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AIR-LAUNCHED WINDSONDE

Stephen F. Rohrbough and Lyle E. Koehler
Honeywell Inc.
Systems and Research Division
Research Department
St. Paul, Minnesota 55113

Contract No. AF19(628)-6082
Project No. 6670
Task No. 667001
Work Unit No. 66700101

FINAL REPORT

Period Covered: 15 June 1966 through 30 June 1969

29 August 1969

Contract Monitor: James F. Morrissey
Aerospace Instrumentation
Laboratory

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OFFICE OF AEROSPACE RESEARCH
UNITED STATES AIR FORCE
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ABSTRACT

An air-dropped instrumented sonde for measuring wind profiles has been developed. It requires no tracking, no aircraft loitering, and is relatively inexpensive. The instrument is essentially an arrow-shaped sonde that remains at zero angle of attack during descent. Wind direction and velocity are inferred from orientation of the sonde axis with respect to vertical and magnetic north. An air-bearing gyroscope and a magnetometer are used to measure this orientation.

Performance of the sonde has been verified through both balloon-launched and aircraft-launched tests. Balloon launchings provided preliminary test results indicating that the concept was viable and also indicating areas of improvement required to eliminate intermodulation problems within the sonde electronics. Aircraft launchings provided wind data that compared favorably with concurrent radiosonde measurements.

The results of the study indicate that a further development effort aimed toward providing better knowledge of conditions at launch is required.

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SECTION I

INTRODUCTION

In weather forecasting and general atmospheric circulation, one of the important parameters is a vertical profile of the wind. To obtain this information over a large area of the earth, it is essential that a sensor be developed that can be released from an aircraft and provide the wind information without requiring tracking of the sensor or loitering of the aircraft. If a world-wide grid of wind profiles is to be obtained, a large number of sensors will be required, and the ultimate cost, in quantity, of the individual sensor and sonde must be low. Thus, the following guidelines for developing a system to obtain wind profiles were established.

- Accurate wind measurement from 30,000 feet to sea level
- No tracking required
- High descent rate to eliminate aircraft loitering
- Inexpensive

A logical approach to the development of a wind sensing device was first to examine the available sensing techniques and how they might be utilized within the bounds stated above. Position, velocity, and acceleration techniques were examined, and a preliminary error analysis was made on appropriate methods.

Following laboratory and dummy sonde testing, the next step was field testing. Since successful ejection from an aircraft is a difficult problem in itself, the first flight tests were scheduled to be released from balloons. Eleven sondes were dropped from three balloons during two field tests. After these tests showed system feasibility, the more difficult problem of sonde ejection, retardation, and release from an aircraft was attempted. Nine active sondes and three dummy sondes were tested during this phase.

This report covers the development, analysis and testing of the Windsonde.

SECTION II
TECHNICAL APPROACH

There are three methods of determining a wind profile, and each method can be approached in several different ways. The methods are:

- Measure wind velocity directly
- Measure accelerations caused by wind shears and integrate to obtain wind velocity
- Differentiate successive position determinations

SENSING TECHNIQUES

A falling body can be designed to have any amount of wind drift. A system that determines the wind profile by measuring the accelerating forces acting on the body should be designed for small wind drift. On the other hand, a velocity or position measuring system would function more accurately with a large amount of wind drift, allowing the body to pick up the wind speed. A small-wind-drift sonde generally requires a very high fall velocity. Since the sonde measures the resultant of the wind velocity and the fall velocity, a high fall rate requires that the data be determined more accurately than for a sonde falling more slowly. However, the slow-falling sonde will wind drift more and have a longer fall time. Thus, it is more susceptible to time-related errors.

Sonde Velocity Sensors

Investigations of various velocity measuring systems indicated that the most promising device would be a type of scanning doppler radar on a sonde that had a high wind drift. Even so, this approach had several objections. The first is the difficulty in getting good returns over a sea surface (including the effect on the measurement of water particle movement). Next the effect of clouds below the sonde would complicate the measurement. Lastly, the individual cost in mass production appeared high.

Sonde Position Sensors

The possibility of accurately determining the position of the sonde as it falls generally requires tracking, which violates the established guidelines, or a transponder system. The latter yields position information to some

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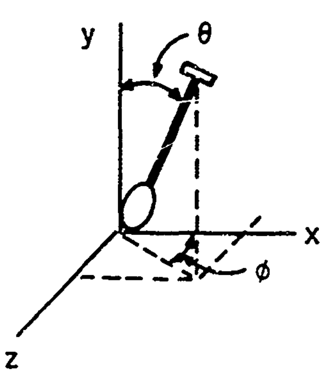
known reference. In remote areas this reference would have to be the deploying aircraft, and the accuracies required are greater than that from available aircraft position information.

Sonde Acceleration Sensors

The above and subsequent considerations led to acceleration measurements as the best technique for gathering wind data. By using a fast-response, arrow-shaped sonde design, accelerations would be inferred from attitude measurements. The sonde consisted of the required electronic equipment in a non-lifting container rigidly connected by a tube to a lightweight lifting tail section. Such an aerodynamic body falling through the atmosphere tilts away from vertical through an angle θ whose tangent is the relative wind (body-drift velocity minus true wind speed) divided by the fall velocity. This angle then is related to the horizontal body acceleration, and, thus, through integration, the drift velocity can be determined. The axis of the sonde lies in the wind direction plane, and the angle ϕ of this plane from north gives the wind direction. The problem resolved into the methods by which on-board measurements of the two angles could be made (see following sketch).



The solar detector method for attitude measurement was considered, but it has the obvious disadvantage of being usable only during daylight and, then, when there are no interfering clouds. Other sun-related measurements that could eliminate the cloud interference problem generally have noisy signals.

A rotating differential pressure gauge requires very high rotation rates to detect the very small pressure change associated with a small change in wind magnitude. In addition, the sonde's angle of attack must be known accurately.

It would appear that accelerometers perpendicular to the sonde axis could be used. However, the accelerations on the falling-arrow type sonde are along the axis of the sonde except during its response to a change in wind velocity. This means that there would be no information from accelerometers during constant-wind-velocity conditions. Thus the data could not be readily integrated to obtain the wind information.

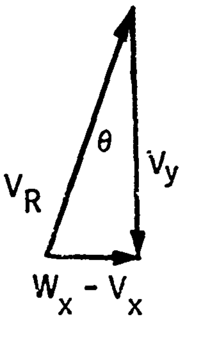
Spin coils and the use of a gyroscope were examined as the best candidates for determining the vertical tilt angle. The results of this examination are presented in a subsequent discussion.

ARROWSONDE SIMULATIONS

To better understand the effects of fall rates and angle uncertainties, the mathematical relationships for the acceleration-type sonde were determined. A computer program that allowed changing of the various inputs was written to determine the effects of tilt-angle error and ballistic parameter changes.

Tilt-Angle Errors

It is possible to make a good approximation of the total wind error when the uncertainty in θ takes the form of a constant error, using the simple formula derived here. The falling-arrowsonde responds rapidly to any change in wind V_R, as shown in the following sketch.



