NOAA Technical Memorandum ERL WPL-16

U.S. DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
Environmental Research Laboratories

PERFORMANCE TEST RESULTS

FOR A XONICS ACOUSTIC DOPPLER SOUNDER

Duane A. Haugen

Wave Propagation Laboratory
Boulder, Colo.
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INTRODUCTION

A two-month lease agreement effective 3 March 1976, between the Wave Propagation Laboratory (WPL) and Xonics, Inc., Van Nuys, California was arranged at the request of the Wind Shear Program Management Office, FAA, Washington, D.C. The object was a performance evaluation test of an acoustic Doppler wind measuring system manufactured by Xonics, Inc. Test procedures were designed to obtain answers to the following questions:

a) Is the device an operational system that can dependably operate unattended for long periods of time?

b) Is the system subject to limitations imposed by environment (e.g. ambient wind speeds or rainfall rates)?

The first question was reasonably well answered by the field program. Not enough information was obtained to answer the second question definitively. However, it was possible to infer valuable performance characteristics of the system over the range of meteorological conditions encountered.

The tests were performed at the NOAA Table Mountain Test Site, about 10 miles north of Boulder, Colorado. Wind speeds observed ranged from 0 to 10 m/s at 2.5 m and 0 to 20 m/s at 148 m. Rain occurred only once during the two month period in the form of a light drizzle. Data were obtained under turbulence conditions ranging from nearly laminar, thermally stable flow, to strong, gusty, thermally unstable flow.

TOWER INSTRUMENTATION SYSTEM

The 150-m tower at Table Mountain was instrumented at 31, 67, 95, 125, and 148 m to measure wind speed and wind direction. The wind speed and direction sensor used is a prop-vane anemometer, model 8002, manufactured by R. M. Young Co. It has a low speed threshold of roughly 0.5 m/s. However, for the purposes of this report, no data will be presented for average wind speeds less than 1.0 m/s.

The anemometers were mounted on booms extended 2.5 m north of the tower structural members. This provided sensor exposures with unobstructed air flow except for a 90-degree sector centered roughly on 195 degrees azimuth. However, as the experimental procedures evolved during the test period, the possible degradation of the wind data due to tower shadow effects became negligible relative to other aspects of the analyses.

In addition to the wind measurements on the tower, a two-axis sonic anemometer, EG&G Model 198-2, was mounted at a height of 2.5 m to measure the so-called surface wind speed and direction. This anemometer was installed in the open area east of the tower where the Xonics equipment was also located, well-removed from any possible turbulent wake effect induced by buildings or the tower.

After the manufacturer-recommended procedures were used to check the electronic calibration of the prop-vanes, the anemometers were mounted at 1.5-m intervals along a sawhorse 2.5 m high oriented perpendicular to the wind direction, in order to obtain anemometer matching data in naturally turbulent conditions. Two and a half hours of data were obtained over a wind speed range of 1.5 to 12.5 m/s. Ten-minute mean wind speeds were obtained for each anemometer. Differences in the mean speeds observed were small — within ± 10 cm/s. No systematic bias was observed for any of the anemometers.

All the anemometer outputs were telemetered by signal cable to a computer-controlled data acquisition system. Each output was sampled once a second and the data were processed in real time to provide the time-averaged wind data required.

XONICS ACOUSTIC DOPPLER SOUNDER SYSTEM

The acoustic Doppler sounder tested is a two-axis system that provides time-averaged values of the two orthogonal horizontal wind components. A vertically pointing antenna transmits a 4.5 KHz sound pulse every 2.5 seconds. Two fan beam receiving antennas are placed in orthogonal directions from the transmitter and oriented to receive the scattered sound waves from the transmitter beam over the height range desired. The transmitter-receiver base lengths were 143 m for these tests and oriented to provide N-S and E-W wind components.

The Xonics system is controlled by a mini-computer which provides real-time processing of the wind component data at five equally-spaced heights. The heights used for these tests were 44, 70, 96, 122, and 148 m, thus providing four levels at which radar-tower comparisons could be made.

For a period of a few months just preceding these tests, the Xonics system was operated at Los Angeles International Airport. Each antenna was enclosed in a Fiberglas-lined cuff designed to minimize sidelobes. A Tedlar sheet was stretched tightly over the cuff opening to protect the receiver equipment from the elements. The configuration of the receiving antennas was changed before installation at Table Mountain in a manner that later proved to be significant.

In the initial installation at Table Mountain, each receiver cuff was extended to provide a shield from the weather. The Tedlar sheet was removed and only a sheet stretched over the receiver horn itself was used. Finally, the outsides of the cuff and the shield were lined with a synthetic "horsehair" material. This material, acoustically transparent, was also placed across the shield opening. It was introduced with the expectation that it would damp out acoustic noise caused by high wind speeds or rainstorms.

