FIG. 2. Residual of measured relative to computed Doppler velocity during the anomaly observed as the Vega 2 balloon overflight Aphrodite Terra. Abscissa, elapsed time after 1985 June 15 UT.

contributing error to the measured balloon positions and velocities. We generally anticipate rms uncertainties of about 15 km in the coordinates and 1 m/sec in the velocities. The main factor limiting the accuracy of the transverse-velocity determinations is the interplanetary plasma, a highly variable error source, difficult to assess. From spacecraft tracking data and quasar radio interferometry as well as theoretical arguments we expect the average uncertainty in velocity to be \( \approx 0.6 \) m/sec.

The data reduced thus far consist chiefly of the Doppler measurements at the five "main" tracking stations. Within intervals of overlap the measurements with the different antennas agree to better than 1 Hz. In a model of pure zonal atmospheric motion these preliminary results indicate an average wind velocity of \( 69 \pm 1 \) m/sec for the Vega 1 balloon and \( 66 \pm 1 \) m/sec for Vega 2. Provisional balloon trajectories have also been determined, and some material has been obtained bearing on the small-scale turbulence in the Venus atmosphere. Further details are given in two accompanying letters,\(^7\),\(^8\) and in our report in the special issue of Science.\(^7\)

Doppler data based on the signals recorded with the international radio telescope network have yielded the profile plotted in Fig. 2, which depicts a major "anomaly" encountered along the Vega 2 balloon path.

Meteorological data along the Vega 1, 2 float paths

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The Fege balloons transmitted in situ measurements of pressure, temperature, vertical wind velocity relative to the balloon craft, cloud-particle backscatter coefficient, and ambient light level in the Venus middle cloud layer. Doppler tracking has yielded estimates for the velocities of atmospheric motion.

During their flight through the Venus atmosphere the Vega 1 and Vega 2 balloon craft measured the pressure and temperature of the ambient medium, the vertical wind-velocity component (relative to the gondola), the cloud-layer backscatter coefficient, the mean illumination level, and the number and time of possible lightning flashes. In addition, the ground radio telescope network measured the balloon positions and drift velocities by the differential VLBI technique; these data are now being processed.

The zonal component of the wind velocity has been derived from the Doppler shift of the balloon radio-signal frequency. All parameters were measured during the 46-h operational flight of each balloon as it drifted westward with the wind, nearly parallel to the Venus equator. The local time of the
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balloon insertion points was close to midnight; the active mission concluded on the dayside hemisphere 30°-35° beyond the morning terminator.

Figures 1, 2 chart the time profiles of the ambient parameters measured aboard the gondolas over the full course of the two balloon flights. These time lines include successive periods of measurement and telemetry to earth. The data transmitted by each balloon over its 48-h life were collected during 90-min or 30-min intervals distributed along the trajectory; the cumulative measurement time was 22h30m.

From comparison of curves a and b in each figure, it is clear that the pressure and temperature fluctuations are strongly correlated. Evidently these variations reflect the vertical motions of the balloons, but the strong correlation also suggests that the balloons and their gondolas did not contaminate the temperature measurements. The minimum temperature and pressure variations compatible with these correlations (ΔT = 0.1°K, ΔP = 0.1 mbar) argue for a high level of sensitivity and stability in the sensors and the electronics.

After their ballast was jettisoned the two balloon craft rapidly rose from their deployment height of ≈50 km (P ≈ 900 mbar) to their mean float ceiling of ≈53 km (535 mbar). At this stage, according to preflight estimates, the overpressure in the balloon skin was ≈28 mbar. Overpressure was retained throughout the active flight of the Vega 1 balloon and for the first 32h of Vega 2. Their float heights diminished gradually from the ≈535-mbar level to ≈620 mbar by the end of the second day of drift, as the helium slowly leaked out. The initial mass of helium in each balloon and the helium loss rate have been derived from the telemetry data by using measurements obtained when the vertical component of the relative wind velocity was zero (that is, below the anemometer sensitivity threshold). During flight each balloon lost less than 0.5% of its original 2.1 kg of helium. As this value is approximately the nominal loss indicated by preflight tests of the rate of helium diffusion through the balloon skin, we rule out any appreciable leakage due to microcracks in the fabric.

