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ANNUAL REPORT ECOM C-0423-4

WIND TUNNEL STUDIES AND SIMULATIONS OF TURBULENT SHEAR FLOWS RELATED TO ATMOSPHERIC SCIENCE AND ASSOCIATED TECHNOLOGIES

REPORT NO. 4
1st ANNUAL REPORT
30 JUNE 1969

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UNITED STATES ARMY ELECTRONICS COMMAND FORT MONMOUTH, N. J.

CONTRACT DAAB07-68-C-0423
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Prepared under Contract

DAAB-07-68-C-0423

United States Army Electronics Command

Fort Monmouth, New Jersey

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CER69-70JEC-8

Task I - Fort Huachuca

Study of Airflow in Simulated Temperate and Tropical Forest Canopies

W. Z. Sadeh

The flow visualization investigation using a short model canopy described in Progress Report No. 3 was completed. In addition to the previous three configurations the visualization was carried out for three additional cases. The latter are: 1) Canopy of regular geometrical configuration of an average density of 18 trees/ft^2 (1 tree/51.5 cm^2). A hexagonal distribution within a diagonal distance of about 2.83 in was employed; 2) Canopy of same average density with one, two, three and five emerging trees. They were about twice the height of the canopy being located along and/or off the center line and at various positions along the canopy; 3) Canopy without the stem, i.e., trunkless canopy, in order to observe the crown effects.

Photographs of the flow pattern in cases (2) and (3) are shown in Fig. 1. The effect of the emerging trees is clearly observed. A completely different flow field is obtained when such a disturbance exists. The crown effect on the flow is also discernable. The high level of turbulence within the crown shelter and the degree of obstruction introduced by the crowns are easily visualized. A technical report about the visualization studies is in preparation.

Technical Report ECOM C-0423-3 "Flow Field Within and Above a Forest Canopy" describing the results about the mean velocity and turbulence intensity distribution within and above a canopy was completed and submitted for approval. A discussion about employing the logarithmic velocity law is also presented in this report.

The reduction of the turbulence energy spectra data was completed. Currently, analysis of these results is in progress.

The new hot-wire anemometer system is currently operational. Despite a few minor difficulties inherent for a new instrument its noise level is of the order of 200 to 300 μV independent of the output signal and its frequency response is beyond 100 KHz. The linearizer module, i.e., the double squaring-amplifier module, was also complete. Consequently, it is now possible to use the hot-wire method for low velocities with large turbulence developed by Sadeh.

Presently, this new system is used for measuring the mean and fluctuating velocities inside and above the canopy. Simultaneously, the shear stress measurement are now being conducted. Next, investigation of the dependence of the turbulence characteristics upon canopy density will be conducted. THis will be achieved by using a canopy of an average density of 10 trees/ft^2 thus, half of the actual density. Furthermore, the dependence of the flow field on the upstream velocity will be completed by this fall.

With the completion of these investigations a bottle brush model canopy as described in the research proposal will be used for further studies of the flow field. Various brushes are now being analyzed for determining the most suitable model.

Task II

Group A, Sub-Task 1- Deseret Test Center

E. C. Nickerson

During the past year exploratory studies were carried out in the Army Meteorological Wind Tunnel in order to develop techniques for the simulation of stably-stratified boundary layer flows. Previous qualitative experiments had shown that a very stable layer could be produced by blowing air over blocks of solid CO_2 that had been placed in the entrance region of the wind tunnel. An elevated inversion could then be formed by heating the tunnel floor beneath the layer of cold air. In order to put these qualitative results on a more quantitative basis, vertical profiles of temperature and horizontal velocity were obtained when the blocks of CO_2 were arranged in several different ways.

The blocks of CO_2 that were used were approximately 10 inches by 10 inches by 2 inches. Initially, the blocks were placed in an upright position and oriented so that the passing air would come into contact with both sides of the blocks. Boards with nails protruding from them were placed on the tunnel floor upstream from the test section. The nails served to support the blocks in the upright position. It was believed that the placement of the blocks in a vertical position rather than a horizontal position would produce a deeper layer of cold air (by virtue of the deeper layer of air in contact with the cold surfaces), and also a more intense cold source (since a larger surface area would be exposed to the passing air).

It soon became apparent, however, that it would not be possible to obtain temperature profiles that were reasonably time-independent with the arrangement described above. The effectiveness of CO_2 in cooling the air decreased quite rapidly as the blocks decreased in size, and as a layer of ice was deposited on the exposed surfaces.

In order to increase the useful life span of the cold source, the individual blocks were spread flat on the tunnel floor in a checkerboard pattern. A honeycomb stack of CO_2 was placed at the upstream edge in order to increase the depth of the cold layer.

Elevated inversions were obtained by heating the test section of the tunnel floor to a temperature of 40° to 50°C. The intensity of the strong horizontal temperature gradient between the cold CO_2 and the heated metal surface of the tunnel floor was reduced by cooling the first three meters of the test section to -5°C.

Temperature profiles and smoke traces of velocity profiles corresponding to the experimental configuration described above appeared in the Progress Report dated September 1968. Even with the increased life span of the CO_2 blocks in the second experimental set up, the upward and downward traverses of the temperature carriage at any particular location resulted in temperature profiles that differed by 5°C or more in the lowest few centimeters.

Replenishment of the cold source with additional blocks of CO_2 does not seem to be the answer to the problem of non-stationarity. For even if the rate of loss of CO_2 could be established and new blocks introduced at the proper rate, the mere act of opening and entering the tunnel would destroy the established flow conditions. By the time the proper flow conditions were re-established, it would be time to add additional amounts of CO_2.

Temporal variations in the strength of the cold source affected the temperature profiles in two separate ways: directly due to variations in heat loss as the air passed over the dry ice, and indirectly, due to the reaction of the heated plate to changes in the temperature of the passing air. Ideally, one would like to obtain a uniform surface temperature over the test section, or at least a constant temperature gradient. Because of the secondary effect mentioned above, it proved to be extremely difficult and time consuming to obtain and maintain a reasonably constant temperature over even a short length of the heated test section.

On the basis of the difficulties encountered in using CO_2 as a cold source and because of the additional complicating effects of CO_2 on the density profile, it was decided to perform some experiments in which liquid nitrogen was used as a cold source. Because of the fact that the molecular weight of nitrogen is very close to that of air, the boiling away of liquid nitrogen would not be expected to cause any appreciable changes in the density profile.

The experimental apparatus was illustrated in the Progress Report of December, 1968. Liquid nitrogen was piped into four open shallow containers that were placed about 40 cm upstream of the test section. Temperature profiles corresponding to the above mentioned experimental set-up also appeared in the December Progress Report. Unfortunately, the profiles showed that the new cold source did not provide the steady conditions that were desired.

In comparing the gross features of both methods, it was found that the liquid nitrogen method was capable of producing temperature inversions that were slightly more intense than those produced by the CO_2 (25°C in a vertical distance of 25 cm.). Moreover, of the two methods, the liquid nitrogen method offers the best possibility of achieving a quasi-steady-state condition. Improvements in the materials used to construct the open tanks and supporting base so as to maintain a level base for the liquid nitrogen would help significantly. Also needed would be some means of accurately measuring the depth of the liquid nitrogen, and a way to regulate the inflow so as to maintain the proper level in the open containers. In addition, it would be desirable to have a large enough supply of liquid nitrogen so that it would not be necessary to change storage tanks while an experiment was in progress.

Liquid nitrogen offers the possibility, in principle, of achieving under limited conditions the simulation of elevated inversions that are reasonably time-independent. It appears, however, that it would be much more economical and probably more practical to use a system of heated grids to produce thermally stratified flows. After the initial expense of constructing the grids and arranging for their installation, the cost of operating such a system would be a small fraction of what it would cost to operate the liquid nitrogen system. Questions relating to the resulting turbulence intensities and spectra would have to be examined carefully; however, the advantages of achieving a steady-state system are of prime importance. It is, therefore, recommended that any further quantitative work on stably stratified flows in the Army Meteorological Wind Tunnel be directed toward the construction and utilization of a system of heated grids.

Sub-Task 3 - A Note on Roughness

K. D. Nambudripad, J. E. Cermak

Any study involving flow over a rough boundary encounters considerable difficulties due to the large number of parameters required to describe the different possible geometric forms of roughness. The most that can be done to relate the different forms of roughness to some standard form of roughness, like the Nikuradse sand grain size. In many areas of geophysical fluid mechanics, particularly for modelling of airflows over buildings, cities, etc., it is necessary to know the roughness height needed to make a certain boundary fully rough to ensure adequate similarity of the laboratory and atmospheric flows.