EXPERIMENTAL PROCEDURES

Before the test period began, WPL, Xonics, and FAA personnel agreed upon a test plan that seemed best suited to provide answers to the questions listed in the introduction of this report. The objective was to obtain a data sample just large enough to answer the questions and small enough to be manageable. Certain fundamental analyses of the test results were maintained on a current basis to permit continuing examination of the test plan rationale.

The tests were started on 12 March with data being collected for ten minutes each hour. The transmitting antenna was located 103 m north and 97 m east of the tower. The N-S receiver was 143 m north of the transmitter; the E-W receiver, 143 m east of the transmitter. Scatter diagrams of each wind component were kept current for each level on a daily basis. The Xonics data showed excellent agreement with the tower data for wind speeds less than about 10 m/s at altitude; they showed large discrepancies for higher wind speeds. A number of field modifications were tried, including the use of preamplifiers in the receiver circuits; introduction of a new, more powerful driver in the transmitter; removal of the horsehair; software changes — all designed to improve the signal levels for Doppler frequency shift detection. By 5 April it was decided by Xonics personnel that none of the modifications attempted had perceptibly improved the results. They then proposed to move the transmitter 202 m northeast. They felt it was possible that strong winds blowing through the tower and the tower guy wires could be generating sound noise at frequencies which interfered with the Doppler signal.

The period before the move, from 12 March to 7 April, is designated Period I. The data presented for this period were obtained with an observation schedule of ten minutes on, fifty minutes off, each hour the system was in operation.

The new location of the transmitter was 246 m north and 241 m east of the tower (345 m northeast of the tower). The N-S receiver (previously the E-W receiver) was 144 m south of the transmitter; the E-W receiver (previously the N-S receiver), 144 m west of the transmitter. No horsehair was used on the receiver cuffs during this period. The various electronic improvements introduced in Period I were maintained during the second period. However, it was soon decided that moving the transmitter had not improved its performance.

The period between 7 and 20 April is designated as Period II. The data are based on the same observation schedule as for Period I for 7 April through 15 April. A small amount of data was obtained between 16 and 20 April on an observation cycle of 15 minutes on, 15 minutes off.

The last set of field modifications restored the receiver configurations to a state approximating that used at the Los Angeles Airport. The cuff extensions (or weather shields) and the Tedlar sheet over the receiver feed horn were removed on the E-W receiver. The N-S receiver configuration was left unchanged. Both receiver feed horns were mechanically damped with caulking material to minimize any resonant vibrations in the horns themselves. The relative locations of the transmitter and the receivers were the same as for Period II.

This period, from 20 to 30 April, is designated as Period III. The major analysis effort has been concentrated on this period. The observation cycle was 15 minutes on, 15 minutes off for all the data collected during this period.

DATA PROCESSING PROCEDURES

All the analyses presented here are based on speed data that have been averaged over either 10 or 15 minutes depending on the particular observation cycle adopted in each of the experimental periods. It will be seen that this choice of averaging periods has appeared to serve the comparison test purposes adequately. In all cases, the comparisons will be between mean wind speed components at different levels in the atmosphere. If there is good agreement between the two systems the differences between the pairs of values will be uniformly distributed about a mean difference of zero. The range of differences will be "reasonably small".

The tower speed and direction sensors were each sampled once a second. The N-S and E-W components were computed for each speed and direction sample and all subsequent comparison statistics are based on these components. The basic outputs from the acoustic system were the component data also, but averaged over 1-min periods where each 1-min average is based on 24 samples. For comparison purposes, these 1-min values were then averaged over the 10- or 15-min periods as required.

Each 1-min average of the acoustic system is qualified according to a data editing algorithm designed to identify periods of questionable signal levels for peak Doppler frequency shift detection. Five qualifier codes were used for categorization of confidence in the derived 1-min wind values from the system. Only the 1-min averages with one of the top three qualifiers have been used in this report. Further, if less than 60% of the 1-min averages had one of the top three qualifiers for any 10- or 15-min period, the entire period was excluded from the analysis.

DISCUSSION OF RESULTS

Selected examples of results will be presented for each of the three test periods. However, Period III will be emphasized since it represented the final configuration of the system.

