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Army Electronics Command
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UNITED STATES ARMY ELECTRONICS COMMAND - FORT MONMOUTH, NEW JERSEY

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13. ABSTRACT

The general characteristics of wind speed and direction variability at heights of 1.5 and 4.0 meters are presented as functions of space.time. averaging time of data, mean wind speed, lag time, thermal stability (between 0.5 and 4.0 meters), and orientation of sensor line relative to mean wind direction. In addition, there is an example of mean longitudinal and lateral wind component differences and standard deviation as a function of horizontal distance separation at a height of 4.0 meters.

The data show wind speed differences of less than 0.8 mps for distance separations between instruments of 150 to 175 meters and the mean wind speed less than 4 mps. Wind direction differences vary from 10 to 50 degrees. Moreover, it is shown that the standard deviation of the longitudinal wind differences has the same general characteristics as the wind speed, whereas the standard deviation of the lateral wind is similar to the wind direction.

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FOREWORD

This study was undertaken in response to a request by the Selected Systems Effectiveness Program (SSEP) of the Joint Technical Coordinating Group for Munitions Effectiveness. The paper depicts the general characteristics of wind variability subject to space, time, averaging time of the data, height of measurement, wind speed, temperature difference, and orientation of sensor line relative to the mean wind direction. The study cannot be all-inclusive since data utilized were collected at White Sands Missile Range and cannot depict all types of terrain. Moreover, the data generally cover wind regimes under 10 meters per second and temperature differences over a small range, i.e., -1.34 to a +2.25 degrees Celsius.

CONTENTS

INTRODUCTION

Wind variability plays a major role in predicting the impact point of an unguided rocket and in the prediction of diffusion of toxic contaminants. In the past, studies on wind variability have been directed, for the most part, toward determining an optimum "simple sampling" of the wind (see for example, Beer and Sarrubbi [1], Hertz and Beer [2], Rachele [3], Karna et al. [4], and Rachele and Armendariz [5]). The term "simple sampling" is defined as the determination of an averaged wind obtained over a certain time interval. This averaged wind, measured at a given point and for a given time, serves as a predictor for another wind measurement made at a position which is removed horizontally and the measurement made at the same time or sometime later.

The purpose of this report is to present the variability of the wind speed and direction at heights of 1.5 and 4.0 meters as a function of horizontal distance separation between sensors, time, averaging time of the data, mean wind speed (taken from the predictor station), lag time, thermal stability, and orientation of sensor line relative to the mean wind. The idea is to make a measurement at some position A and compare this measurement to one made at some position B. Position B is horizontally removed between 25 and 300 meters from A and measurements are made either simultaneously with A or with a time lag. Variability is defined as the standard deviations of the absolute differences between the measurements of the wind taken at two separate positions.

Mean absolute differences of horizontal wind speed and direction at heights of 1.5 and 4.0 meters above ground and mean temperature difference between 0.5 and 4.0 meter heights were computed from more than 150 hours of data collected at selected times during January and March 1970 from the T-Array at White Sands Missile Range. Averaging time and lag time were varied, and data were classified into downwind and crosswind with respect to the mean wind direction. The T-Array consists of fast-response wind and temperature sensors placed at heights of 0.5, 1.5 and 4.0 meters and separated horizontally 25 to 300 meters along two perpendicular lines in the configuration of a T. Additional details concerning the T-Array may be found by referring to Armendariz et al. [6].

DISCUSSION OF RESULTS

Horizontal distance separation of the sensors varies from 25 to 300 meters. Figures 1 through 4 illustrate the effect of mean wind speed changes upon the mean speed and direction differences at heights of 1.5 and 4.0 meters at a near-midpoint horizontal difference separation. In Figures 1 and 2, the sensor height is 1.5 meters, horizontal distance separation

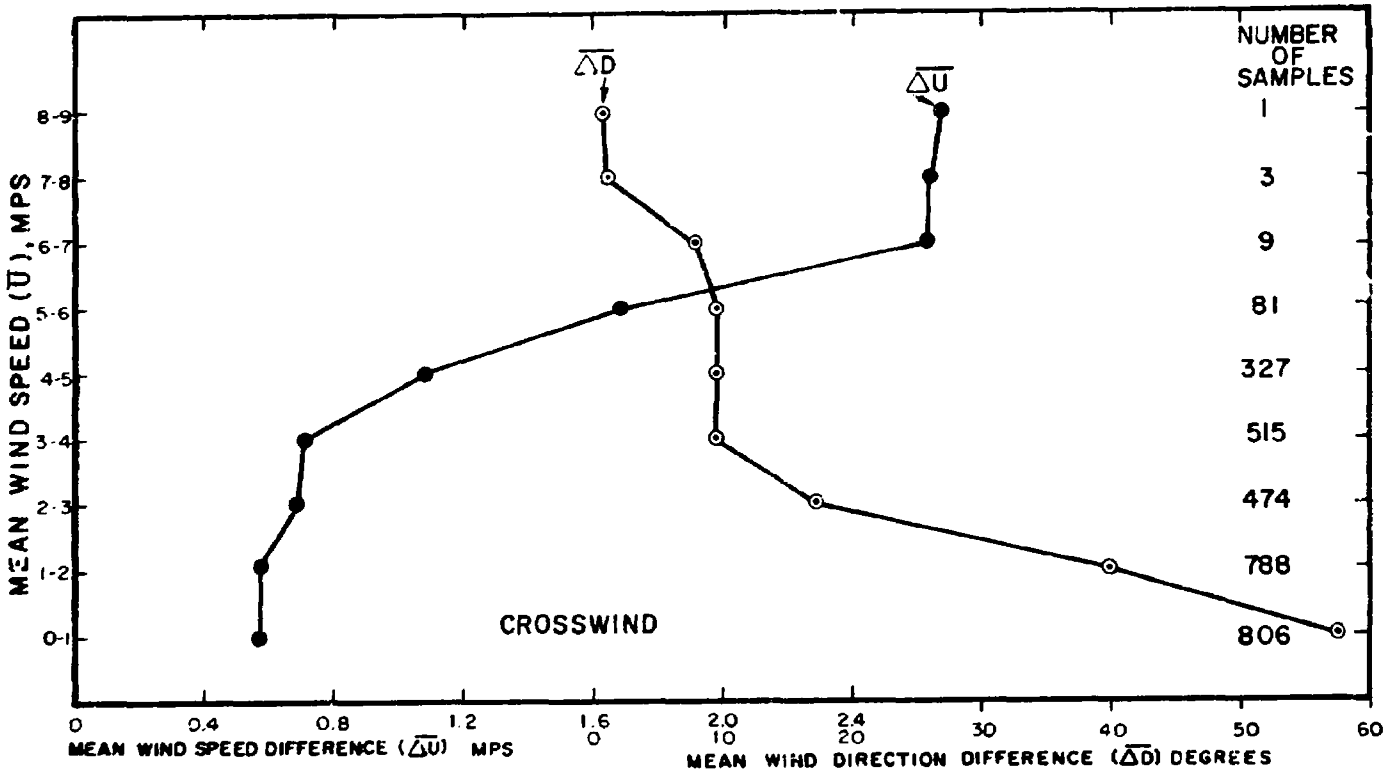

FIG. 1. MEAN WIND SPEED AND DIRECTION DIFFERENCE AT A HEIGHT OF 1.5 METERS AND A DISTANCE SEPARATION OF 150 METERS VERSUS MEAN HORIZONTAL WIND SPEED (15 SECOND AVERAGES AND ZERO LAG TIME.)

