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TECHNICAL REPORT

WIND TUNNEL STUDY OF THE DUGWAY PROVING GROUND TOWER GRID

BY

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ABSTRACT

A wind tunnel study has been carried out in order to simulate mean flow conditions and turbulence characteristics in the vicinity of the Tower Grid at Dugway Proving Ground. Significant modifications of the upstream flow conditions were found to occur primarily in the region between the Grid Center and the downstream meteorological tower where the turbulence increased and local accelerations of the flow occurred.

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I. INTRODUCTION

Boundary layer effects attributable to the presence of non-uniformly distributed roughness elements within the atmospheric surface layer are beyond the scope of current theoretical models. The three-dimensional nature of such flows requires either a field study or the simulation of field conditions by some sort of modelling procedure. Whenever possible, it would be desirable to have both types of studies, since adequate field data are usually much more difficult and expensive to obtain than model data. Model studies can provide detailed information on the mean flow conditions and turbulence characteristics, but a certain amount of field data is required in order to verify the degree of similarity between model and prototype. The Tower Grid at Dugway Proving Grounds presents just such an opportunity to coordinate a field study and a model study. The relatively simple distribution of large roughness elements readily lends itself to a wind tunnel study. Moreover, the data generated from the model study will provide background information for the eventual development of numerical models suitable for the simulation of atmospheric flows.

The objective of the present study was to determine the extent to which the Tower Grid affects the mean flow conditions at the Dugway Proving Ground test site. This involved a qualitative study of the effects of the Tower Grid on the mean flow by smoke visualization and a study of the distributions of mean velocity and turbulence.

II. MODELLING THE TOWER GRID

In order to simulate the prototype flow conditions certain requirements had to be met in the modelling.

(a) All significant roughness elements interior to the circle of radius 100-m were included in the model and scaled by 1/50th of their prototype counterparts. The size of the wind tunnel however necessitated the removal of a few samplers on either side of the wind tunnel model.

The individual roughness elements corresponding to the prototype towers consisted of straight pieces of tubing or rods. The two prototype elements were scaled according to the following table

	Model	Prototype
Height	13 in.	17-m
Diameter	0.1 in.	12.7 cm.
Height	1.2 in.	1.52-m
Diameter	0.03 in.	3.8 cm.

The metal segments were inserted into a 3/4 inch-thick plywood base which extended the width of the tunnel floor. Simplified models of the Gun and Rocket Towers, the Vault, Light Banks, and Meteorological Towers were also constructed and affixed to the plywood base, at the proper locations.

Since there were two primary wind directions it was desirable to have the capability of changing the orientation of the model with respect to ambient wind direction. Provision was therefore made for the non-symmetrical model components to be moved to corresponding alternative locations at the different wind directions. This procedure replaced the original idea of rotating a 12 ft-diameter plywood disc.

A ramp approach was used upstream of the model to compensate for the upper surface of the plywood base not being the same height as the top of the rough surface upstream.

(b) The Reynolds number of the model based on the diameter of the roughness elements must be equal or at least very close to the prototype Reynolds number. This is achieved at a tunnel wind speed of the order 50 ft/sec.

(c) The impinging wind profiles, when scaled by $\frac{U_*}{k} \ln (\frac{z}{z_o})$, should be similar for both model and prototype. The model z_o must therefore be chosen to make the boundary fully rough. On the basis of some recent computations by Nambudripad and Cermak (1)., it appeared that a model z_o characterized by a Nikuradse sand grain size of 0.1 inch would ensure similarity between the model and prototype flow. The value z_o = 0.1" was used. However, it was still necessary to artificially thicken the boundary layer in order to have it sufficiently deep (23 in.) when it encounters the model.

III. EXPERIMENTAL EQUIPMENT AND PROCEDURE

The experimental study was carried out in the 12' x 12' working section of the Colorado State University low speed Environmental Wind

Tunnel. Measurements were obtained for conditions of zero horizontal pressure gradient and neutral stability and a wind speed of 50 ft/sec in the two directions corresponding to the N.W. and S.E. on a prototype. Since the primary objective was to determine the extent to which the Tower Grid affects the mean flow conditions, it was decided to make qualitative determinations by smoke visualization and to base more detailed conclusions on the distribution of mean velocity and turbulence data.

3.1. Velocity Measurements:

Mean flow velocity profiles were obtained using a pitot-static tube and an electronic pressure transducer. Velocity profiles were measured for the two ambient wind directions along the model streamwise centerline, and at five other base lines, Figs. (5) and (6). Additional velocity profiles were obtained in the pie-shaped segment downstream of the model center.

3.2. Turbulence Measurements:

An approximate distribution of the turbulence was measured with a single-wire constant current anemometer unit, with the wire inclined at 45° to the wind direction. Turbulence intensity profiles were obtained at locations similar to those for the velocity profiles but for only one (S.E.) wind direction.

3.3. Smoke Visualization:

Proper smoke visualization was impossible at the test speed of 50 ft/sec. However, puffs of Titanium Tetrachloride liquid released upstream of the model produced streaks on the model floor which gave some indication of the nature of the mean flow on the floor.

3.4. Thickening the Boundary Layer:

The boundary layer over the model was thickened so that all elements of the model (except the tall Rocket Tower) were within the shear layer. The method consisted in laying roughness elements (consisting of semi-rigid tufts) over a build-up of foil cans at the entrance to the wind tunnel test section.

This technique for thickening the boundary layer seriously modified the mean flow and turbulence characteristics. This accounts for the boundary layers upwind of the Grid extending so far to the tunnel centerline especially at the larger distnaces from the floor. Farther downstream of the entrance region, the flow characteristics recover from the modifications. However, this recovery was too far downstream for all of the model to be placed in the fully developed turbulent boundary layer.

IV. EXPERIMENTAL RESULTS

4.1. Smoke Visualization:

Puffs of Titanium Tetrachloride released upstream of the model produced streaks on the model floor from which the nature of the mean flow around the Tower Grid could be deduced qualitatively.

(a) The streaklines behind each circle of roughness elements were practically continuous with those in front of the circle.

(b) Wakes of any considerable size existed only behind the larger obstacles such as the Gun and Rocket Towers and the Vault. The wakes behind the first two were small and "perforated" on account of the non-solid construction of these structures. Recovery of the streaklines was quite rapid behind those Towers. The wake behind the Vault was the largest and longest.

(c) The streaklines showed very little lateral deviation anywhere except in the above-mentioned wakes.

The above observations indicate that the Tower Grid did not qualitatively modify very much the mean flow through it, in the sense that apart from quantitative obstructions to flow, the nature of flow was virtually unchanged.

4.2 Results from Velocity Profiles:

Velocity profiles measured on five base lines are presented in Fig.(5a) through (5e) for each wind direction. Quantitative modifications to the general flow around the Tower Grid is, however, best seen in Fig. (3), which is a plot of the wind speeds across the wind tunnel at various heights.

