INVESTIGATIONS TO DEVELOP WIND TUNNEL TECHNIQUES FOR MEASURING ATMOSPHERIC GASEOUS DIFFUSION IN MODEL VEGETATIVE SURFACES

Colorado State University
Department of Civil Engineering
Fort Collins, Colorado

First Annual Report
July 1, 1960 to July 1, 1961

Contract No. 12-14-100-4546(41)
U. S. Department of Agriculture
Agricultural Research Service
Fort Collins, Colorado

September 26, 1961 CER61EJP60

INVESTIGATIONS TO DEVELOP WIND TUNNEL TECHNIQUES FOR MEASURING ATMOSPHERIC GASEOUS DIFFUSION IN MODEL VEGETATIVE SURFACES

Colorado State University
Department of Civil Engineering
Fort Collins, Colorado

First Annual Report
July 1, 1960 to July 1, 1961

Contract No. 12-14-100-4546(41)
U. S. Department of Agriculture
Agricultural Research Service
Fort Collins, Colorado

September 26, 1961

CER61MP60

TABLE OF CONTENTS

First Annual Report

"INVESTIGATIONS TO DEVELOP WIND TUNNEL TECHNIQUES FOR MEASURING ATMOSPHERIC GASEOUS DIFFUSION IN MODEL VEGETATIVE SURFACES"

Summary

During the first year of the contract, the following items have successfully been completed:

a. Wind tunnel test section and instrumentation was adapted to the particular needs of the diffusion study.

b. Preliminary theoretical studies were conducted to establish the most fruitful line of approach for future experimental and theoretical investigations.

c. Data were taken on the reference case of diffusion from a line source within the boundary layer over a smooth wall.

d. The data for the case of diffusion from a line source into the boundary layer on a smooth wall were analyzed and presented in a manner which is thought to be most meaningful for comparison with further studies with rough boundaries, and for establishing similarity criteria for modeling atmospheric conditions in the wind tunnel. They will be presented in detail in a Ph.D. dissertation, which is now available as a first draft.

e. Different possibilities have been explored for modeling boundary roughness elements which can be taken to represent natural crops, and which can be produced economically in sufficiently large quantities to cover a representative area of the boundary.

Personnel Active on the Project

During the first year of the project, Dr. J. E. Cermak, Professor of Engineering Mechanics, E. J. Plate, Assistant Research Engineer and Assistant Professor of Civil Engineering, and Michael Poreh, Junior Civil Engineer, have been active on the project. On September 1, 1961, Dr. J. E. Cermak left for Cambridge, England, to study under a one year post doctoral fellowship. Until he returns in September 1962, E. J. Plate will assume full responsibility for the continuation of the project and for the execution of the contract.

On October 1, 1961, a graduate assistant, Mr. Suznnai, will join the team working on this project.

Fiscal Information

A total amount of $18,571.39 has been spent on salaries and wages; $2,570.82 have been used for materials, including adaptation of the wind tunnel and varied boundary materials.

Wind Tunnel Adaptation

The first problems facing the experimentor were to prepare the test section of the large wind tunnel for the exacting demands of experimentation in two dimensional flows and to develop the instruments for feeding gas into the flow and for sampling concentrations.

4.1 Test Section -

As described in Semi-Annual Report No. 1 3.2 (ref. 1), the test section of the large wind tunnel of Colorado State University's Aerodynamics Laboratory was chosen for the experiments. A large number of preliminary experiments were carried out to determine the nature of the flow in this test section. A careful survey of the flow field showed that the flow was not truly two dimensional, but that the streamlines within the boundary layer converged. The flow convergence was much more rapid than could be explained by the growth of the boundary layer alone, and secondary circulation had to be suspected. An attempt to remedy the situation by changing the entrance section to the blower failed. It was found instead that the difficulty initiated in the entrance cone of the test section. The problem was solved finally, by installing a honeycomb built of paper tubes of 2 ft. length and 2 in. diameter into the entrance of the test section. The honeycomb was followed by a 40-mesh screen. The final arrangement of the wind tunnel test section is shown in figure 1.

The honeycomb system had the disadvantage of increasing the turbulence level of the ambient air in the wind tunnel. No reliable data have as yet been taken which could show clearly the effect of ambient turbulence on the growth of a boundary layer or on the growth of a turbulent diffusion flume. It is known, however, that the turbulence of the ambient air will affect the turbulence level (or intensity) inside the boundary layer only at the outer edge of the boundary layer. Since this region was only of minor interest (natural boundary layers usually are so large that the diffusion processes affecting crops are only influenced by the flow within the boundary layer) the slight increase in ambient turbulence was accepted.

The test section floor downstream from the honeycomb was roughened by a layer of 1/4 inch gravel to trip the laminar boundary layer. In this manner, an exceptionally stable boundary layer flow could be generated, and a flow was obtained which was homogeneous laterally across the test section at least within the central 2 ft.

4.2 Instrumentation -

The gas feeding instrumentation has been described in some detail in the Semi-Annual Progress Report No. 1. That report also described some considerations which lead to the gas sampling system that was used. The analysis of the sample was done by colorimetric methods. The details of the sampling procedure and of the analysis are described elsewhere. (Davar's thesis, "Diffusion from a Point Source within a Turbulent Boundary Layer", ref. 2). The investigation of diffusion over smooth walls, which are described later, indicated that the distance of the source of gas above the ground is of importance only in a zone very close to the source itself. Since a large number of variables influence the problem in this zone a detailed investigation has been postponed. This made further development of the adjustable height source unnecessary, so that the design described in Semi-Annual Progress Report No. 1, p. 7, has not been tried out. However, some investigations of this system will be performed in the near future.

Diffusion from a Line Source Into A Boundary Layer Flowing Over a Smooth Wall.

Diffusion processes in vegetated regions can be modeled in a laboratory wind tunnel only if sufficiently accurate and comprehensive model laws are found that relate the boundary layer and its cover, the atmospheric air flow, and the diffusion process itself. For obtaining these laws, one should first express the process of diffusion in mathematical form, convert the equations into dimensionless forms and obtain the model laws by inspectional analysis of these dimensionless equations.

Mathematical efforts to proceed along these lines are handicapped however, by a difficulty inherent to all turbulence problems, namely, that the number of equations which are known to govern the process is less than the number of unknowns. This is due to the fact that no completely successful physical model has been found which relates average turbulence quantities to mean flow parameters.

Therefore, approximations have to be developed, or assumptions introduced, which derive their justification from indirect experimental evidence only, and the desirable case of using experimental data only for verifying theoretical conclusions can generally not be hoped for. Essentially, then, this study has attempted to present the experimental data in a form which makes the structure of the process apparent, and which also permits some reasonable estimates for the extension of the experimental findings in a wind tunnel to the actual situation over vegetated regions in the field. The results are summarized in the theses of M. Poreh which will be completed soon. The following is a short outline of the thesis and of the results to be found in it:

5.1 Introduction-

Theoretical investigations were carried out during the period of preliminary experimentation in the wind tunnel. The study indicated the following:

a. The velocity field near an arbitrary boundary (smooth, rough, vary, etc.,) is similar with respect to distance, i.e., by dividing all velocities through a suitable reference velocity, and all distances from the boundary by a suitable reference length, the velocity profiles at different stations downwind can be made coincident.

b. Velocities over rough boundaries can be studied most conveniently in terms of their deviations from corresponding velocities in the flow field over a smooth boundary, (see fig. 2 taken from ref. 3).

c. It appears advantageous to relate parameters referring to diffusion in boundary layers in smooth and rough walls in the same way investigators relate the two flow fields.