Approximate estimates as to whether a certain surface is smooth or rough for the case of rough plates can be made using the local skin-friction coefficient - Reynolds number diagrams such as the one given by Schlichting ("Boundary Layer Theory" Fig. 21.7, p. 611). This diagram has been replotted using the dotted line representing the fully rough regime where x/k_s becomes independent of the Reynolds number. The plot (Fig. 2) gives the approximate value of k_s for any velocity from 1 fps to over 200 fps at distances of (x =) 1, 10, 50, and 100 ft. Also plotted on the figure are the values of k_s that give a fully rough condition up to any distance from $x = 1$ ft to $x = 1000$ ft for four representative velocities $U_\infty = 2, 10, 50$ and 100 fps. These curves can be used only for a homogeneously rough surface for which the equivalent Nikuradse sand grain size is known and the roughness extends to the origin of the turbulent boundary layer.

An important parameter which determines whether a particular surface is aerodynamically smooth or rough is the shear-velocity-roughness

Reynolds number $\frac{u_* k_s}{\nu}$ where k_s is the Nikuradse sand grain size. It is therefore, necessary to relate the average physical roughness height, k, of any arbitrary roughness pattern to k_s. Also, determination of u_* requires the correct form of the velocity profiles close to the wall. This is still in the purely empirical stage and there is no way to predict this distribution for arbitrary roughness patterns.

An exploratory set of measurements were made in the new wind tunnel which has a width of 12 ft and an adustable ceiling height of 7 to 9 ft. It has a 52 ft long test section and is open circuit. The shear plate arrangement developed at Colorado State University* was used to measure the drag. It was kept at a distance of 30 ft from the upstream end of the wind tunnel test section. The remaining area was partly covered with boards to obtain a smooth surface flush with the shear-plate. A sloping ramp provided a smooth transition at the upstream end of these boards. The roughness studied consisted of about 0.25 inch mean-diameter gravel glued closely and randomly on a cardboard which was carefully attached on the top of the shear-plate. The complete set-up and the roughness arrangement are shown in the two photographs. (Fig. 3).

Velocities of 10, 20 and 30 fps were used for the drag measurements The measured wall shear stress τ_o is shown plotted against the ambient velocity U_∞ (Fig. 4). τ_o is found to be proportional to U_∞^2, which means that the total skin friction coefficient $C_f = \tau_o/1/2\rho U_\infty^2 = 2(u^*/U_\infty)^2$ is a constant = 0.0134. In Fig. 5 the values of C_f are plotted against the Reynolds number $R_\ell = U_\infty \ell/\nu$. For the sake of comparison the curves for smooth flat plate and the fully rough region (Schlichting) are also

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* "Wind Drag Within A Simulated Forest Canopy Field," G. Hsi, and J. H. Nath, Colorado State University, Technical Report, No. CER68-69GH-JHN6, Aug. 1968.

shown on the same plot. The experimental points fall roughly on the line of constant $\ell/k_s = 200$, giving $k_s = .01$ ft or 0.12". Thus $k_s = k/2$. From the nearly constant value of the drag coefficient, it is possible to conclude that the boundary acts as fully rough under the conditions tested. The 0.25 inch size has particular significance in regard to the urban diffusion studies being made for Fort Wayne, Indiana and corresponds to the average height of the buildings in the city when properly scaled down.

Velocity profiles (Fig. 6) were obtained using an x-y plotter, at the leading edge, center and trailing edge of the rough surface for ambient velocities of 20 and 30 fps. Fig. 7 shows a typical plot of y/δ and u/U_∞, giving the power law $u/U_\infty = (y/\delta)^{1/8}$.

Sub-Task 5 - Lagrangian Similarity in Turbulent Diffusion

S. Putta, J. E. Cermak

Ground level concentrations were predicted for continuous line sources by assuming a realistic probability density function for a particle released in a turbulent shear layer.

The following assumptions were made in arriving at the results:

1. The flow field is neutral.
2. The line source is steady and continuous. It is kept at ground level normal to the direction of the wind.
3. The contaminant released is passive.
4. The density function is skewed in x-direction and is half normal in z-direction.
5. Dispersion is two-dimensional for the line source.
6. The probability density function for a single particle is similar at all times after release. (Lagrangian similarity).

Lagrangian similarity hypothesis suggests that, for a single particle released from a line source, the probability of finding the particle at any place downstream at time t after release is of the form:

$$f_{x,z}(x,z,t) = \frac{1}{\sigma_x \sigma_z} F\left(\frac{x - x_{mean}}{\sigma_n}, \frac{z}{\sigma_z}\right) \qquad (1)$$

where $\sigma_x \propto \sigma_z \propto u_* t$. (2)

It is found from the analysis of P. C. Chatwin (1968) that

$$\sigma_x = 0.149\ u_* t \qquad (3)$$

$$\sigma_z = b u_* t \quad . \qquad (4)$$

A value for $b = 0.4$ has been suggested by Pasquill (1966) and Ellison (1959), which was found to be in agreement with the observed puff dimensions.

The following skewed distribution was used for $f_{x,z}(x,z,t)$.

$$f(\xi,\eta,t) = \frac{1}{\pi\sigma_x\sigma_z}\left(1 + \frac{1}{6}\lambda_3 H_3 + \frac{1}{24}\lambda_4 H_4 + \frac{1}{72}\lambda_3^2 H_6\right) \text{xp}\left[-\frac{\xi^2}{2} - \frac{\eta^2}{2}\right]$$

where $\xi = \dfrac{x - x_{mean}}{\sigma_x}$ and $\eta = \dfrac{z}{\sigma_z}$

λ_3 = Skewness coefficient

λ_4 = Coefficient of excess kurtosis and

H_n are Hermite polynomials.

It can be seen that the above density function becomes Gaussian for $\lambda_3 = \lambda_4 = 0$.

For a continuous line source ground-level concentrations $\chi_{ce}(x,0)$ were obtained by superposition of the instantaneous puffs as follows:

$$\chi_{ce}(x,0) = Q \int_0^\infty f(\xi,0,t)\, dt = Q \sum_{t=0}^{\infty} f(\xi,0,t) . \tag{5}$$

Q = number of particles released per second.

The above summation was performed in the computer CDC 6400 for different values of λ_3 and λ_4 using Eq. (3). It was found that $\chi_{ce}(x,0) = Q \cdot \dfrac{m}{u_* x^p}$.

The values of m and p were increasing as the range of x increased but they were found not to be sensitive to the values of λ_3 and λ_4 .

Values of m and p for different ranges of the distance x from the source are tabulated below, for different values of z_o and for constant shear velocity, $u_* = 1.0$. For other values of u_* , m increases proportionally while p remains the same.

Range of x[Ft] \ z_o[Ft]	0.001		0.01		0.1		0.5		1.0	
	m	p	m	p	m	p	m	p	m	p
1-10	0.9906	0.8588	0.422	0.6417	0.0821	0.3245	0.0218	0.2183	0.0122	0.2043
10-100	1.223	0.943	0.716	0.859	0.185	0.642	0.037	0.412	0.0173	0.325
100-1,000	1.395	0.971	1.046	0.939	0.521	0.860	0.169	0.728	0.0817	0.644
1,000-10,000	1.531	0.984	1.344	0.975	1.068	0.961	0.587	0.905	0.402	0.87

Sub-Task 5 - Spectra of Turbulent Energy and Scalar Fields at Large Wave-Numbers

D. M. Kesic, J. E. Cermak

As only a limited progress has been made in the analytical study of turbulent energy transfer, construction of elementary physical models for this process is a necessity. Such a model is used in the completed study on spectra of turbulent energy and scalar fields mixed by turbulence.

For the case of isotropic turbulence, a vorticity approximation concept is used in expressing the spectrum transfer function. A new explicit expression for the three-dimensional energy spectrum function is obtained as the solution of the spectrum equation:

$$E(k) = [\alpha\varepsilon^{2/3}k^{-5/3} + (\varepsilon\nu)^{1/2}k^{-1}]\exp\{-\frac{3}{2}\alpha\nu^{-1/3}k^{4/3} - \nu\varepsilon^{1/2}k^{2}\} \quad .$$

The one-dimensional energy spectrum is computed and the critical test in the dissipation range shows a good agreement with available measurements.

The same concept of vorticity approximation is used in representing the interaction of velocity and scalar fields. The spectrum function of a passive scalar contaminant undergoing isotropic turbulent mixing is deduced for the entire universal equilibrium range and for arbitrary Prandtl (or Schmidt) numbers as

$$G(\chi) = \{\frac{2Pr^{3/2}\cdot C}{(Pr + 1)x} + \frac{\beta\cdot C}{x^{5/3} + x^{17/3}}\}[\frac{1 + x^{4}}{(1 + x^{4/3})^{3}}]^{\beta/4}$$

$$\exp\{\frac{2Pr^{3/2}\cdot x^{2}}{Pr + 1} - \frac{\beta\sqrt{3}}{2}T_{au}^{-1}\frac{2x^{4/3} + 1}{\sqrt{3}}\} \quad , \quad \chi = (\frac{\varepsilon}{\partial\ell^{3}})^{1/4} \quad .$$

For corresponding values of k and $\nu/\partial\ell$ the solution produces $k^{-5/3}$, k^{-1}, and $k^{-17/3}$ subranges. One-dimensional spectra are computed and a good agreement with available data is obtained.