The fall velocity is V_z, horizontal velocity of the sonde is V_x, and the horizontal wind velocity is W_x. The relative wind experienced by the sonde is $W_x - V_x$, and

$$W_x - V_x = V_z \tan\theta$$

When the arrow has fully weathercocked into this position, the resultant inertial acceleration is along a line joining the center of pressure and the center of mass, that is, along the sonde axis. The horizontal component may be denoted by a_x, and the vertical component is $g - \frac{dV_z}{dt}$. Then

$$a_x = \left(g - \frac{dV_z}{dt}\right) \tan\theta$$

The error in measuring the instantaneous relative wind, $W_x - V_x$, is related to the uncertainty in the measurement of θ by

$$\frac{\partial(W_x - V_x)}{\partial\theta} = V_z \sec^2\theta$$

There is also an uncertainty in the drift velocity V_x after an elapsed time, t, because the acceleration in the x-direction is not precisely known. Here the dependence on the resolution in θ is

$$\frac{\partial V_x}{\partial\theta} = \frac{\partial}{\partial\theta}\int_0^t a_x dt = \int_0^t \left(g - \frac{dV_z}{dt}\right) \sec^2\theta dt$$

Since θ is generally small (less than 5 degrees), $\sec^2\theta$ is very nearly equal to 1, and may be considered as a constant. With the further assumption of zero velocity at $t = 0$

$$\frac{\partial V_x}{\partial\theta} = \sec^2\theta \int_0^t \left(g - \frac{dV_z}{dt}\right) dt = \sec^2\theta\,(gt - V_z)$$

For the case under consideration, $\Delta\theta$ is a small fixed quantity. Then

$$\Delta(W_x - V_x) = V_z \sec^2\theta\Delta\theta, \text{ and } \Delta V_x = (gt - V_z)\sec^2\theta\Delta\theta$$

Summing these errors, the wind-measurement error is

$$\Delta W_x = gt \sec^2\theta\Delta\theta \simeq gt\Delta\theta$$

Table I is a compilation of one of the computer simulation runs. The ballistic coefficient was taken to be 0.005 with a fixed bias error in θ of 0.5 degree. Included in the table are the altitude, fall time to reach that altitude, the wind velocity, W_x, the total error in W_x measured by the sonde at that instant, the total error in W_x as measured by the sonde averaged over the preceding 1000 feet, and θ. Also included is the calculated total instantaneous error as determined from the expression derived above, ΔW_x (t) (g) $(\Delta\theta)$ $(\sec^2 \theta)$.

It is obvious from the table that, for such a sonde, a 0.5-degree uncorrected error in θ will result in approximately a 20-ft/sec uncertainty at the end of the flight. If this θ error is reduced to 0.1 degree, the corresponding uncertainty in W_x at the end of the flight is 4 ft/sec. The above situation is a worst case, that is, the error has been considered as a fixed amount but unknown. In actual practice, $\Delta\theta$ is also a function of time. However, that portion of the error that is a fixed bias can be removed if a second "fix" on the actual wind is obtained at some later time in the flight.

Effect of Ballistic Parameter Change

To better understand the effect of different sonde fall rates on the required angle measurements, several computer simulation runs were made. A severe wind-shear profile was established, and the value of the ballistic coefficient $\frac{C_D A}{W}$ was changed for each run using the standard atmosphere density tables. This had the effect of changing the fall rate and fall time. From this, the wind-drift effect at any moment was analyzed with and without an error on the wind magnitude angle θ. (For this analysis a two-dimensional wind profile was used.)

Several computer runs were made with ballistic coefficients ranging from 0.005 to 0.050. The former is a relatively low wind-drifting body, while the latter has a rather large amount of wind drift. As expected, the larger ballistic coefficient allowed the arrow to weathercock to a larger angle; however the higher wind drift meant that the angle quickly became small and was more difficult to determine.

In one of the computer simulation runs, the density profile was changed by 5 percent. This produced a maximum error in V_z of 2.5 percent. This also results in a 2.5 percent error in obtaining the relative wind $(W_x - V_x)$.

Table I. Error in Wind Magnitude for a Body with $\frac{C_D A}{W} = 0.005$ and a Bias Error in θ of 0.5 degree

Altitude (1000 ft)	Fall Time (sec)	W_x (ft/sec)	Total Instantaneous Error in W_x (ft/sec)	Total Error in W_x Average over last 1000 feet (ft/sec)	θ (deg)	Total Calculated Instantaneous Error $[(t)(g)(\Delta\theta)(\sec^2\theta)]$ (ft/sec)
30	0	81.0	-	-	0	-
28	11.55	91.4	-3.25	-2.99	1.710	-3.24
26	16.60	122.6	-4.70	-4.47	4.506	-4.67
24	20.95	108.0	-5.91	-5.63	1.311	-5.88
21.9	24.95	50.0	-7.07	-6.81	-4.578*	-7.00
19.9	28.65	46.4	-8.11	-7.89	-4.032	-8.05
17.7	32.65	42.4	-9.23	-9.12	-3.555	-9.17
15.1	37.45	37.7	-10.58	-10.36	-3.111	-10.51
12.6	42.25	33.0	-11.93	-11.93	-2.761	-11.85
10.9	45.45	30.9	-12.83	-12.83	-2.566	-12.75
8.5	50.25	25.6	-14.18	-14.18	-2.319	-14.11
7.0	53.45	22.7	-15.08	-15.08	-2.179	-14.00
4.7	50.25	18.6	-16.43	-16.43	-1.999	-16.35
2.5	63.05	14.6	-17.77	-17.55	-1.849	-17.70
0.4	67.85	10.8	-19.12	-19.12	-1.724	-18.95

* In a two-dimensional wind profile the minus angle means that there has been a 180-degree shift in the wind direction.

SECTION III

ARROWSONDE ATTITUDE MEASUREMENT

It was decided (Section II) that the best approach to the problem was to make acceleration measurements on an arrow-shaped sonde having low wind-drift. Two methods were examined to determine the sonde orientation. The first was to use the magnetic-field vector measured by a spin-coil magnetometer plus the antenna-pattern null as seen by the aircraft. In the second, a vertical reference gyro was employed for tilt-angle measurement and a magnetometer for wind-direction determination.

SPIN-COIL TECHNIQUE

Initial effort expended on the spin-coil technique was to determine the errors in the sonde tilt angle due to errors in the measurement of the spin-coil voltage or phase and the antenna pattern (which determines the body roll position). The information from the spin-coil generates the equation of a cone about the earth's magnetic field, the surface of which contains the sonde axis.

The spin-coil arrowsonde concept utilized a spin-coil either along or perpendicular to the sonde's axis. The coil's output voltage and transmitter antenna pattern provide enough data to compute the sonde's orientation. Our analysis examined each case separately, and the error equations in both the wind magnitude θ and direction ϕ were derived. The effect of various size errors in the maximum voltage measurement and the antenna position which is keyed to the coil were determined. The errors $d\theta$ and $d\phi$ are functions of ϕ, θ, the magnetic inclination δ, and the measurement errors in coil voltage and antenna position.

Error Analyses of Z - Axis Coil

An error analysis was performed on part of the spin-coil system to determine the error model and restrictions for this sensing technique. Examined first was the Z-axis spin-coil (rotating about the sonde axis) combined with a measurement of the angle with respect to the aircraft of a spinning antenna coupled mechanically to the spin-coil. The information generated by the sonde is the phase angle between the spin-coil zero crossing and the antenna-pattern zero crossing (or marker) and the maximum voltage generated by the coil. With knowledge of the magnetic bearing of the aircraft and its altitude above the sonde and the magnetic field strength and inclination in the locality. the wind magnitude angle θ and the wind direction angle ϕ can be determined. The equations relating the above parameters are coupled and complex and require an iterative solution.

Figures 1 and 2 show the errors generated by a system using an error of 1 degree on the antenna pattern zero crossing (db) and a measurement error of one part in 1000 on the voltage maximum of the spin-coil (de_{max}/e_{max}) added as RMS errors. In this instance, the aircraft elevation is zero; that is, the sonde is falling slowly such as would be the case for a shear probe, and the aircraft is moving away rapidly so that the sonde tends always to be directly behind the aircraft, and the magnetic field inclination angle is 60 degrees. Note that for tilt angle (θ) of 1 degree and 10 degrees there is little difference in the tilt-angle error for easterly or westerly winds, and the errors are a maximum of slightly more than 1/2 degree for these wind directions. If there were only north-south winds, then accuracies of close to 1/10 degree would be possible and such accuracies would be entirely suitable even for true-wind measurements. At larger inclination angles (closer to the pole), accuracies will increase. Conversely, at positions near the equator, the accuracies decrease.

Also considered were aircraft elevation angles up to 45 degrees, and aircraft bearing angles. The errors described above can be decreased by about 30 percent when the aircraft is flying a due south heading. The wind direction errors are a strong function of the tilt angle of the sonde. Note that the maximum wind direction error occurs 90 degrees away from the maximum error in the wind magnitude. For a tilt angle of 1 degree there is as much as a 30-degree uncertainty in the wind direction. However, very small tilt angles for slow-falling sondes mean very light winds, a case when the direction is not as important.

