from the Pioneer Venus sounder measurements.[4] Our wind-speed estimates, thus far very provisional, are shown in Fig. 4.

Positive values of the velocity correspond to a wind directed toward the west.

Despite the quite large scatter of the estimates we have obtained, the Venera 13 data are definitely in qualitative agreement with the measurements on the previous Venera and the Pioneer flights: at all heights were recorded winds directed toward the west; the wind speeds are small in the lower troposphere, no more than 1-2 m/sec at the surface; wind shear begins in the lower troposphere at a level of ≈10 km; throughout the bulk of the atmosphere the wind velocity is in the neighborhood of 50 m/sec. There is some evidence for a further rise in the wind speed toward the upper boundary of the measurements.

Both landers recorded the presence of atmospheric turbulence in the cloud deck at heights of 50-60 km. The wind speed oscillated by up to 2-2.5 m/sec on the Venera 13 descent, and by 1-1.5 m/sec on the Venera 14 descent. The typical spatial scale of these fluctuations is ≈1-1.5 km. While the amplitude of the variations is similar to that measured on the Venera 11, 12 missions,[2] the spatial scale appears to be 1.5-2 times as great. Conceivably velocity fluctuations on this scale might reflect the operation of other processes as well, such as changes in the mean wind speed or atmospheric waves. On the whole, however, the Venera 13 data qualitatively bear out the findings from Veneras 9-12.

The authors wish to thank their colleagues and the staff of the Center for Deep Space Communications, who have contributed so much to the successful completion of this experiment.

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Acoustic measurements of the wind velocity at the *Venera 13* and *Venera 14* landing sites

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The surface wind velocity at the *Venera 13* and *Venera 14* landing sites is estimated from the Groza 2 acoustic-sensor signals to be in the 0.3–0.6 m/sec range.

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To employ acoustic sensors for measuring wind velocities is somewhat unusual. Nevertheless, the acoustic measurements carried out on the Venera 13 and Venera 14 landers yielded results which in all likelihood can be interpreted as wind noise picked up by the microphones. Wind-speed measurements in the dense atmosphere of Venus by means of acoustic sensors may prove particularly convenient because of their simplicity.

The Groza 2 [Thunderstorm] experiment aboard the new landing craft included a microphone and appropriate electronic circuitry for measuring acoustic noise both along the descent path and on the surface of the planet. An electromagnet-type microphone was specially developed for operation in the complex environment of the Venus atmosphere. It remained operational at temperatures up to 800°K and pressures up to 100 bar. The microphone accepted a 2-kHz frequency band, from 400 to 2500 Hz, with peak sensitivity near 1700 Hz (under standard conditions). In the Venus surface environment the sensitivity maximum shifted somewhat toward lower frequencies. Unlike the case[1] on Venera 11 and Venera 12, the electronics, sealed inside a compartment, incorporated two channels: high and low sensitivity. The first channel covered the range 55-82 dB; the second, 95-120 dB (under standard conditions). The low-sensitivity channel operated during descent, in the presence of strong aerodynamic noise, while the high-sensitivity channel was used on the surface. In this letter we describe the results acquired from the high-sensitivity channel.

Upon landing, the instrument initially recorded the noise produced by the spacecraft systems, themselves (the cap on the television camera was removed by pyrotechnic charges, the drilling equipment came into operation, and so on). Figure 1 shows a trace of the signals received from the microphone on Venera 14 during the first 4 min after landing. The arrows mark noise events whose sources have been identified. In the interval between the 180th and the 240th second, on the other hand,

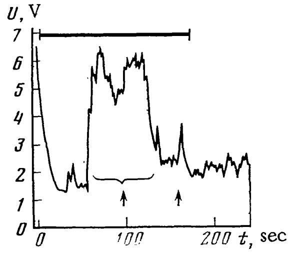

FIG. 1. Acoustic noise recorded by the Venera 14 lander on the surface of Venus, March 5, 1982. Vertical axis, output signal U (the full scale corresponds to the range from 55 to 82 dB; horizontal axis, elapsed time after landing. The heavy bar indicates the period when the spacecraft systems were operating. The arrows indicate noise associated with equipment operation. Presumably the signal from t = 180 to 240 sec represents wind noise in the microphone armature.