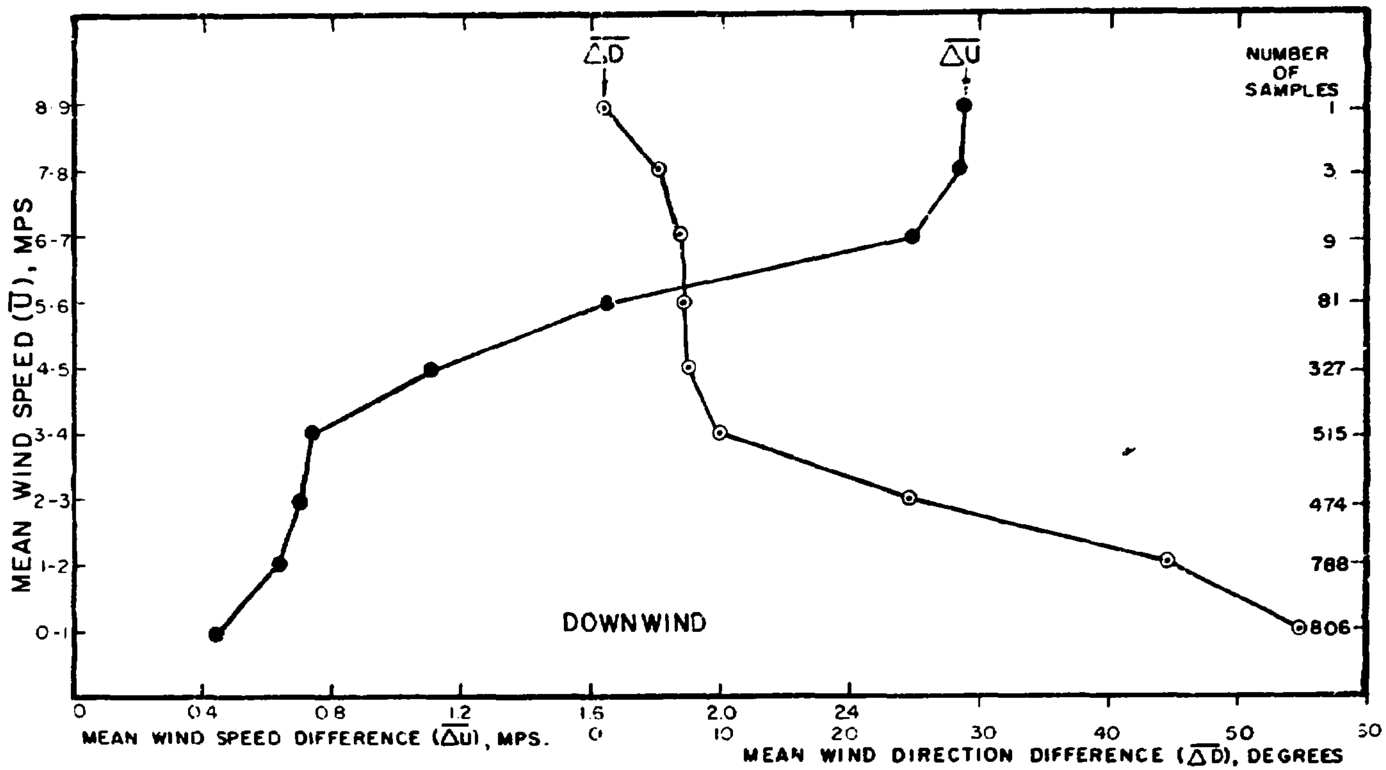

FIG. 2. MEAN WIND SPEED AND DIRECTION DIFFERENCE AT A HEIGHT OF 1.5 METERS AND A DISTANCE SEPARATION OF 150 METERS VERSUS MEAN HORIZONTAL WIND SPEED (15 SECOND AVERAGES AND ZERO LAG TIME.)

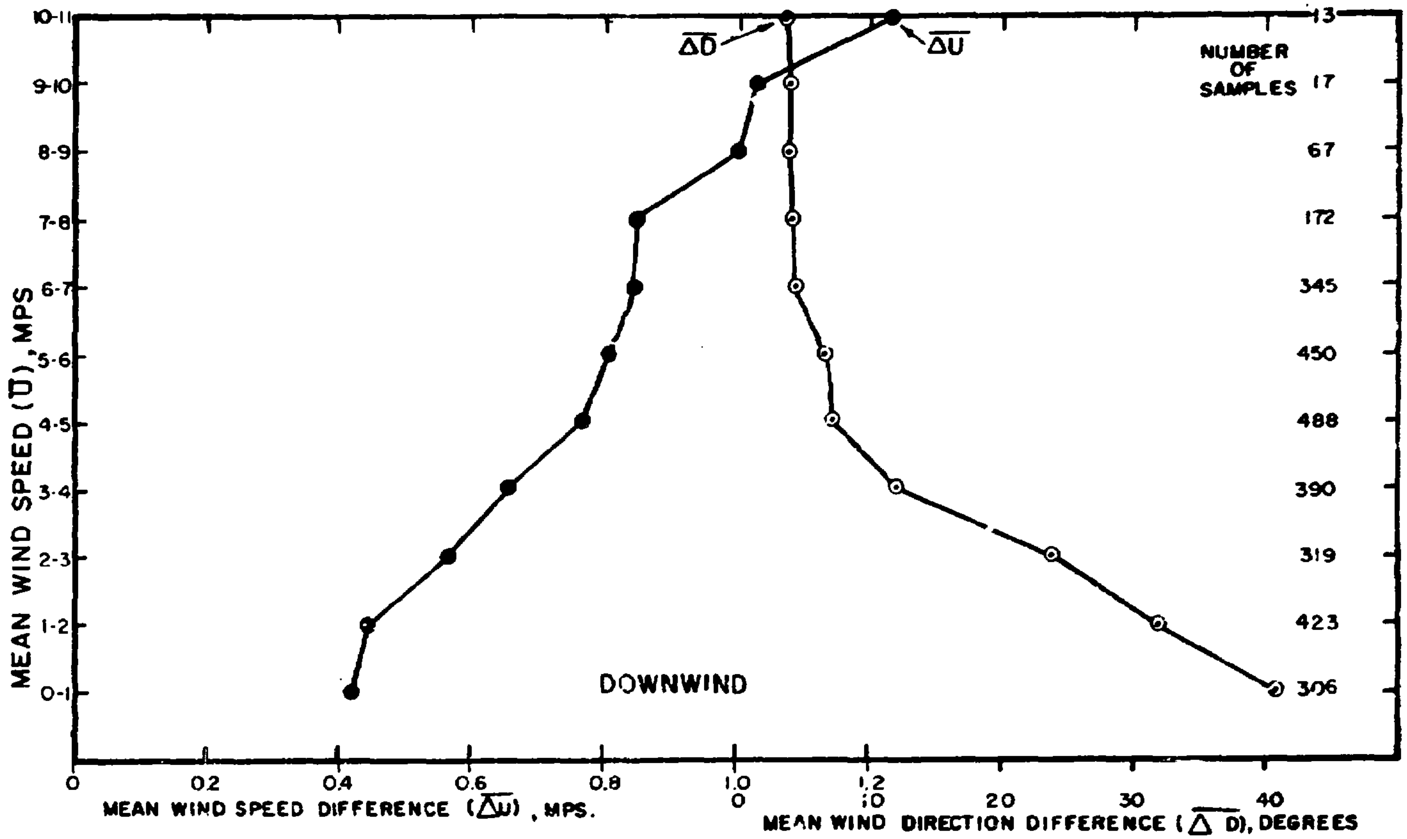

FIG.3. MEAN WIND SPEED AND DIRECTION DIFFERENCE AT A HEIGHT OF 4.0 METERS VERSUS MEAN WIND SPEED WITH A HORIZONTAL DISTANCE SEPARATION OF 175 METERS (ONE MINUTE AVERAGE AND ZERO LAG TIME.)