The errors plotted in Figures 1 and 2 are based on a full solution to the equation done on the computer.

With the assumption that the tilt angle is small, a relatively simple equation defining the errors can be established:

$$d\theta_{RMS} = \left\{(\cot\delta\cos\phi)^2 db^2 + \left(\frac{de_{max}}{e_{max}}\right)^2 \left(\frac{180}{\pi}\right)^2 (\sin\theta - \cot\delta\sin\phi)^2\right\}^{1/2} \text{deg}$$

$$d\phi_{RMS} = \left\{\left(1 - \frac{\sin\phi}{\tan\delta\sin\theta}\right)^2 db^2 + \left(\frac{de_{max}}{e_{max}}\right)^2 \left(\frac{180}{\pi}\right)^2 \left(\frac{\cos\phi}{\tan\delta\sin\theta}\right)^2\right\}^{1/2} \text{deg}$$

These errors compare within a few percent to the full-solution errors for all tilt angles of interest.

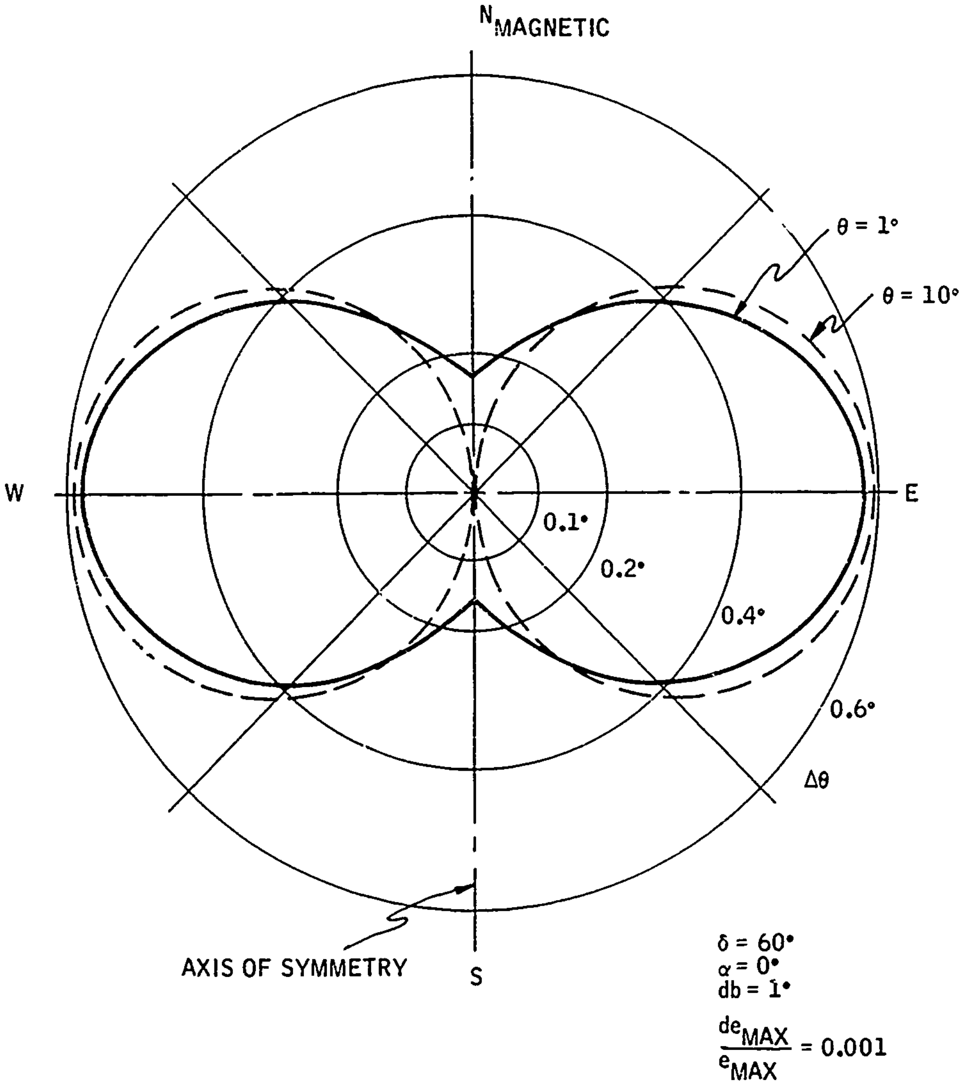


Figure 1. Tilt-angle Errors Using Z' Axis Spin Coil and Antenna Pattern

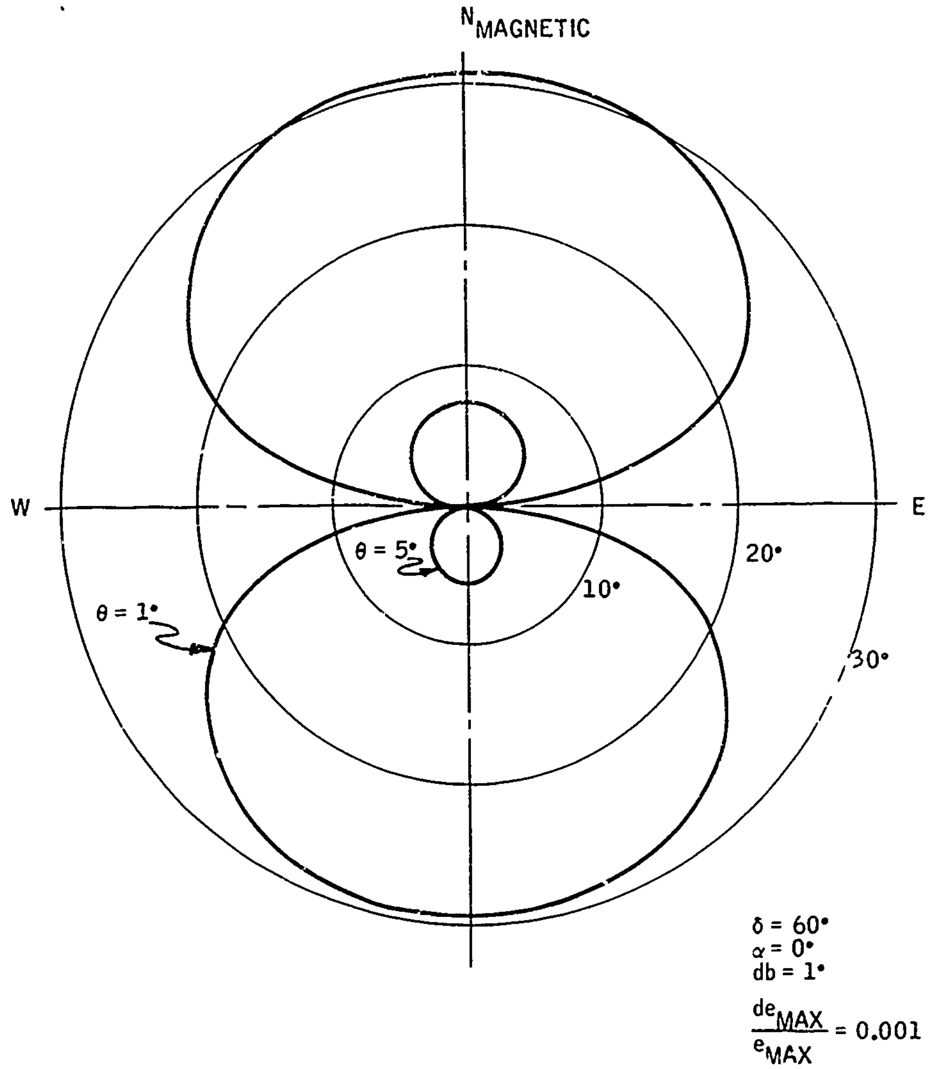


Figure 2. Wind Direction Errors Using Z' Axis Spin Coil and Antenna Pattern

In the above discussion, the use of the radiating antenna pattern to assist in determining the wind information was suggested. An error of 1 degree in the antenna pattern was used in the error equations. The following discussion illustrates what accuracies are attainable theoretically and what can be expected from an operational system.