A technical report on this study has been completed and will be distributed soon.

Task II

Group B, Sub-Task 3 - Deseret Test Center

Diffusion in Simulated Forest Models

R. N. Meroney

During the final quarter under this grant period, plume measurements within the model forest canopy were examined for consistency, and they were compared to prototype information. Some inconsistencies were observed for the data measured for two elevated source releases within the forest. These data will be repeated during the next quarter. The Krypton-85 diffusion system will be utilized during these measurements. This will provide an opportunity to evaluate the effect of plume bouyancy, since the previous system involved a Helium tracer.

A computer program has been prepared to evaluate diffusion plume growth in the established flow region in the model canopy. The program is based on an alternating direction implicit method which is uncondionally stable. The program should provide a verification of eddy-diffusion coefficients generated from the diffusion experiments. Figure (8) compares concentration profiles predicted by the numerical experiment with actual measurements.

Dr. R. N. Meroney has presented the results of these measurements at the Ninth Conference on Agricultural Meteorology, September 8-10, 1969, in Seattle, Washington. Preparation of a final report of diffusion within the model forest canopies has been postponed until the projected additional measurements have been evaluated.

Sub-Task 4 - Diffusion in a Stably Stratified Boundary Layer

R. N. Meroney

The diffusion measurements reported in the Quarterly Report No. 3 have been analysed to study the plume growth both vertically and laterally. Effect of the source elevation on plume shape was also studied. Figure (9) illustrates the vertical growth of plume issued from an elevated point-source 4" above the wind tunnel floor under stable conditions. The centerline of the plume has a tendency to maintain itself at the same height until the lateral and vertical diffusion has increased which causes it to bend down with increasing distance from the source.

Effect of source elevation on the ground concentration was studied in comparison with Smith's (1957) solution of the point source problem assuming power law variation of velocity and diffusion coefficients. Figure (10) shows the data for plumes issued at three different heights in stable stratification of flow along with the theoretical curve given by Smith. Although the general form of variation is the same, the theory predicts a slower rise and a slower attenuation of ground concentration. The data also allows a comparison of the ground concentration computed from the reciprocal theorem given by Smith (1957). According to this theorem, if concentration distribution for a ground source is known, the axial ground concentration downwind of an elevated point source may be determined from it as the concentration at the height of the source at the given distance. Figures (11) and (12) show the axial ground concentrations, downwind of sources at 2" and 4" elevations respectively, obtained from the ground source data by the application of reciprocal theorem of Smith and the ones measured directly. The reciprocal theorem is based on the fact that the solutions of diffusion equation, for power law variation of velocity etc., are Green's functions. The comparison shows that this is only approximately true in the flow investigated.

Pasquill (1966) has questioned the validity of the extension of Batchelor's (1964) Lagrangian similarity theory to non-adiabatic flows. Gifford (1962) and Cermak (1963) gave the following expressions for rates of advance of a plume in vertical and axial direction in such a flow:

$$\frac{d\bar{x}}{dt} = \frac{u_*}{k}\,[f(z) - f(z_o)]$$

$$\frac{d\bar{z}}{dt} = bu_*\phi(\frac{z}{L})$$

where $f(z)$ is non-dimensional velocity and L is Monin-Obukov stability length. According to Pasquill (1966) it is inadequate to regard $\frac{d\bar{z}}{dt}$ as uniquely determined by diffusive conditions at $\bar{z}$ alone. He contends this would be analogous to asserting that k_z is a linear function of height. A theoretical effort is being made to clarify the situation and prove, by solving the diffusion equation from $\frac{d\bar{z}}{dt}$ and $\frac{d\bar{x}}{dt}$, that the form of the above equation is correct.

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3. F. A. Gifford (1962) "Turbulence nad diffusion in turbulent atmosphere", Journal of Geoph. Res., Vol. 67, pp. 3207-3212.
4. F. Pasquill (1966) "Lagrangian similarity and vertical diffusion from a source at ground level", Jr. Royal Meteo. Soc., Vol. 92, pp. 185-195.
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Task III - Aberdeen Proving Ground

Turbulence Effects on the Mean Missile Trajectories

E. J. Plate, F. F. Yeh

A Summary of Conclusions and Suggested Studies on the Aberdeen Project

A. Probability density functions

1) The present hot-wire techniques are sufficient for a fairly accurate measurement of joint probability density of two turbulence variables. The newly acquired Colorado State University high-speed analog-to-digital converter, together with the present CDC 6400 computer can certainly give a more versatile calculation on the higher-order correlations of turbulence variables.

2) From the experimental evidences, the turbulence variables are not exactly jointly Gaussian, but are found to be more consistent with the modified Edgeworth's form of a Gram-Charlier series (Longuet-Higgins 1963, J. of Fluid Mechanics) i.e., the non-linear interaction amoung eddies are more likely a "weak" type of interaction. A further study along this line can be done if we have a conclusive measurement on the so-called "filtered" correlation function of the turbulence variable.

3) The even-correlations of turbulence variables can be approximated by the Gaussian distribution, since the tilting angle θ on the iso-probability contours of our measured joint density can be calculated by

$$\theta = \frac{1}{2} \tan^{-1}\left(\frac{2\overline{uv}}{\overline{u^2} - \overline{v^2}}\right) .$$

B. <u>Application of the experimental results to the dispersion density function of missile target</u>

In evaluating the dispersion function of the missile target, the problem will still involve the unknown interactions between the turbulence components and the missile itself, and will be even more complex if one considers the elastic properties of the flying missile, which may by some resonance action exaggerate the effect of turbulence in certain frequency ranges. These problems are suggested to be studied and the next stage (phase 4) of this project is to calculate the response of the specific missile to the turbulence field.

For the present report, we will assume that the dispersion vector of missile target $(\vec{X}'_e)$ is simply a linear combination of all the instantaneous vectors of wind turbulence $(\vec{V}'_i)$ along the trajectory.

$$\vec{X}'_e = \sum_{i=0}^{n} C_i \vec{V}'_i \quad .$$

The probability distribution function of $\vec{X}'_e$ for any real number $\vec{x}'_e$ may be written as

$$F_{\vec{X}'_e}(\vec{x}'_e) = \int_{-\infty}^{+\infty} d\vec{V}'_o \int_{-\infty}^{\frac{\vec{x}'_e - C_o \vec{v}'_o}{C_i}} d\vec{V}'_1 \int_{-\infty}^{\frac{\vec{x}'_e - (C_o \vec{v}'_o + C_1 \vec{v}'_1)}{C_2}} d\vec{V}'_2 \cdots \int_{-\infty}^{\frac{\vec{x}'_e - (\sum_{i=0}^{n-1} C_i \vec{v}'_i)}{C_n}} d\vec{V}'_n f_{\vec{V}'_o, \cdots, \vec{V}'_n}(\vec{V}'_o, \cdots \vec{V}'_n) \ .$$

The joint density function in the integral can be simplified by the assumption as we used in the technical report, "Approximate Joint Probability Distributions of the Turbulence along a Hypothetical Missile Trajectory Downwind of a Sinusoidal Model Ridge, by Plate, Yeh, Kung, 1969, Colorado

State University. However, for the exact calculation, space-time correlations of the normal components of the turbulence with respect to the missile trajectory are required. Experimentally, this means to map out space-time correlations for all velocity components for the whole boundary layer. We reduced the problem to requiring simultaneous measurements of the velocity components in the longitudinal direction (u-component), and in the direction perpendicular to the ground (w-component) at two different points in space. For each pair of points, one point was the hypothetical launch point, while the other was always at different points in space. A total of 160 point-pairs were used. The analog data were converted, at the ESSA research laboratory in Boulder, to digital data and recorded on digital tape.

Wind Tunnel Operation and Maintenance

J. A. Garrison

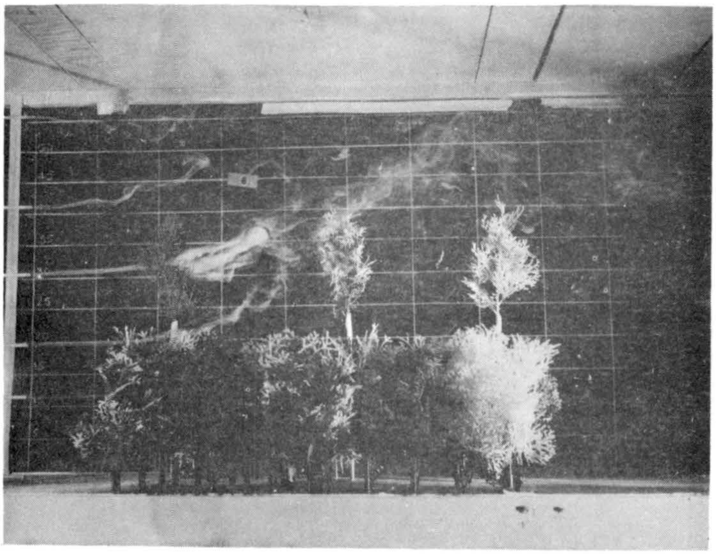
Operation was normal for this quarter. Extra windows were put into the wall of the Army wind tunnel at the extreme end of the test section to permit flow visualization studies at that location. The floor in this section was also replaced as it was found to be too irregular for work within the boundary layer close to the floor.