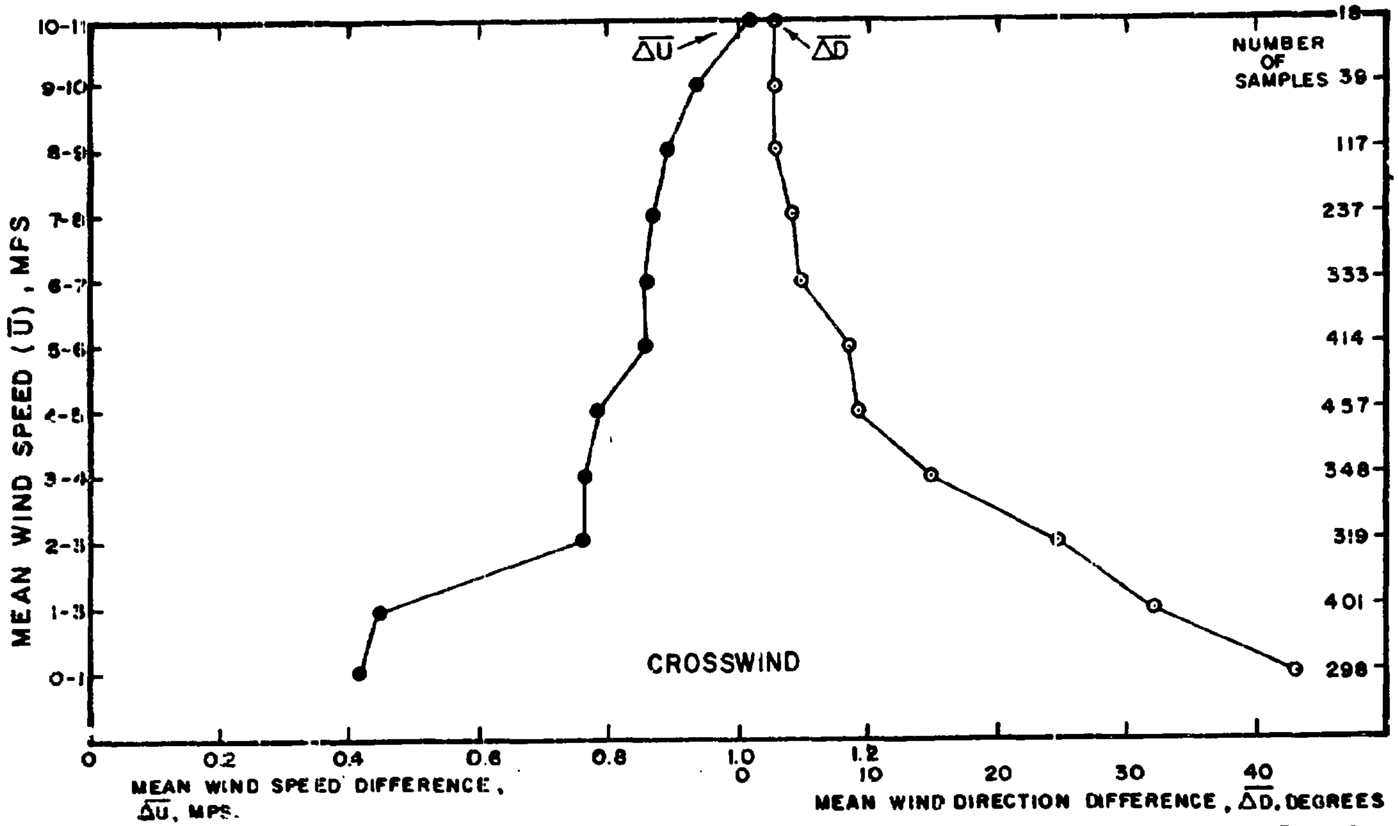

FIG.4 MEAN WIND SPEED AND DIRECTION DIFFERENCE AT A HEIGHT OF 4.0 METERS VERSUS MEAN WIND SPEED WITH A HORIZONTAL DISTANCE SEPARATION OF 175 METERS (ONE MINUTE AVERAGE AND ZERO LAG TIME.)

150 meters, and 15-second averages are used at zero lag time. The number of samples available for each interval of mean wind speed is shown on the right side of the graphs, and it can be noted that this number drops off quite rapidly at wind speeds greater than 6 mps. In Figure 1, the sensors were on a line approximately normal, whereas in Figure 2 the sensor line was approximately parallel to the mean wind direction. In each figure the direction difference decreased rapidly from about 55 degrees to about 10 degrees, with a mean wind speed increase from near zero to 3-4 mps, then decreases less rapidly with further mean wind speed increases.

In contrast, there is a gradual increase in speed difference with a mean wind speed increase from near zero to 3-4 mps, then a more rapid increase in speed difference with further mean wind speed increase. There does not appear to be a significant difference due to the difference in alignment of the sensors, parallel or normal to the mean wind direction, in this situation. The variation of wind speed and direction difference is very much the same in Figures 3 and 4 in which the height of the sensors was 4.0 meters, horizontal distance separation between wind measurements was 175 meters, and a 1-minute average wind was used with a zero lag time. Direction difference decreases rapidly from about 40 degrees at near zero to about 8 degrees at 5 mps mean wind speed, the decrease becoming more gradual with further increase in wind speed. The mean speed difference increases with increase in mean wind speed from about 0.4 mps at 1-2 mps mean wind to approximately 1.0 mps at 9-10 mps.

The effect of horizontal distance separation from 25 to 300 meters on the mean wind speed difference at various mean wind speeds in both downwind and cross wind situations is presented in Figures 5 and 6. Wind speed differences are greater in the crosswind than in the downwind case, particularly with mean wind speed greater than 6-7 mps. Figures 7 and 8 present the effect of distance separation on the mean wind direction difference at various mean wind speeds. Direction differences are a little greater in the crosswind case, particularly at mean wind speeds less than 6-7 mps; an increase of distance separation from 25 to 300 meters does not increase the wind direction difference significantly except for winds at 3 mps or less.

Figures 9 and 10 show the effects of averaging time from 15 to 600 seconds on wind speed and direction differences at various mean wind speeds at a height of 4 meters, horizontal distance separation of 25 meters, and zero lag time. The greatest wind speed differences in Figure 9 occur with strong mean wind speeds and short averaging time. A change in averaging time does not affect the speed differences significantly at mean wind speeds less than about 5-6 mps. It is significant that when the mean wind