At the height corresponding to the top of the horizontal samplers, Fig.(3) indicates that the horizontal samplers cause only a small defect in the flow velocity but no general deformation of the flow. The larger roughness elements, the Gun Tower and the Vault are the only appreciable obstructions to the flow, although the flow fully recovers from their effects before the downstream Meteorological Tower is reached. Apparently there is a flow acceleration downstream of the large roughness elements. This flow acceleration which is observed only a short distance behind the individual elements may be due to the "necking" effect of the bases of these structures. At the height corresponding to the top of the tall vertical samplers, the velocity defect due to those samplers is quite considerable. The larger structures, especially the Gun and Rocket Towers, are the major obstacles to the flow, however. In fact, the effect of the Rocket Tower persists for quite a long distance downstream of the model. The wind speed recorded at the top of the downstream Meteorological Tower is only about 80% of the unobstructed wind speed.

Above the level of the Meteorological Towers, the Rocket Tower constitutes the major obstacle. Its effect is definite and sizeable and persists for long distances downstream. The flow over the Gun Tower and the Light Banks appears to be slightly accelerated.

At all heights, the flow seems to be accelerating between the model center and the downstream Meteorological Tower. This is suggestive of an expansive flow in that region of the Tower Grid. Hence, releases from a source about the center of the Grid may be expected to diffuse quite rapidly in the lateral direction.

4.3 Results from Turbulence Measurements:

The procedure used to thicken the boundary layer over the model seriously modified the turbulence structure of the flow to such an extent that only a few representative turbulence intensity profiles, Fig.(7), have been considered worthy of presentation in the present report. Shear stress distributions were found to be similar to the turbulence profiles.

It is obvious, however, from the turbulence intensity profiles shown that the turbulence downstream of the Tower Grid is considerably increased.

V. CONCLUDING REMARKS

(a) Apart from the wake regions of the larger obstacles, the basic flow around the Tower Grid is directionally changed very little by the roughness, presumably due to the rather low size-to-spacing ratio within the Grid system.

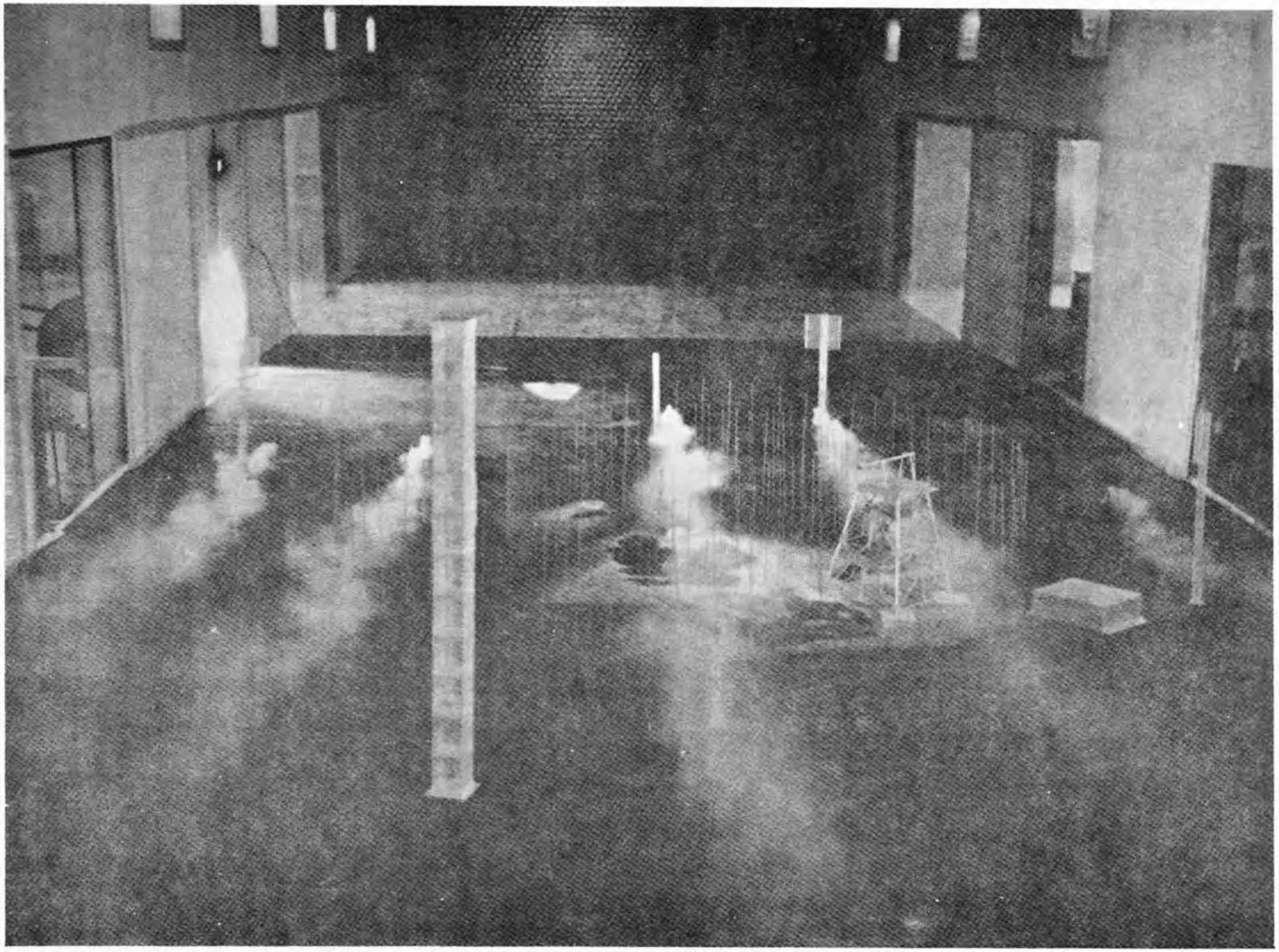
(b) The Tower Grid acts to increase the Turbulence in the flow, which will result in enhanced diffusion downstream of the Grid Center.

(c) The expansive nature of the flow between the Grid Center and the downstream Meteorological Tower, suggested by the acceleration of the flow in that region, implies that diffusion will be quite rapid there in all directions.

(d) The turbulence immediately downstream of the Grid Center was only slightly less for the N.W. wind than for the S.E. wind due to the influence of the Rocket Tower in the former case. In all other respects, the flow conditions corresponding to the two prevailing wind directions were found to be nearly identical.

VI. REFERENCES

Nambudripad, K.D., and J.E. Cermak, 1969: "A Note on Roughness." Unpublished Colorado State University Fluid Mechanics Report.