We can, for example, postulate a transmitting antenna which has a pattern that results in a 100-percent sinusoidal modulation of the signal amplitude to a fixed receiver location when the transmitting antenna is rotated at a constant rate. Then the equation for angular resolution $\Delta\theta$ is

$$\Delta\theta = \frac{N}{V}\left(\frac{\pi}{\omega \tau_1}\right)^{1/2}$$

where N/V is the noise-to-signal voltage ratio, ω is the antenna rotation rate, and τ_1 is the sampling time. A numerical calculation based on this equation was made for the following conditions:

- Spin rate of 200 revolutions/second
- Transmitter power of 86 milliwatts
- Maximum range of 245 miles
- Sampling time of 2.5 seconds
- Receiving antenna effective aperture of 1 square foot
- Bandwidth of one kHz
- Effective antenna noise temperature of 300°K
- Transmitting antenna gain equal to 1/2-wave dipole

Angular resolution for these conditions is 5×10^{-3} radians, or about 1/4 degree. At closer range, the resolution for this ideal case would be better because the noise-to-signal ratio, and thus the angular uncertainty, varies linearly with range. Theoretically, then, resolution considerably better than 1/4 degree could be expected.

In practice, the transmitting antenna's pattern will almost certainly have some irregular, asymmetrical shape which varies with the relative elevation and polarization of the receiving antenna. Although a thorough experimental study would provide enough data on the pattern so the desired angle could be computed, there is no guarantee that antennas with identical radiation patterns could be mass-produced successfully. A further complication is that the signal path will not always be direct; i.e., reflections from the ground or from the airframe may completely alter the apparent orientation of the sonde. Ground reflections could lead to very large errors, while airframe reflections would introduce a secondary error related to polarization effects.

These difficulties are not insurmountable. Using a pulsed transmission mode, the receiver could be gated to respond only to a direct signal. However, even with a sophisticated gating system, some interferenece may occur, and reflections from the airframe may not be eliminated. It is also possible to achieve high resolution by making the sonde's antenna extremely directional, but the dimensions would be prohibitive unless a frequency much higher than 1680 MHz is used. A very directional antenna also has the necessary disadvantage that the received signal amplitude fluctuates greatly during rotation, such that, if the same transmitter is used for telemetry, the data quality may be seriously degraded.

There is one additional limitation. The relative bearing between sonde and aircraft also enters into the computation and may have an uncertainty considerably greater than 1/4 degree.

Errors Associated With X-Axis Coil

Error equations for the X-axis spin-coil, located perpendicular to the sonde axis, were also derived. With a coil oriented in this manner, the sonde must be rotated about its axis to obtain the optimum (least-error) position for solving the equations. Since it is difficult to keep the sonde from rolling, this is no problem. However, the antenna position would not necessarily allow the optimum position for least error as required above for all winds. The errors determined for this arrangement were comparable to those of the Z-axis coil.

Conclusions

From the foregoing discussion, it is apparent that a precise analysis of the resolution attainable with a system meeting the cost limitations of an expendable sonde is very complex. However, the absolute orientation of the sonde may be determined with an accuracy approaching ±1 degree with moderate complexity; any substantial improvement on this figure would be costly.

GYROSCOPE TECHNIQUES

Another method of obtaining the vertical tilt angle is through the use of a gyroscope. Such a sonde would use a free gyroscope to determine the angle between the sonde axis and local vertical. Thus the wind magnitude would be read out directly, the fall velocity, sonde drift velocity, etc., being known as before. The wind direction angle is obtained by having a magnetic-field sensor keyed to the gyroscope. As the sonde rolls, the angle between magnetic north and the magnetometer (and thus the gyroscope reference) would be known. The combined outputs would then give the wind direction.

The selection of a gyroscope involved the establishment of a set of parameters that must be met. Since the sonde acquires a nearly horizontal position during ejection from an aircraft, the gyroscope must be constructed to allow a 90-degree maneuver with negligible drift. Since the roll position during ejection is uncertain, the gyroscope's rotor must have 360-degree freedom of motion in both axes. The only gyroscope that could meet these requirements was a gas bearing free rotor unit.

The Honeywell GG406 met the free-rotor requirement but did not have the required drift accuracy over the mission time required for the Windsonde because it was originally designed to run on missions of only 10 to 12 seconds. However, replacement of the hollow rotor with a solid brass rotor increased the angular momentum and maintained a higher spin rate. With a solid-rotor unit, the major torques causing drift are: case rotation, autoerection, rotor unbalance, and bearing torque. For acceptable performance during the test program, the drift rate had to be less than 0.5 deg/min. The modified GG406 had a predicted drift of 0.4 degree at the end of 1 minute and 1.2 degrees after 2 minutes. The mission time for the Windsonde is anticipated to be less than 90 seconds.

Gyroscope Errors

A computer error analysis was made using selected values of gyroscope drift rates. Rates chosen varied from the best anticipated value of 0.1 deg/min to 0.5 deg/min. Eighteen runs were made using different wind profiles, drift-rate errors, and initial-condition errors. The results are presented in Figures 3, 4, and 5 and in Table II. The particular runs presented are for a high-shear wind profile. However, there was no difference noted between the errors at any point for several other wind profiles.

The data were tabulated and plotted at approximately 2000-foot altitude intervals. The first four columns in Table II are, respectively, the sonde altitude, the time from launch to reach that altitude, the true wind speed (feet per second), and the tilt angle θ. Since only a two-dimensional wind profile was considered, the values for θ are both positive and negative. This means that a 180-degree change in the wind direction occurred. In the actual sonde, there will be no signs on the tilt angle; the wind direction will come from a second measurement.

The remaining four columns are each divided into three subcolumns: "a" is for a drift error of 0.1 degree after 1 minute (corresponds to Figure 3), "b" is for a drift error of 0.25 degree after 1 minute (corresponds to Figure 4), and "c" is for a drift error of 0.5 degree after 1 minute (corresponds to Figure 5). Column 5 is the error in feet per second in the calculated value of wind speed due only to the drift error in the gyroscope. Column 6 assumes that the true wind was unknown by 1.414 ft/sec at the time of the sonde