These versions indicated the desirability of first investigating the case of diffusion in a boundary layer over smooth walls before studying the rough case.

5.2 Details of the Experiments -

5.2-1 Mean velocity profiles - Mean velocity profiles for wind speeds of approximately 9, 12, and 17 fps were measured at stations which were located between 32 ft. and 61 ft. downstream from the test section entrance. Typical velocity distributions are shown in figure 3.

The characteristic boundary layer height δ was computed. The change of δ within the test section is given in figure 4 .

By using δ as the length parameter, and the ambient velocity as velocity parameter, dimensionless profiles were calculated. As can be seen from figure 5, similarity exists, at least approximately.

5.2-2 Concentration profiles - Two series of experiments were performed (see figure 1).

Series I - The source of gas was located at station 33-1/2 ft. Concentration profiles were taken at 3, 5, 9, 15, and 21 ft. downstream for each velocity. Each point was usually repeated twice. Typical profiles are given in figure 6.

These concentration profiles were analyzed and found to be similar if expressed in dimensionless profiles. (Figure 7).

The characteristic length of the flume λ is defined as the height where the concentration is 50 per cent of the maximum concentration of the profile.

The shape of the dimensionless profile was found to be independent of X . The parameter λ is approximately proportional to $X^{0.8}$ while C_{max} decreased inversely proportionally to $X^{-0.9}$. (Figure 8).

The functional form of the eddy diffusivity was computed from the data.

Series II - The source has been located at station 15-1/2 ft., and concentration profiles were taken at stations 33-1/2, 39, 51 and 59 ft.

These measurements showed a similarity with respect to the boundary layer height δ as shown in figure 9. The maximum concentration dropped inversely proportional to δ and U ambient. (Figure 10).

5.2-3 Diffusion zones - The experimental results and the governing equation suggested a division of the boundary layer into 4 zones. See figure 11.

(1) The zone very close to the source where the influence of the source is recognized.

(2) The intermediate zone which exhibits a similarity with respect to λ. This is the important zone in as much as atmospheric models are concerned.

(3) A transition zone.

(4) A final similarity zone.

5.2-4 Concentration and mass flow - An important distinction between concentration at a point and flow of matter at a point has to be made for practical application. This is illustrated by the following:

If gas is sprayed with the wind to destroy insects instantaneously by contaminating the air to a given value of concentration, the concentration profiles will give the right information. On the other hand, if fine powder is sprayed and it acts by contact with flies or insects, the information required is what percentage of sprayed material will pass through a unit area prependicular to the flow at a given point. The distribution of mass flow is not similar to the concentration profiles. It is given by the Uc profiles. These profiles have been calculated for the intermediate zone. A typical distribution is given in figure 12.

Selection of Suitable Roughness Elements

The selection of suitable roughness elements was guided by consideration of flow conditions available, material cost, and significance of element behavior.

The available flow conditions are restricted by the present blower to 18 fps, approximately. In order to obtain roughness elements which deflect in this for range of velocities, very flexible materials must be chosen.

After considering many different materials, including small plants molded in plastic, wires whose insulation is cut off partly to serve as leaves, plastic tubing, rubber and others, it was discovered that manila paper had some of the desired properties. The paper, however, depended too much on the air humidity; therefore, paper was abandoned. The present choice is 1/4-inch strips of plastic sheeting, of sizes between 0.003 inch and 0.03 inch. Preliminary experiments show that this material has most of the desired features, including a very low price.

The material for use in the experiments will be chosen so that it deflects considerably in the range of velocities available. Before any attempt can be made to relate model roughness to prototype roughness, experiments will be performed and the results analyzed. First results are expected before the end of the year.

Program for Second Study Year

The present setup of the wind tunnel makes it possible to perform a large test program for the second study year. The wind tunnel can be operated practically continuously, and the only difficulties expected could be due to instrumentation problems. In view of this fact, it is planned to start with an extensive study of the most feasible roughness sizes, heights, and thicknesses, and thereby to determine the most meaningful arrangements to be used during the study with flexible boundaries.

While the roughness elements are constructed in the Hydraulics Laboratory shop, some problems on diffusion over smooth boundaries will be briefly explored. The first one is to determine the distances at which the deviation of the diffusion pattern created by an elevated line source from that generated by a line source located at the ground level becomes insignificant. An exhaustive survey of the diffusion field at short distances behind the elevated source is, however, not contemplated at the present time.

Another short investigation to be performed while roughness elements are constructed study on the influence of a single, rigid roughness element on the diffusion pattern. For this purpose, a plate is stretched across the test-section floor, in a manner resembling a fence perpendicular to the wind. The line source is placed either upstream or downstream (at a fixed distance from the plate) and mean concentrations will be determined at different distances downstream from the source. This study is facilitated by the fact that the velocity fields produced by boundary layer flow in this wind tunnel have been investigated in a Ph.D. dissertation by H. Nagabhushanaiah, (ref. 4) so that no velocity data except checks need to be taken.

The study of the flexible boundaries will be initiated by a careful survey of the mean velocity field above and between the boundary roughness elements. Then, a tracer will be inserted from a source located at the ground, and concentration profiles will be taken in and above the roughness elements.

Roughness elements of different flexibility will be used to obtain the case of rigid roughness elements as a limiting case of flexible roughness elements.

Theoretical investigations will be made to relate flexible and non-flexible roughness to smooth boundary conditions.

References

1. Semi-Annual Report No. 1, 1 July 1960 to 30 December 1960, Contract No. 12-14-100-4546(41) USDA, ARS, Fort Collins, Colorado, January 1961.

2. Davar, K. S., Diffusion from a point source within a turbulent boundary layer. Ph.D. Thesis, Colorado State University, June, 1961.

3. Hama, F. R., Boundary layer characteristics for smooth and rough surfaces. Tras. The Society of Naval Architects and Marine Engineers, 62, 1954.

4. Nagabushanaiah, H., Flow characteristics over a flat plate in a boundary layer. Ph.D. Thesis, Colorado State University, (in preparation).