1. Photograph of Model in Wind Tunnel

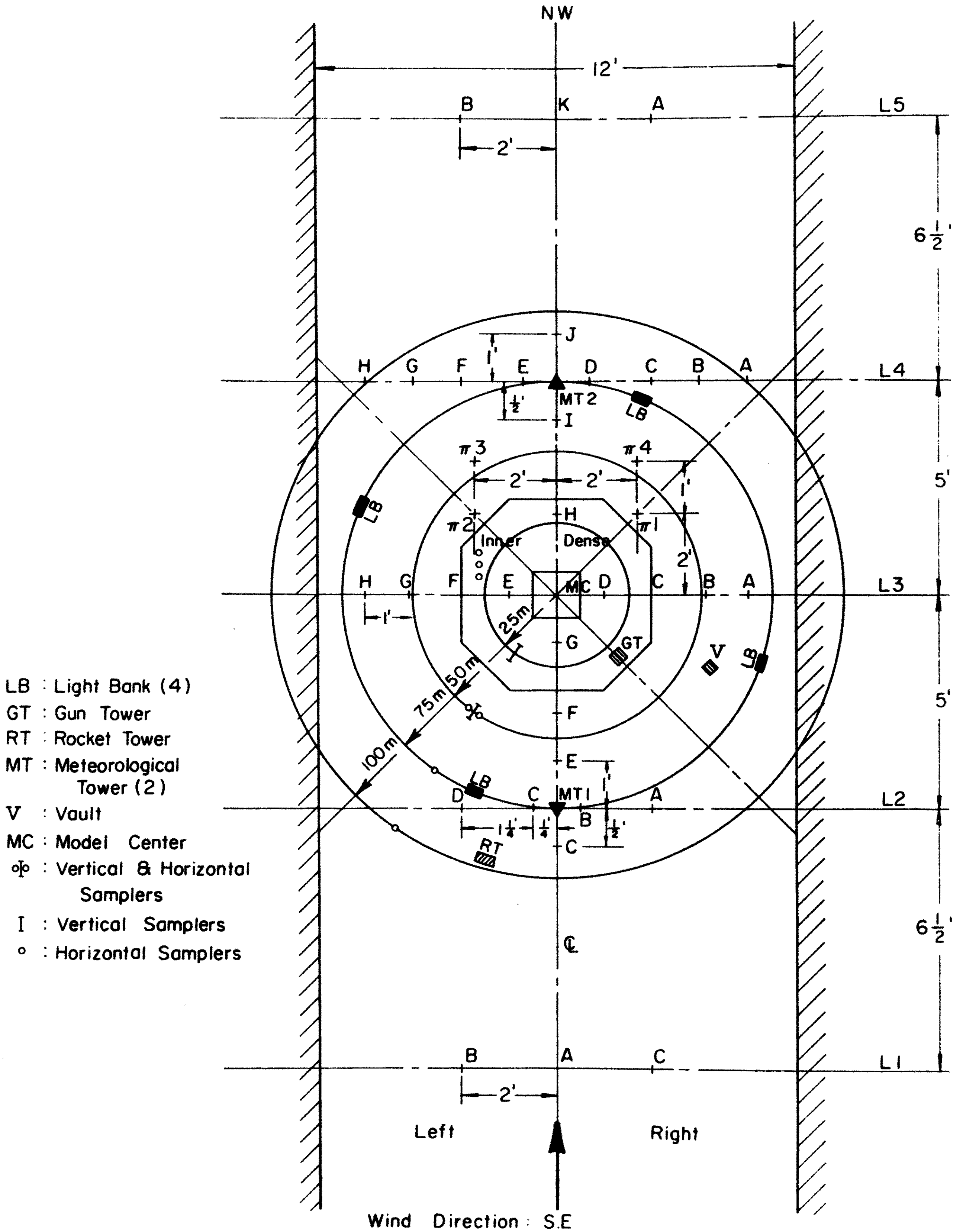


Fig. 2a Schematic Arrangement of