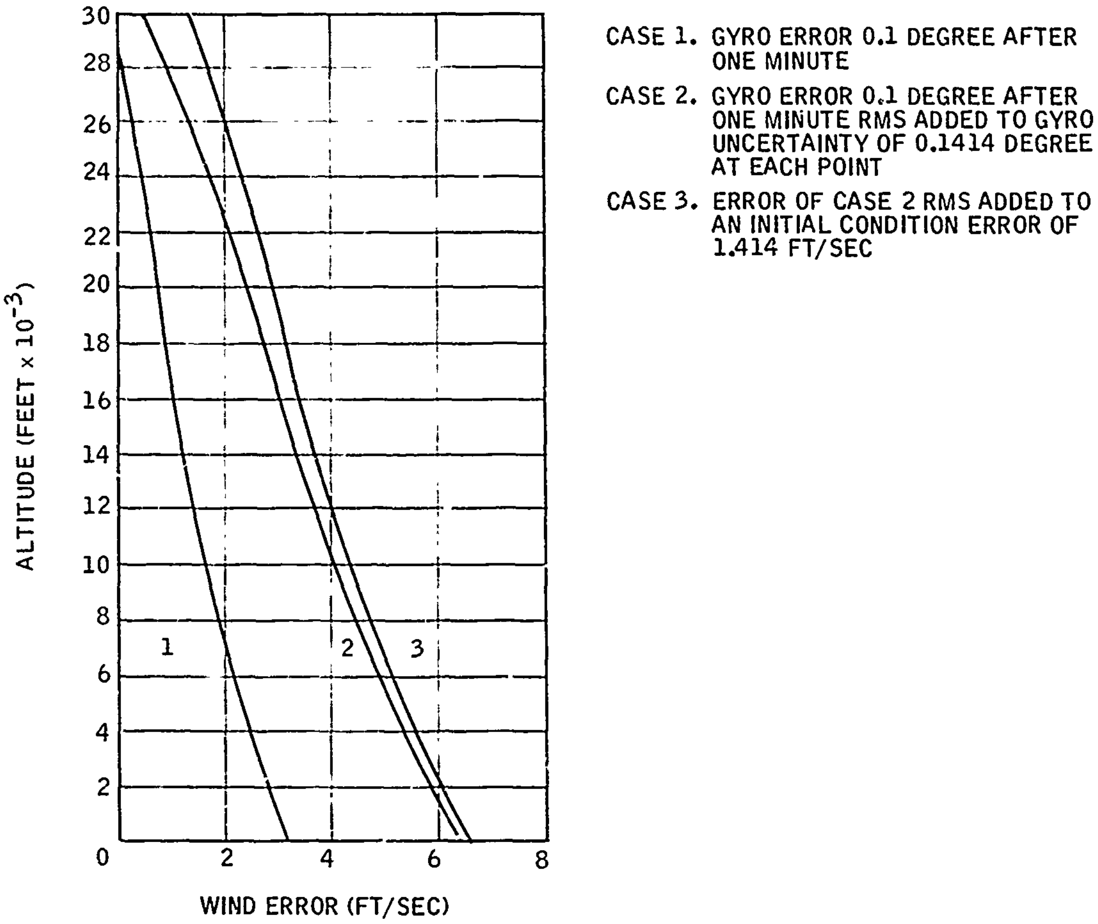


Figure 3. Wind Magnitude Error for 0.1-deg/min Gyroscope Drift

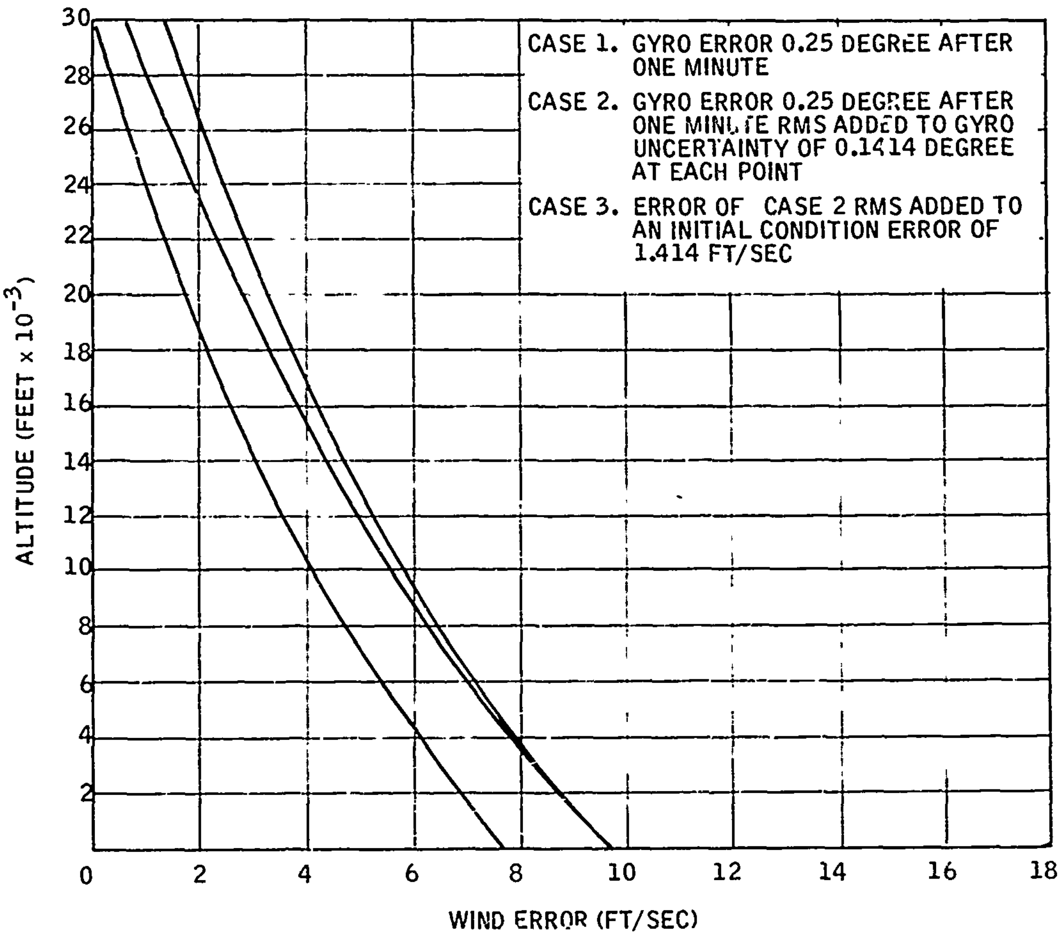


Figure 4. Wind Magnitude Error for 0.25-deg/min Gyroscope Drift

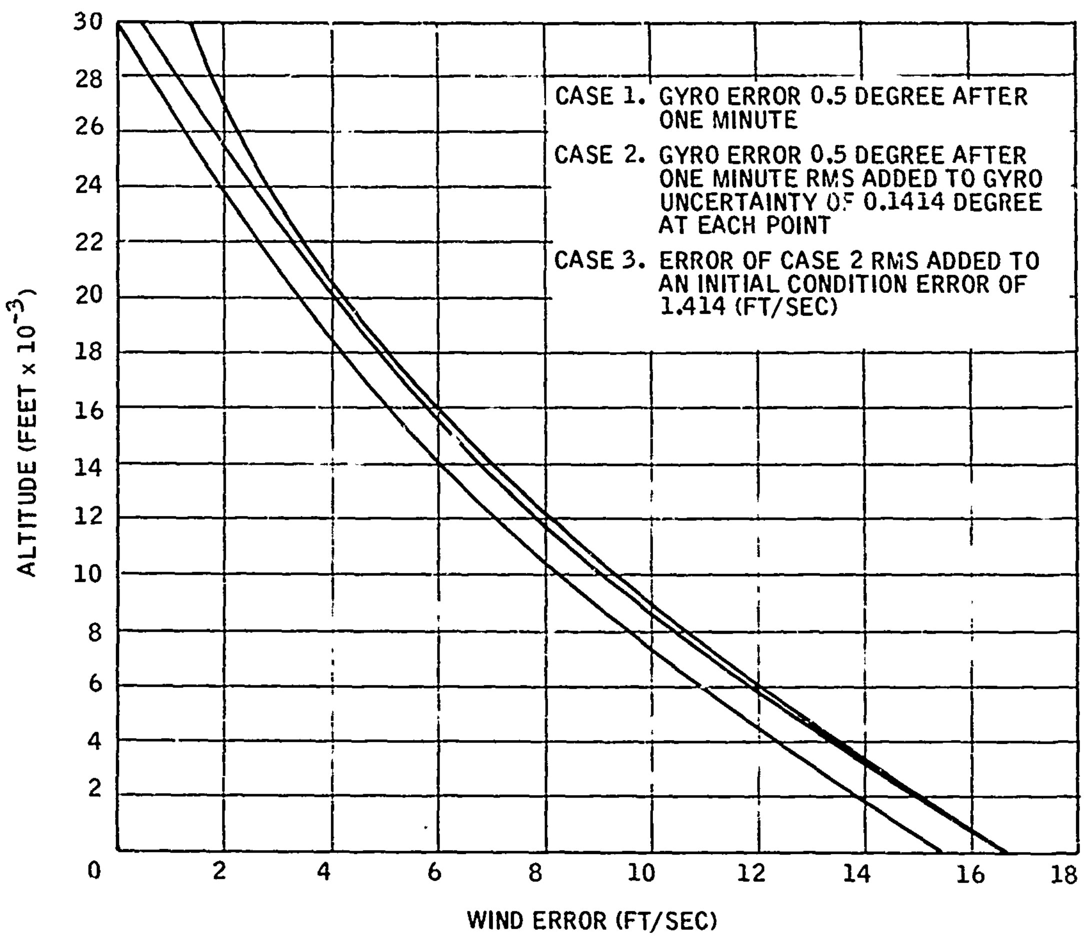


Figure 5. Wind Magnitude Error for 0.5-deg/min Gyroscope Drift

Table II. Wind-Magnitude Errors Due to [illegible]scope Drift and Initial-Condition Errors

