measure the vertical temperature profile from which the density gradients could be determined. This in turn made it possible to calculate the Väisälä-Brunt period for each of the six experiments. Knowing the frame rate of the cinefilm, it was possible to estimate the time for the turbulent "wake" to reach its maximum diameter after the relatively short mixing interval, and also to determine the time that the rate of horizontal spreading became maximum (Fig. 2). The experiments show two characteristic times related to the wake collapse phenomenon. The maximum vertical expansion phase occurred at about 0.44 times the Väisälä-Brunt period of the fluid. After this, vertical wake collapse started, and at about 2.0 times the Väisälä-Brunt period the maximum rate of horizontal spreading occurred. The small experimental cell did not permit studying the long time characteristics of the horizontal spreading phase due to side wall effects.

The ratio of the maximum diameter of wake expansion before collapse to the mixer diameter was also studied as a function of Väisälä-Brunt period at mixer depth. This study indicated that the maximum vertical wake diameter is proportional to approximately the cube root of the Väisälä-Brunt period. This relation appears to be reasonable because the turbulence of a fixed amount of mixing will certainly diffuse a bit further before vertical collapse occurs when the density gradient is low (Väisälä-Brunt period long). Therefore, the amplitude of the wake collapse phenomenon will be somewhat greater for long Väisälä-Brunt periods than for short periods. However, the various phases of the phenomenon will proceed faster when the Väiälä-Brunt period is short.

Eckart (*1*) has given average values of Väisälä-Brunt periods for the oceans and atmosphere of the world as a function of depth and height, respectively. Adaptation of his data indicates that T for the ocean varies between about 8 to 35 min/cycle for depths from 1 km to near the surface. Near the surface, diurnal and seasonal variations of the T become important. For the atmosphere between a height of 100 km and near the surface, T varies from about 4 to 10 min/cycle. Again near the surface, T is quite variable.

Although the experiments were done on a very small scale, they likely have significant geophysical implications. The experiments predict that the wake collapse phenomenon is not unusual in connection with bodies traveling in the oceans or in the atmosphere. The characteristic time for the most active part of the vertical wake collapse phenomenon is predicted to occur on the order of the Väisälä-Brunt period at the location where the body is operating. The contrails (vapor trails) left by aircraft often spread very extensively horizontally in a way that leads to the feeling that wake collapse actually does occur. Pilots have told me that the contrails spread much more horizontally than they do vertically. This also lends credence to the wake collapse theory.

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Resonance Rotation of Venus

Abstract. *Combination of two types of radar data shows the orbital plane and equator of Venus to be included by less than 2 degrees, and the sidereal rotation period to be 243.09 ± 0.18 days (retrograde)—remarkably close to the 243.16-day period for which the spin would be in resonance with the relative orbital motions of Earth and Venus. In this resonance, Venus would make, on average, four axial rotations as seen by an Earth observer between successive close approaches of the two planets. Estimates of the instantaneous spin period, accurate within about 0.01 day, would provide important information on the difference of Venus's equatorial moments of inertia, on their orientation, and on the magnitude of the tidal torque exerted on Venus by the sun.*

Radar observations during the past few years have for the first time enabled reliable determination of the rotation rate of Venus. In 1961, measurements made at its close approach to Earth (inferior conjunction) indicated that the spin angular velocity of Venus was very low (*1, 2*); the possibility of the rotation being retrograde was also pointed out (*3*). Radar data from the 1962 inferior conjunction, obtained with more sensitive equipment, established that the rotation was retrograde (*4*), with a sidereal period of 250 ± 40 days (*5–7*). Soon thereafter it was noticed (*8*) that this period was close to 243 days, for which Venus would present the same "face" to Earth at each inferior conjunction. Reduction of the observations from the close approaches of 1964 and 1966 yielded estimates ranging from about 242 to 246 days, with the quoted errors being generally consistent with this spread (*9–12*).

