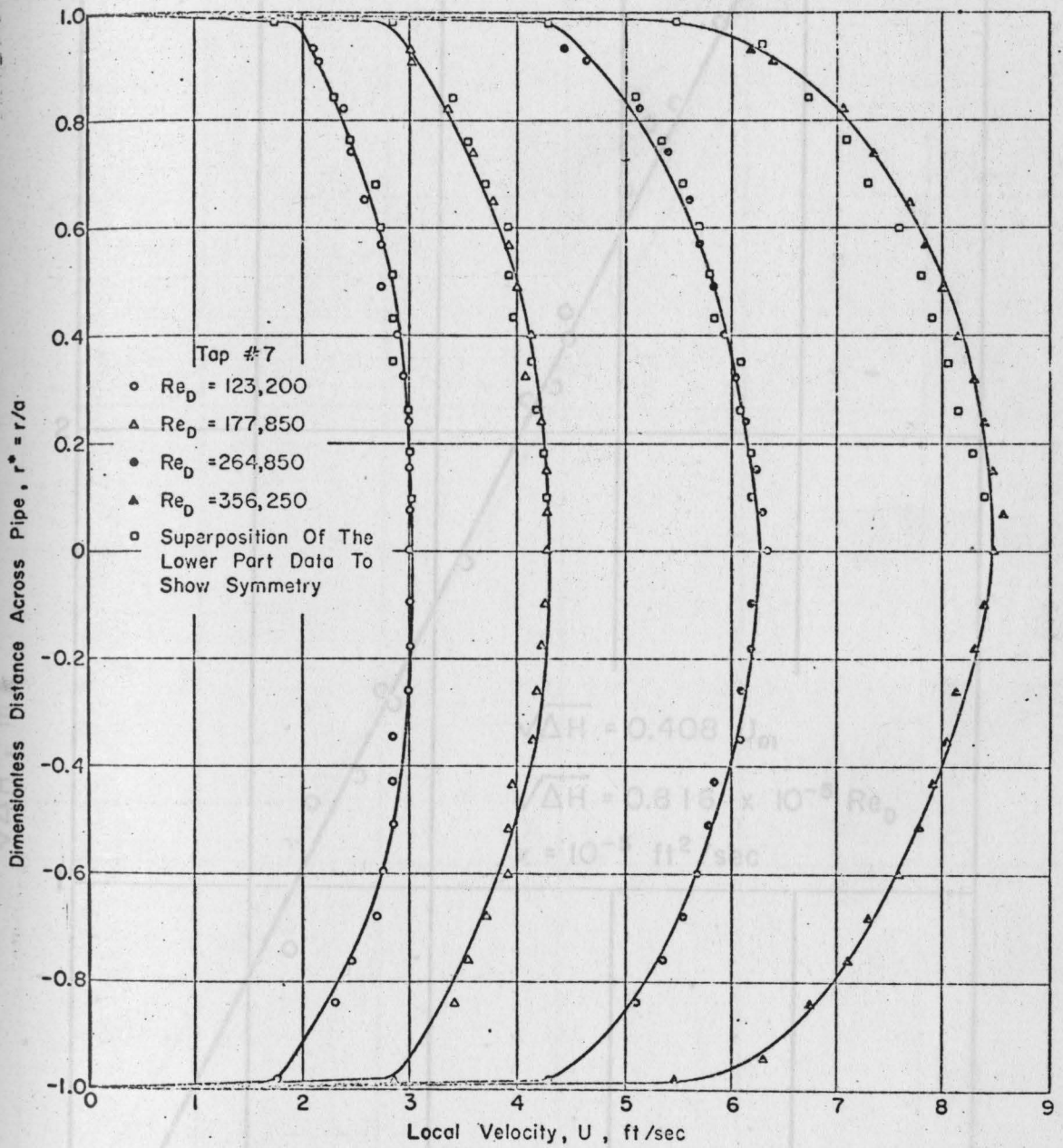


Fig. 6--Mean Velocity Distribution Across Pipe

Fig. 7--Calibration of the