Altitude (1000 ft)	Fall Time (sec)	W_x (ft/sec)	θ (deg)	Error in W_x Due to Gyro-Drift Error (ft/sec)			Error in W_x Due to Gyro-Drift Error and Initial-Condition Error (ft/sec)			Error in W_x Due to Gyro-Drift Error and Gyro Uncertainty (ft/sec)			Error in W_x Due to Gyro-Drift Error, Uncertainty Error, and Initial-Condition Error (ft/sec)		
				a*	b*	c*	a	b	c	a	b	c	a	b	c
30.0	0	81.0	0	0	0	0	1.41	1.41	1.41	0	0	0	1.41	1.41	1.41
28.0	11.5	90.3	1.54	0.12	0.30	0.60	1.42	1.45	1.54	0.92	0.96	1.1	1.69	1.71	1.79
26.9	16.6	122.3	4.48	0.25	0.62	1.2	1.44	1.54	1.88	1.4	1.5	1.8	1.96	2.04	2.30
24.9	20.9	109.8	1.52	0.38	0.95	1.9	1.47	1.76	2.37	1.7	1.9	2.5	2.22	2.39	2.91
22.0	24.8	51.3	-4.50	0.53	1.3	2.6	1.51	1.93	2.99	2.1	2.4	3.3	2.50	2.78	3.61
19.9	28.8	46.3	-4.02	0.69	1.7	3.4	1.57	2.23	3.71	2.4	2.9	4.2	2.79	3.22	4.40
17.7	32.8	42.3	-3.54	0.87	2.2	4.3	1.66	2.59	4.55	2.8	3.4	5.1	3.11	3.71	5.29
15.5	36.8	38.3	-3.17	1.1	2.6	5.3	1.77	3.00	5.48	3.1	4.0	6.1	3.44	4.24	6.27
13.8	40.0	35.2	-2.92	1.2	3.1	6.1	1.87	3.37	6.28	3.4	4.5	7.0	3.71	4.69	7.11
11.7	44.0	31.4	-2.65	1.4	3.6	7.2	2.02	3.87	7.35	3.8	5.1	8.1	4.07	5.29	8.22
9.7	48.0	27.7	-2.43	1.7	4.2	8.4	2.19	4.42	8.49	4.2	5.8	9.3	4.44	5.92	9.40
7.3	52.8	23.3	-2.21	2.0	4.9	9.8	2.43	5.12	9.95	4.7	6.6	10.8	4.89	6.73	10.91
5.8	56.0	20.6	-2.08	2.2	5.4	10.9	2.60	5.62	11.0	5.0	7.2	11.9	5.21	7.29	11.96
3.6	60.8	16.5	-1.92	2.5	6.3	12.5	2.88	6.42	12.6	5.5	8.0	13.6	5.69	8.17	13.63
0.7	67.2	11.3	-1.74	3.0	7.4	14.8	3.29	7.56	14.9	6.2	9.3	15.9	6.36	9.42	16.00

a. $\Delta\theta$ = 0.10 degree after 1 minute
b. $\Delta\theta$ = 0.25 degree after 1 minute
c. $\Delta\theta$ = 0.50 degree after 1 minute

release. This error and the wind error caused by the gyroscope drift were then added at each data point as RMS errors. Column 7 assumes that the accumulative alignment, uncaging, etc., errors add RMS and total 0.1414 degree. These were then added to the gyroscope-drift error at each data point as RMS errors before the wind error was calculated. Column 8 then assumes both the errors in Columns 6 and 7 are present and essentially RMS adds Column 7 and 6. Note that Columns 5, 7, and 8 correspond to Case 1, 2, and 3 in the figures, respectively.

Note that under the worst conditions (Column 7 and Figure 5, Case 3) the total error is less than 10 ft/sec down to an altitude of 9000 feet. With a 0.25-degree gyroscope-drift error, the error does not reach 10 ft/sec at any time. Other points can readily be obtained from the figures or table.

Prototype Testing

A modified version of the GG406 was built to determine if it would meet the desired specifications. For the prototype, a 2-inch-diameter solid brass rotor was used. A hole drilled through the center of the sphere gave it a preferred spin axis and facilitated spinup. The gyroscope was assembled such that it could be spun up in two positions at right angles to one another. Optical pickoffs were used to eliminate the error imposed by the drag of the standard potentiometer pickoffs.

The spinup and uncaging of the gyroscopes in the balloon-dropped Windsonde consisted of a motor with a teflon friction cone attached to its shaft. A mechanical linkage was used to withdraw the drive system and to uncage the gyroscope upon command.

Since the gyroscope's rotor might be spun up at right angles to the sonde axis, it was necessary to determine what error might occur in rotating the gyroscope body through 90 degrees as well as any uncaging error. A microscope was mounted to permit viewing of the top of the rotor. The magnification of the microscope allowed a 0.05-degree position change to be easily discernible. The rotor was then spun up and a null position determined with the motor attached. The motor was then withdrawn, and no detectable shift in the rotor position was noted. Repeated caging and uncaging actions showed no detectable shift in the spin axis due to the caging action.

During the 90-degree maneuver, the hole in the rotor must pass across two gas bearing ports, one on each bearing cap. Although these would appear to compensate one another, a torque may be applied to the rotor. To determine the effect of this maneuver on the vertical alignment, a second test was made utilizing the microscope. With the gyroscope attached to a dividing head, the microscope was positioned to view the end of the rotor the same as it was during the uncaging tests. After spinup and uncaging, the gyroscope was rotated through 90degrees and then back to its original position. No change in the spin axis position was discernible. This process was repeated several times with the same results. The position of the microscope was then changed so that we could look at the rotor after the 90-degree maneuver. The rotor was spun up, the gyroscope rotated through 90-degrees and a null position determined. The gyroscope was then returned to its original position, spun up, and rotated through 90-degrees. No change in the null position was noted. Repeated tests yielded the same results.

The outcome of these two tests indicated that the uncaging and 90-degree maneuver errors were nearly negligible, and they would certainly be less than the values used in the gyroscope error analysis presented earlier.

The rundown time constant (loss of 63 percent of the rotor's original speed) was about 2.2 minutes. Since the loss in angular momentum with speed matches the decrease in many of the error torques with speed, no significant deterioration in drift rate was noticed during long rundown times. The rotor spin-axis position was typically 1 degree at 1 minute, 10 degrees at 5 minutes and 15 degrees at 7 minutes from its starting position. The ball began to wobble due to loss of inertial stability and hydrostatic bearing torques at about 15 degrees and 8 minutes rundown.

Gyroscope Drift Measurement

The first measurements of the gyroscope drift were made with a rotor start speed of 12,000 rpm, and the average drift was approximately 2 deg/min. It appeared that most of the torques causing the drift were case-oriented, and we hypothesized that rotating the gyroscope case about the rotor's spin axis might average out these torques. A test was established that considered gyroscope case rotations comparable with those that would be acceptable for the falling Windsonde. The gyroscope was mounted on a Genisco rate table and rotated at rates to 3 rad/sec. With a rotation rate of at least 0.1 rad/sec the drift rate decreased to around 0.2 deg/min for the first 2 minutes.

Figure 6 shows the gyroscope with its gas bottle. The hole in the side allows spinup while horizontal.

CHOICE OF GYROSCOPE TECHNIQUE

Based on the above discussion, it was apparent that the gyroscope vertical sensing technique best fit the guidelines outlined earlier. It has sufficient accuracy and low enough drift when the sonde is rolling to yield accurate wind data. It does not require tracking of the sonde. Aircraft loitering is not required as the sonde will fall fast, and the gyroscope lends itself to mass production, which is essential for an inexpensive sonde. As a result, the gyroscope was chosen as the vertical sensor.