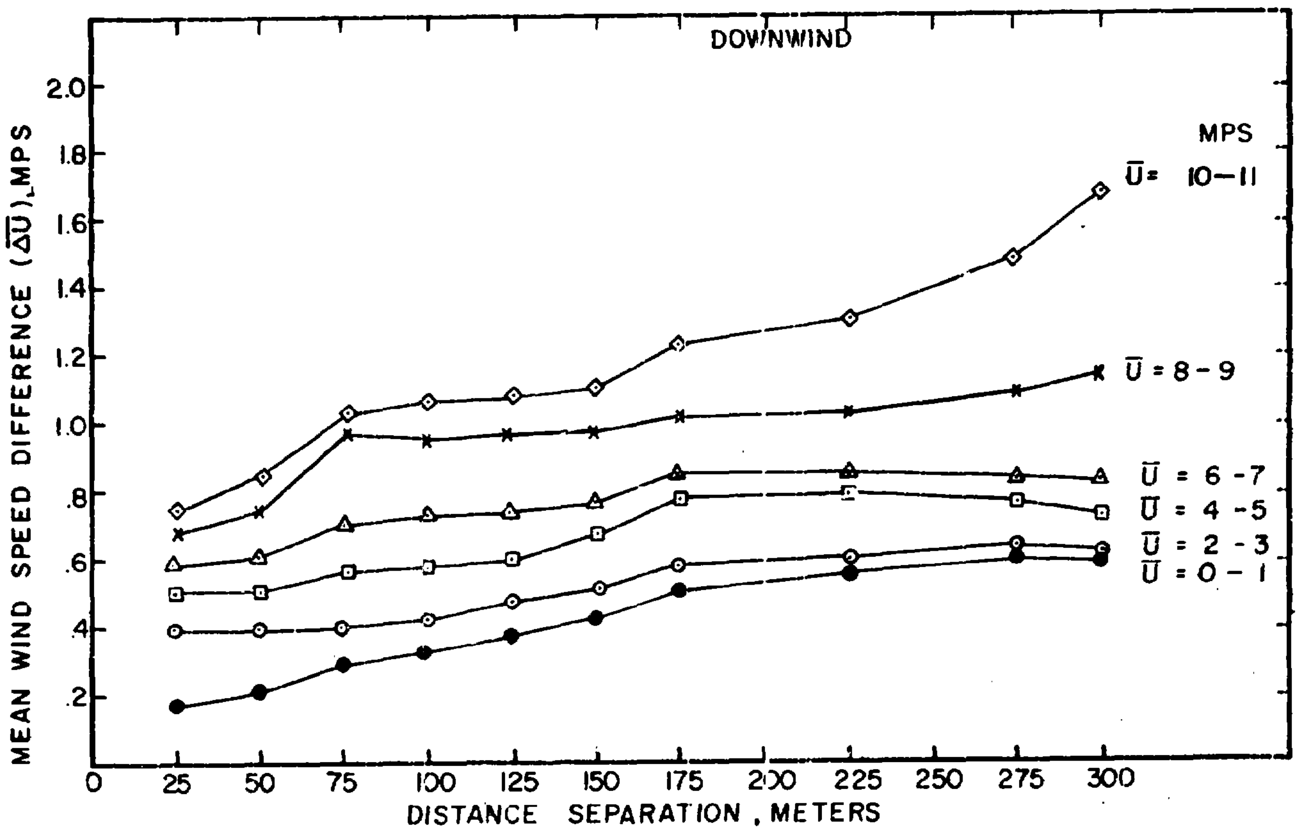

FIG. 5 MEAN WIND SPEED DIFFERENCE VERSUS HORIZONTAL DISTANCE SEPARATION AT A HEIGHT OF 4 METERS AT VARIOUS MEAN WIND SPEEDS (ONE MINUTE AVERAGES AT ZERO LAG TIME).

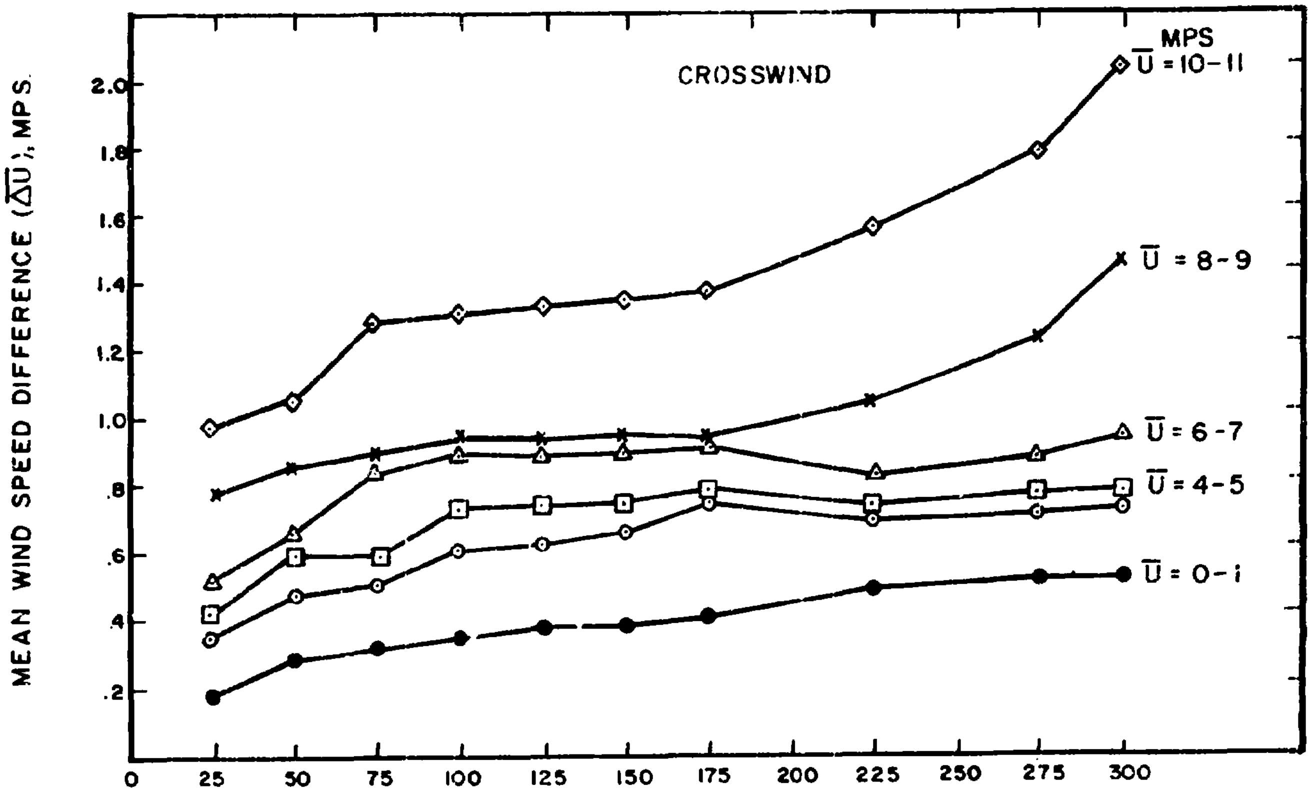

FIG. 6 MEAN WIND SPEED DIFFERENCE VERSUS HORIZONTAL DISTANCE SEPARATION AT A HEIGHT OF 4 METERS AT VARIOUS MEAN WIND SPEEDS (ONE MINUTE AVERAGES AT ZERO LAG TIME.)

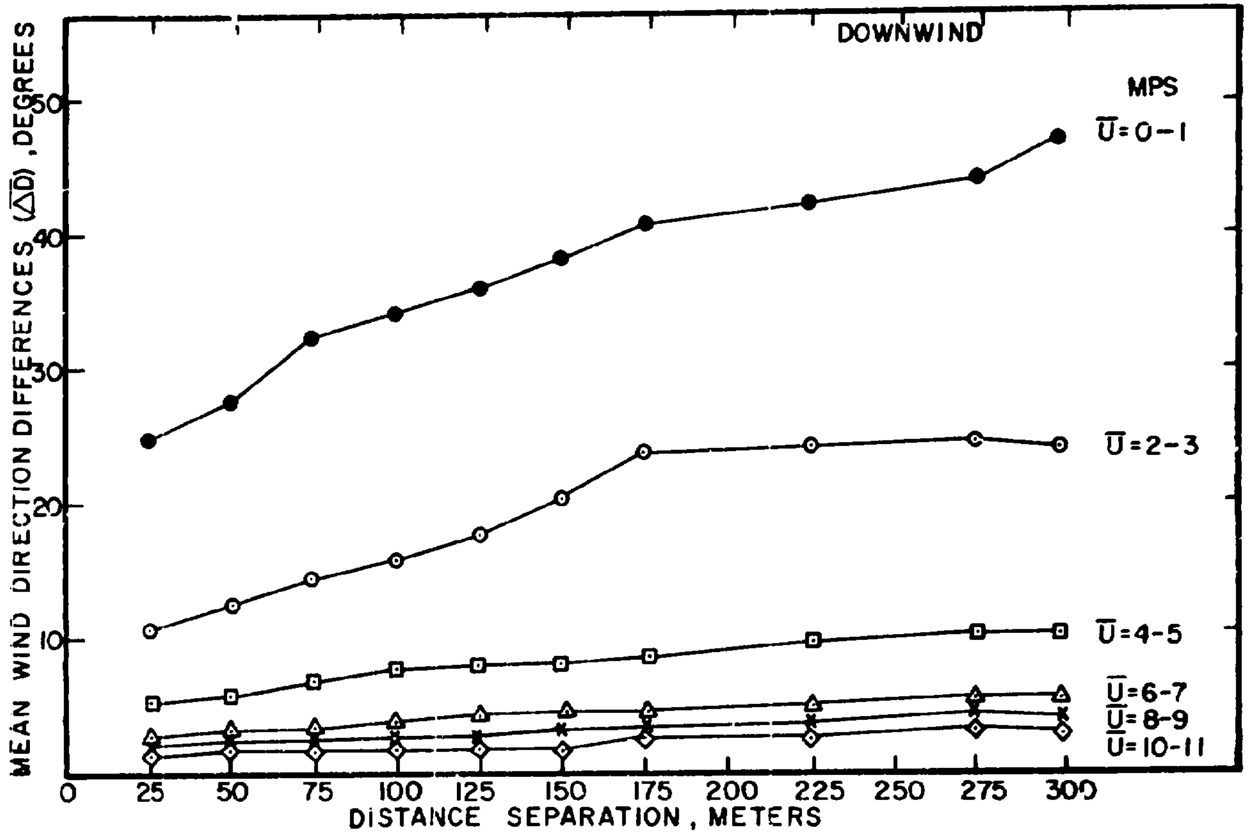

FIG. 7 MEAN WIND DIRECTION DIFFERENCE VERSUS HORIZONTAL DISTANCE SEPARATION AT A HEIGHT OF 4 METERS AT VARIOUS MEAN SPEEDS (ONE MINUTE AVERAGES AT ZERO LAG TIME.)