Examples of system performance for Periods I and II may be seen in Figs. 1 and 2. Each of the graphs is a plot of the algebraic difference between wind components vs the surface wind speed. The E-W component is denoted U, the N-S component, V. Plots for two levels, 70 and 148 m, are presented for both wind components for both periods. Following is a summary of what appear to be the significant features of these plots:

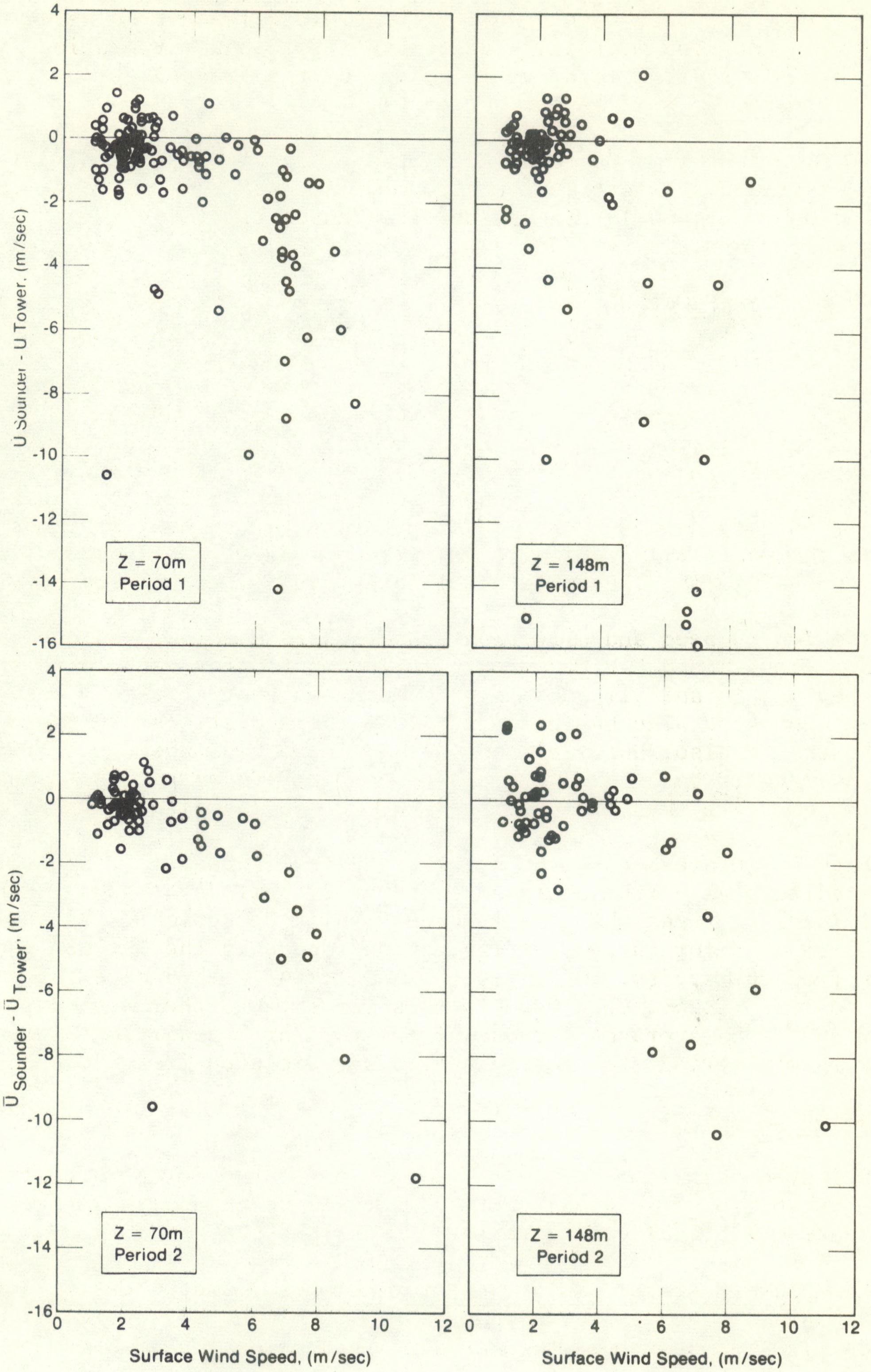

Figure 1. Sounder-tower wind differences, U-component, at 70 and 148 m vs surface wind speed for periods I and II.