Total hours of operation for this quarter amounted to 152, but during the first 21 days of the quarter, the tunnel drive was under repair.

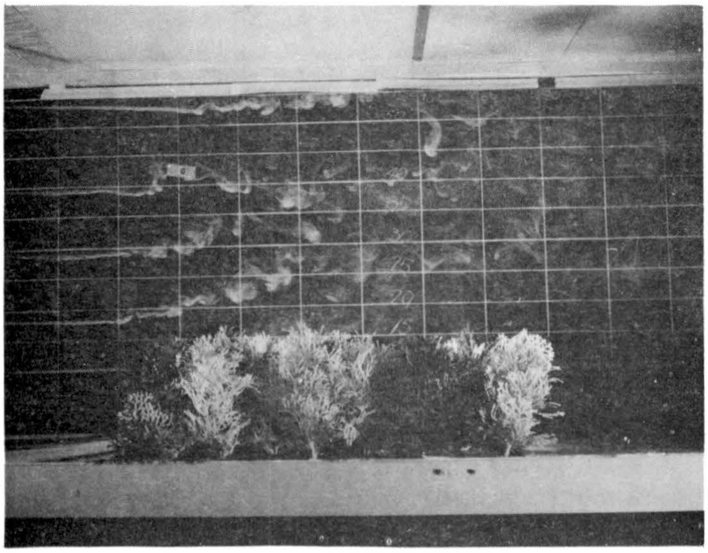
With the exception of the major failure of the large motor-generator set during the end of the third quarter, the problems encountered during the contract year were small enough to cause no significant interruption of the scheduled work. With the overhaul of the synchronous motor, the upgrading of the electrical ground system, the addition of new visualization windows and cleaning of the area around the operating platform, the facility has been improved during the year. Some repair to the roof mechanism and an inspection and modification of the variable transformers under the floor of the tunnel are planned for the coming contract year.

Total hours of operation during the contract year are:

28 volt Generator	4842 hours
Motor-Generator Set	2041 hours
Air-Drive Motor	1959 hours



Case 2: Emerging Trees



Case 3: Trunkless Canopy

Fig.1-Smoke visualization of flow within and above the canopy.

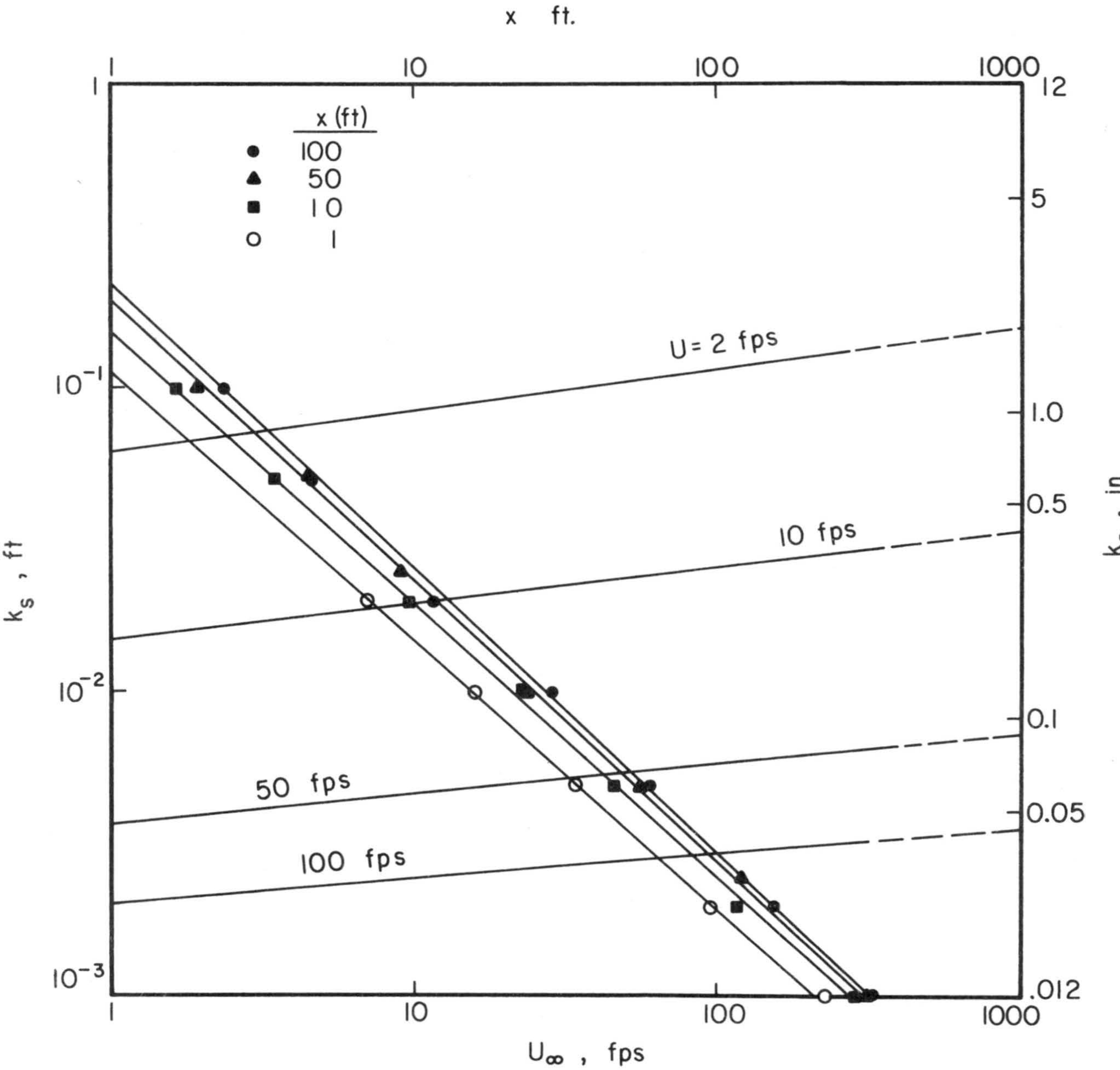


Fig. 2 Fully rough regime - Schlichting.

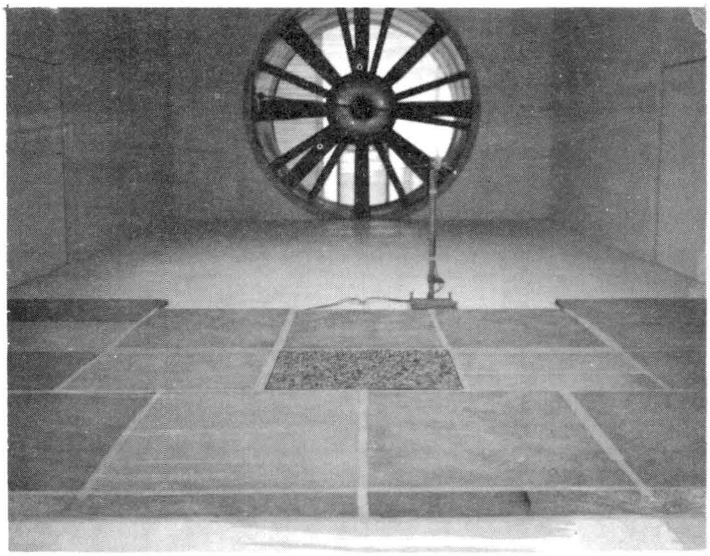


Fig. 3a General arrangement of shear plate, looking downstream.

Fig. 3b Close-up of the roughness arrangement.