Each of these determinations of spin period has involved one of two methods (*13*): In the first (*5, 6*), the total radar echo from the planet is analyzed in frequency, and spectral regions containing unusually high power ("features") are noted; by following the the spectral positions of these features as a function of time, the spin vector can be estimated. In the second method (*6, 9*), the echo from a particular annulus, or ring, on the planet is isolated and its bandwidth is measured. Since this bandwidth is proportional to the magnitude of the sum of the planet's inertial spin vector and the apparent spin vector (due to the relative orbital motion of planet and observer), a series of such measurements enables the inertial vector to be estimated unambiguously. The first method has the advantage that, independently of the improvement attributable to statistics, the accuracy of the determination of period increases in direct proportion to the time interval over which the observations extend. A disadvantage stems from the somewhat subjective nature of the necessary identification of features, from separate spectra, as being associated with the same physical region on the planet. The identification is especially difficult in general because of the strong dependence of the radar reflectivity of a region on the aspect from which it is viewed, and because of the present limitations on achievable signal-to-noise ratios and resolution. For Venus this difficulty is markedly reduced since, as mentioned earlier, the planet presents almost the same aspect at each close approach to Earth. Although completely objective in applica-

Table 1. Estimated parameters for Venus spin vector. R.A., right ascension.

Determination	Rotation period, retrograde (days)	North Pole (deg)		Feature 1 (deg)		Feature 2 (deg)	
		R.A.	Declination	Latitude	Longitude	Latitude	Longitude
Present	243.09 ± 0.18	275.3 ± 1.8	65.8 ± 1.2	−35 ± 1.4	12.1 ± 1.7	−14.7 ± 4.1	142.5 ± 1.9
Past	242–246 (*9–12*)	250–272 (*9–11*)	64–72 (*9–11*)	−26.7 ± 1.8 (*10*)	0.0* (*10*)	−12.4 ± 2.1 (*10*)	15.7 ± 0.8* (*10*)

*Based on different definition of origin of longitude on Venus.

Table 2. Correlation coefficients: 1, rotation period; 2, right ascension of pole; 3, declination of pole; 4(6), latitude of first (second) feature; 5(7), longitude of first (second) feature.

	1	2	3	4	5	6
2	−0.21					
3	0.17	0.38				
4	.04	−0.22	−0.17			
5	.00	−0.91	−0.41	−0.04		
6	−0.16	−0.07	−0.17	0.03	0.10	
7	0.03	−0.85	−0.38	.19	.81	−0.34

tion, the second method does not yield a spin rate whose accuracy improves so rapidly with the time span of the data.

Our intent here is primarily to present the more accurate results obtained from an analysis that combined both described methods, and secondarily to point out the possibilities of use of different types of radar data to obtain substantially greater accuracy and reliability in estimating Venus's spin vector. The bandwidth data employed in our analysis were obtained in 1964 at Cornell's Arecibo Ionospheric Observatory (*9*); the spectral feature data, in 1964 at Jet Propulsion Laboratory's Goldstone facility (*10*) and in 1966 at Lincoln Laboratory's Haystack facility (*12, 14*). Given that the orbits of Earth and Venus, as well as the radius of Venus, are already known with very great accuracy (*15*), the bandwidth data depend only on the three scalar parameters that define the spin vector. Data for each feature depend, in addition, on the two scalar parameters associated with its physical location on the planet's surface. Explicit choices for these parameters are: sidereal period, right ascension, and declination of the spin vector (referred to the mean equinox and equator of 1950.0); and the latitude and longitude of each feature, with the zero of longitude being arbitrarily defined by the intersection of Venus's equator with Earth's (1950.0) on 20 June 1964 (more precisely, Julian ephemeris date 2,438,566.5), which very closely coincides with an inferior conjunction as well as a summer solstice. The numerical values for latitude and longitude thus depend on the accuracies with which a feature can be resolved and the pole direction determined. Different Venus coordinate-system definitions have been used by others (*5, 6*).