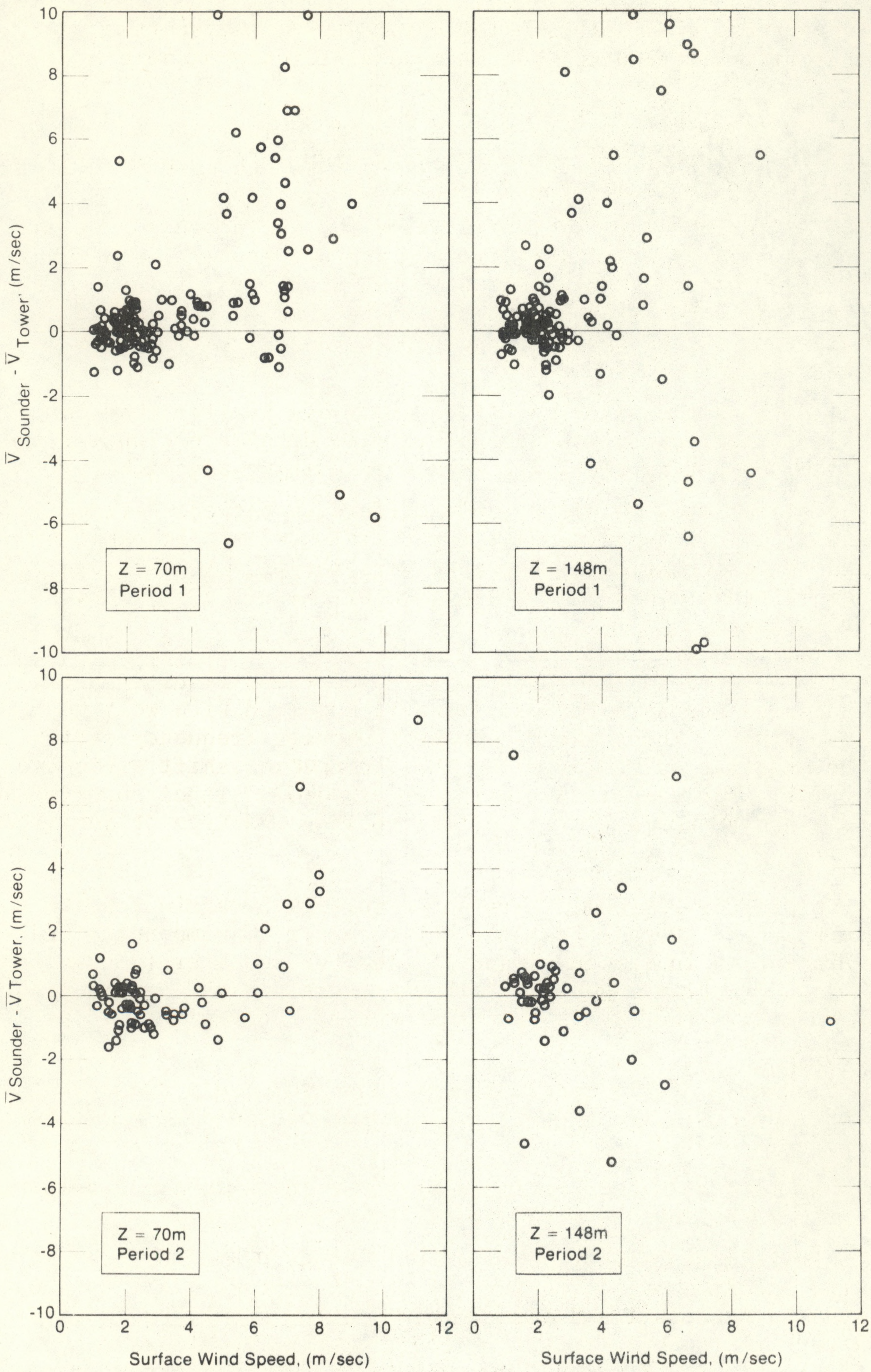

Figure 2. Sounder-tower wind differences, V-component, at 70 and 148 m vs surface wind speed for periods I and II.

a) For surface wind speeds below about 4 m/s, the scatter is uniformly distributed about a mean difference of zero.

b) With a very few exceptions, the algebraic differences for the low wind speed cases are within ± 2 m/s. This should be considered excellent agreement given the large separation distance between the tower and the Doppler radar.

c) The differences are extremely large for surface wind speeds greater than 4 m/s. The error in the U-component occasionally exceeds 10 m/s in magnitude and when it occurs, is an underestimate. The error in the V-component is of the same magnitude but is just as likely to be an overestimate as an underestimate.

d) The data sample size for 148 m was always smaller than for 70 m, a reflection of a higher rate of data rejection for the higher height by the Xonics software editing algorithm.

e) The graphs show no appreciable difference between Periods I and II. This suggests that the position of the transmitter and the orientation of the receivers relative to the tower are not relevant factors in evaluation of the overall system performance.

It should be noted in the interpretation of these results that all the high wind speed cases in Periods I and II occurred with west to west-southwest winds. Thus, the U-component Doppler frequency shift caused by the wind was quite large and the V-component shift quite small or near zero for these cases. Any noise or erroneous signal superimposed on the "wind signals" would therefore tend to show the type of behavior observed for the U and V components.

Similar plots for Period III are shown in Fig. 3, again for the 70 and 148 m heights. Recall that the N-S receiver (V-component) had the same configuration as in Periods I and II; the E-W receiver (U-component) had the shield and Tedlar removed. Both receivers had the receiver horns mechanically damped. The significant features of these plots are as follows:

a) The damping of the receiver horns has produced a dramatic improvement in the overall performance of the system regardless of surface wind speed.

b) There is a mean underestimate of about 1 m/s in the U-component at 70 m for surface wind speeds above about 4 m/s.

c) There is some indication of erratic behavior at surface wind speeds above 4 m/s for the V-component at 148 m as was seen in Periods I and II. However, with the exception of a very few points, this plot could also be read as a mean underestimate of about 3 m/s for the higher wind speed cases.