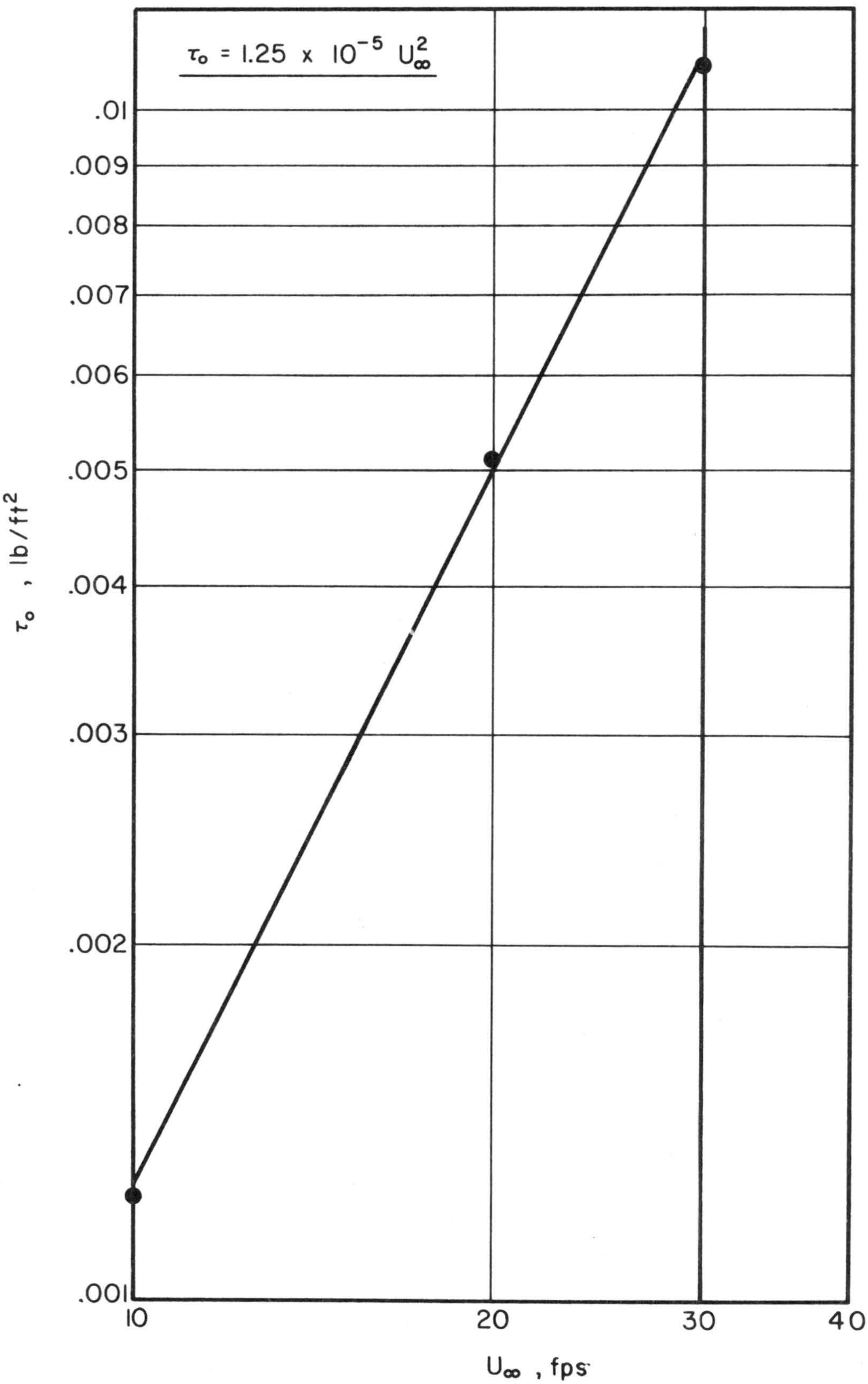


Fig. 4 Variation of wall shear stress τ_o with ambient velocity U_∞ .

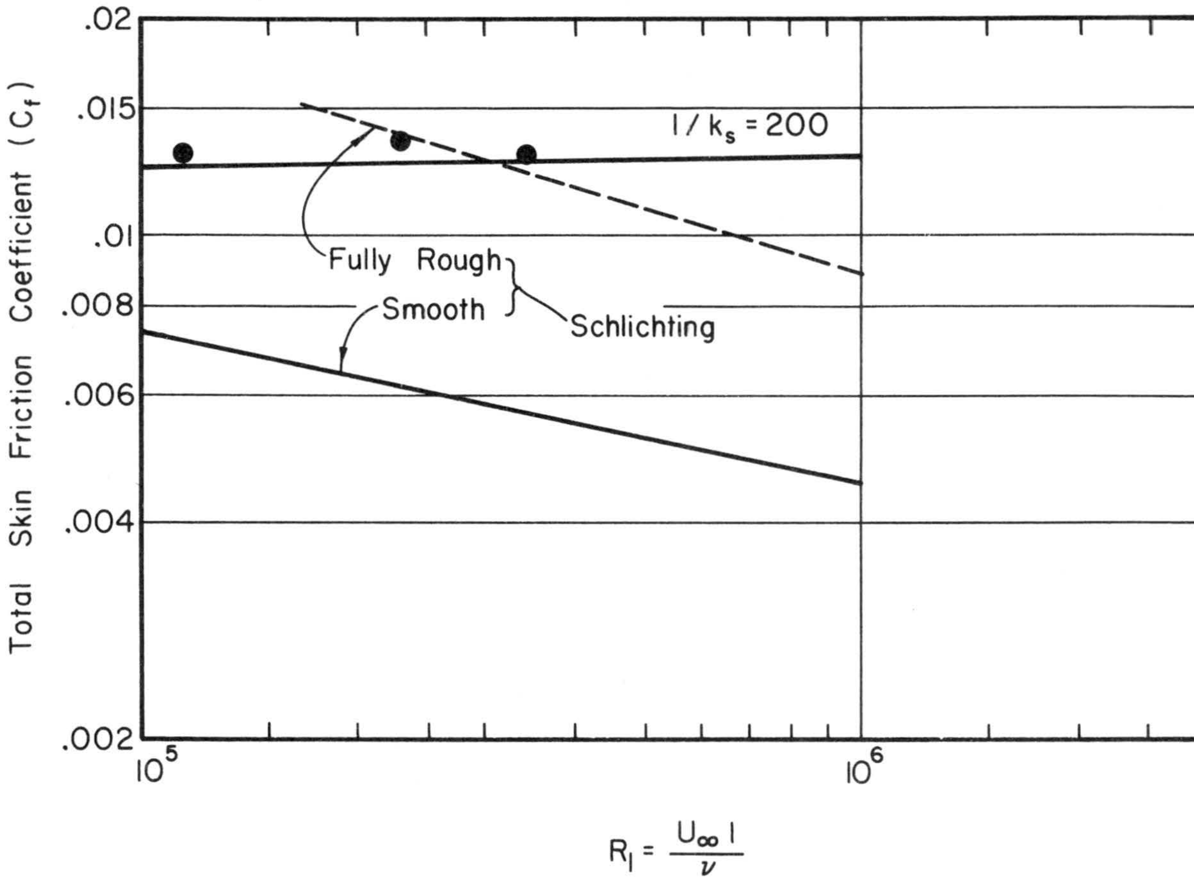


Fig. 5 Variation of total skin friction coefficient with Reynolds number.