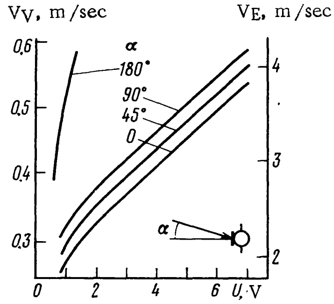

FIG. 2. Output signal U as a function of the wind velocity V_V on Venus and V_E on the earth when the microphone is employed as an anemometer. The angle α specifies the direction of the wind relative to the microphone diaphragm.

there was a substantial acoustic signal of unknown origin. After the 240th second the Groza 2 measurement channels were interrogated only during 8-sec cuts alternately at intervals of 200 and 392 sec. In all these cuts the signal was present. One of us (L. V. K.) was suggested that the signal could represent wind noise in the microphone armature. The microphone was mounted on a light bracket attached to the spececraft landing ring, raised about 250 mm above its top plane.

To test whether this conjecture was correct and to calibrate the microphone with its armature as a device to measure wind speeds, the microphone together with the bracket and other appurtenances was placed in a low-velocity aerodynamic tube. Air was blown through with the microphone entrance cone in various positions relative to the direction of flow. The flow rate was taken to represent the wind speed. Then the Groza 2 system was turned on and the output signal of the acoustic channel was recorded. The ventilation was performed under standard conditions. Figure 2 illustrates the results. For a 90° flow direction (the curve 90° in Fig. 2) an output signal between 1.4 and 2.4 V corresponded to a flow velocity of 2.4 to 2.8 m/sec; the signal did not depend very strongly on variation of the angle α between 0° and 90° (Fig. 2). On the other hand, if the stream was directed toward the back side of the microphone the signal dropped by a factor of 4-5.

The calibration data may be converted to the Venus surface environment by utilizing the principle of equal specific kinetic energy for the two flows:

$$\rho_0 V_0^2 = \rho_V V_V^2, \tag{1}$$

where the subscript 0 refers to standard conditions, and V to the Venus environment. At the 6051.9-km level[2] the atmospheric density ρ_V = 65 kg/m^3; since ρ_0 = 1.293 kg/m^3 we have

$$V_V = 0.141\ V_0. \tag{2}$$

The velocities V_V are also indicated along the left-hand scale in Fig. 2.

If we take the angle α (Fig. 2) to be 90°, the error in estimating V_V, in the sense of an underestimate, may reach a factor of 4-5 (the curve labeled 180°), whereas any possible overestimate of the wind velocity, as the 0° and 45° curves indicate, would amount to no more than 20%. We will first suppose that α = 90°, and will show that the possible error turns out to be considerably smaller than a factor of 4-5; probably it is not much different from unity.

With these remarks let us turn to the experimental data. Figure 3 shows all the measurements in the acoustic channels following touchdown of the two landers (Venera 14 on the left, Venera 13 on the right). As Fig. 3a demonstrates, the noise level remained approximately constant (output signal within 1.4-2.4 V) for almost 1 h after landing. According to Fig. 2, this level would correspond to a wind velocity V_V = 0.35-0.39 m/sec at the Venera 14 landing site (13°15' S, 310°09' E). In the case of Venera 13 (7°30' S, 303° E) the noise was much louder. The signal surpassed the upper level of the instrument throughout the period up to the 4765-sec postlanding mark, after which it began to weaken. Converted to wind speeds, the three values recorded at t = 4765, 4965, 5357 sec give V_B = 0.56, 0.54, 0.51 m/sec. All the preceding values of the signal correspond to $V_B \geq$ 0.57 m/sec.

Thus the wind velocities recorded in these experiments all lie between 0.35 m/sec and more than 0.57 m/sec, although the measurement conditions formally leave room for error on the low side by several times. However, by comparing our data against certain other evidence we can significantly diminish the range of possible error due to an incorrect choice of curve in Fig. 2.

The first line of evidence consists of published information. Direct measurements on the Venera 9 and Venera 10 landers yielded wind velocities V_V = 0.45 and 1.0 m/sec, respectively.[3] According to the Doppler measurements, as spacecraft descend through the Venus atmosphere (a generalization carried out by Kerzhanovich et al.[4]) they will encounter a surface wind velocity of no more than 1.0-1.2 m/sec. Pioneer Venus radio interferometry[5,6] provided the estimate $V_V \leq$ 1 m/sec. With some degree of caution, then, values above 1 m/sec can be excluded. Accordingly, V_V cannot have been underestimated by more than a factor 2.9 for Venera 14, or 1.8 for Venera 13. As for an overestimate of the velocity, such an error, as mentioned above, may not exceed 20%, although in view of the possible influence of the spacecraft in would be more reasonable to adopt a margin of 50%. Hence the possible errors in determining the wind