TABLES

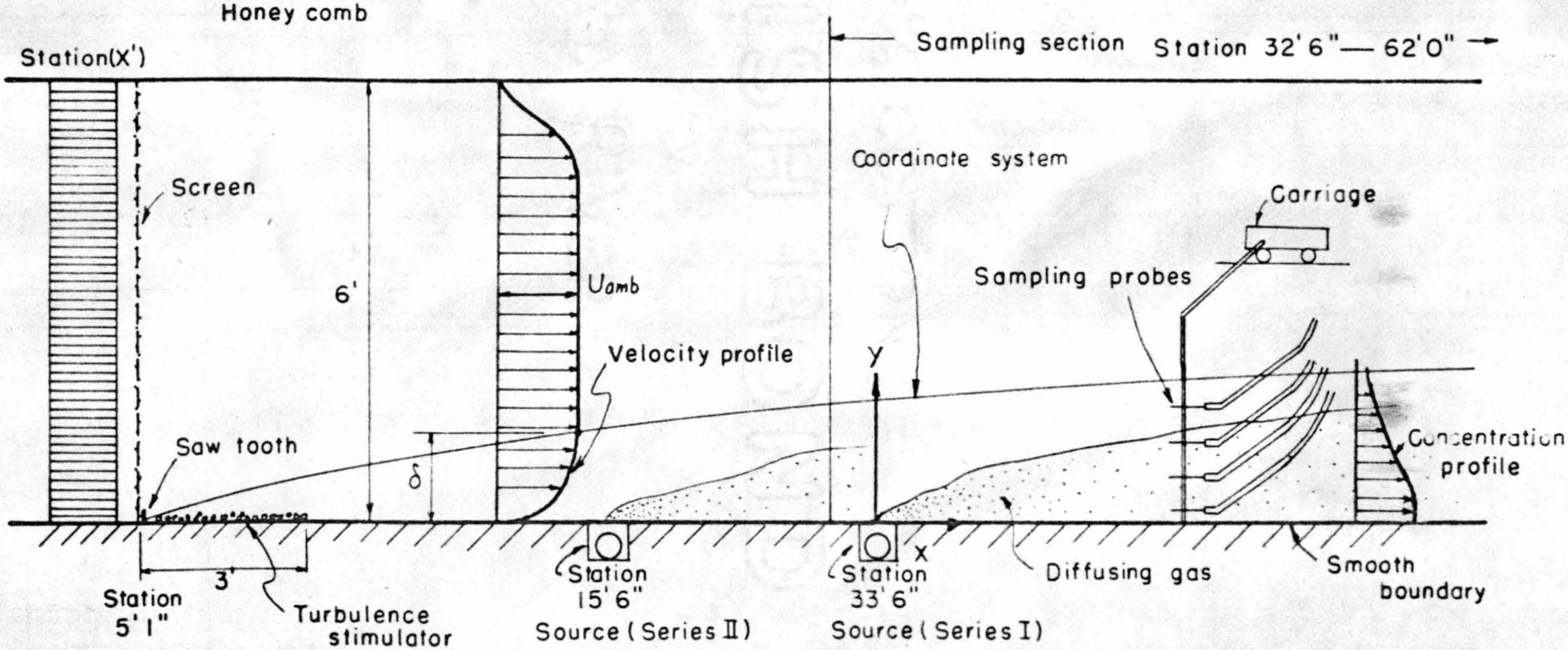
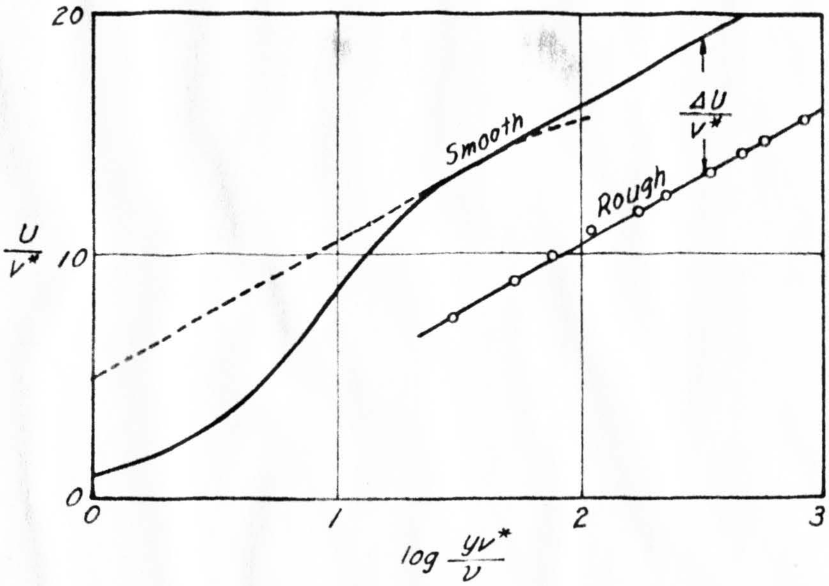
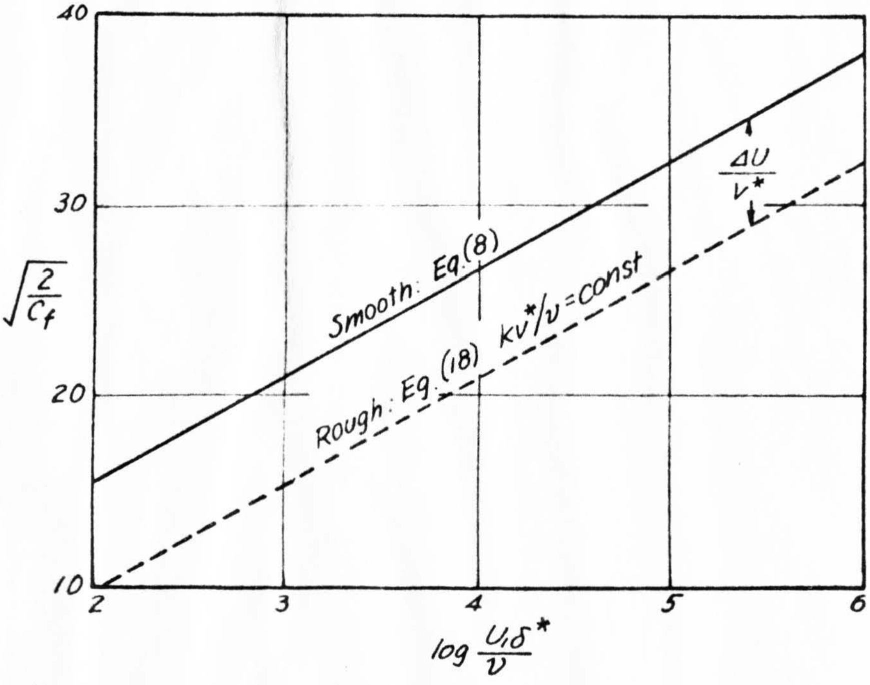