Pipe Plume with the Blower

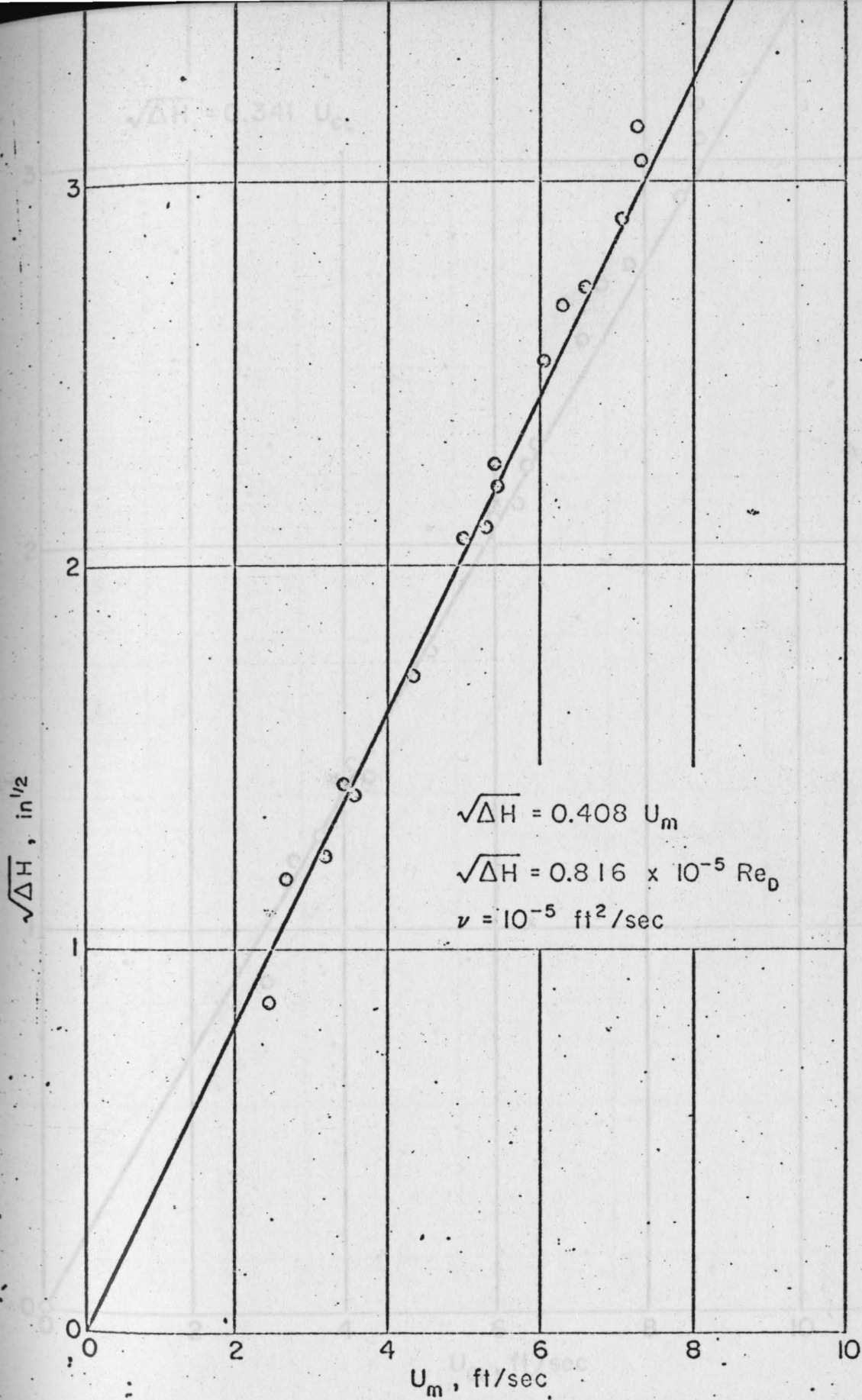


Fig. 7--Calibration of the Pipe Flume with