Model in the Wind Tunnel (S·E Wind)

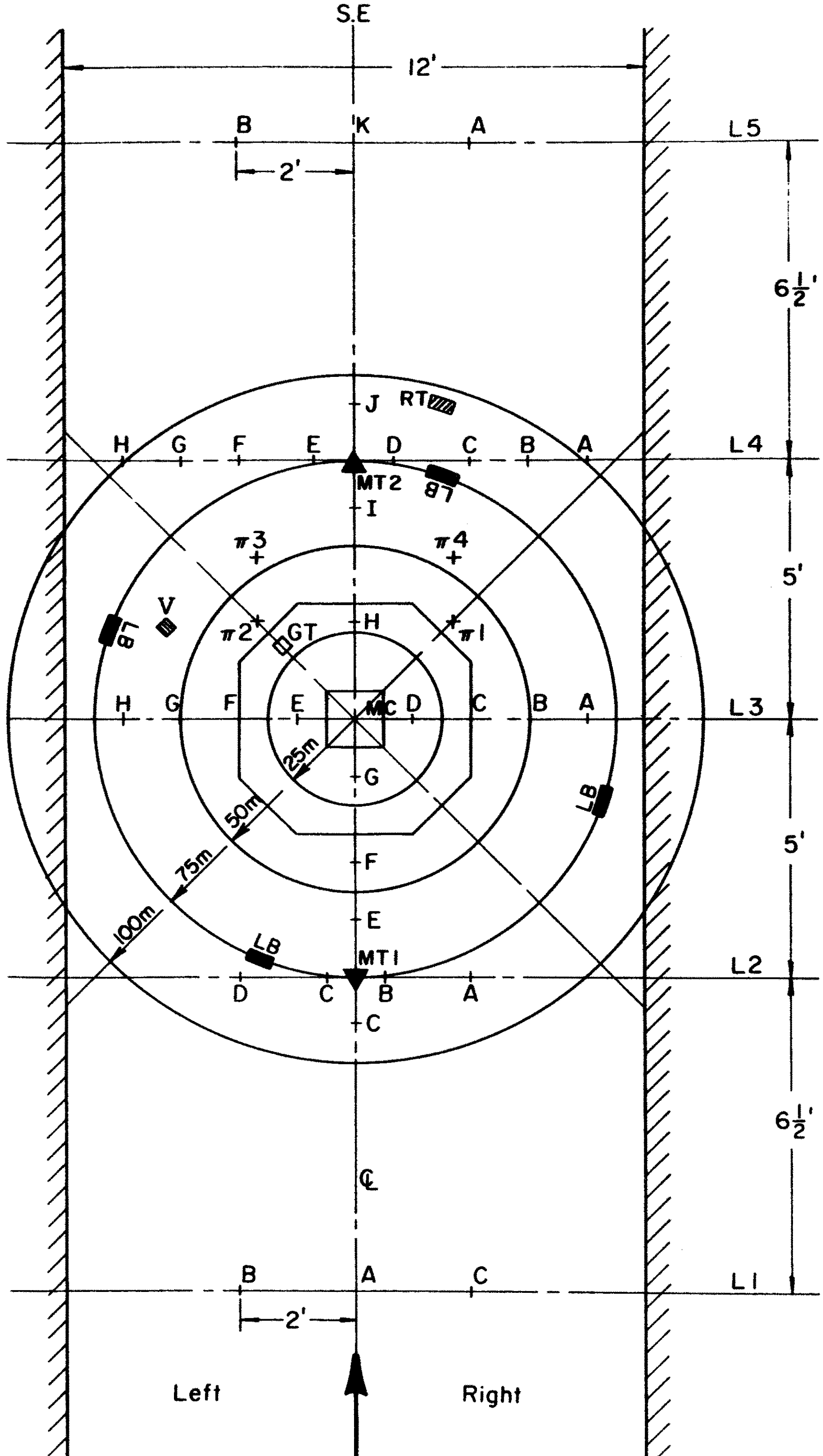
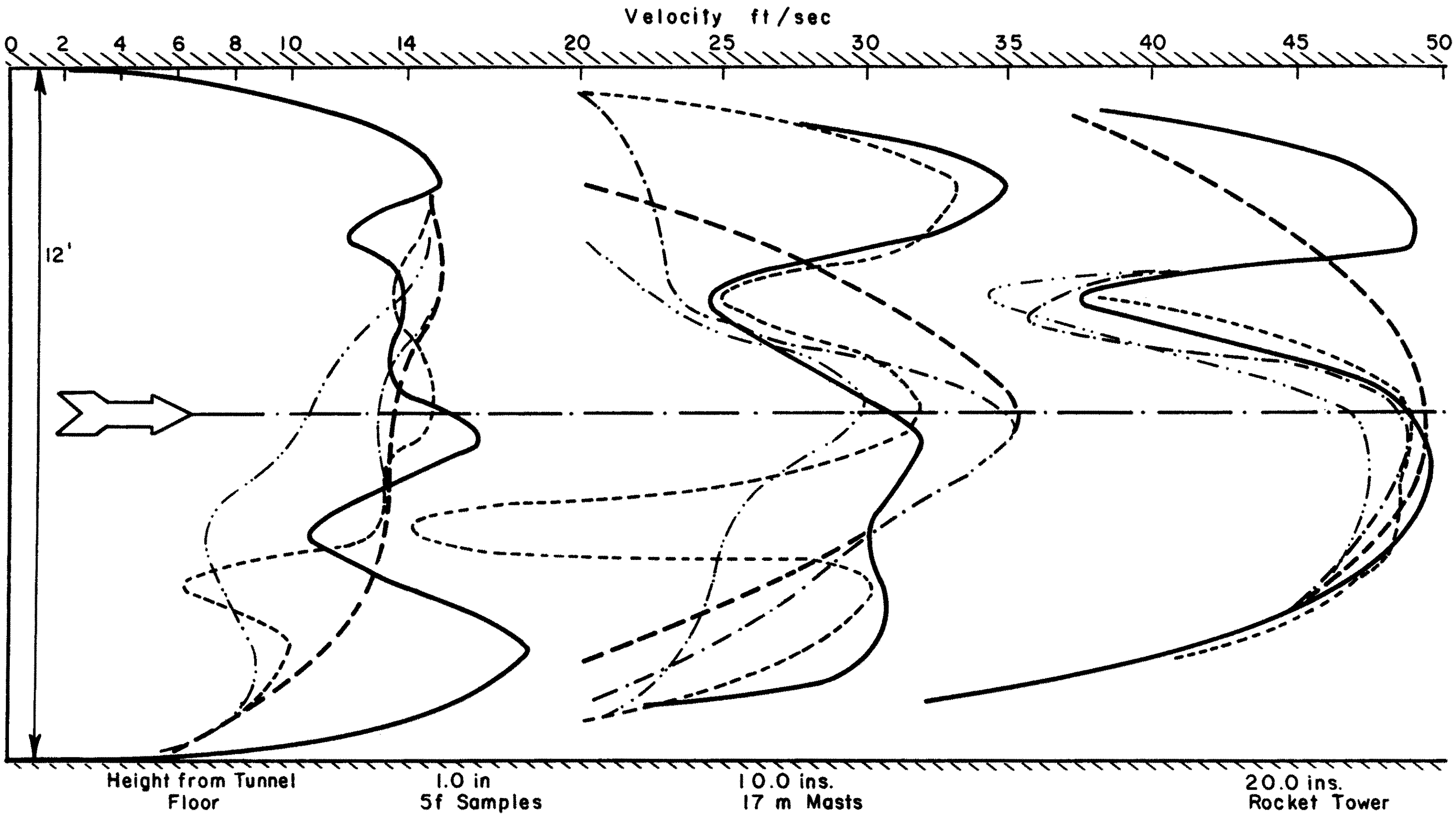