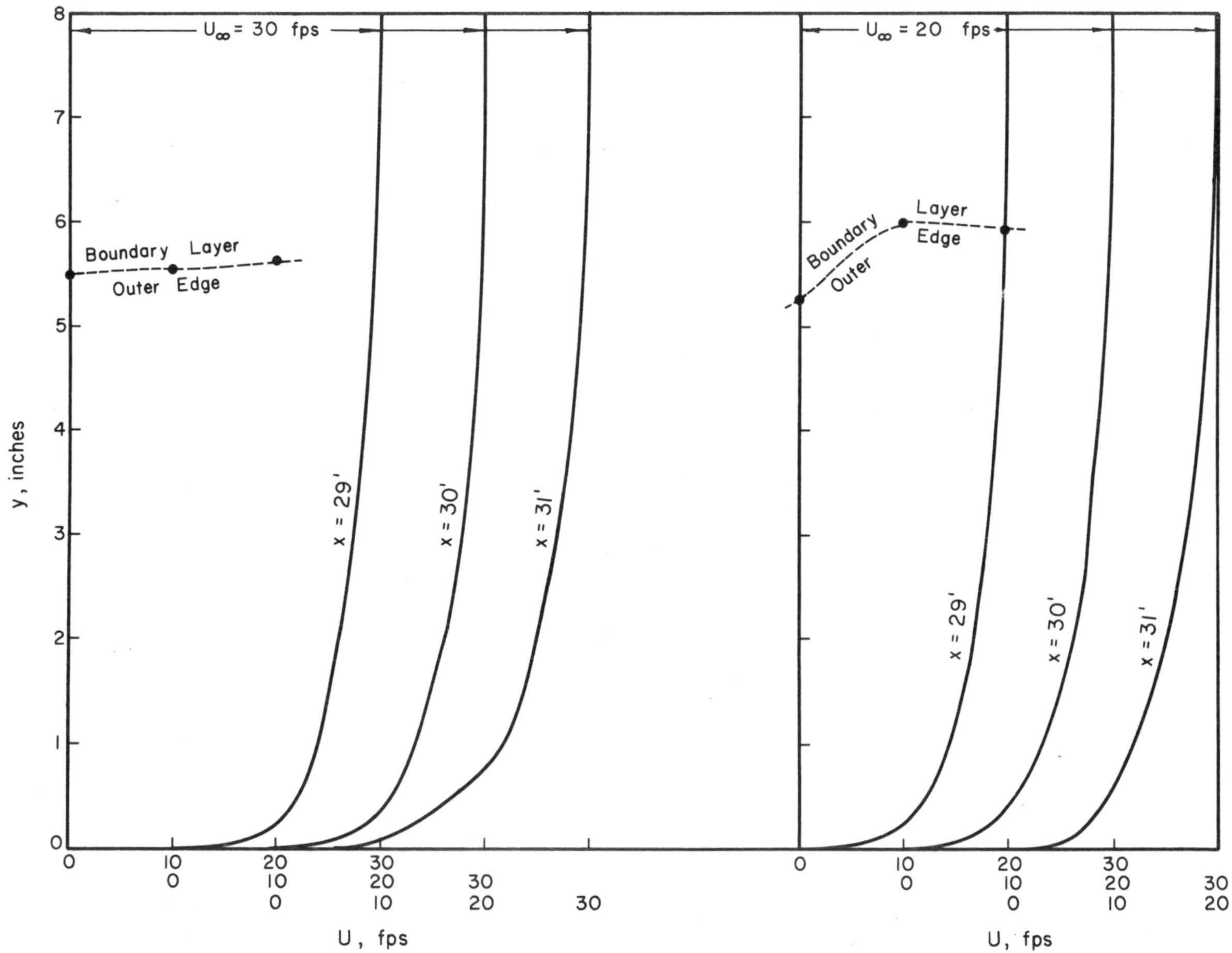


Fig. 6 Velocity profiles over roughness.

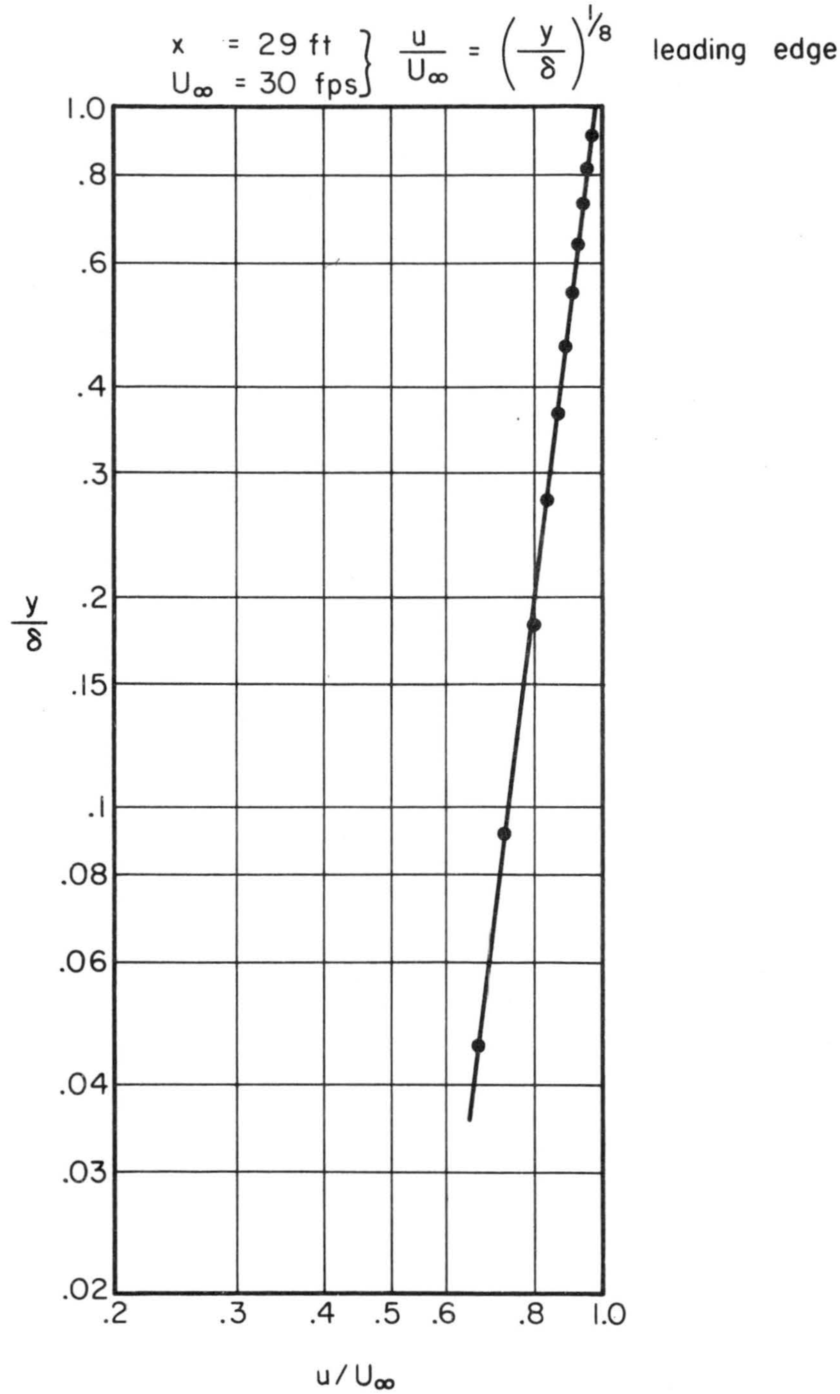


Fig. 7 Variation of $\frac{u}{U_\infty}$ with y/δ .

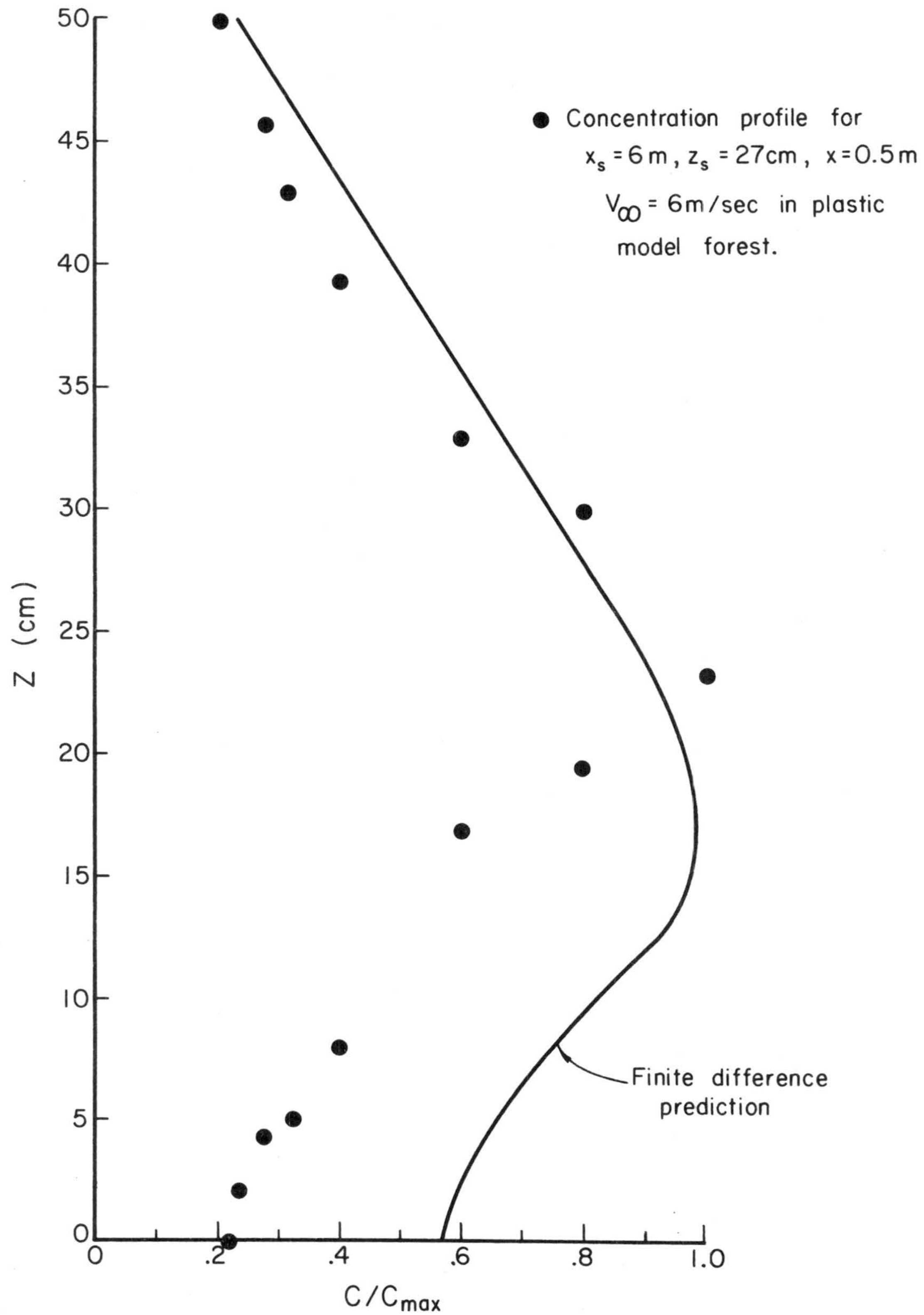


Fig. 8 Comparison between diffusion in plastic tree canopy data and simplified finite difference model.