It should be noted here that the high wind speed cases in Period III occurred equally frequently from the north and the west. Thus, the

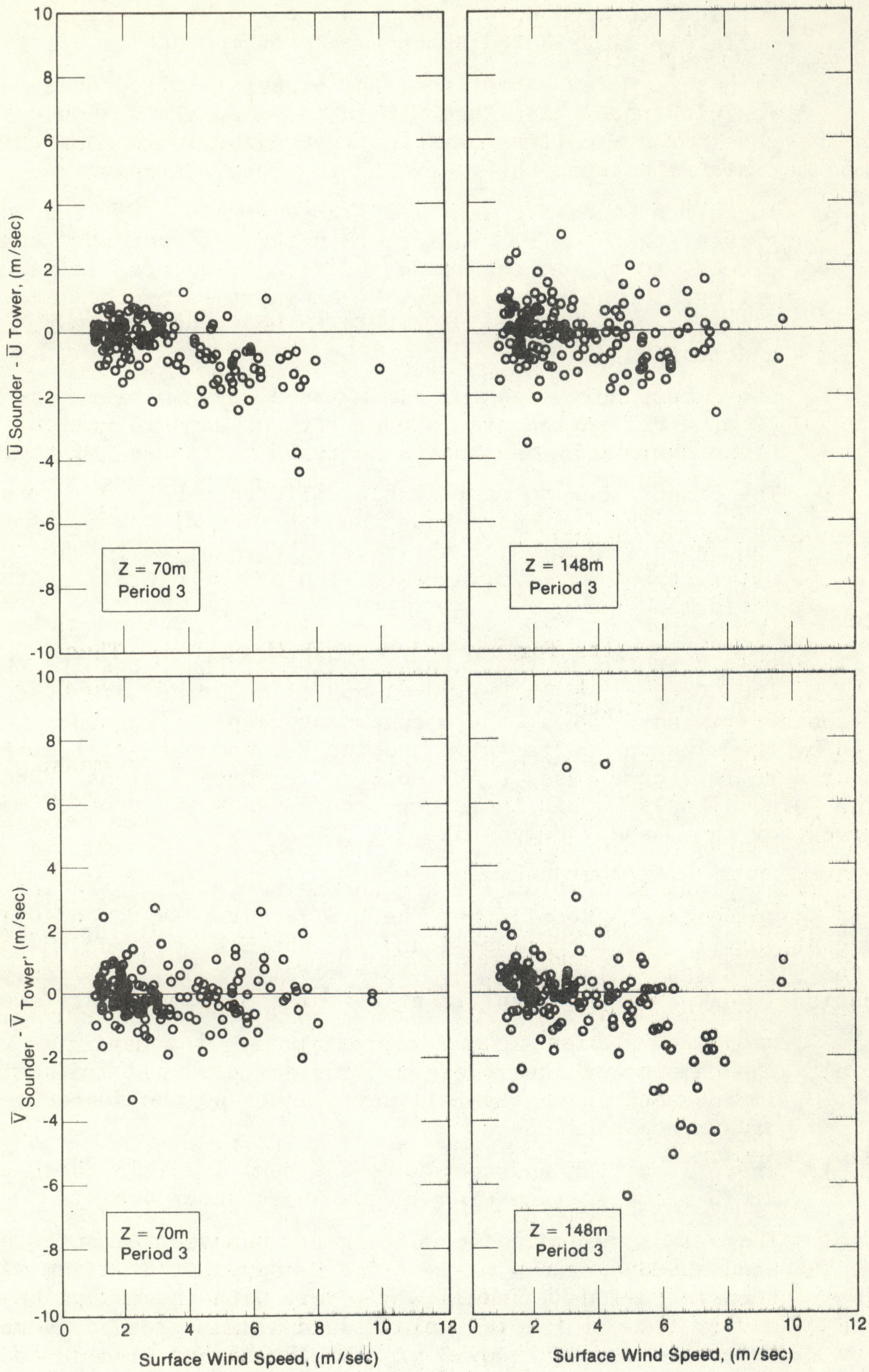

Figure 3. Sounder-tower wind differences, U- and V-components, at 70 and 148 m vs surface wind speed for period III.

behavior of the system under high speed conditions does not appear to be direction-sensitive.

Plots for the 96- and 122-m heights in Period III are not shown for the sake of brevity. However, it is important to note that they show good agreement for all cases, identical to that shown for the V-component at 70 m and the U-component at 148 m. That is, the behaviors noted in points (b) and (c) above for Period III are only for the components and heights discussed.