the Blister Meter

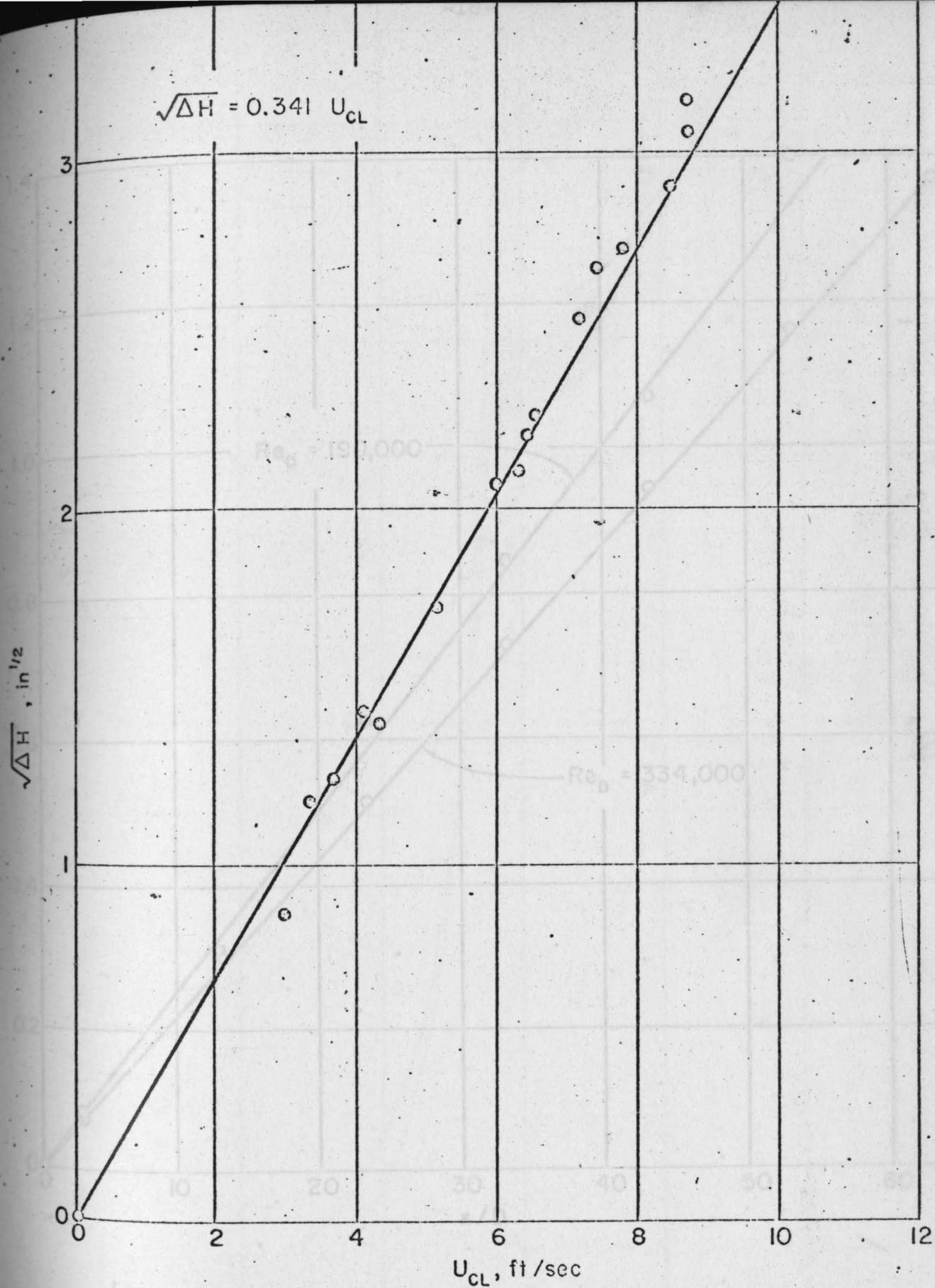


Fig. 9--Static-pressure Distribution along Pipe Wall.