FIG. 1 TEST SECTION GEOMETRY



(a) Typical Velocity Profile for Rough Surface



(b) Surface-Resistance Formular for Rough and Smooth Surface

Fig. 2

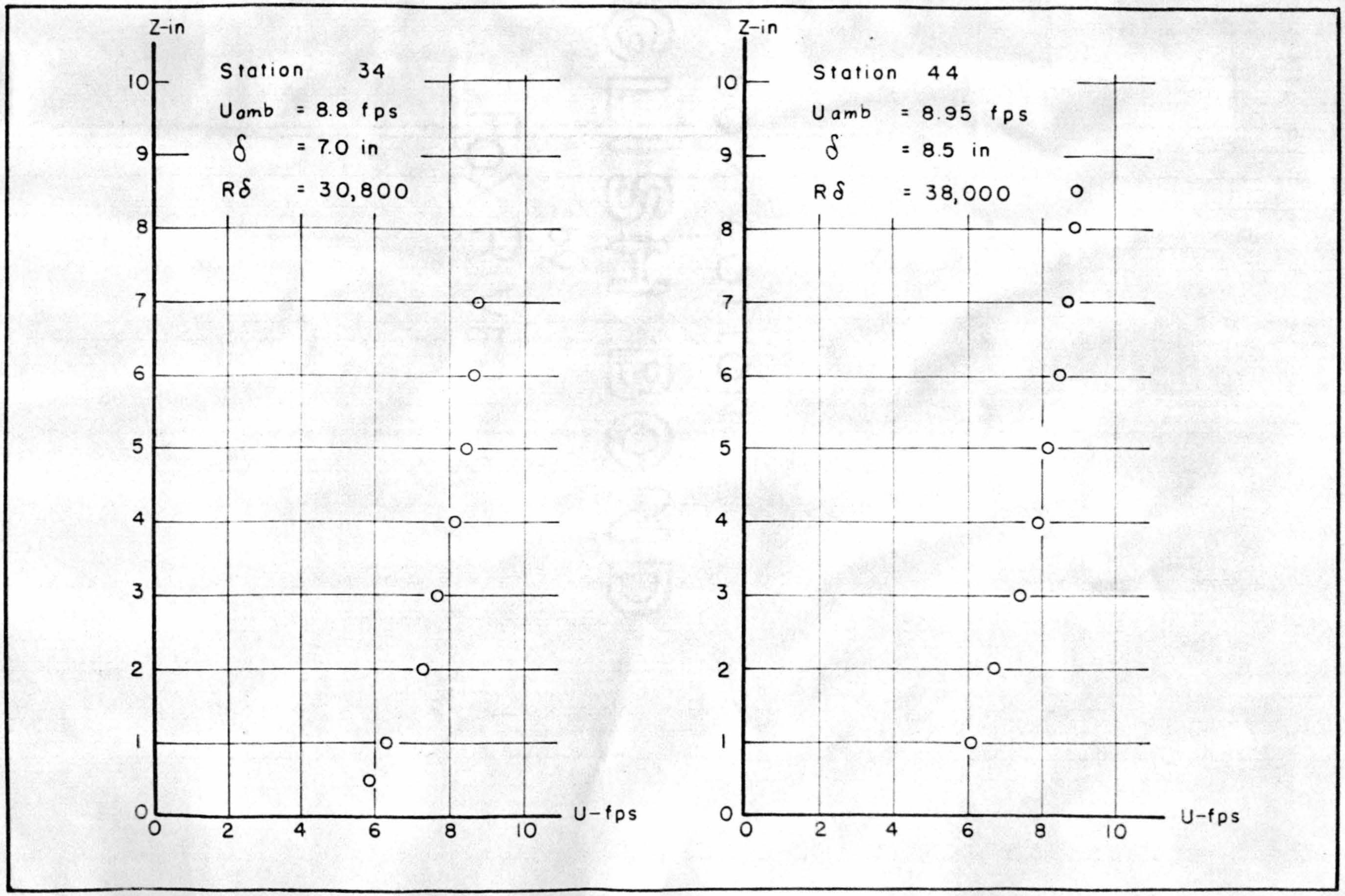


Fig 3 - Typical Vel[illegible]