In any comparison study involving tower instrumentation, one must consider possible contamination of the results when the wind direction is through the tower to the anemometers. In addition, unless the site of the comparison study is horizontally homogeneous, topographical effects can, in principle, produce undesirable biases in the data. Plots of the wind component differences at 70 and 148 m vs wind direction for Period III are shown in Fig. 4. No directional sensitivity is evident in any of these plots. It should be noted the underestimate bias previously discussed for the U-component at 70 m occurs with wind directions between 220 and 360 degrees. The best exposure for the tower instrumentation was the two northerly quadrants. Clearly, there is no difference in the underestimate bias between northerly and westerly winds; there is also no bias of the results for any other wind direction. Thus, there is no evidence of contamination of the results due to tower shadow effects or to topographical factors.

Another analysis evaluated the radar's ability to measure the winds as a function of height. That is, instead of comparing wind speeds at any given level, we compared the wind speed differences between levels. For this purpose, the differences between adjacent levels for the U- and V-components were examined independently. Denoting these differences ΔU and ΔV respectively, we plotted the algebraic differences between the radar and tower ΔU's and ΔV's vs. surface wind speed. These plots are presented in Figs. 5 and 6 for Period III. The results indicate uniform scatter in the cases where the surface wind speed is quite low ($\leq$ about 3 m/s), increasingly larger differences with increasing surface wind speed, and a marked bias towards overestimating the magnitude of the shear for surface winds exceeding 4 m/s. However, the only erratic behavior is for the ΔV comparisons which must be a reflection of the shield influence in some manner. The ΔU-comparison shows acceptable results for the receiver configuration in the final mode used during the tests.

Finally, we present in Fig. 7 a bar graph showing the percentage of 15-min periods in which 40% or more of the 1-min averages were qualified as "poor signal-to-noise" data by the software data editing algorithm. These data are presented independently for the U- and V-components as a function of height. It is well known that atmospheric attenuation of acoustic energy increases markedly with increasing frequency and is particularly marked for relative humidities of roughly 8 to 25%. For the dry environment at Table Mountain (RH's of the order of 20%) and the radar frequency of 4.5 KHz, these results indicate that the effective range of the radar tested is probably not much in excess of 200 m.