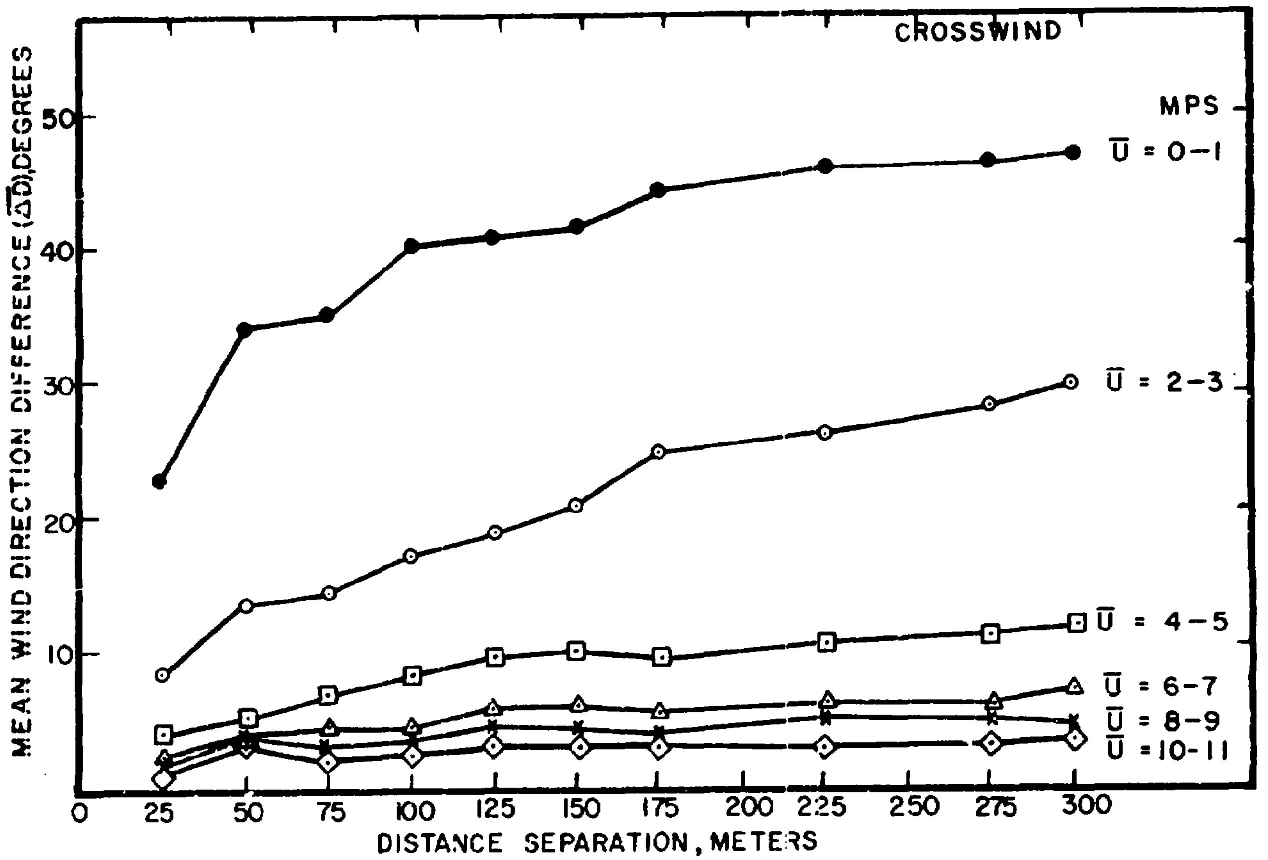

FIG. 8 MEAN WIND DIRECTION DIFFERENCE VERSUS HORIZONTAL DISTANCE SEPARATION AT A HEIGHT OF 4 METERS AT VARIOUS MEAN WIND SPEEDS (ONE MINUTE AVERAGES AT ZERO LAG TIME)

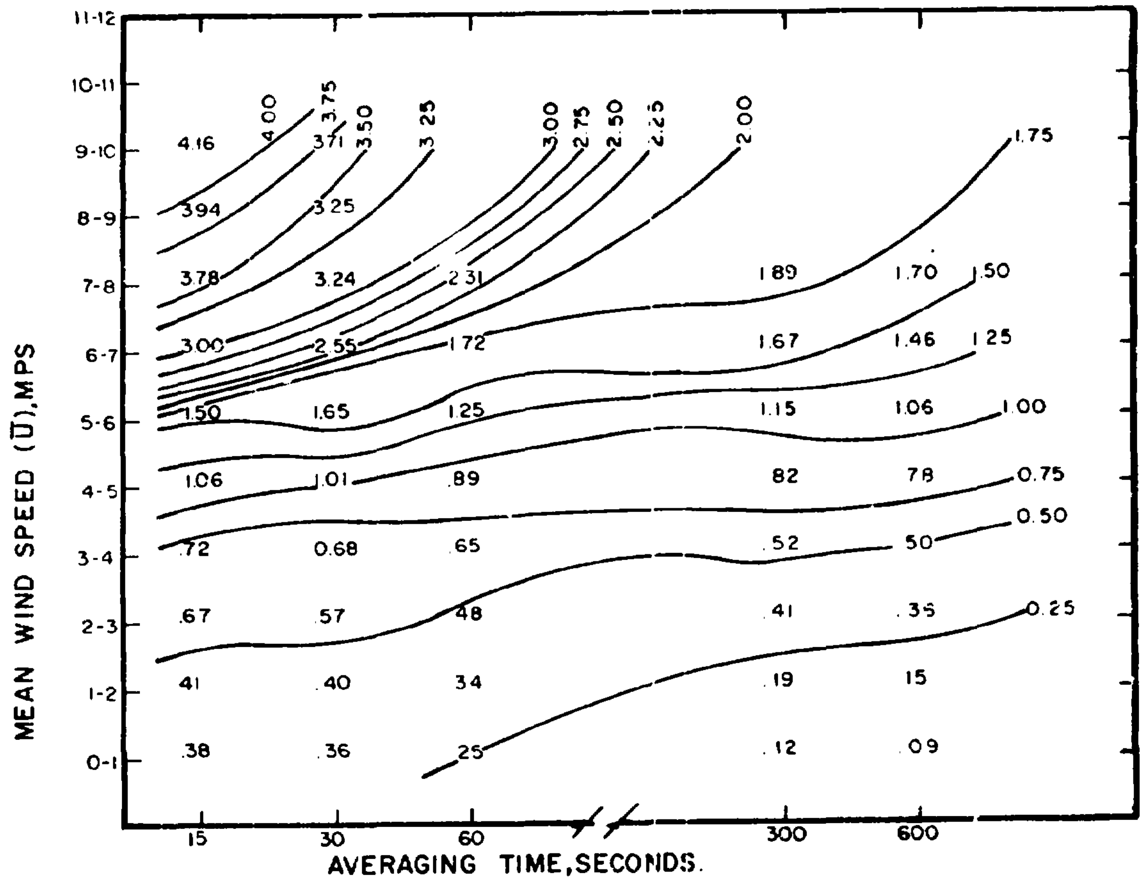

FIG. 9 MEAN WIND SPEED DIFFERENCE VERSUS AVERAGING TIME AND MEAN WIND SPEED AT A HEIGHT OF 4 METERS AND DISTANCE SEPARATION OF 25 METERS, AND ZERO LAG TIME.