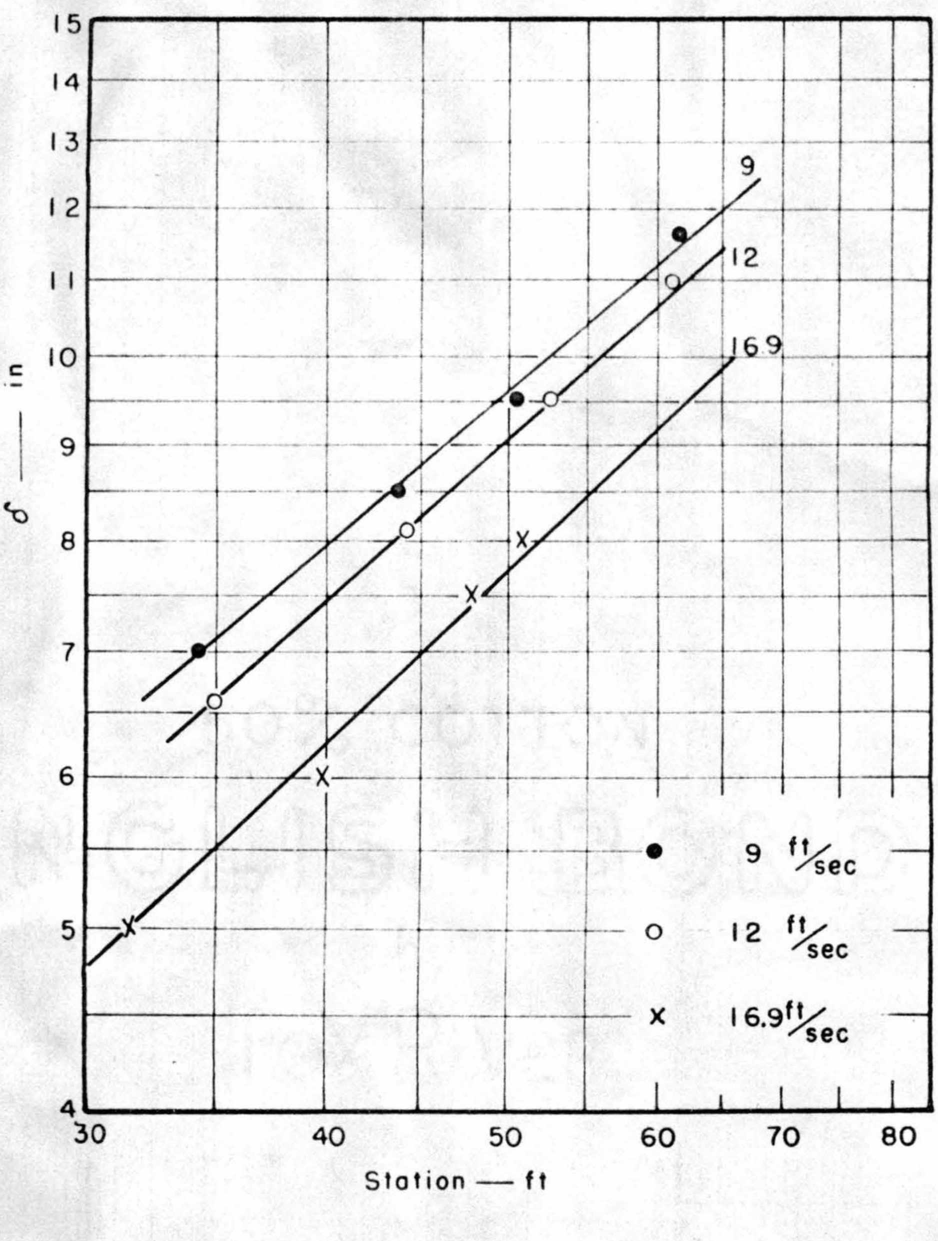


FIG. 4 VARIATION OF THE BOUNDARY LAYER THICKNESS

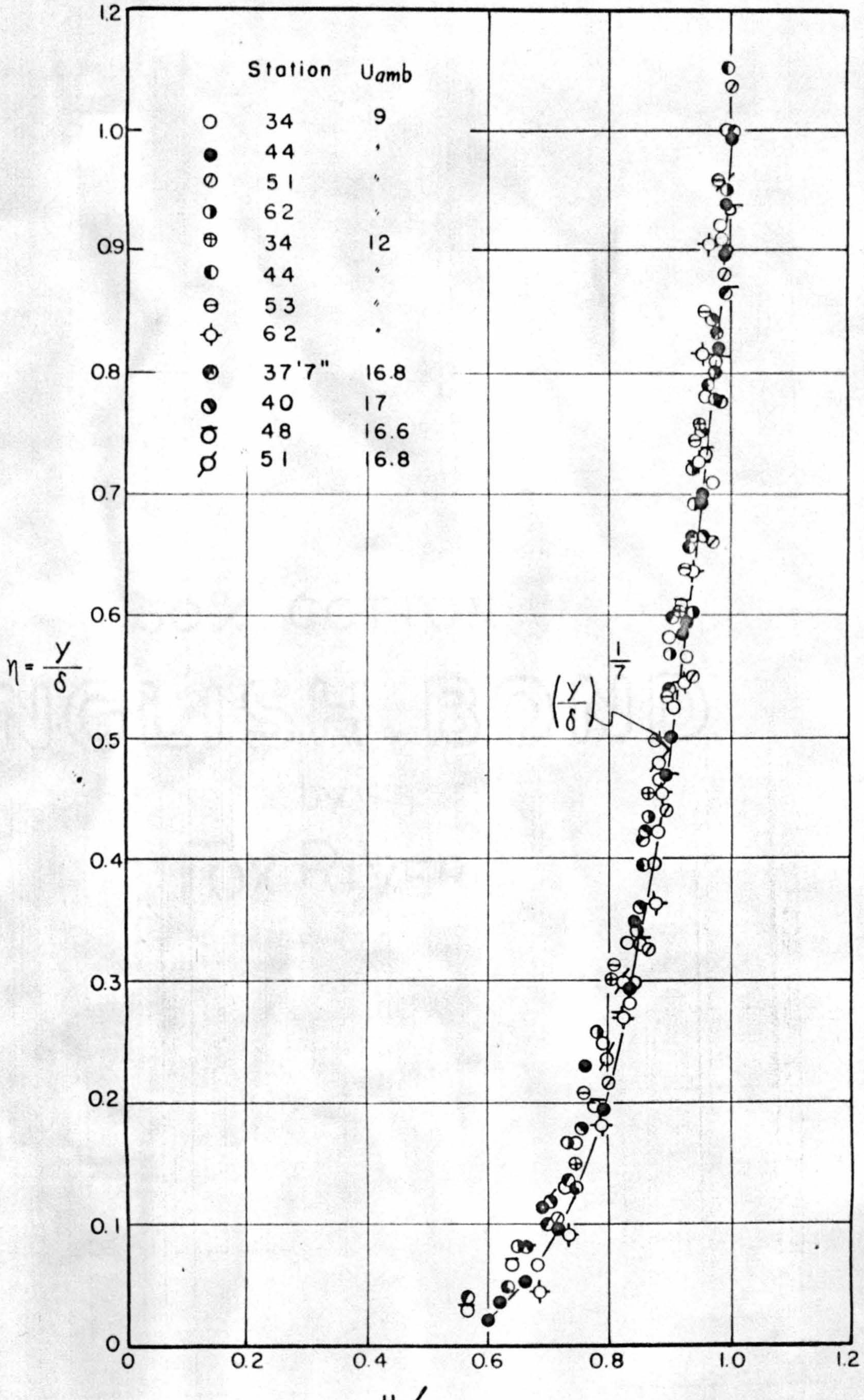


FIG. 5 UNIVERSAL VELOCITY PROFILE

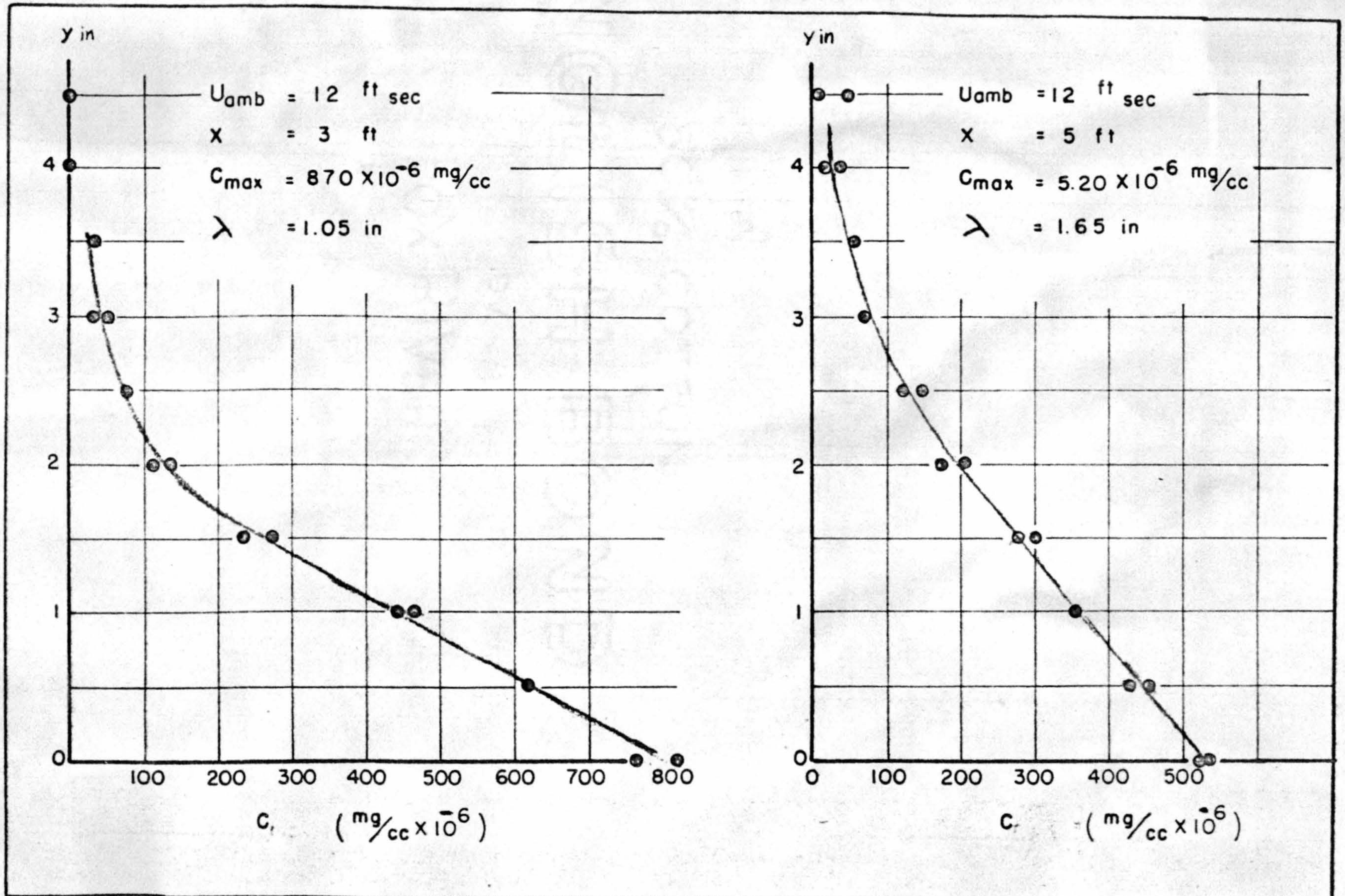