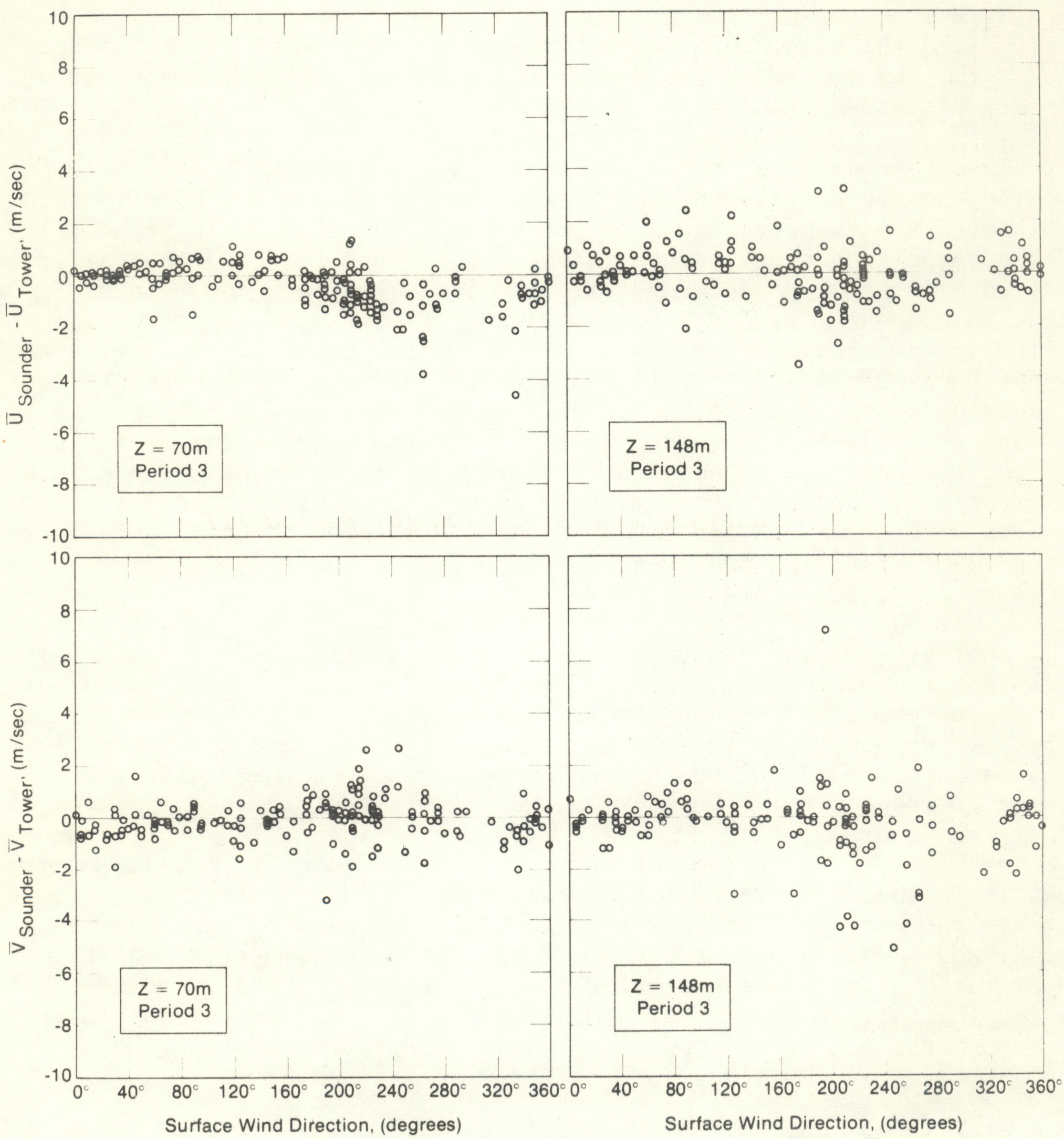

Figure 4. Sounder-tower wind differences, U- and V-components at 70 and 148 m vs surface wind direction for period III.

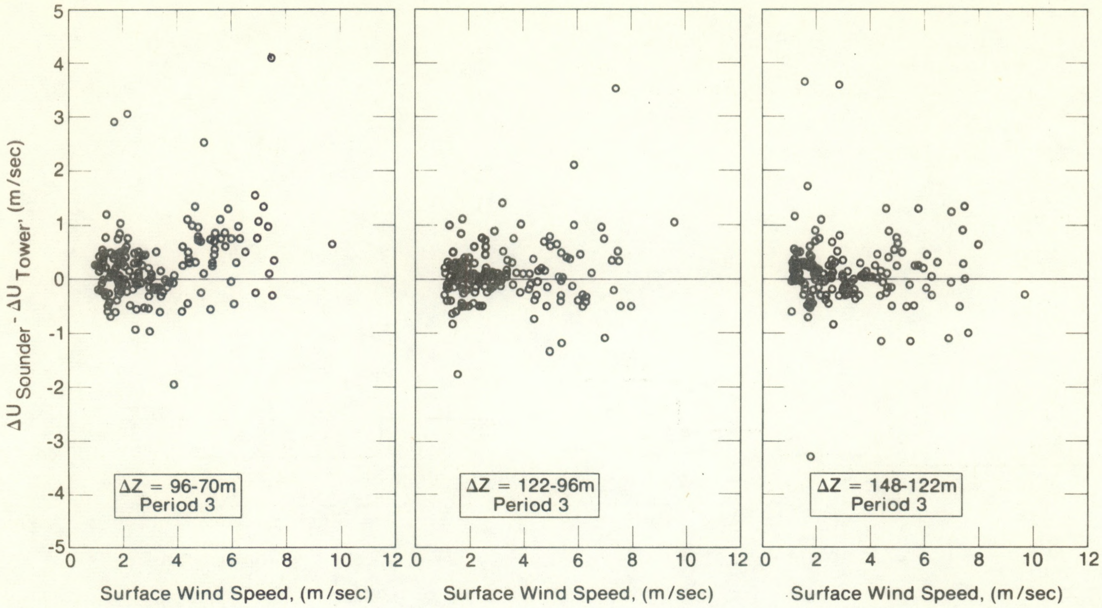

Figure 5. Sounder-tower wind shear differences, U-component, for indicated heights vs surface wind direction for period III.