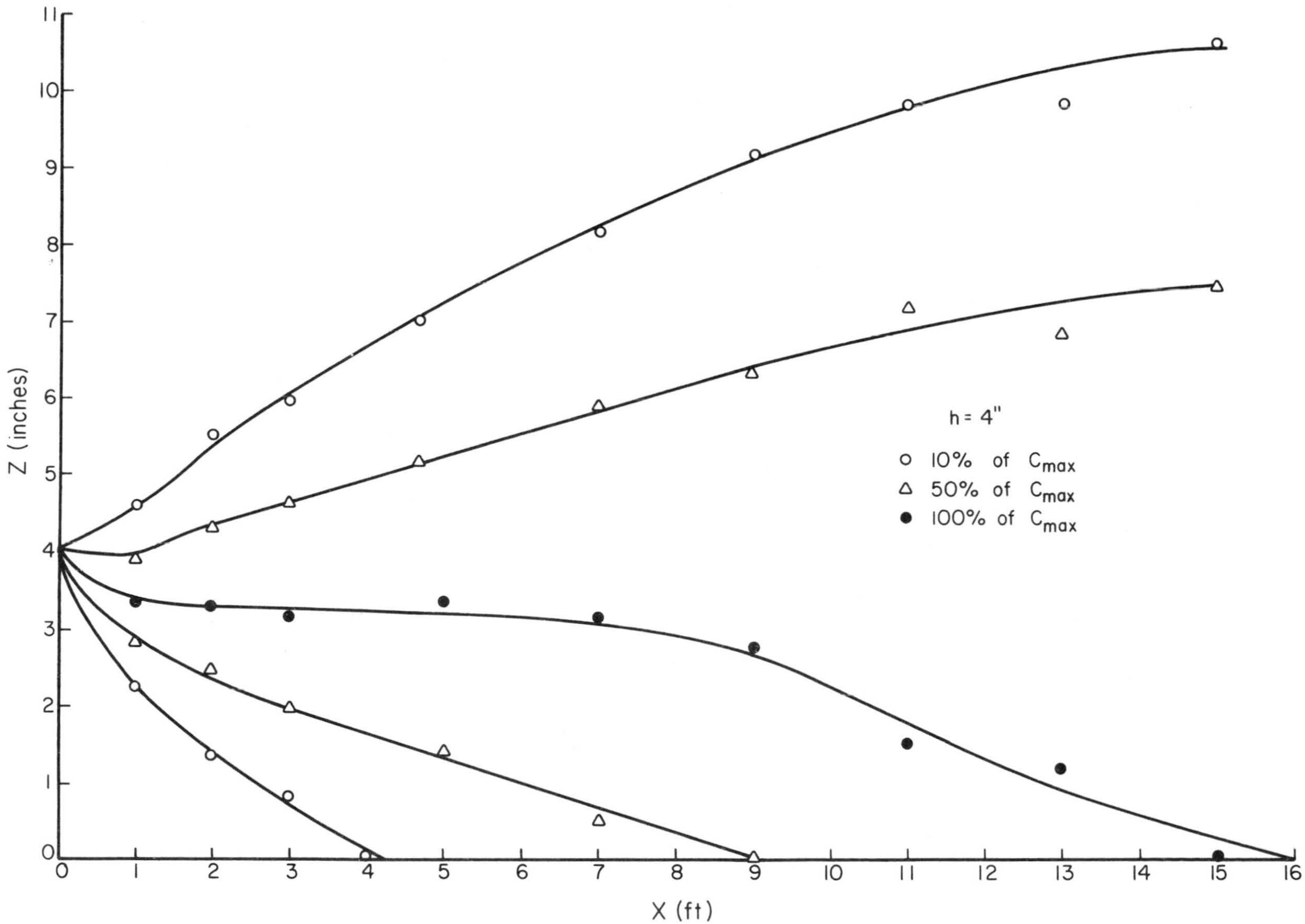


Fig. 9 Plume spread in vertical plane through centre line.

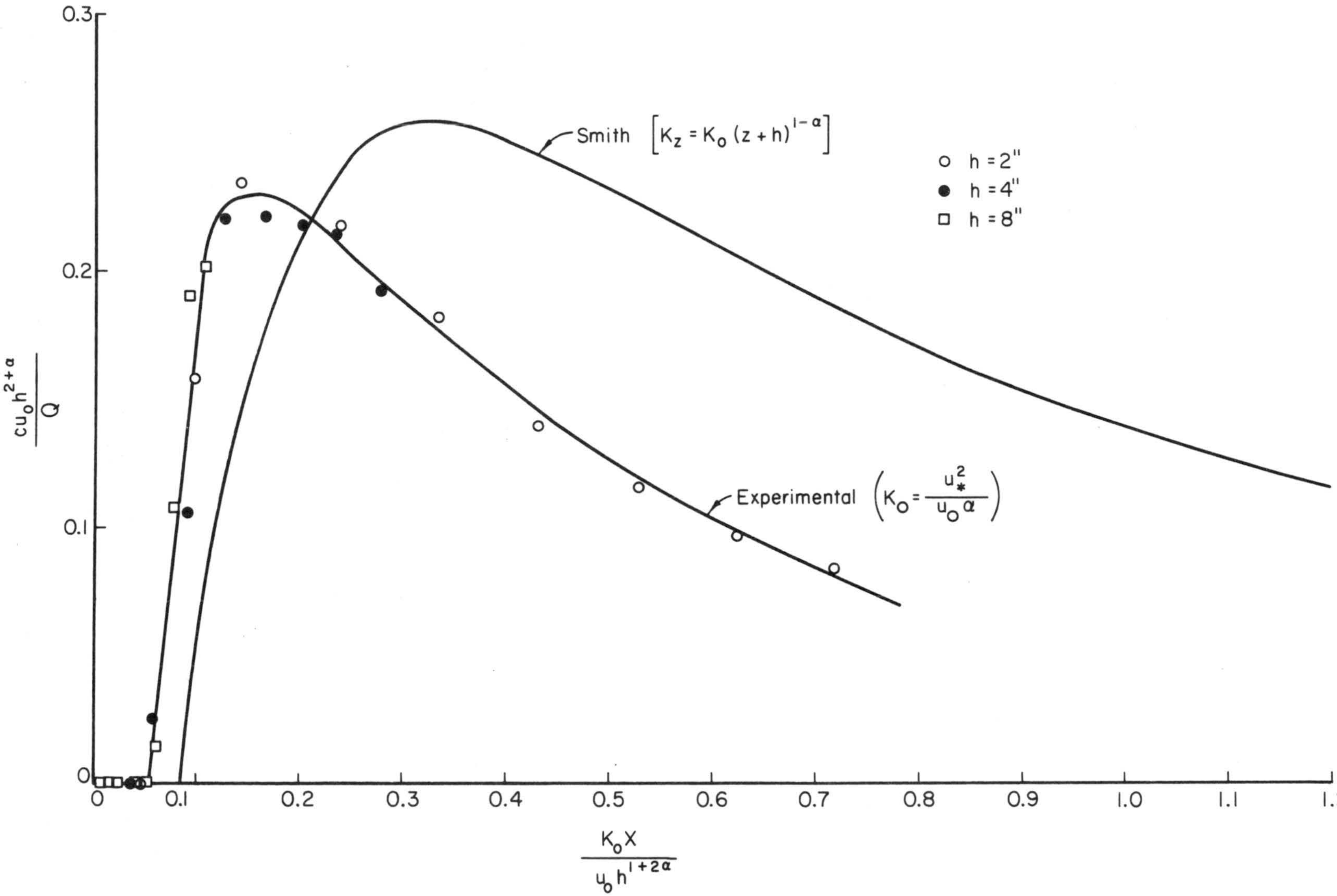


Fig. 10 Variation of maximum ground concentration elevated point source.