FIG. 6 CONCENTRATION PROFILES

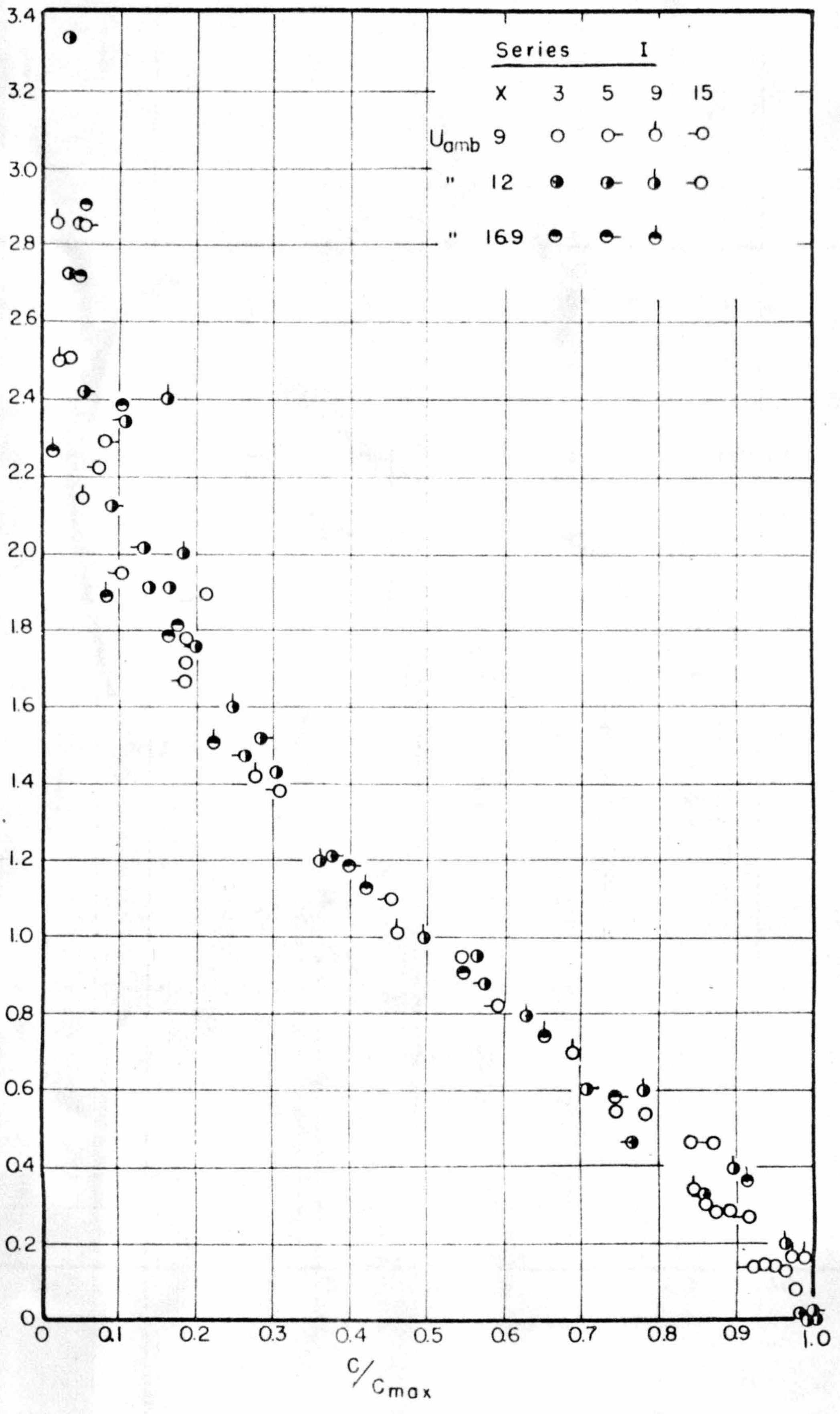


FIG. 7 DIMENSIONLESS CONCENTRATION PROFILES IN THE INTERMEDIATE ZONE

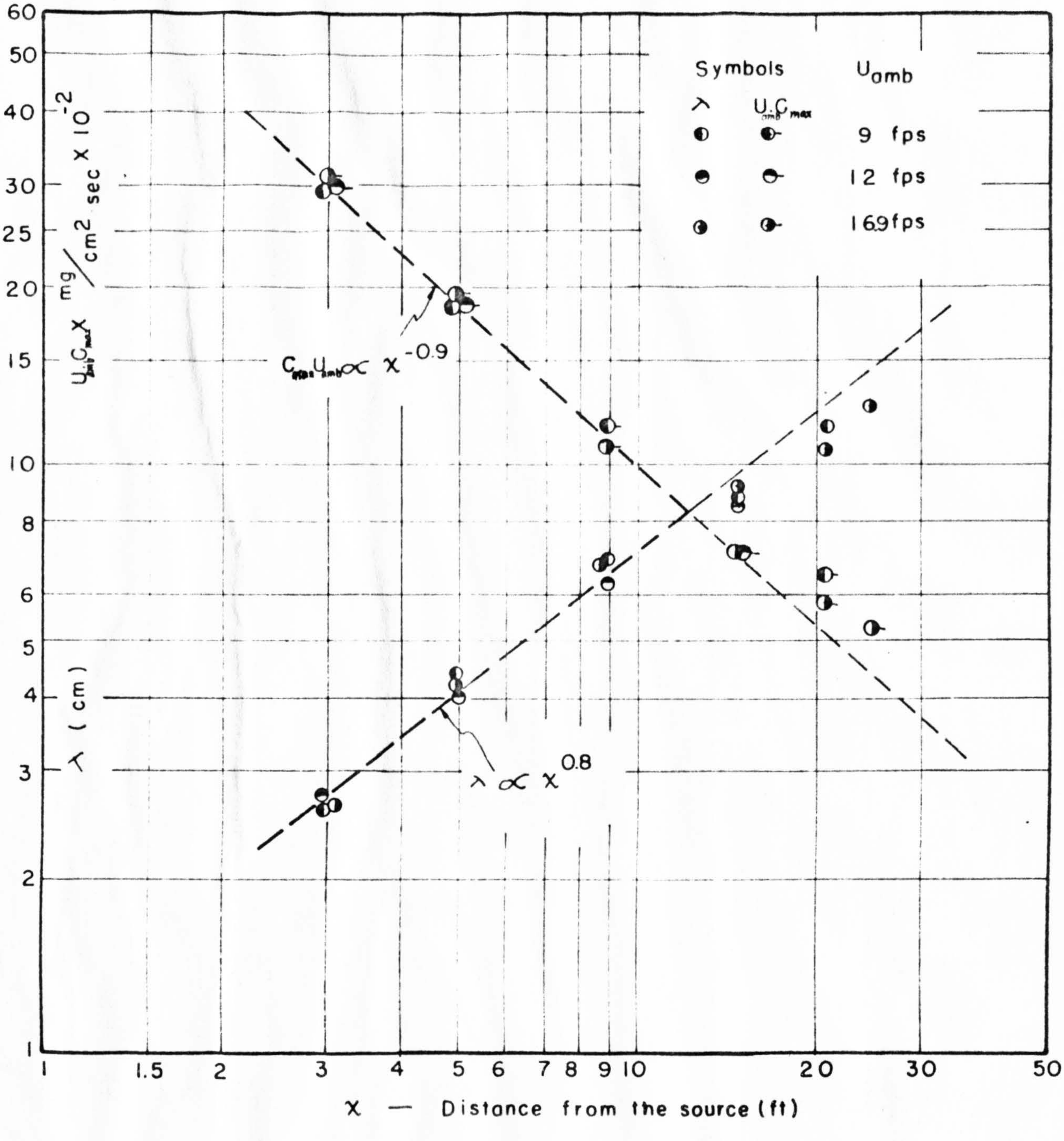


FIG. 8 VARIATION OF λ AND $U_{amb} \cdot