Fig. 8--Calibration of the Pipe Flume with the Blister Meter

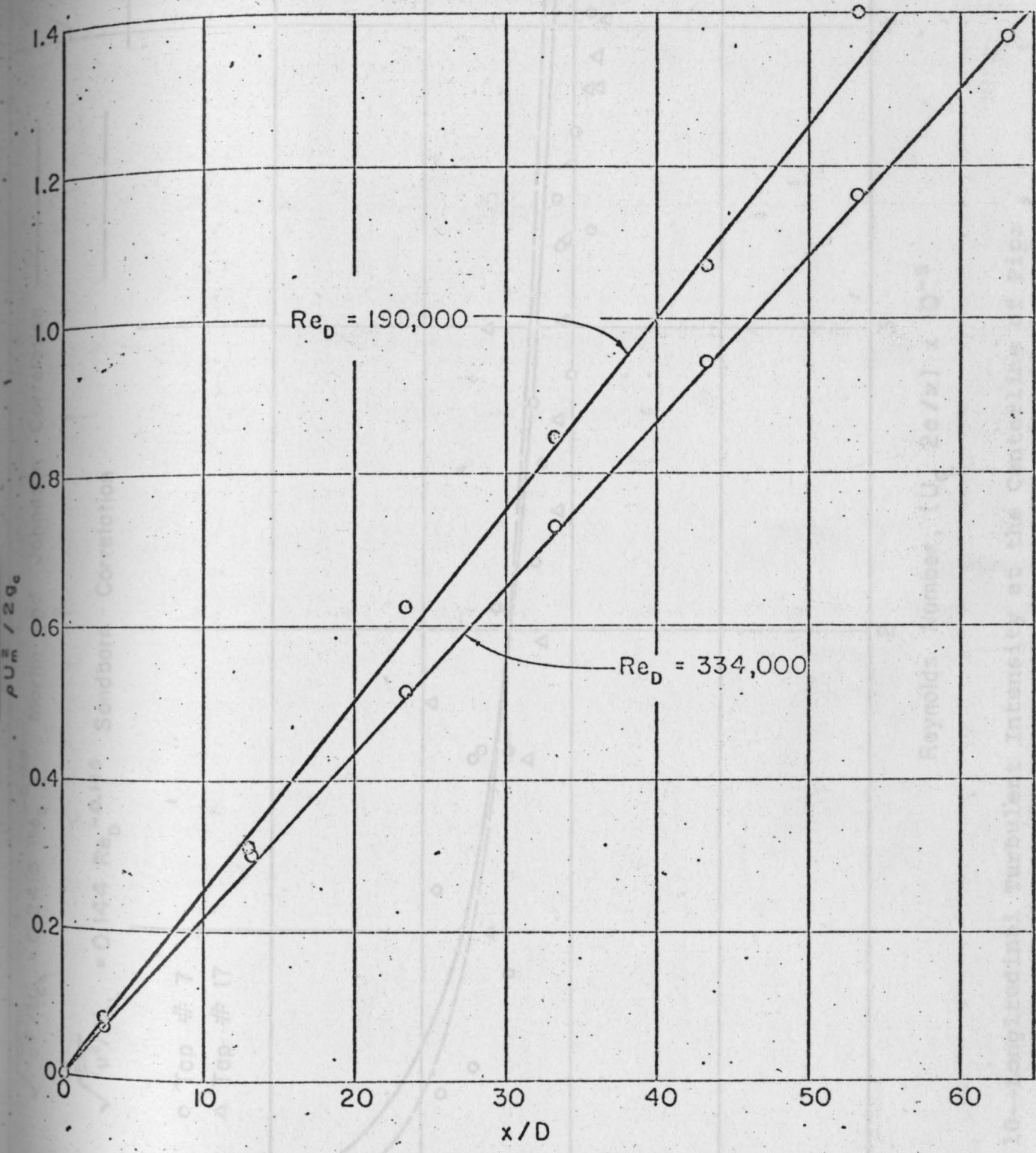


Fig. 9--Static-pressure Distribution along Pipe Wall