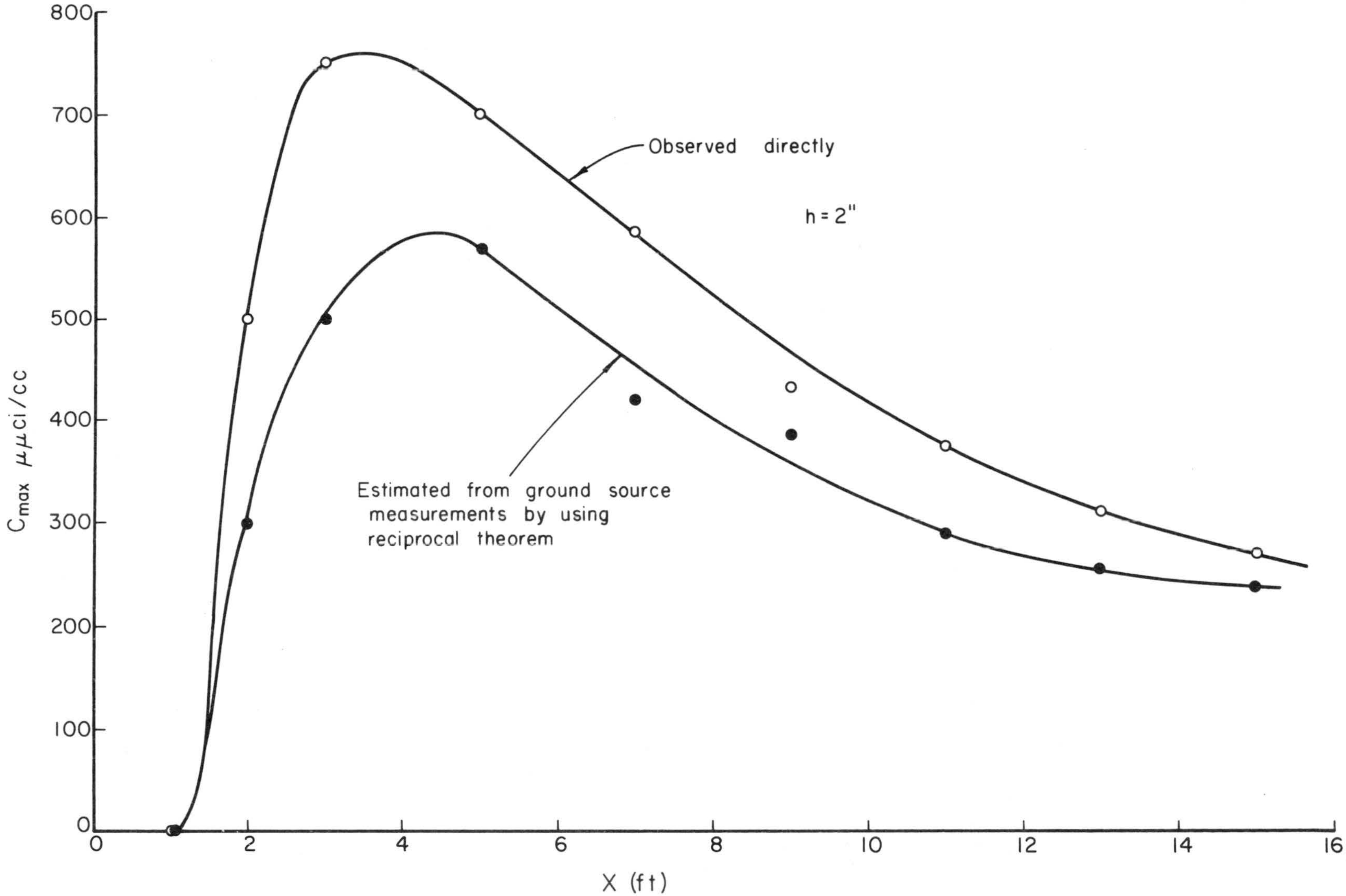


Fig. 11 Ground concentration variation downwind of an elevated h = 2" point source.

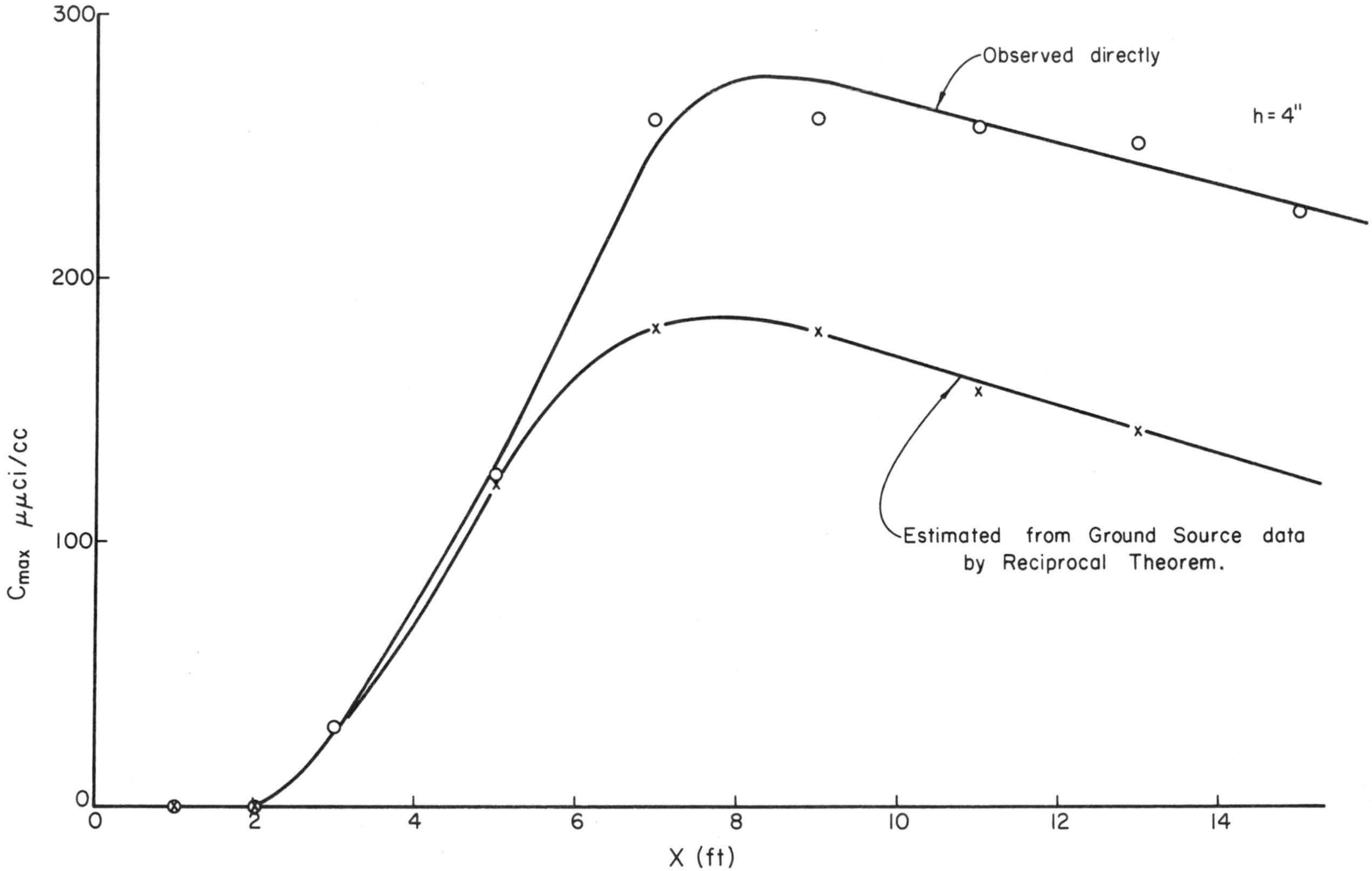


Fig. 12 Ground concentration variation downwind of an elevated point source h = 4" .

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1. ORIGINATING ACTIVITY *(Corporate author)* Colorado State University Foothills Campus Fort Collins, Colorado 80521	2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED 2b. GROUP

3. REPORT TITLE

"WIND TUNNEL STUDIES AND SIMULATIONS OF TURBULENT SHEAR FLOWS RELATED TO ATMOSPHERIC SCIENCE AND ASSOCIATED TECHNOLOGIES"

4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*

1st Annual Report

5. AUTHOR(S) *(Last name, first name, initial)*

Cermak, J. E.; Garrison, J. A.; Meroney, R. N.; Nickerson, E. C.; Plate, E. J.; Sadeh, W. Z.

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
June 30, 1969	34	5

8a. CONTRACT OR GRANT NO. DAAB07-68-C-0423 b. PROJECT NO. c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) CER69-70JEC-8 9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)*

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13. ABSTRACT

The 1st Annual Report is a summary of accomplishments, in the Fluid Dynamics and Diffusion Laboratory at Colorado State University, of both an experimental and analytical nature in the following specific studies:

1. Airflow in simulated temperate and tropical forest canopy.
2. Methods of modeling diffusion tests ahead of time to design most efficient and economical field experiments.
3. Use of controlled models of field tests to extend empirical data on CB transport and diffusion.
4. Extend wind tunnel investigation to thermally stratified boundary layers and broader ranges of surface roughness.
5. Investigation of longitudinal dispersion through both shear flow and turbulence.
6. Extend the Lagrangian similarity hypothesis considering a more realistic probability function.
7. Model Dugway Proving Ground and study mean wind patterns near the ground when flow aloft is oriented SW-SE.

14. KEY WORDS	LINK A		LINK B		LINK C	
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Simulation						
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