Fig. 2b Schematic Arrangement of Model in the Wind Tunnel
(N·W Wind)



Legend:

— — Location L_1, —·— Location L_2, - - - - Location L_3, —— Location L_4, —··— Location L_5

Fig 3 Effect of Roughness Elements on the Flow Past the Model (S·E Wind)

(Mean Velocity Profiles Across the Wind Tunnel at Three Heights and Five X-Locations.)

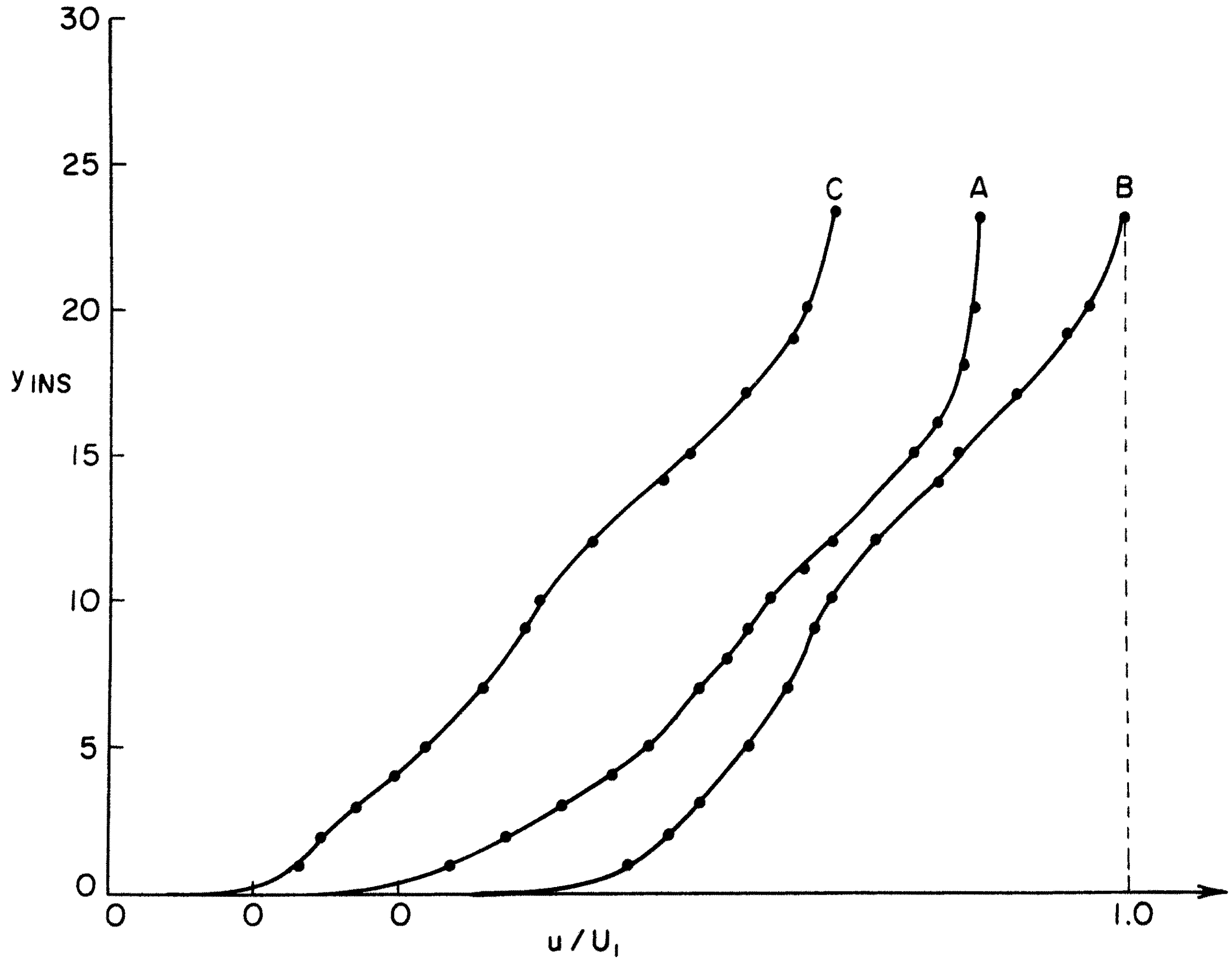


Fig. 4 Initial Velocity Profile -- Baseline L_1, Both Wind Directions

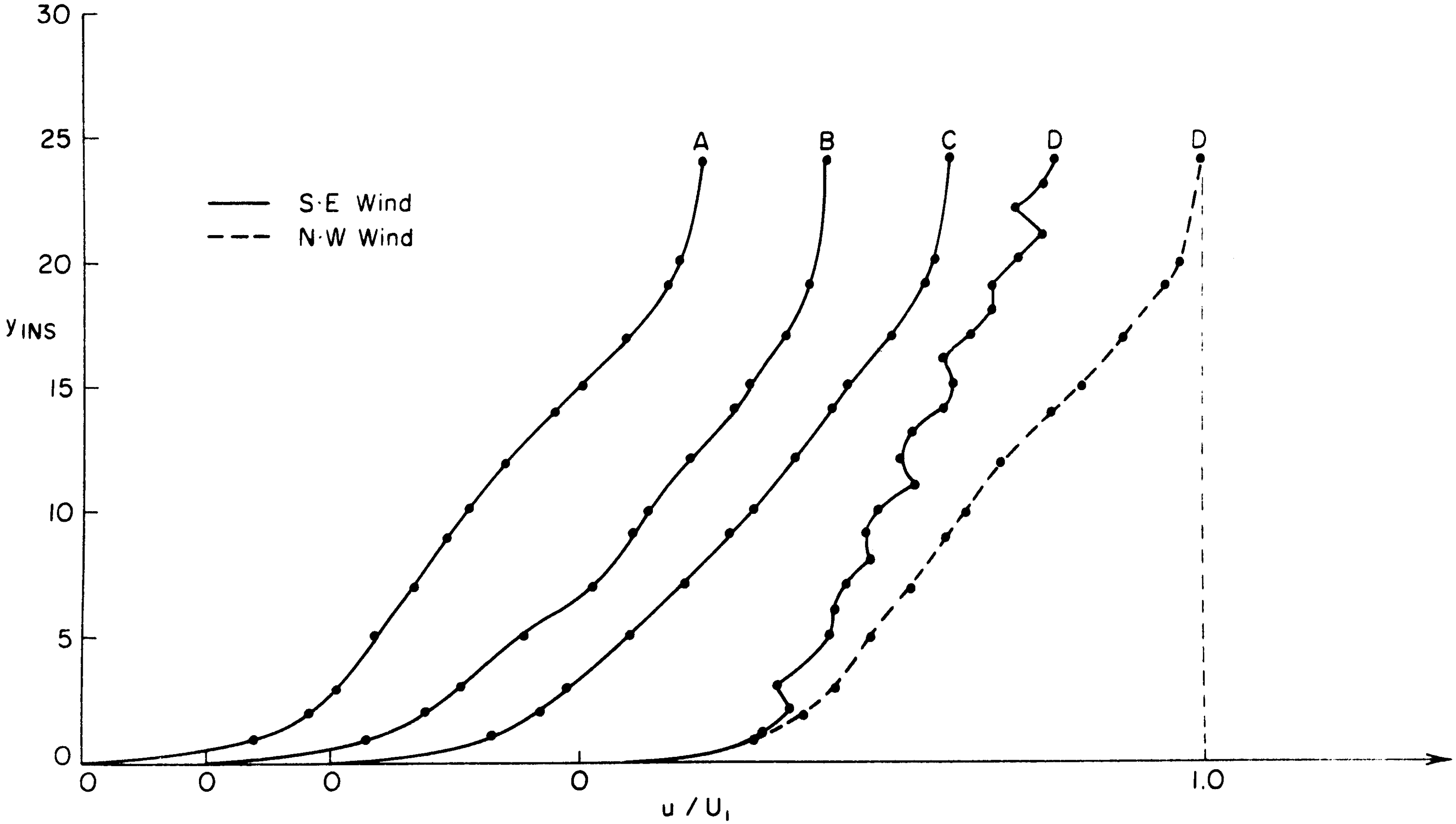


Fig 5a Velocity Profiles on Baseline L_2

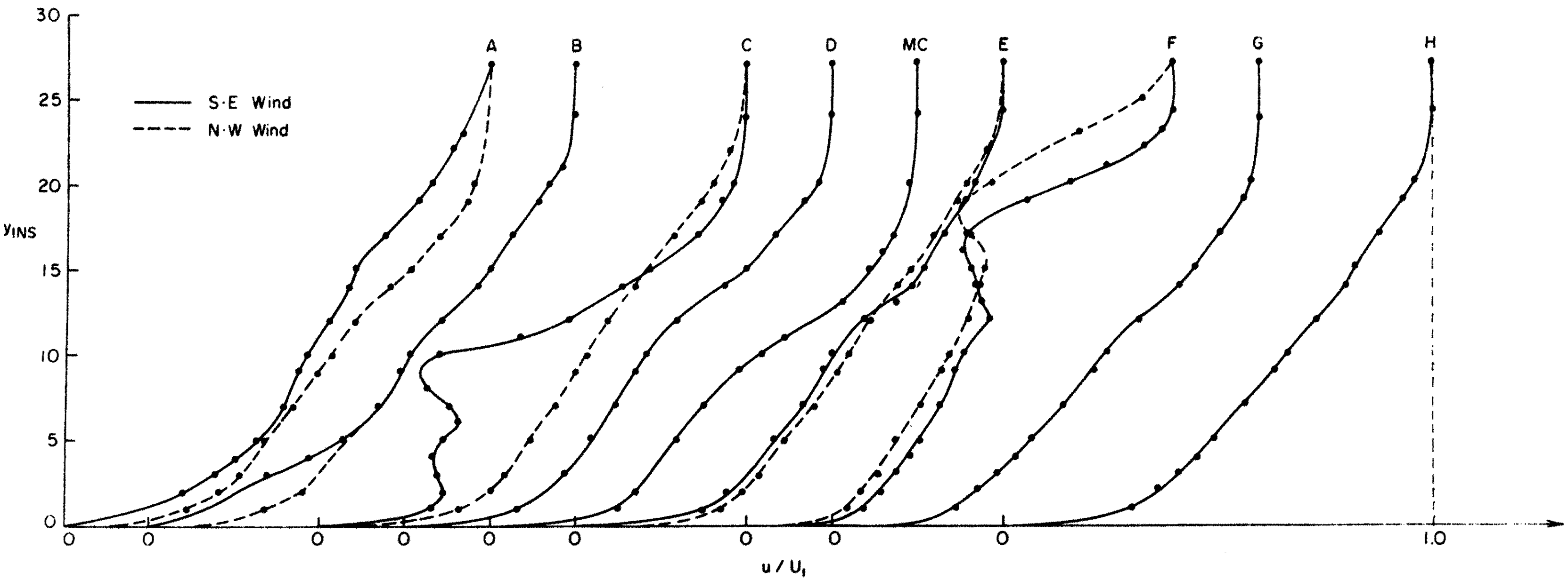


Fig. 5b Velocity Profiles on Baseline L_3