Both balloons exhibited a great many excursions from their equilibrium float height due to vertical motions in the atmosphere. The fluctuations in the float height are shown by curves d in Figs. 1, 2; the corresponding vertical atmospheric velocities by curves c. These vertical motions have a substantially higher amplitude and velocity than expected. Vega 1 executed large vertical movements repeatedly during its life, the largest excursion occurring in the first few hours of flight. The Vega 2 balloon, on the other hand, floated very calmly for the first 20h; the

FIG. 1. Vega 1 balloon meteorological measurements; a) pressure; b) temperature; c) vertical wind velocity; d) vertical velocity of balloon; e) illumination sensor readings. Time zero is 1985 June 11^{t/2} UT.
amplitude of its vertical motions was \( \approx 100 \) m. Then its behavior changed, coming to resemble that of Vega 1. Near the morning terminator, 34 hours after deployment, Vega 2 several times plummeted deeply to about the 800-mbar level. Calculations based partly on preflight measurements indicate that during these downdrafts the overpressure in the balloon dropped to zero below the 650-mbar level. Nevertheless, according to the final period of telemetry received by the ground stations Vega 2 subsequently recovered its equilibrium float altitude.

This loss of overpressure in the balloon during strong downdrafts would have significantly altered the balloon’s response to vertical gusts. So long as overpressure persists, the amplitude of the vertical excursions from the equilibrium float height should be proportional to the vertical wind-velocity component (for long-term disturbances). As overpressure is lost the balloon will approach the boundary of the stable float zone, and the amplitude of the vertical displacements will increase sharply. This effect is readily apparent from comparison of curves a and c in Fig. 2. To lower the float altitude by an amount corresponding to a 100-mbar change in pressure requires a 3-m/sec vertical wind; in a 4-m/sec vertical flow the drop in height corresponds to a pressure differential three times larger.

The quantity measured in situ in each gondola was the vertical component of the relative wind velocity. In order to obtain the vertical component of the atmospheric wind velocity a correction was applied for the balloon’s own motion as indicated by the pressure data. Prior to the Vega flights strong vertical winds were not envisaged, so the anemometer telem-

Curve e in Fig. 1 plots the output of the light sensor on Vega 1; the parallel data for the Vega 2 balloon have not yet been analyzed. The illumination sensor was designed to record the variations in the external \( 4000-11,000 \) Å radiation flux as a measure of cloud-layer inhomogeneities, thereby establishing the time when the morning terminator was crossed and the length of the dawn period. This same detector served to register any fast changes in the light level.

The points on curve 1e express the ambient illumination along the Vega 1 balloon path in telemetry units. An increase in the telemetry number corresponds to a decline in the exterior radiation flux. When the balloon was drifting on the planet’s nightside, several cases were recorded of a rise in the light level. Slight fluctuations amounting to one or two units are being ignored for the time being, as they are comparable with the sensor and electronics noise. Certain nightside flux variations correlate with major changes in temperature and pressure. These effects are well above the instrumental errors (one or two telemetry units) throughout the ambient temperature range. They might reflect some modification of the attenuation coefficient for the \( \approx 10,000 \) Å thermal-emission tail of the planetary-surface, or changes in the coefficient for scattering of this infrared radiation by the cloud deck below.

According to the Doppler tracking of the zonal wind flow, sunlight was first recorded by Vega 1 about 3 hours (earth time), or 7° 30', before it crossed the morning terminator. Once the balloon reached the dayside, the light level rose very steeply. Since the telemetry supplied only the six least significant bits of the twelve in the sensor signal, curve le shows abrupt jumps after dawn, as changes occurred in the nontransmitted most significant bits.

Even though the telemetry data are still being analyzed and a different interpretation of the results may seem preferable in the future, we are inclined at this time to draw the following conclusion regarding flashes of lightning; neither balloon detected any appreciable number of light flashes during the intervals for which the telemetry has thus far been processed. Altogether these intervals comprise \( \approx 7^\circ \) of observations distributed more or less evenly over the two flight paths. Just once, on Vega 2, the light sensor recorded an event that might represent either lightning in the atmosphere or a transient (shorter than 30 min) change in the average illumination.