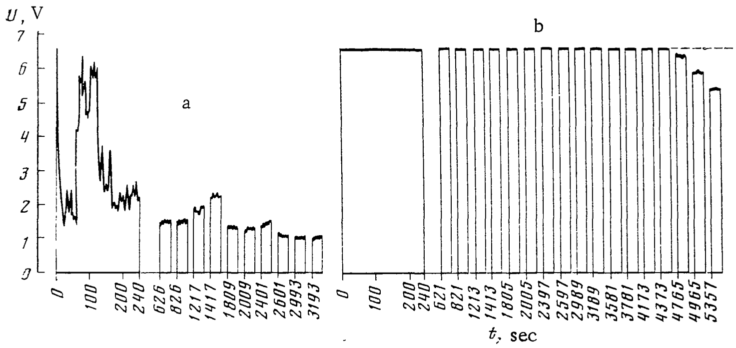

FIG. 3. Output signal in the high-sensitivity acoustic channel during operation of the two landers on the surface of Venus. a) Venera 14; b) Venera 13. Horizontal axis, elapsed time after landing. Following the 240th second, measurements were transmitted during 8-sec cuts every 200 and 392 sec alternately. On Venera 13 the signal prior to the 4765th second exceeded the limiting level marked by the dashed line.

velocity are as follows (meters per second):

	At maximum	At minimum
Venera 13	$\geqslant 0.57^{+0.43}_{-0.29}$	$0.51^{+0.49}_{-0.26}$
Venera 14	$0.39^{+0.61}_{-0.20}$	$0.35^{+0.65}_{-0.18}$.

It is noteworthy that our present results are close to if not coincident with the wind velocities obtained from other experiments (Venera 9 and Venera 10).

A second, independent (and unexpected) source of information on the winds in the Venera 13 and Venera 14 landing areas comes from analysis of the pictures taken on the surface of the planet.[7] A small amount of the soil thrown out as the vehicles impacted had settled onto the landing ring, as the pictures clearly show. Since the spacecraft continued to operate for some time, a sequence of successive images could be obtained, and these demonstrate that the amount of soil on the ring steadily diminished, primarily for the fine-scale particles. Winds are the only possible explanation. One can quantitatively estimate the wind velocity required to sweep particles of radius r off the horizontal surface of the ring. For this purpose the velocity thrust $\rho_V V_V^2 S/2$ (here S is the cross section of a soil particle) may be equated to the friction force kmg_V, where k is the coefficient of friction and $g_V = 8.87$ m/sec^2 is the acceleration of free fall. For simplicity assume that the particles are spherical in shape; however, regard them as not rolling but mainly slipping along the metal surface, so that k = 0.15. Then

$$3\rho_V V_V^2 = 8\, k\rho_s r g. \qquad (3)$$

The diameter d = 2r of a particle swept off by wind of velocity V_V will be

$$d = 3\rho_V V_V^2/4k\rho_s g. \qquad (4)$$

From the empirical dependence on the dielectric constant Kuz'min infers[8] that the average density ρ_s of the surface material on Venus is $\rho_s = 1630$ kg/m^3. The d(V_V) relation computed from Eq. (4) is plotted in Fig. 4 (with d in millimeters). One can readily see that as soon as the wind speed reaches 0.7 m/sec, particles up to 11 mm in diameter will be carried off by the wind. Such behavior is contrary to the observations: large particles stayed on the landing ring. Thus estimates $V_V \approx 0.4$–0.5 m/sec are evidently more realistic. The tilt of the spacecraft may also play some role; for example, if it was inclined by −8° relative to the wind direction, the particles swept off would have been half as large.

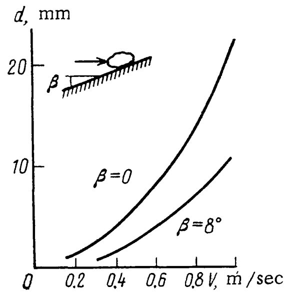

FIG. 4. Size of particles which the wind on Venus would have swept off the surface of the landing ring, as a function of the wind velocity, for horizontal and tilted spacecraft orientations. The large soil particles stayed on the ring, implying that the wind velocity was no more than 0.6 m/sec.

It follows, then, that by interpreting the acoustic noise on the Venus surface as wind noise in the microphone armature, we arrive at estimated wind velocities of 0.35–0.57 m/sec, in good accord with earlier measurements. These values are also consistent with the observed drift of fine soil particles across the surface of the spacecraft landing ring. As Fig. 4 indicates, wind velocities higher than 0.6 m/sec are unrealistic. The velocities derived from the acoustic experiment may therefore be accepted as close to the truth.

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