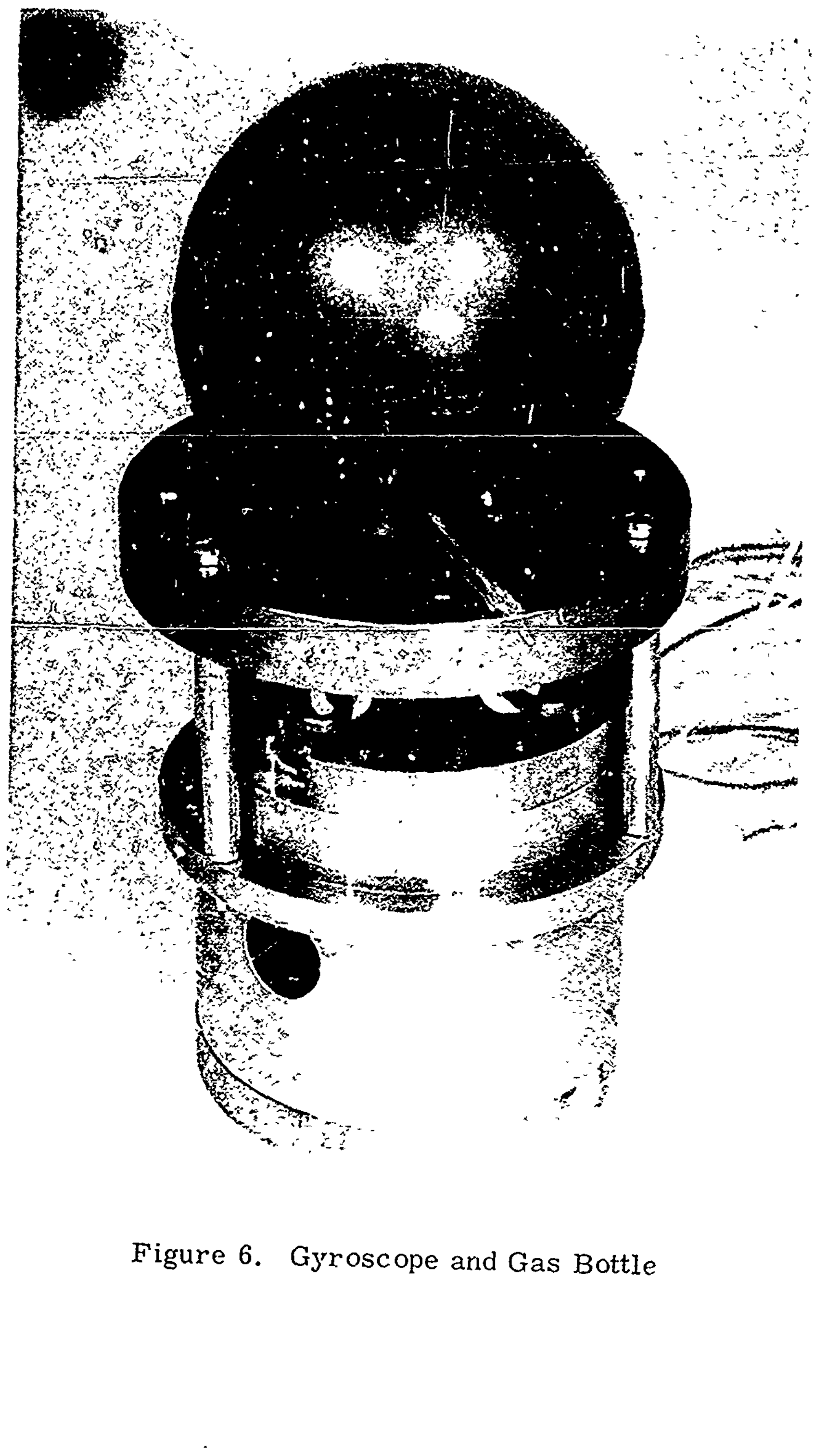


Figure 6. Gyroscope and Gas Bottle

SECTION IV
WINDSONDE DESIGN

With the sensing technique established, the design of the Windsonde itself was undertaken. The aerodynamic response of the sonde was established and testing of a prototype sonde completed before fabrication of sensing units was started.

AERODYNAMIC CONSIDERATIONS

Because of the gyroscope size, the sonde forebody had to be 4 inches in diameter. The error study favored a fast-falling sonde, so a ballistic coefficient, C_DA/W, of 0.005 was chosen. For ease of construction, the tail fin was made as a cruciform shape; a high aspect ratio is desired, and low mass is essential to achieve fast response and good damping of the sonde. Practical considerations led to the tail having a 6-inch span and a 2-inch chord. Then the derivative of the lift coefficient with respect to angle of attack is

$$k = \frac{a}{1 + \frac{2A}{b^2}} \approx 3.6$$

where A is the fin area, b is the span and a ≈6 per radian for this type fin.

To determine a reasonable length of the sonde, the relationship between the moment of inertia and the damping coefficient was examined. This could be determined from the following equation:

$$\frac{4r^2}{\zeta^2} = \frac{2I}{k\rho Ar}$$

where r is the distance between the center of gravity and the center of pressure, ζ is the damping coefficient, I is the sonde's moment of inertia, k is the lift coefficient, ρ is the air density, and A is the fin area. As can be seen, r increases as the two-thirds power of ζ if all other terms remain equal. However, the moment of inertia will also increase with increasing r, making the total effect nearly one to one.

With r equal to 4 feet, the largest value felt to be practical, the damping coefficient becomes approximately 0.45. While this is slightly more underdamped than desired, the response distance is quite small, indicating fast response. Published curves relating body response relative to a step input versus delay distance λ_n show that a 50-percent response to a step change in wind with the above damping coefficient will occur in 0.2 λ_n:

$$\lambda_n = \frac{2\pi V_R}{\omega_n}$$

$$\omega_n = \frac{V_R}{\delta}$$

$$\delta = \frac{r}{2\zeta}$$

so $\lambda_n = \frac{\pi r}{\zeta} = 27.9$ feet

and $0.2\ \lambda_n = 5.6$ feet

Since other factors may affect the response of the sonde, it is safe to assume that a response distance of 8 to 10 feet will result.

V · · TUNNEL TESTS

A half-scale model of the proposed Windsonde was tested in a wind tunnel. Three forebody shapes were employed in the tests, each at two Mach numbers and three angles of attack. The center of pressure was cross plotted against Mach number for the 5- and 10-degree angle of attack tests. However, while the sonde body was held at a constant angle of attack, the tail section was flexed to a smaller angle by the tunnel's dynamic pressure. (During normal operating conditions, the entire sonde will respond when at an angle of attack.) As a result the indicated center of pressure was about one-third the distance from the center of mass to the tail. The true center of pressure was close to the tail fin.

Hemispherical, parabolic, and conical forebodies were tested, each at Mach numbers of approximately 0.3 and 0.5, and with 0-, 5-, and 10-degree angles of attack. With the exception of the 5-degree angle of attack parabolic forebody data, the drag coefficient for the sonde is 0.50 ± 0.09, within the limits of the tests. At high angles of attack, the cylindrical centerbody of the sonde has an effect on the measurements. This produces a different drag force during the actual sonde flights, but it acts for only a short time due to the rapid response of the sonde. As a result of these tests and of the ease of fabrication of such a shape, the hemispherical shape was chosen for the Windsonde forebody.

DUMMY SONDE TEST DROP

The tail boom on the half-scale model used during the wind tunnel tests was slightly shorter than 2 feet, and it appeared to vibrate during the tests. To minimize the moment of inertia of the sonde, it was necessary to hold the weight of the tail boom and fins to minimum. Although the design provided a reasonable safety factor in the strength of these members, the possibility existed that a flutter mode might be set up in the cruciform fin, leading to mechanical failure. To determine whether the sonde had structural integrity, a dummy model of the sonde was constructed. A simple indicator of structural failure was provided in the test model by cementing very small wires to the edges of the fins and connecting these wires in series with the battery supply for a 27-MHz beacon transmitter.