A simultaneous weighted least-squares estimation of seven parameters (three for the spin vector and two each for the two features whose identification seemed most reliable) yielded the results presented in Table 1. The normalized covariance matrix for these estimates is given in Table 2. The observations consisted of 19 Goldstone and three Haystack spectral positions of feature 1 [also called *F* (*10*)], ten Goldstone and three Haystack positions of feature 2 (*G*), and 158 bandwidth measurements. The root-mean-square values of the post-fit residuals were $0.2\sigma_b$ for the bandwidth data and $0.6\sigma_f$ for the feature data, where σ_b was chosen to be three times the effective error for an individual measurement of bandwidth (*9*) so as to strike a better balance between bandwidth and feature data, and σ_f, the error associated with a spectral position, was taken to be 2 hz throughout (*16*).

The most striking aspects of these results are (i) the remarkable agreement of the period determination at 243.09 ± 0.18 days with the Earth-Venus resonance value of 243.16 days (*17*), and (ii) the near-perpendicularity of Venus's spin axis to its orbital plane. Table 1 shows the orbital plane and equator to be inclined by only 1.2°; the ecliptic and Venus's equator, by only 2.2°. Among the planets, only Jupiter has a comparably small inclination (3°) between orbital plane and equator, the corresponding value for all others being greater than 23° (*18*).

The present and past determinations of the difference in feature longitudes (Table 1) are in good agreement. (The absolute longitudes differ mainly because of the difference in definition of origin.) The latitudes are in good agreement for the second feature but not for the first; the discrepancy can be ascribed only partly to the differences in pole position and spin rate; the remainder may be attributable to the subjective problem of associating spectral enhancements with physical features. For this reason especially, one cannot yet conclude reliably that Venus's spin is in fact locked to the relative orbital motions of Earth and Venus.

What other methods can be used to improve the radar determination of Venus's rotation? With a short pulse of radar energy transmitted toward the planet and with the echo analyzed in delay, features can be discerned in the same manner as in the frequency domain. Following in time both the delay and Doppler (that is, frequency) coordinates of a feature provides more powerful and less ambiguous data from which to estimate the spin vector. Such data have already been obtained from some 1964 observations (*14, 19*), but are too limited in extent to be useful. Greater resolution in both coordinates over a longer time span, as well as more accurate bandwidth data, are anticipated during the 1967 inferior conjunction from the Arecibo, Goldstone, and Haystack facilities, which should result in substantial improvement in the average spin-vector estimate. An accurate determination of the instantaneous spin vector may stem from the use of interferometric radar systems. This technique has not yet been applied to planetary observations, but has already demonstrated its potential in lunar work (*20*).

If the shape of Venus's equatorial region were markedly elliptical, as might be expected if Venus's spin were locked to Earth (*21, 22*), radar measurements of the round-trip echo delay to the center of the illuminated disk would be noticeably modulated in time (*22*). Since the periodicity of such a modulation would be distinct from those of all other influences on the echo delays, one could determine not only the average spin period with an accuracy increasing with the time span of the data, but also the differences in equatorial radii and the orientation of the elliptical equator. With the Haystack facility, differences of as little as 0.5 km should be detectable near inferior conjunction (*23*). Another independent estimate of average spin period might be made by accurately monitoring the variations in radar cross section as a function of aspect. All data affected significantly by Venus's rotation should, of course, be combined in a single solution to obtain the most definitive estimate of the spin vector and its time dependence.