Both balloons carried a backscatter nephelometer for monitoring variations in the ambient cloud-layer density. Only the Vega 1 nephelometer yielded data for all the telemetry sessions. Preliminary analysis of these measurements indicates that:

1. In the middle cloud layer where the measurements were made, the overall structure is devoid of any very clear regions, although some density variations of large temporal scale were in fact encountered along the flight paths. Such events correlate with decreases in the light flux and rises in temperature.

2. Cloud-layer fine structure was detected on the flight, the fluctuations amounting to about 20% of
the average backscatter level. On the whole these
variations anticorrelate with the ambient temperature.

An absence of large density variations in the
Venus middle cloud layer has been reported from ear-
er probe missions and is consistent with intensive
convection and zonal flow in the atmosphere, as well as
with a long survival time for the cloud particles.

The decreases in the amount of cloud-particle
backscatter recorded on relatively long time scales
might have occurred as the balloon sank into a less
dense zone of clouds, as is apparent, for example,
from comparison against the cloud-structure observa-
tions by various probes of the Venus atmosphere.

The authors have discussed these wind and other
meteorological measurements further in two of the
Science papers.

Thermal structure in the Venus middle cloud layer

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Thermal structure measurements obtained by the two Vega balloons show the Venus atmosphere in the
middle cloud layer to be near-adiabatic, on the whole; but discrete air masses are present that differ slightly
from one another in potential temperature and entropy. The Vega 1 temperatures are 6.5 K warmer than
measured by Vega 2 at given pressures. Measurements taken by the Vega 2 lander on descent through these
levels agree with the Vega 2 balloon data.

The two Vega balloons did not float calmly at
their equilibrium height in the Venus atmosphere but
from time to time moved vertically by a few kilometers
because of the sizable vertical flows that they en-
countered. The concomitant temperature and pres-
sure variations contain some interesting information
on the atmospheric structure between the 54- and
50-km levels, a region that dominates the middle cloud
layer. As pointed out on an earlier occasion the thermal stratification is slightly unstable there, and
convexion presumably is taking place.

When plotted in the (P, T) plane the temperature
and pressure measurement by each Vega balloon fall
along a straight line; the departures in T amount to
only about ±0.5°K. Although some isolated points
do deviate from the prevailing line by several de-
gresses, they are generally confined to time intervals
when an ambiguity was present in the most signif-
nant bits of the temperature telemetry, which re-
ported readings every 10 min. Thus the (P, T) data
obtained by each balloon separately exhibit a strong
correlation between temperature and pressure.

For equal pressures, however, the temperatures
measured by the two balloon probes differ uniformly
by about 6.5°K, the Vega 1 temperatures being high-
er. Since the balloons were deployed at points ap-
proximately symmetric relative to the equator (lati-
tudes 7°.3 N, 6°.6 S), the offset between the two
(P, T) lines is rather surprising.

Figure 1 plots the temperature and pressure
measurements acquired in the 45°–180° interval of
east longitude. Notice that the differential between
the (P, T) data sets for the two balloons shows no
appreciable longitude dependence. The cause might
be an inherent feature of balloon measurements — the
tendency of a balloon to move along with some par-
ticular air mass. During their flight the two Vega
balloons evidently were located within air masses that
had different thermal histories, with each balloon
spending most of its time in the same air mass as it
floated one-third of the way around Venus.

The source of this temperature differential is of
great interest for the atmospheric dynamics. Waves
in the atmosphere could induce an adiabatic com-
pression, but they would account for the tempera-
ture disparity only if their wavelength were com-
parable with the planet’s circumference; otherwise
the temperature difference should vary with longi-
itude. Another possibility is that the difference in T
reflects transient variability in the atmosphere, or
it might be evidence for an asymmetry between the
northern and southern hemispheres.

To check on the calibration of the data sensors
we have compared the P, T measurements by the
Vega 2 balloon against the data returned by the
Vega 2 landing capsule as it descended through the
middle cloud layer. As Fig. 1 indicates, the ball-
loon and lander data lie along the same straight