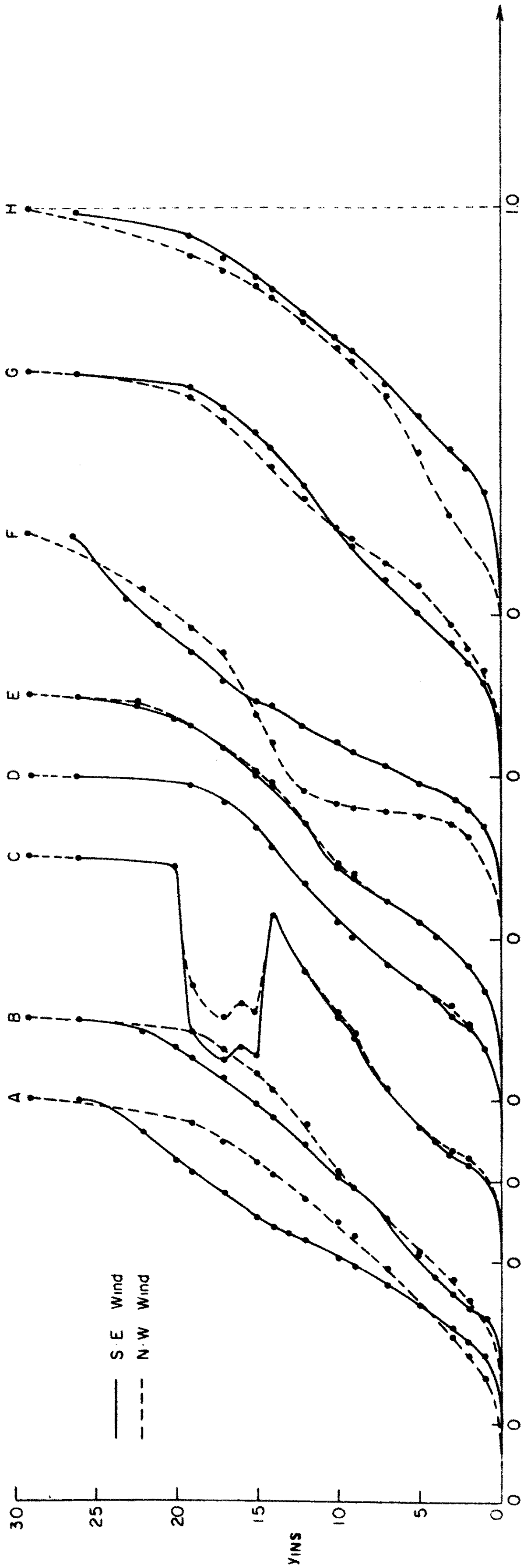


Fig. 5c Velocity Profiles on Baseline L_4

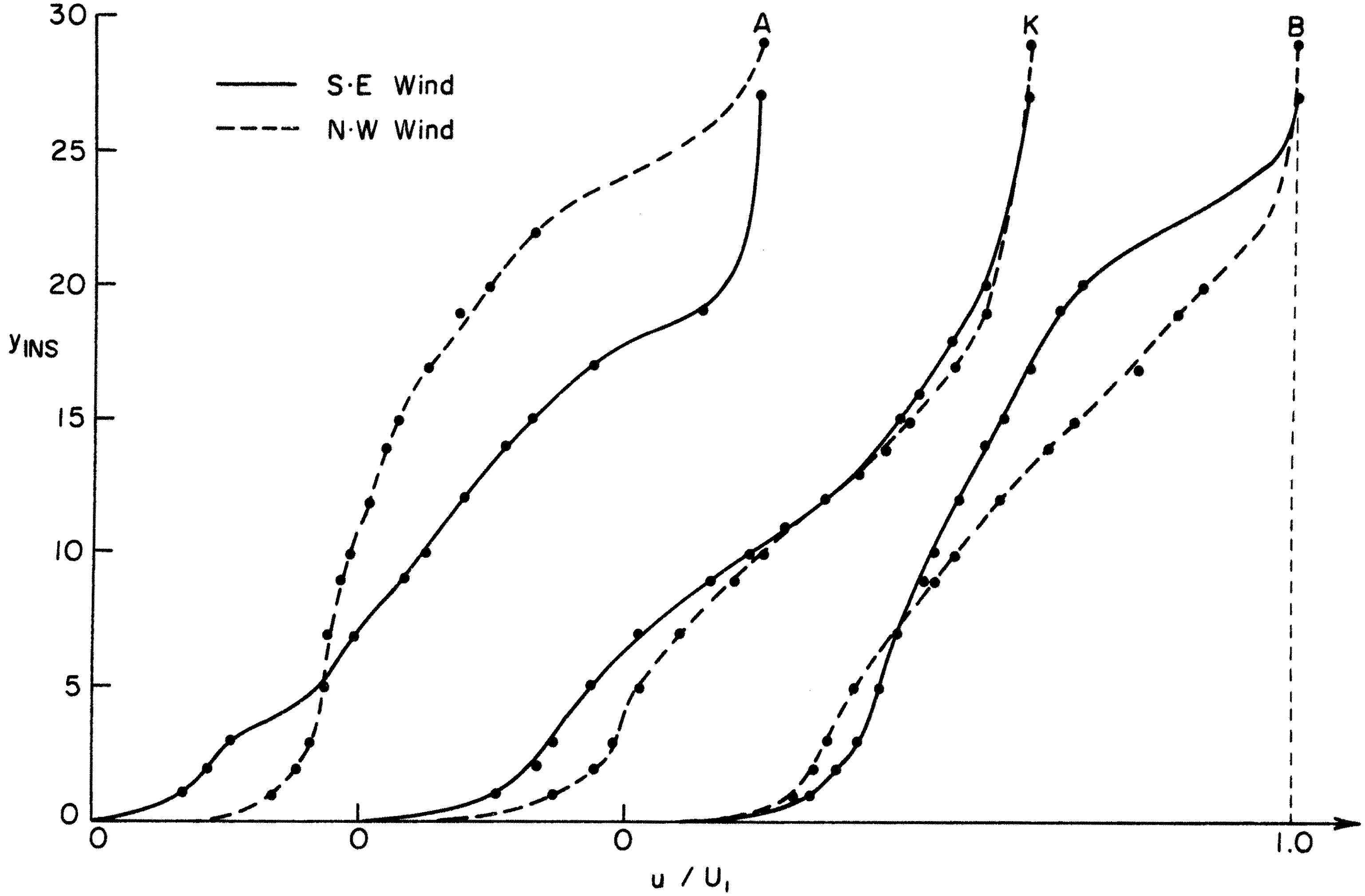


Fig. 5d Velocity Profiles on Baseline L_5, Downstream of Model

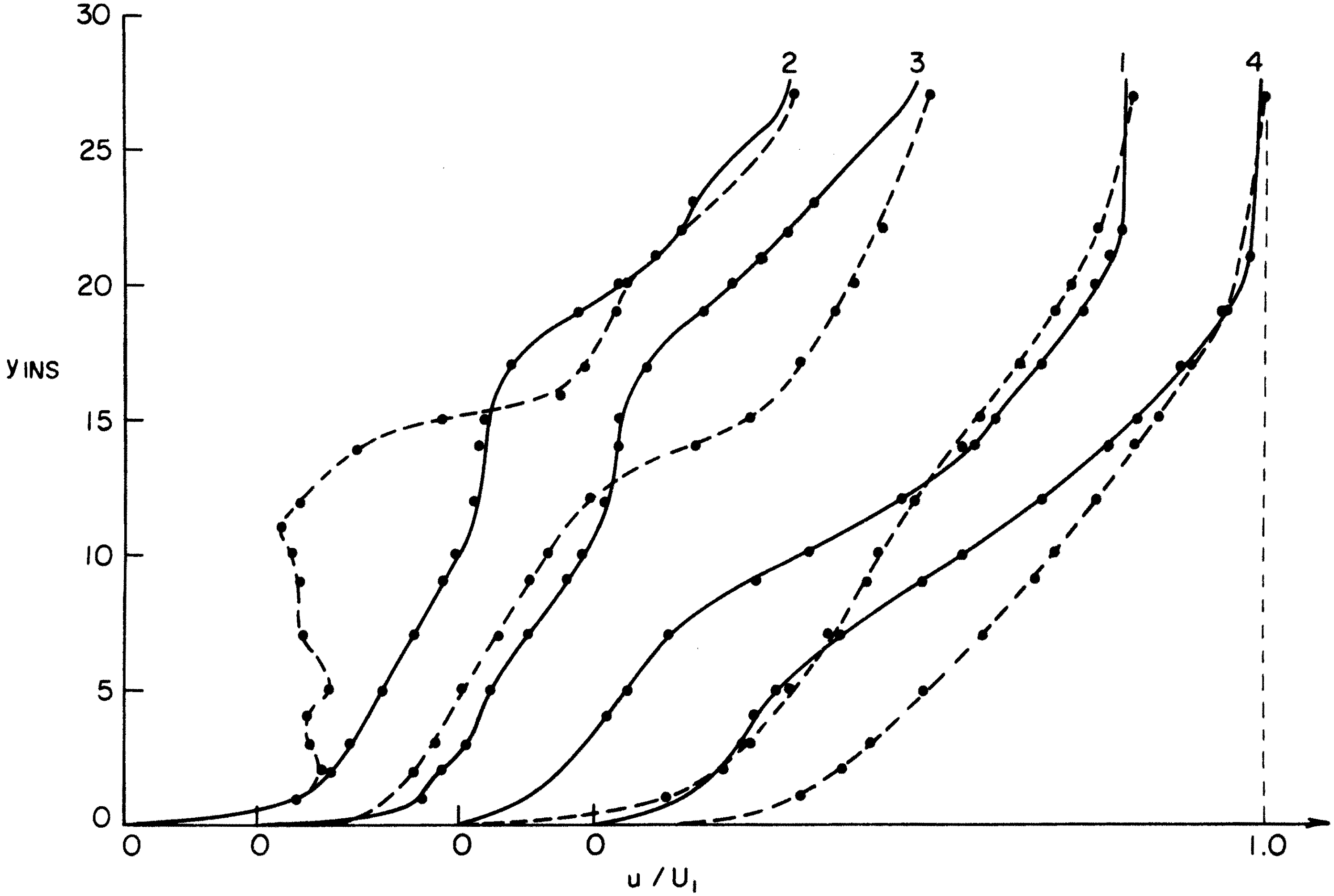


Fig. 5e Velocity Profiles in the Pie-shaped Region Behind Model Center.