C_{max}$ IN THE INTERMEDIATE ZONE

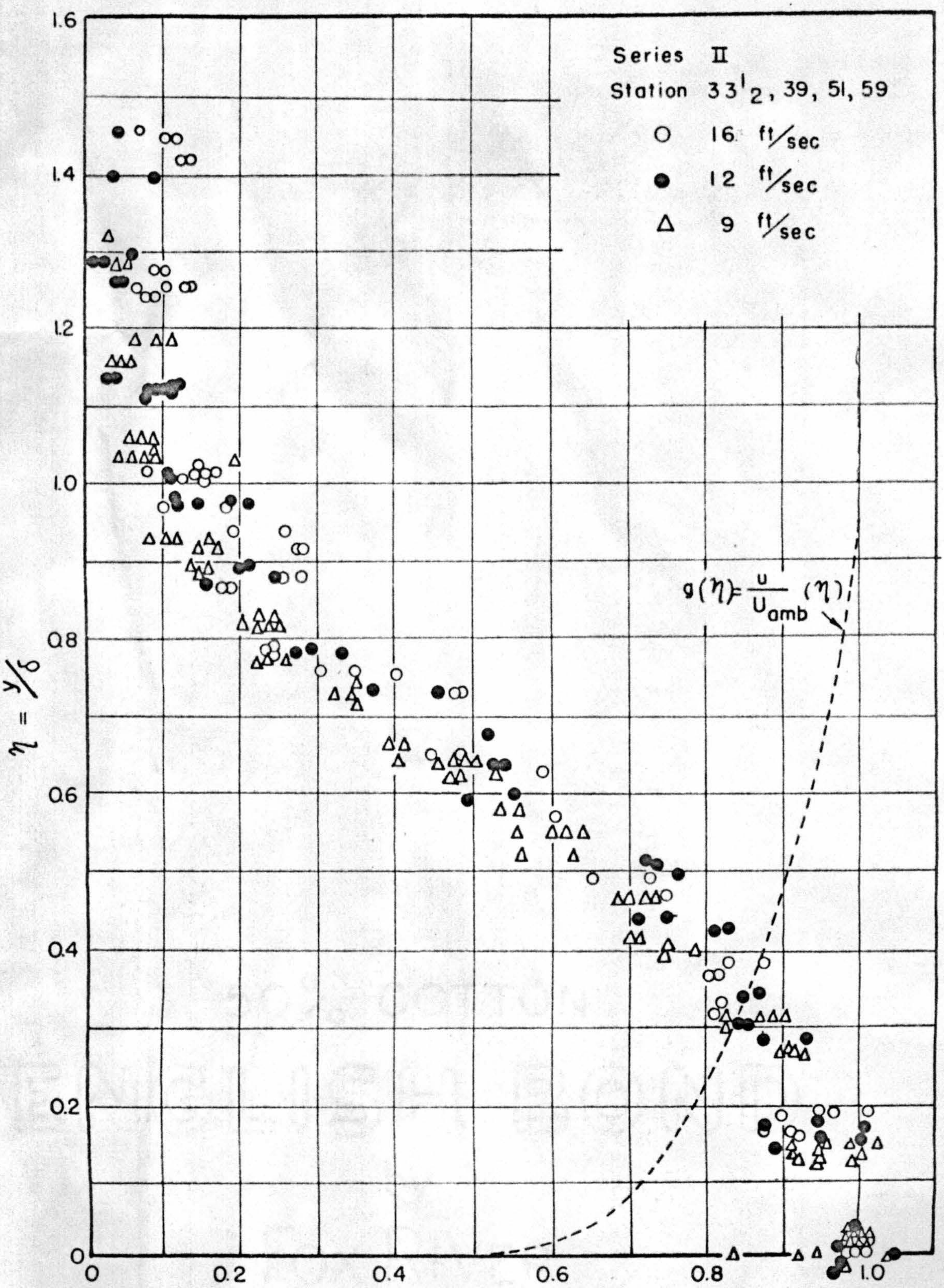


FIG. 9 DIMENSIONLESS CONCENTRATION PROFIL
IN THE FINAL ZONE

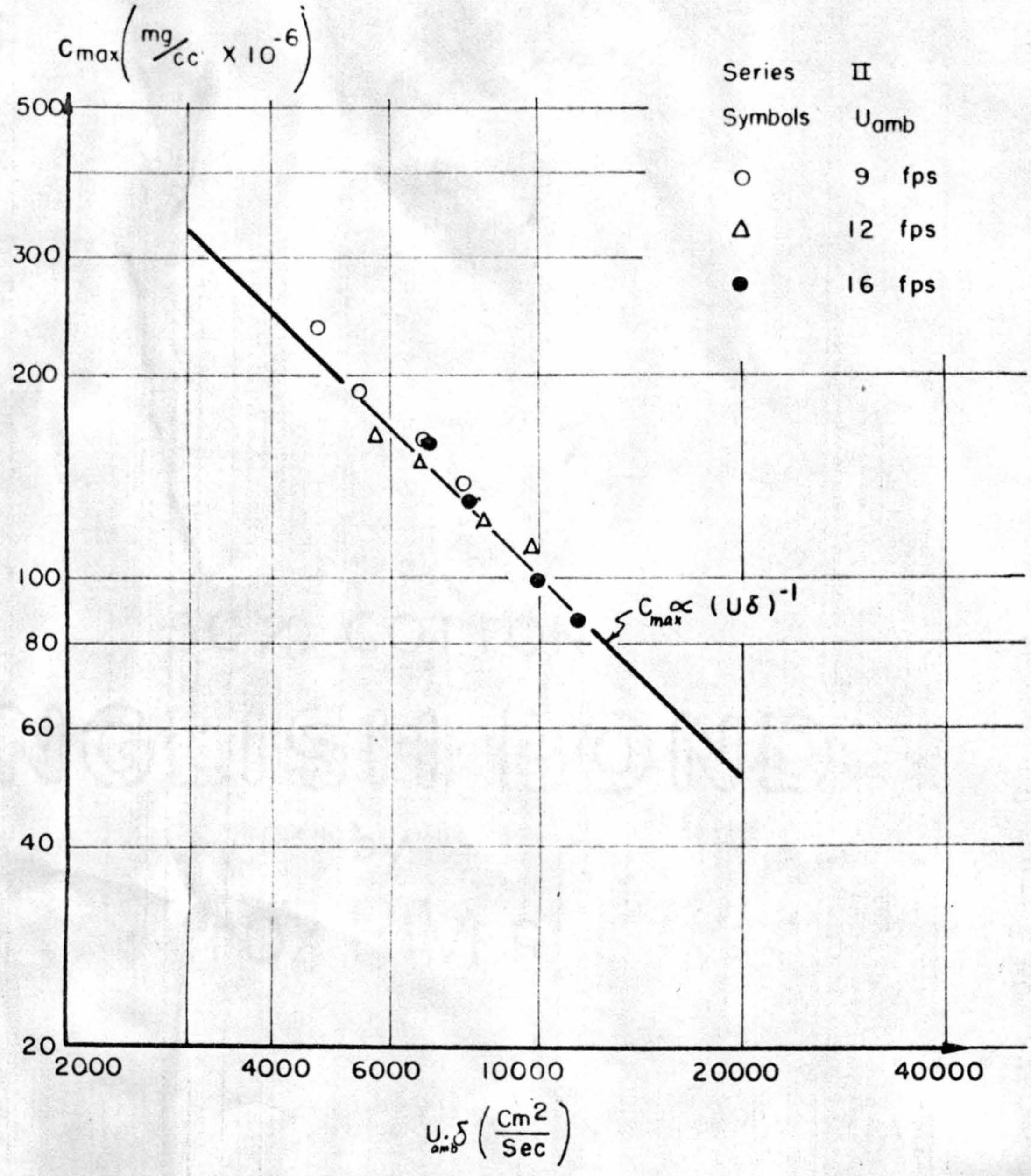