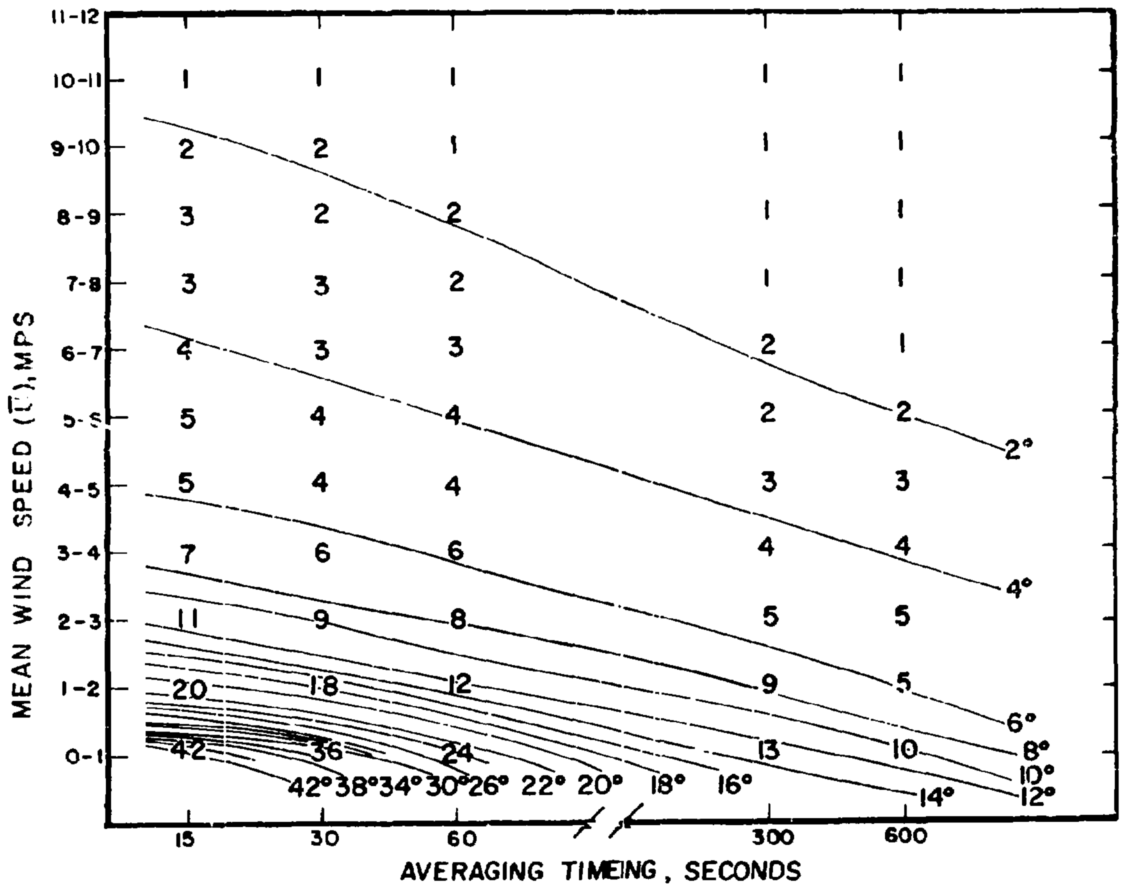

FIG. 10 MEAN WIND DIRECTION DIFFERENCE, VERSUS AVERAGING TIME AND MEAN WIND SPEED AT A HEIGHT OF 4 METERS AND DISTANCE SEPARATION OF 25 METERS, AND ZERO LAG TIME.

speed is 3 to 4 mps there is very little, if any, change in wind speed difference with a change in averaging time from 15 to 600 seconds. Mean wind speeds of this magnitude occur predominantly during neutral stability conditions. Figure 10 shows that the greatest wind direction differences occur with light mean winds and short averaging time. A change in averaging time has the greatest effect on wind direction differences under light wind conditions.

Figures 11 and 12 present wind speed and direction differences versus lag time from 0 to 7200 seconds at various mean wind speeds. An increase in lag time causes an increase in wind speed and direction differences at all mean wind speeds up to a lag of 3600 seconds. Wind direction and speed difference variation in Figures 11 and 12 is quite similar to the variation as a function of lag time found by Armendariz and Lang [7], except that the differences in direction and speed are somewhat less. This is probably due to the smaller horizontal distance separation (75 meters) used here than the separation (275 meters) used by Armendariz and Lang [7].

Figure 13 presents mean wind speed and direction differences at a height of 1.5 meters and a horizontal distance separation of 150 meters versus the mean temperature difference between heights of 4.0 and 0.5 meters. An absolute difference in temperature was obtained by subtracting the magnitude of the temperature at the 0.5 meter level from the magnitude of the temperature at the 4.0 meter level. Therefore a negative value indicates a lapse condition and a positive value an inversion. The wind speed difference is greatest under steep lapse conditions, decreasing to the least difference during a strong inversion. This is most likely to be due to the fact that generally strong winds occur under neutral and steep lapse conditions and light winds during a strong inversion. Mean wind direction differences are about 25 degrees under unstable conditions decreasing to near 10 degrees under neutral conditions, and increasing to 30-35 degrees under stable conditions. This is expected since wind direction is most steady, or varies least, during strong winds which occur during near-neutral conditions, whereas the direction varies greatest under unstable conditions and under light winds which are common during very stable conditions.

The T-Array data were recorded on magnetic tape in wind components. The horizontal wind was computed in longitudinal (u) and lateral (v) components, where the longitudinal (u) component was parallel and the lateral (v) component was perpendicular to the mean wind direction. Mean values of the longitudinal and lateral wind differences $\overline{\Delta u}$ and $\overline{\Delta v}$ and their standard deviations $\sigma\overline{\Delta u}$ and $\sigma\overline{\Delta v}$ were computed, plotted versus horizontal distance separation, averaging time, lag time, and thermal stability, and classified as to downwind or crosswind directions.