Further improvements in techniques that yield precise estimates of the instantaneous spin angular velocity will also enable the difference in the principal equatorial moments of inertia to be inferred. Thus a theoretical analysis of the rotation of Venus (*21, 22*) indicates that, for the spin to be in resonance with the relative orbital motions of Earth and Venus, the fractional difference in these equatorial moments [conventionally defined as $(B\text{-}A)/C$, where $A < B < C$ are the three principal moments] most probably exceeds 10^{-4}. The torque exerted on Venus by the sun, which predominates on an instantaneous basis, will therefore introduce an oscillation in the spin period with an amplitude greater than 0.01 day and a period of about 58.5 days. Estimates of the spin period, accurate within 0.01 day or better, with each involving data that span an interval short compared to 60 days, will provide not only useful information on the value of $(B\text{-}A)/C$ and on the orientation of the inertia ellipsoid, but also an upper bound on the magnitude of the average tidal torque exerted on Venus by the sun (*24*).

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16. Although the operating frequency at Haystack was three times higher than at Goldstone, the accuracy obtainable from Goldstone data was degraded by the limited resolution available in the small-scale graphs included in the published report (*10*). The original data were not obtainable.
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23. The inference of the difference of the principal equatorial moments of inertia from the geometric shape is, of course, dependent on the assumed density distribution (*15, 22*).
24. For Earth to control the present spin of Venus, the average tidal torque exerted by the sun must be less than the average torque exerted by Earth on the permanent asymmetry of Venus's equatorial region (*21, 22*).
25. I thank A. Forni, K. McGrath, and A. Rasinski for the computer programming. Lincoln Laboratory is operated with support from the U.S. Air Force.

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Europium-155 in Debris from Nuclear Weapons

Abstract. *The lithium-drifted germanium detector enables determination of europium-155 on a routine basis in environmental samples contaminated with debris from nuclear weapons. From measurements of europium-155, cesium-144, and strontium-90 in air filters collected between 1961 and 1966, the yield of europium-155 from weapons was estimated at 1400 atoms per 10^6 fissions, which is close to the yield of europium-155 from fast fission of uranium-238.*

In studies of circulation processes in nature, such as in meteorology, hydrography, and ecology, debris from the testing of nuclear weapons has been widely used. The long-lived nuclides Sr^{90} and Cs^{137} are most commonly employed in these investigations, but radionuclides of medium-long life, such as Ce^{144}, Ru^{106}, Sb^{125}, and Pm^{147}, also have found some applications. The great spectral-resolving power of the lithium-drifted germanium detector has made it possible to include 1.7-year Eu^{155} in this family of useful environmental tracers (*1*).

Europium-155 is a fission product having a thermal neutron fission yield, in U^{235}, of 326:10^6 (atoms:fission) (*2*). In debris from nuclear weapons, Eu^{155} was detected for the first time in 1957 in soil on Rongelap Atoll (*3*); later it was measured in global fallout in samples of rain water (*4, 5*), dust (*5*), lichens (*1*), plankton and sea water (*6*), and marine sediments (*7*). Our aim has been to follow the concentration of Eu^{155} in ground-level air for a longer period, and, from these measurements and simultaneous determinations of Ce^{144} and Sr^{90}, to estimate the weapon yield of Eu^{155}.

Since 1961, air samples have been collected at ground level at Risö, Denmark, by means of a 7.5-hp centrifugal pump handling air at about 10^6 m^3/-month. The debris was collected on

Table 1. Europium-155 in air samples (pc/10^3 m^3). The relative S.D. of a single determination was 23 percent (*10*).

Month	1961	1962	1963	1964	1965	1966
January		3.6	10.0	4.9	1.1	0.27
February		4.6		5.6	1.0	.43
March		5.1	19.7	8.5	1.9	.36
April		4.2	17.2	12.1	1.8	.44
May		6.4	18.2	9.5	5.2	.59
June		11.8	25.2	10.5	1.3	.60
July	0.11	9.4	15.5	3.7	1.3	.36
August	.55	4.9	7.6	4.0	0.66	.28
September	1.1	3.7	7.1	2.8	1.3	.21
October	1.9	3.5	8.1	0.83	1.0	.22
November	3.1	4.7	4.1	1.6	0.41	.16
December	5.8	5.7	3.6	1.2	.24	.06