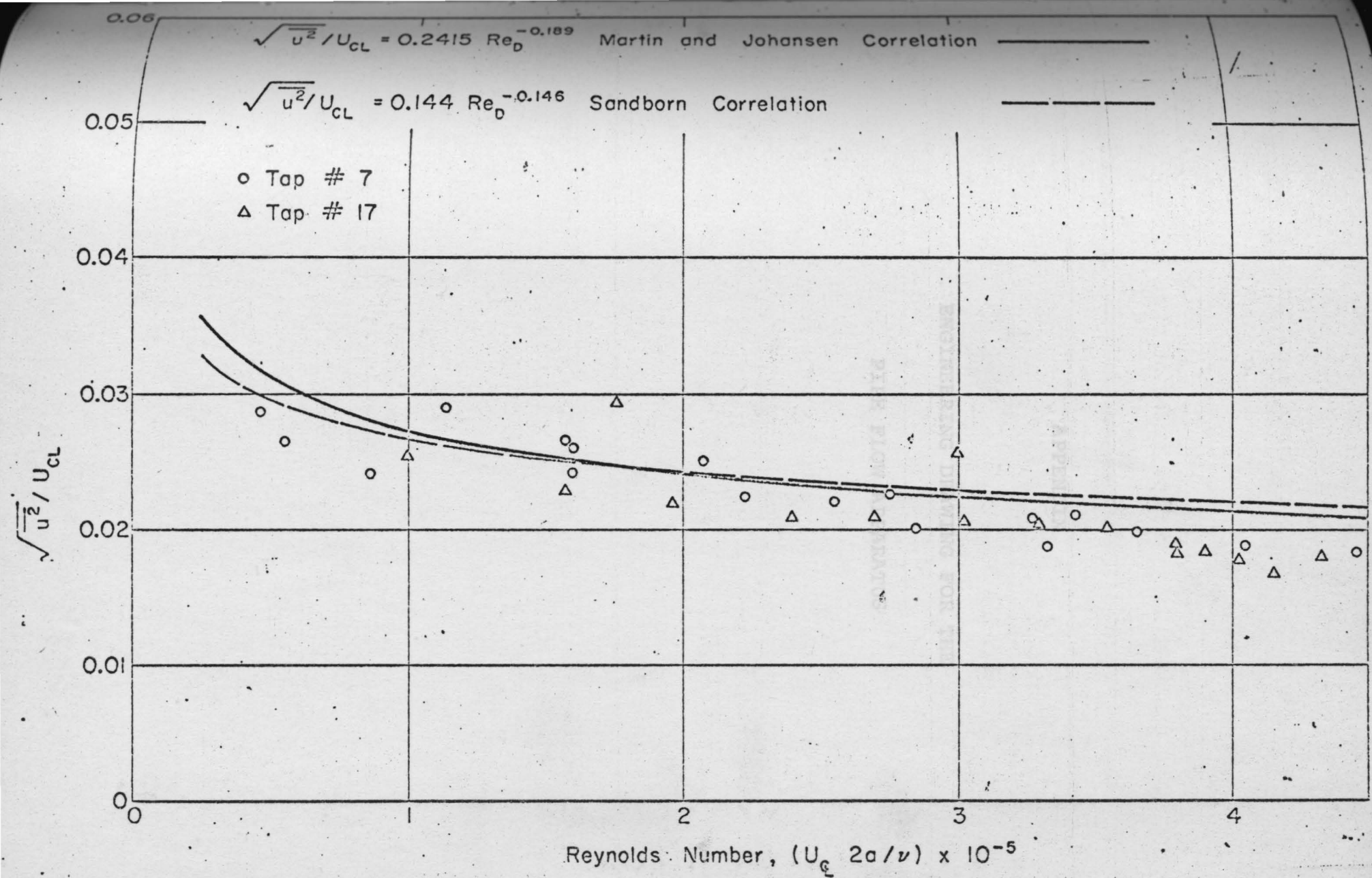


Fig. 10--Longitudinal Turbulent Intensity at the Centerline of Pipe

APPENDIX

ENGINEERING DRAWING FOR THE

PIPE FLOW APPARATUS