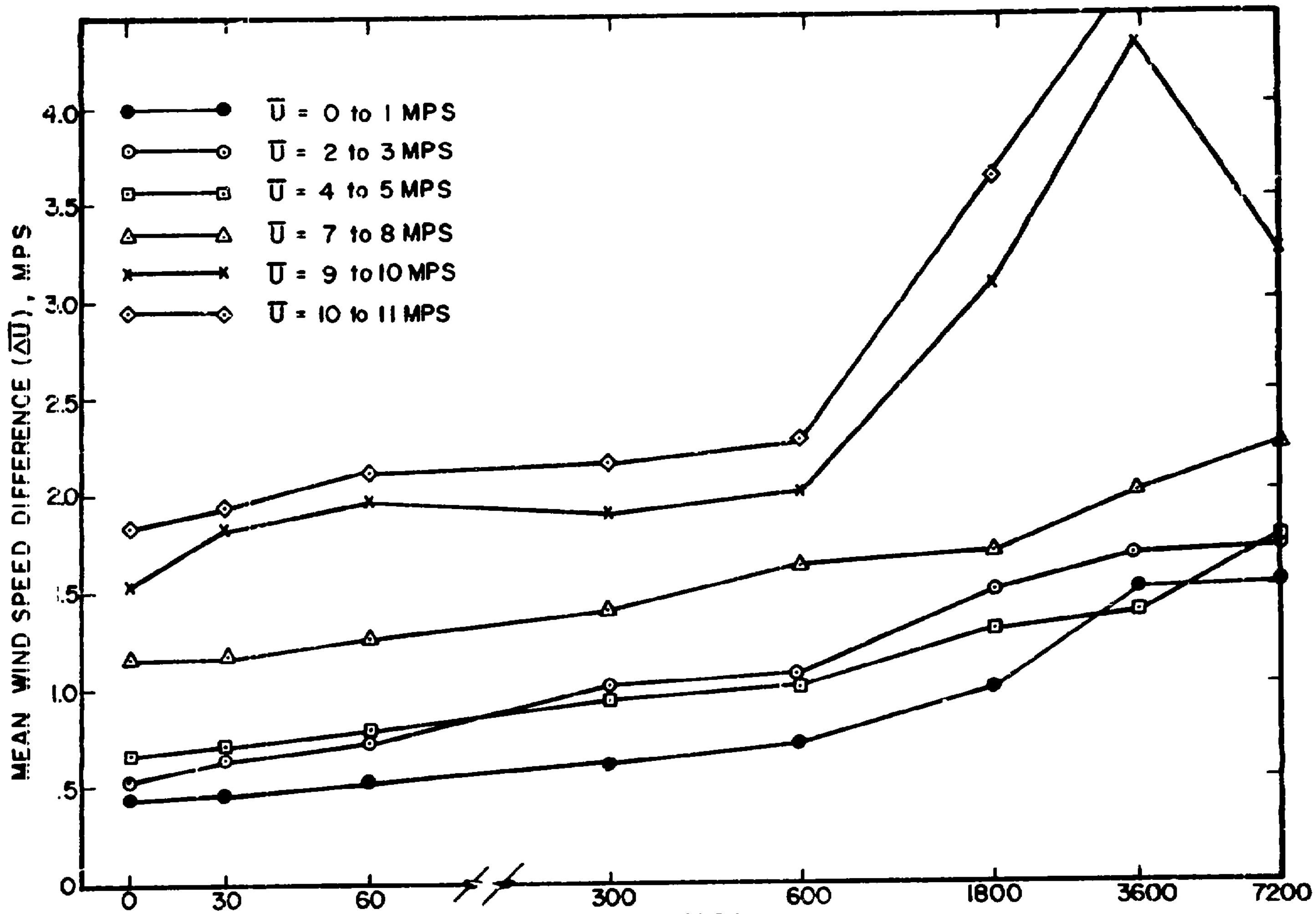

FIG. 11. MEAN WIND SPEED DIFFERENCE VERSUS LAG TIME FROM 0 TO 7200 SECONDS AT A HEIGHT OF 4 METERS & HORIZONTAL DISTANCE SEPARATION OF 75 METERS AT VARIOUS MEAN WIND SPEEDS & 30 SECOND AVERAGES.

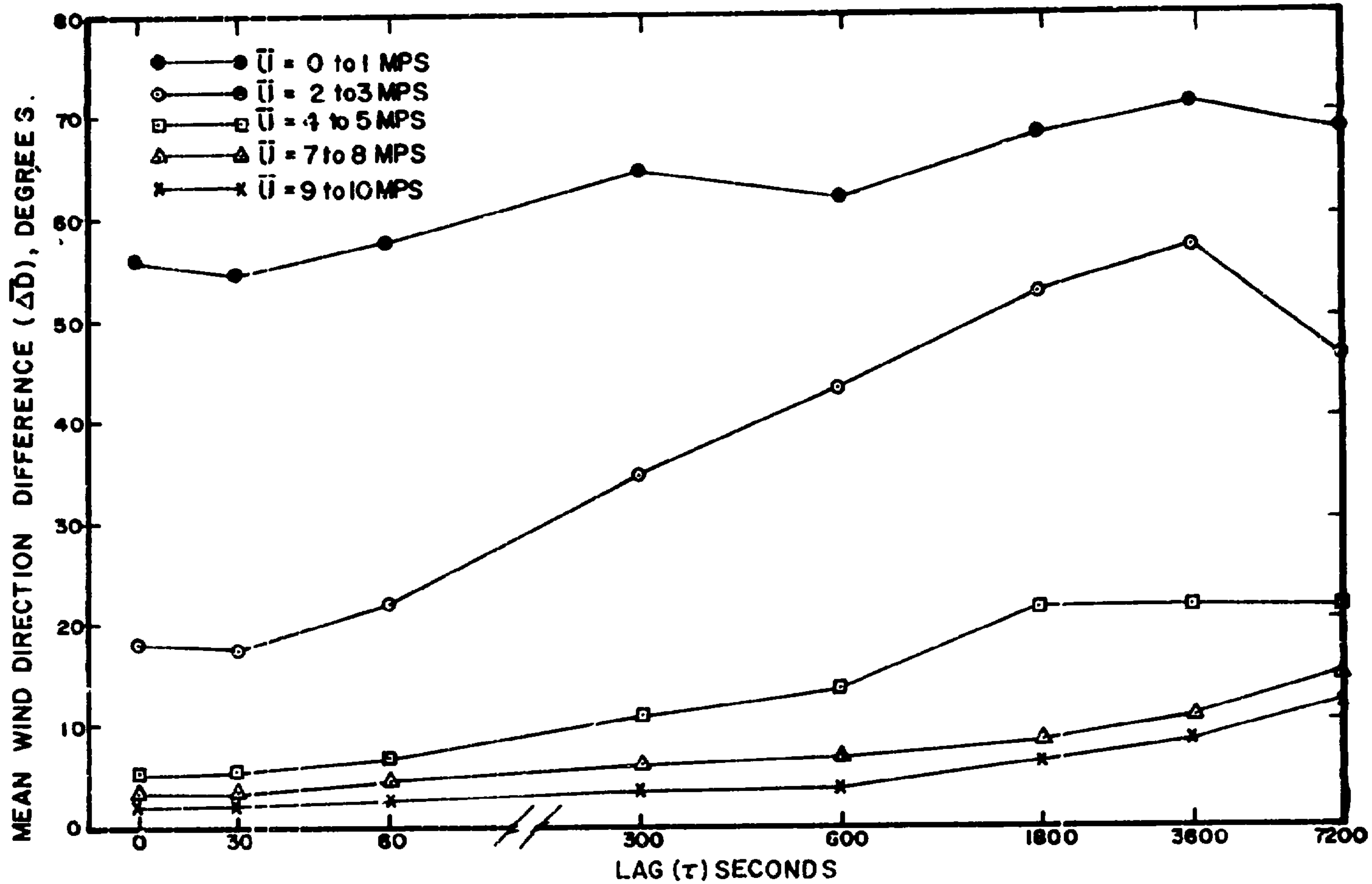

FIG. 12 MEAN WIND DIRECTION DIFFERENCES VERSUS LAG TIME FROM 0 TO 7200 SECONDS AT A HEIGHT OF 4 METERS AND A HORIZONTAL DISTANCE SEPARATION OF 75 METERS AT VARIOUS MEAN WIND SPEEDS & 30 SECOND AVERAGE.