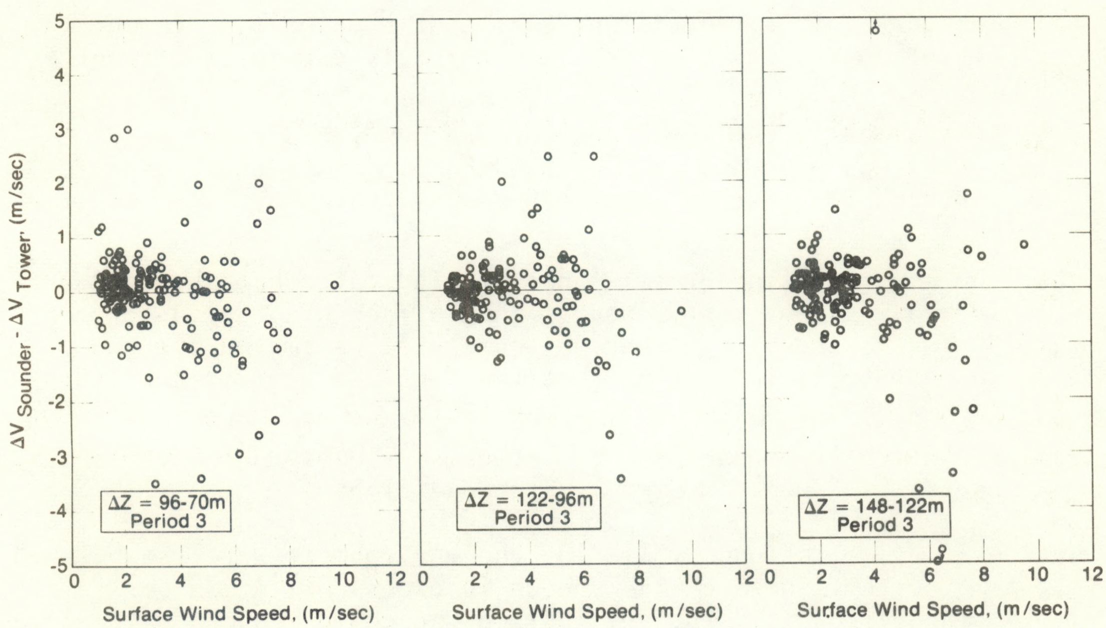

Figure 6. Sounder-tower wind shear differences, V-component, for indicated heights vs surface wind direction for period III.

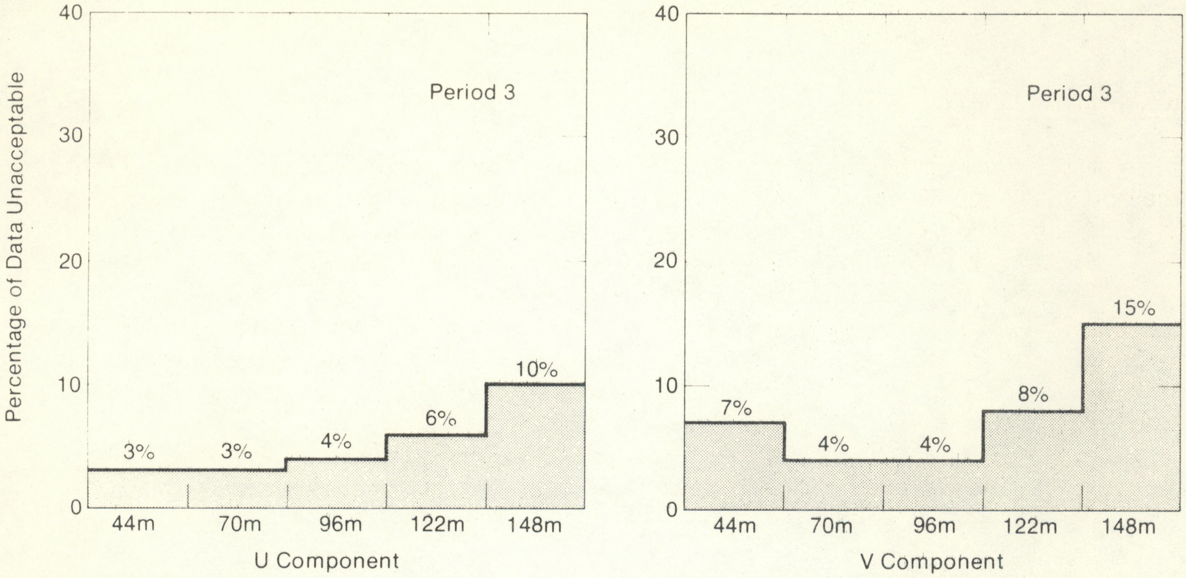

Figure 7. Percentage of time U- and V-component sounder data rejected by the data editing algorithm for indicated heights.

CONCLUSIONS

On the basis of the two-month data sample available and the results summarized above, the following conclusions are suggested:

a) The device cannot be considered an operational system at this time having undergone a number of field modifications during the test period.

b) The data for Period III indicate that a major improvement in performance was achieved by mechanically damping the receiver horns.

c) In Period III the agreement between tower and radar wind speeds was good and well within the limits of uncertainty expected for tests of this type. Only for U at 70 m and V at 148 m did the wind speeds fail to agree.

d) The shear or wind profile analysis indicate that shears are increasingly overestimated as the surface wind speeds exceed 4 m/s for the V component, but are well estimated for the U component, an indication that the final U receiver configuration was near optimum for these tests.

e) The effective range of the system is probably not much in excess of 200 m for dry climate conditions.

No specific limitations imposed by the environment were established by these tests. Neither surface wind speeds in excess of 10 m/s nor rainfall occurred during Period III, the only period one could reasonably analyze for environmental limitations.

ACKNOWLEDGMENTS

Numerous people have worked with me during the test period and the analysis of the data. I would like to express my appreciation particularly to J. Chandran Kaimal, Christopher C. Murdock, and Jim T. Newman.