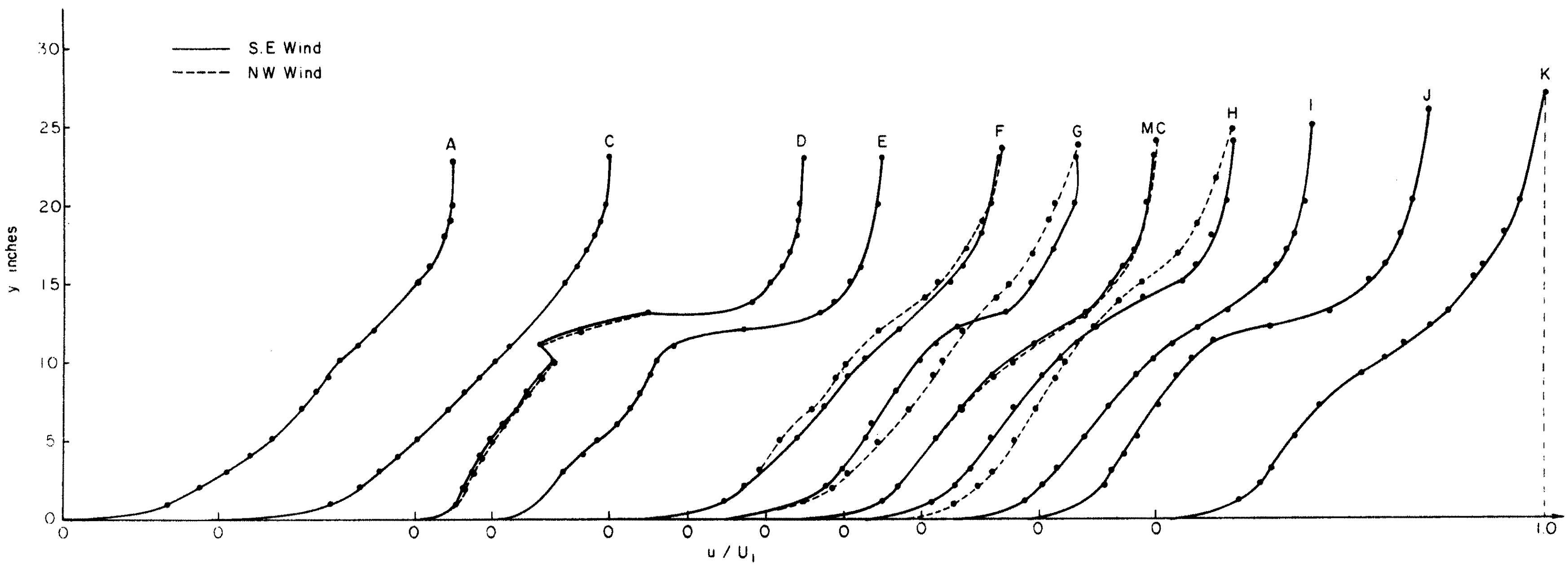


Fig 6 Velocity Profiles Along the Streamwise Centerline

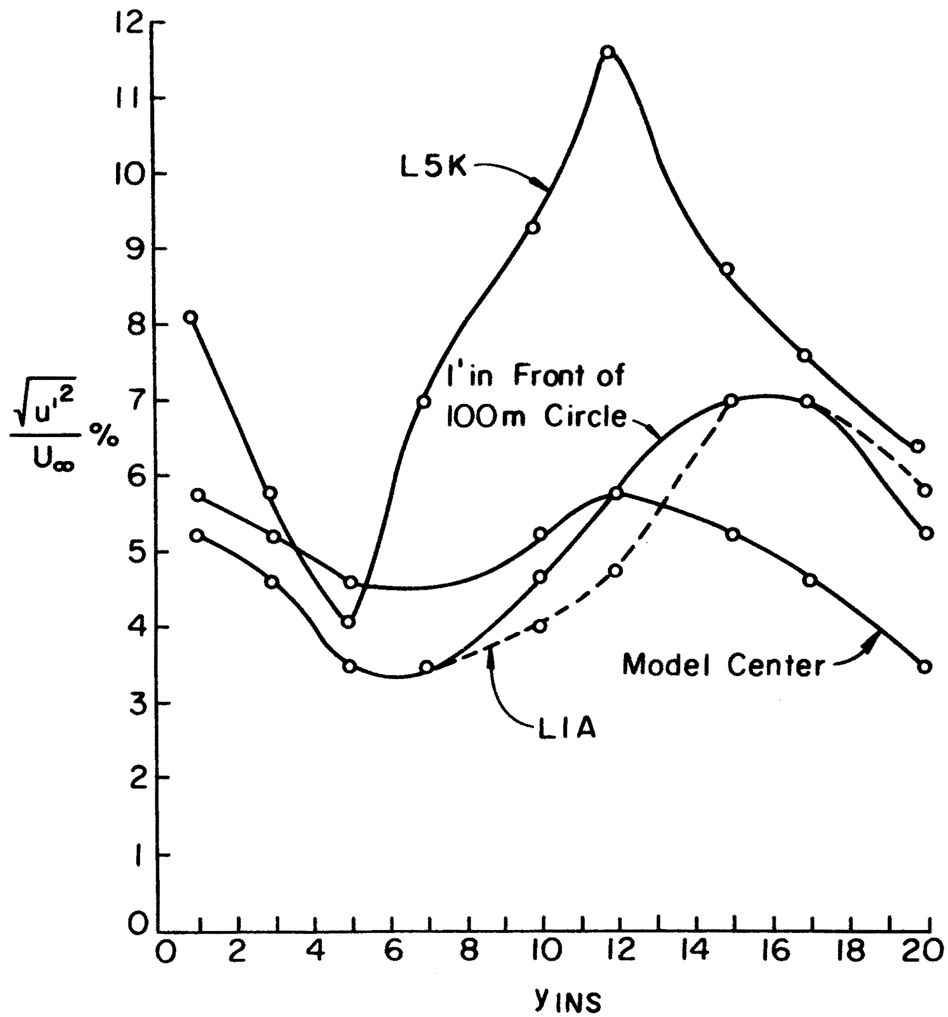


Fig. 7 Turbulence Intensity Profiles

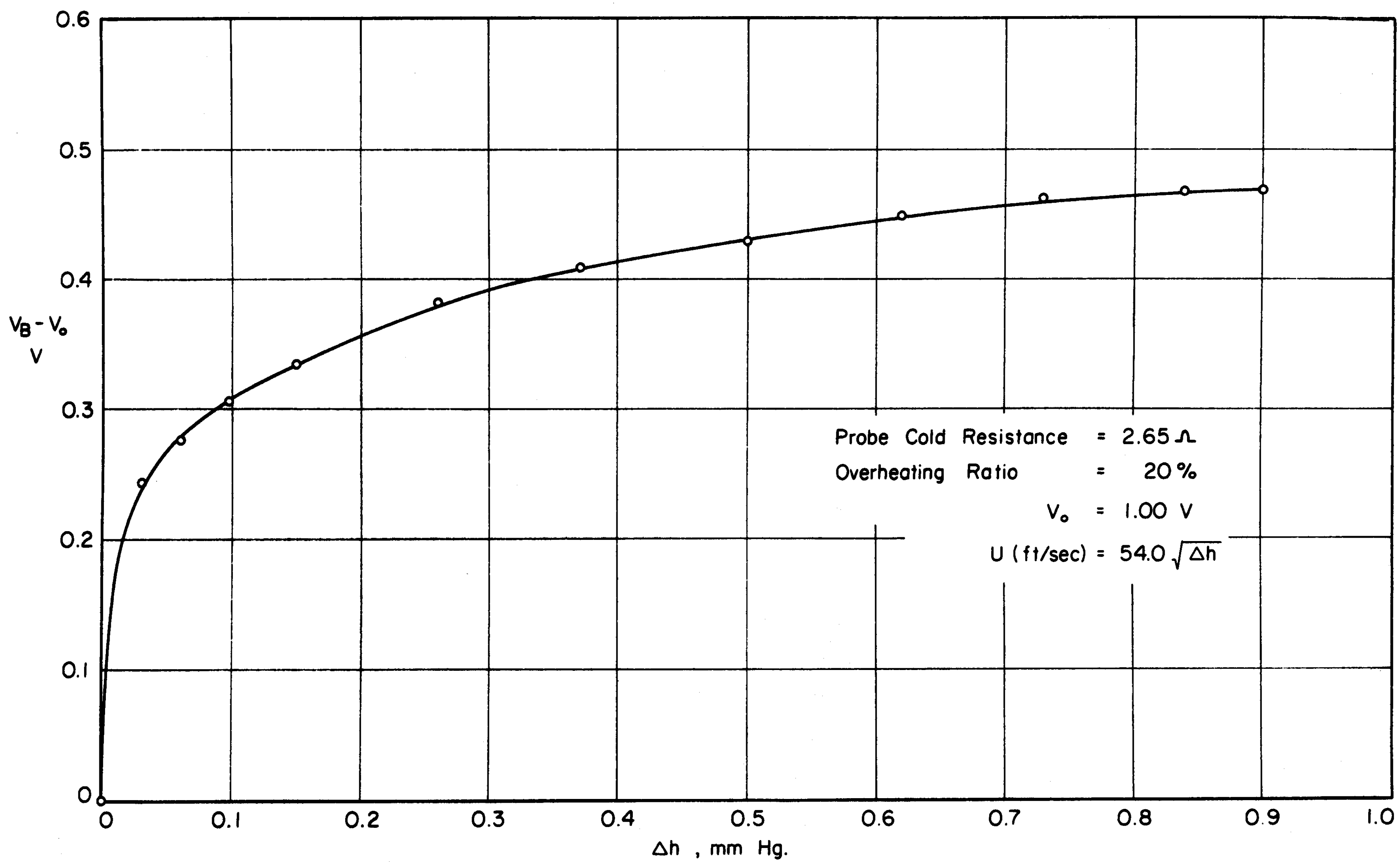


Fig. 8 Typical Hot-wire Calibration Curve

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