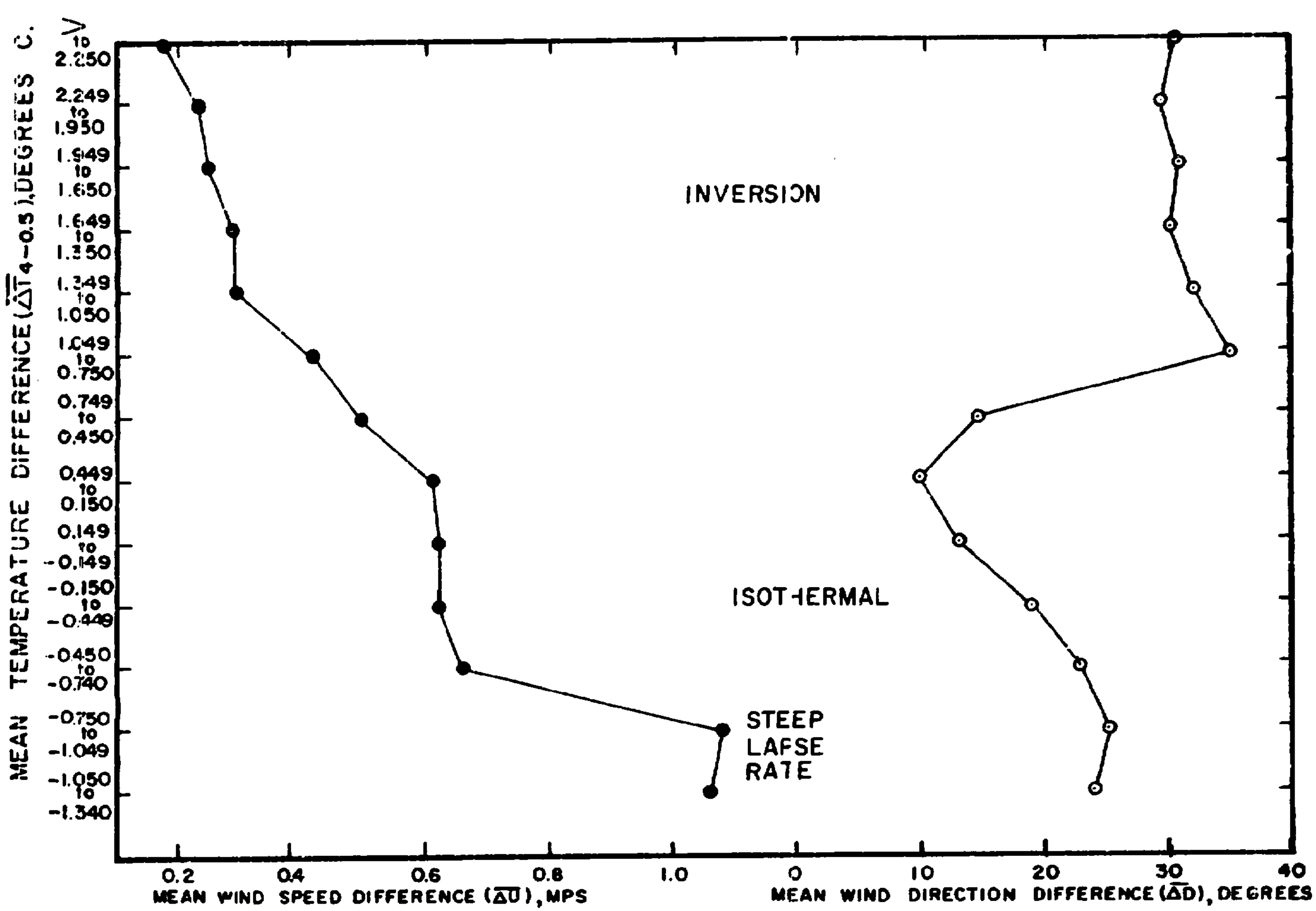

FIG.13 MEAN WIND SPEED AND DIRECTION DIFFERENCES WITH A DISTANCE SEPARATION OF 150 METERS AND A HEIGHT OF 1.5 METERS VERSUS MEAN TEMPERATURE DIFFERENCE BETWEEN 4.0 AND 0.5 METER HEIGHTS USING ONE MINUTE AVERAGES AND ZERO LAG TIME.

Figure 14 presents mean longitudinal and lateral wind component differences and their standard deviations as a function of horizontal distance separation for a height of 4.0 meters. There is a significant increase in $\overline{\Delta u}$ and $\overline{\Delta v}$ as distance separation increases from 25 to 100 meters, then very little change from 100 to 300 meters. Standard deviations of $\overline{\Delta u}$ and Δv vary in about the same manner. Generally longitudinal wind component differences vary similarly to mean wind speed differences, and lateral wind component differences vary similarly to wind direction differences as shown in Figures 5-8.

SUMMARY

At heights of 1.5 and 4.0 meters with a mean wind speed of 4 mps or less and distance separation of 150 to 175 meters, wind speed differences are less than 0.8 mps but wind direction differences are quite large (10 to 50 degrees). Conversely, with increasing mean winds (5 mps or greater), wind speed differences increase from 1 to 2.5 mps, and direction differences decrease to less than 10 degrees. There is no significant difference between crosswind and downwind situations in this comparison. There does not appear to be a significant change in speed and direction differences with an increase in distance separation from 25 to 300 meters unless the mean wind speed is less than about 4 mps.

A change in averaging time of the wind data from 15 to 600 seconds apparently does not significantly change wind speed differences unless the mean wind speed is 5 mps or greater. With strong mean winds, 10 mps or greater, an increase in averaging time causes a marked decrease in speed differences. Conversely, wind direction differences are greatest with light mean winds and short averaging time (30 seconds or less).

An increase in lag time will increase wind speed differences, the most significant increase occurring when the mean wind speed is greater than 5 mps. This is also generally true for wind direction differences.

The temperature difference (ΔT) between heights of 4.0 and 0.5 meters is an indication of thermal stability of that particular layer. Wind speed differences are greatest under steep lapse rate conditions; since strong gusty winds are common at WSMR during this type of temperature regime, large speed differences are expected. Wind direction differences are least under near-isothermal (or neutral stability) conditions, and greatest during inversion when winds are light.

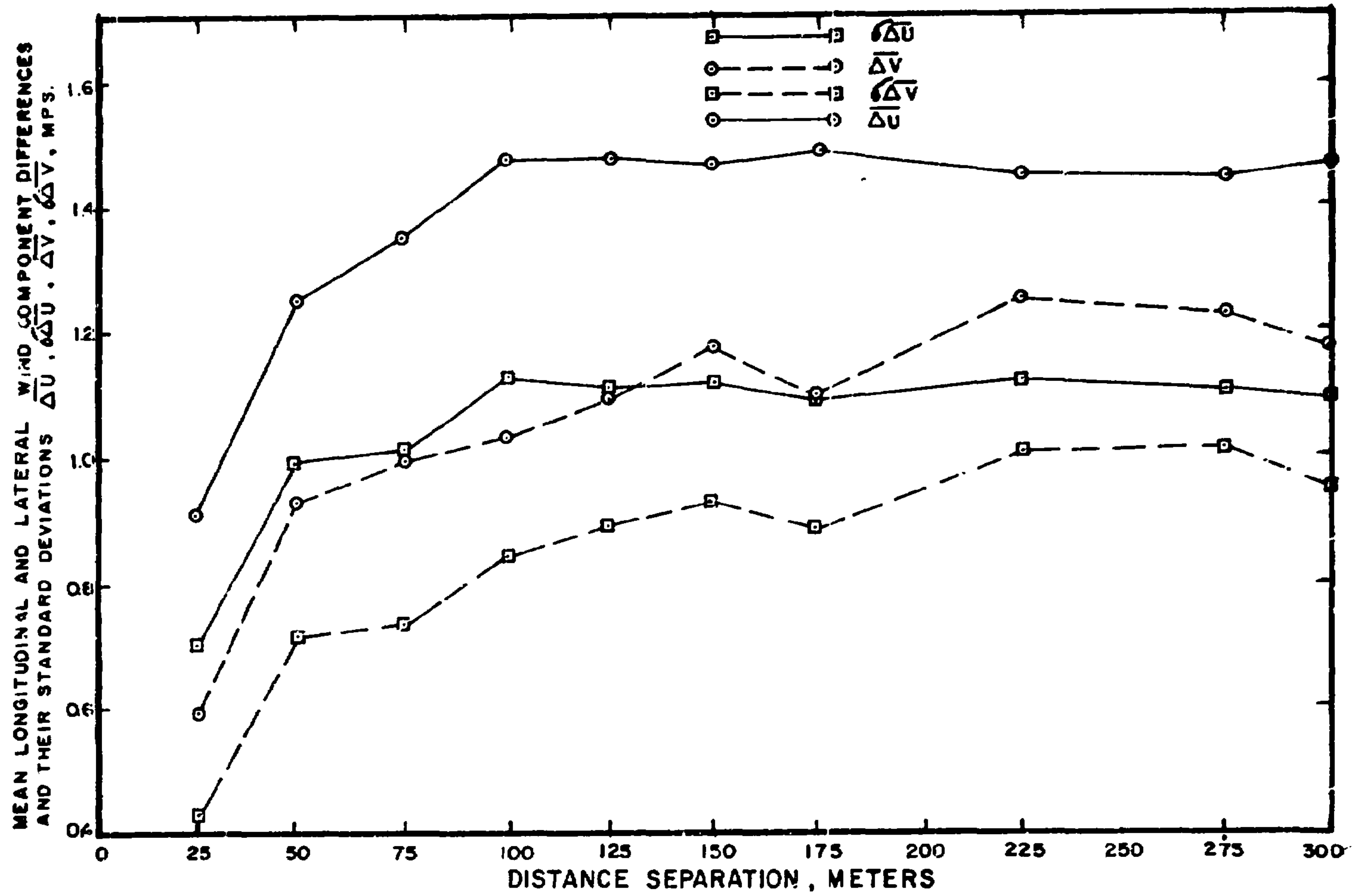

FIG. 14 MEAN LONGITUDINAL AND LATERAL WIND COMPONENT DIFFERENCES AND STANDARD DEVIATION AT A HEIGHT OF 4.0 METERS VERSUS HORIZONTAL DISTANCE SEPARATION.

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