FIG. 10 THE VARIATION OF C_{max} VERSUS $U_{amb} \cdot \delta$ IN THE FINAL ZONE

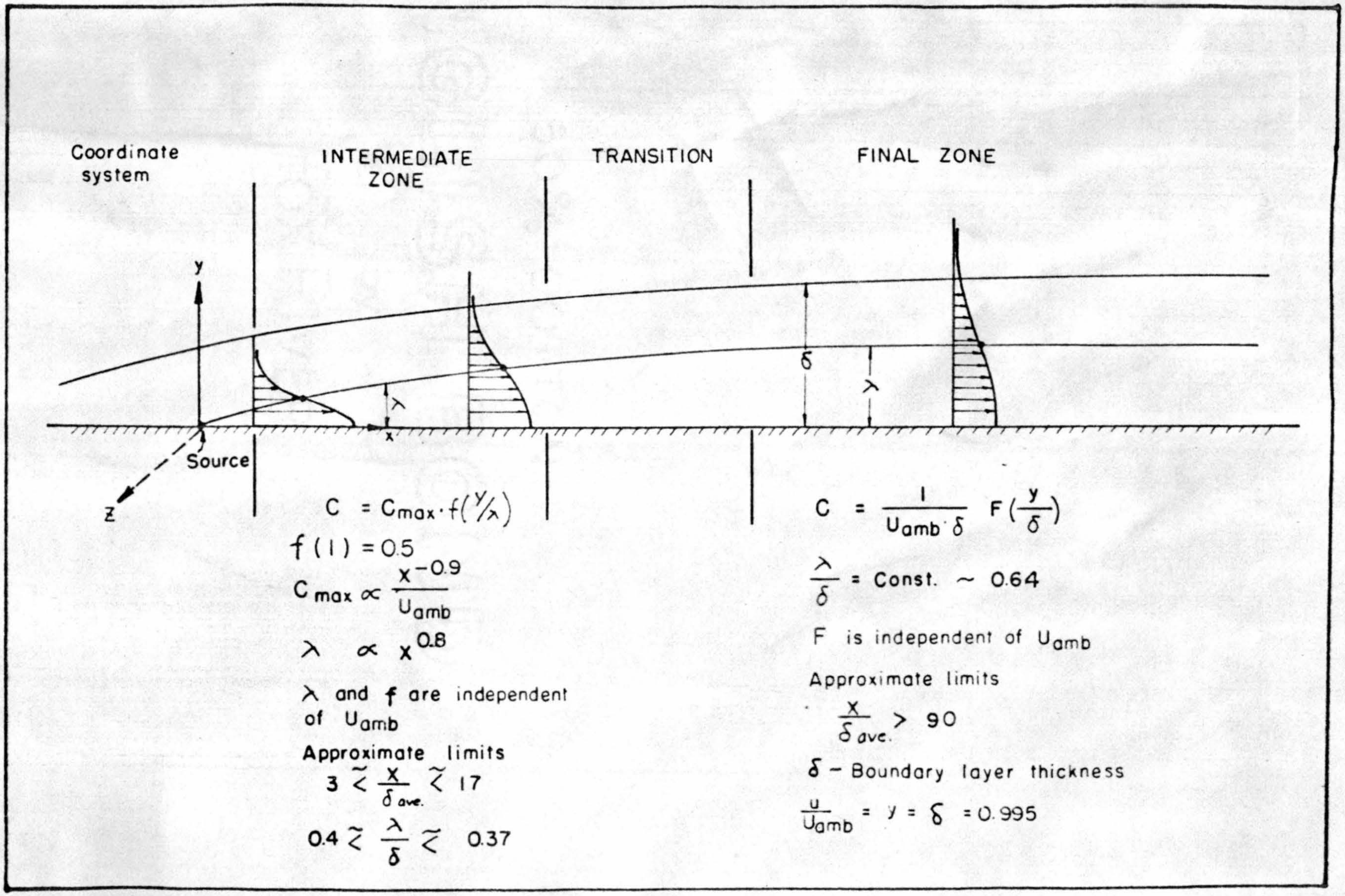


FIG. 11 SUMMARY OF THE EXPERIMENTAL RESULTS

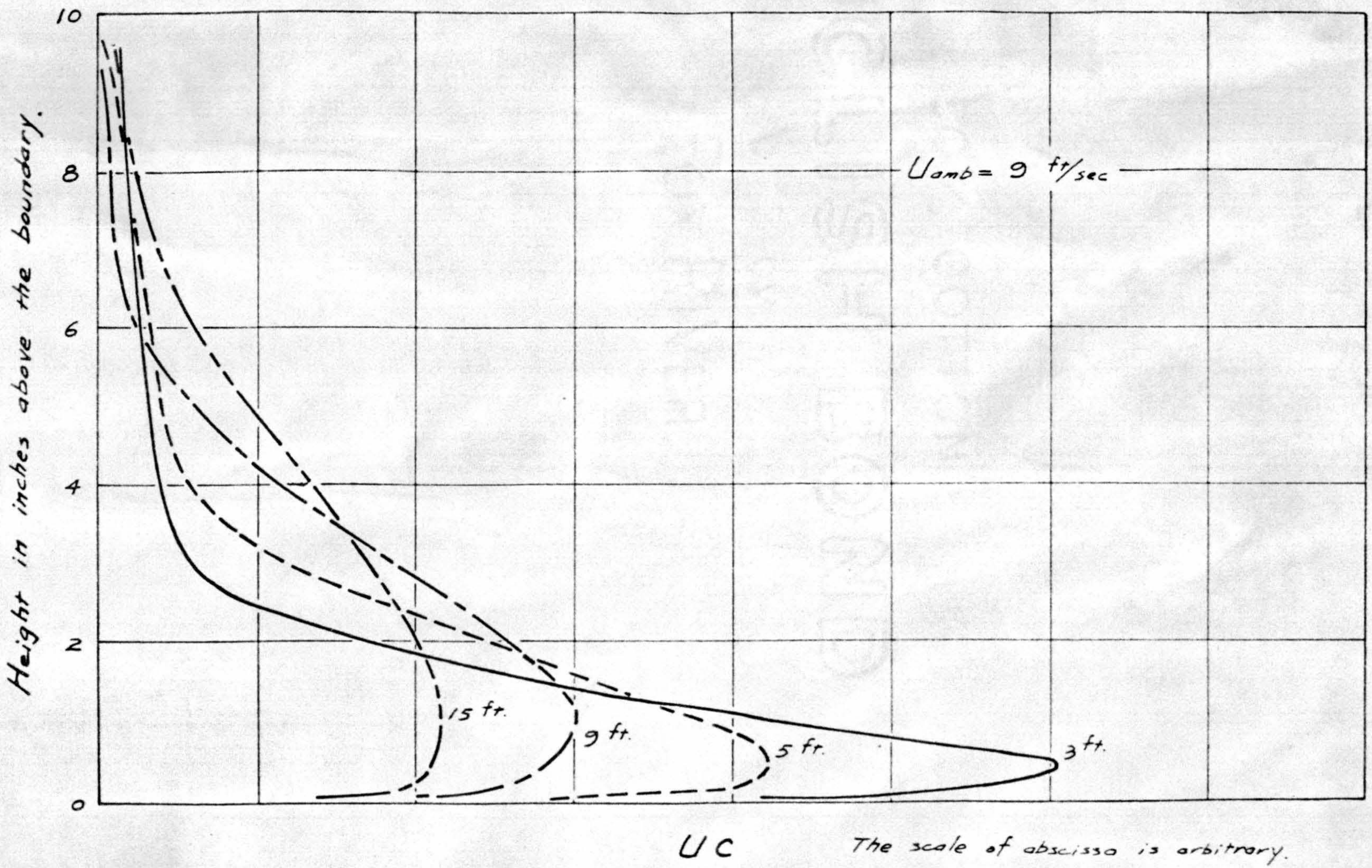


Figure 12. Typical distribution of UC.