Another important design feature which required an experimental check was the sonde's roll rate. To provide this information, a blocking oscillator modulated the transmitter at a frequency which was determined by the resistance of a photoconductive cell. In addition to the electronics, the sonde contained sufficient ballast to bring its weight up to the design value, about 9 pounds. Recovery of the test sonde was desirable, even if it were totally destroyed, because the distribution of parts would provide back-up information on whether failure occurred during flight. There was a possibility that the sonde could be tracked visually during its fall, so the sonde was painted dull black on one side, leaving the other half bright aluminum.

The dummy sonde was dropped from an altitude of 11,000 feet over Camp McCoy, Wisconsin. During the drop, the sonde was observed from the aircraft for the first portion of its flight, but visual contact was not made by the observers on the ground. However, the beacon transmitter functioned throughout the flight, indicating that the tail assembly remained intact. Fall time was 29 seconds as predicted, so the actual ballistic parameter of the sonde was close to the calculated value.

The roll-rate signal was distinct for a little more than half the flight, until the hazy sky conditions masked the roll signal. The roll rate was approximately 1.5 revolutions per second throughout the flight. It is interesting that the sonde's angular velocity varied so little as its airspeed increased from 120 ft/sec at release to approximately 400 ft/sec in midflight. With the use of canted tail fins to induce roll, the equilibrium angular velocity should be proportional to airspeed. In this test, however, the sonde continued to roll at the rate imparted to it as it left the launch fixture. This rate was very close to the 1-rps terminal roll rate designed into the tail fins. Examining the torques and moment of inertia involved, we found that many seconds are required for the sonde to approach its equilibrium roll rate when its airspeed is low. If the sonde is dropped with no initial rotation, it will take much longer to acquire a satisfactory roll rate than an estimate which assumes a linear variation with airspeed would indicate.

An adequate roll rate is essential, not only to obtain roll position information from the aspect sensor, but also to minimize gyroscope drift. Accurate wind measurements thus require that the sonde be given an initial rotation.

ELECTRONICS DESIGN

With the mechanical strength of the sonde established, the electronics were investigated. The sonde's electronics were required to transmit the gyroscope's pickoff outputs and the direction information signal to a suitable ground receiving station. The ground station receives, processes and stores the information for later data analysis.

Sonde Electronics

The gyroscope yields the tilt angle of the sonde from vertical, but another sensor is required to establish the angular orientation of the sonde about its roll axis. Sensors to detect the sun's position and the earth's magnetic field were considered. A photoconductor to detect the sun's position was not desirable since this required daylight and clear sky conditions. As a result, some form of magnetometer was considered. Either a Hall-effect device or a fluxgate magnetometer would meet the size requirements of the Windsonde, but it is unlikely that a fluxgate magnetometer could be produced at low enough cost for use in an expendable sonde. Although Hall-effect devices would probably serve the purpose, they have the disadvantage of low sensitivity. To produce a usable output signal in the earth's field, flux concentrators, a fairly high primary current, and further signal amplification would be necessary to raise the signal level high enough to modulate the telemetry transmitter.

A data-transmission technique was chosen which calls for a subcarrier signal to be modulated by one of the gyroscope pickoff signals. The subcarrier generator can be directly modulated by the earth's magnetic field as well. Since the permeability of ferromagnetic materials is a function of the applied magnetic field, the inductance of an iron-core coil can be influenced by an external field. This holds true for powdered-iron cores used in many radiofrequency applications. Generally, such materials are selected to have a constant permeability in weak fields, but, as saturation is approached, there is a region in which permeability changes rapidly with applied field. Thus an oscillator using an iron-core coil which is biased by a strong magnetic field will have an operating frequency that is quite sensitive to field changes.

A breadboard model of this magnetometer subcarrier generator was constructed, using a slight variation of the basic scheme. Two oscillators operating in the 1-MHz range were adjusted to give a difference frequency of approximately 100 kHz. The oscillator coils had powdered-iron cores biased in opposite directions by small permanent magnets. Mixing the two signals produced a 100-kHz subcarrier which was subsequently amplitude modulated by one of the pickoff signals. Advantages of the difference-frequency technique were high sensitivity and good stability, since such factors as temperature drift were cancelled while magnetic effects were doubled.

In addition to the oscillator-mixer circuit described above, the first-generation sondes had an integrated-circuit linear amplifier which brought the signal from pickoff 2 to a level which was sufficient to modulate the 135-kHz subcarrier and an emitter-follower circuit which provided impedance matching from pickoff 1 to a summing circuit. In the summing circuit, the modulated subcarrier and pickoff 1 signals were added linearly; the composite waveform was then applied to the frequency-modulation terminals of the 1680- MHz transmitter.

Ground-Station Electronics

The ground station for the balloon tests operated in the following manner. From the antenna, the 1680-MHz signal was fed to the mixer or parametric down-converter, emerging at the 30-MHz intermediate frequency. At this point, it was fed both to the GMD receiver and to a Nems-Clarke 1037 receiver. At the output of the Nems-Clarke's wideband f-m detector, low-pass and high-pass filters separated the pickoff 1 signal from the modulated subcarrier. The pickoff 1 signal could be fed directly to the recorder. When the modulated subcarrier was fed to the f-m and a-m detectors, the magnetometer and pickoff 2 signals, respectively, were recovered, fed to the recorder and stored on magnetic tape for later computation.

Sonde Release System

Three sondes were to be dropped for the first balloon flight test. The second flight test had two sets of four sondes. As a result the sonde cutdown control circuit was built to handle four units. A schematic of the circuit can be seen in Figure 7. The circuit was designed to reduce any interference between sondes as well as to protect each sonde from possible short circuits that might occur during a sonde's release.

The first ground command signal advanced the stepping switch one-half step and sent an unlatch signal to each sonde, ensuring that the power was off in each sonde. The second command signal advanced the stepping switch one-half step, removed the unlatch command and began the start up sequence of the first sonde. A latching relay turned on the -18 volts and -12 volts in the sonde, activating the transmitter. A 55-second thermal delay relay was also activated. At the end of the delay, the piston actuator on the gas supply was fired, giving support to the gyroscope. The spinup motor was also started at this time. Had the piston actuator leads shorted upon firing, the fuse Fu5-1 would have opened, protecting the spinup circuit. Thirty-five to 40 seconds were required to spin up the gyroscope.

Gyroscope uncaging and sonde cutdown were initiated by a third ground command. This first actuated EC2-1, a smokeless squib that uncaged the gyroscope. After a 1-second delay, the cutdown squib EC1-1 actuated. This cut the supporting cords and the six electrical leads going to the sonde. During this 1-second delay, the gyroscope was uncaged while the sonde was hanging vertical providing the vertical reference. If any of the cut wires shorted to one another or to ground, operation of other sondes was unaffected since each line was fused to protect the power supply and cutdown circuit. The remaining sondes were released by repeating the same sequence of commands.

The canister that held the sondes was divided internally into four compartments. Each sonde was attached to the top of the canister in its compartment such that its tail fin was held directly over a pair of deflector plates by means of a small leaf spring. At release the falling sonde would slide off the deflector plates and achieve a counterclockwise roll.

GYROSCOPE GAS BOTTLE TEST

The gas supply for the gyroscope is contained in a steel bottle 3 inches in diameter with a 0.050-inch-thick wall. Since the bottle is filled to 4000 psi, there was some concern about what would happen to the bottle if it were to break. Because of this concern, a test was established that would subject a filled bottle to high stresses. A bottle that had been filled and armed was dropped from a height of 6 feet and then from 40 feet onto a concrete slab. Examination of the bottle after the drops indicated that it and its piston actuator were intact. The actuator was fired, the bottle top opened, and the gas flow timed showing that the drop had not affected its operation nor endangered anyone.

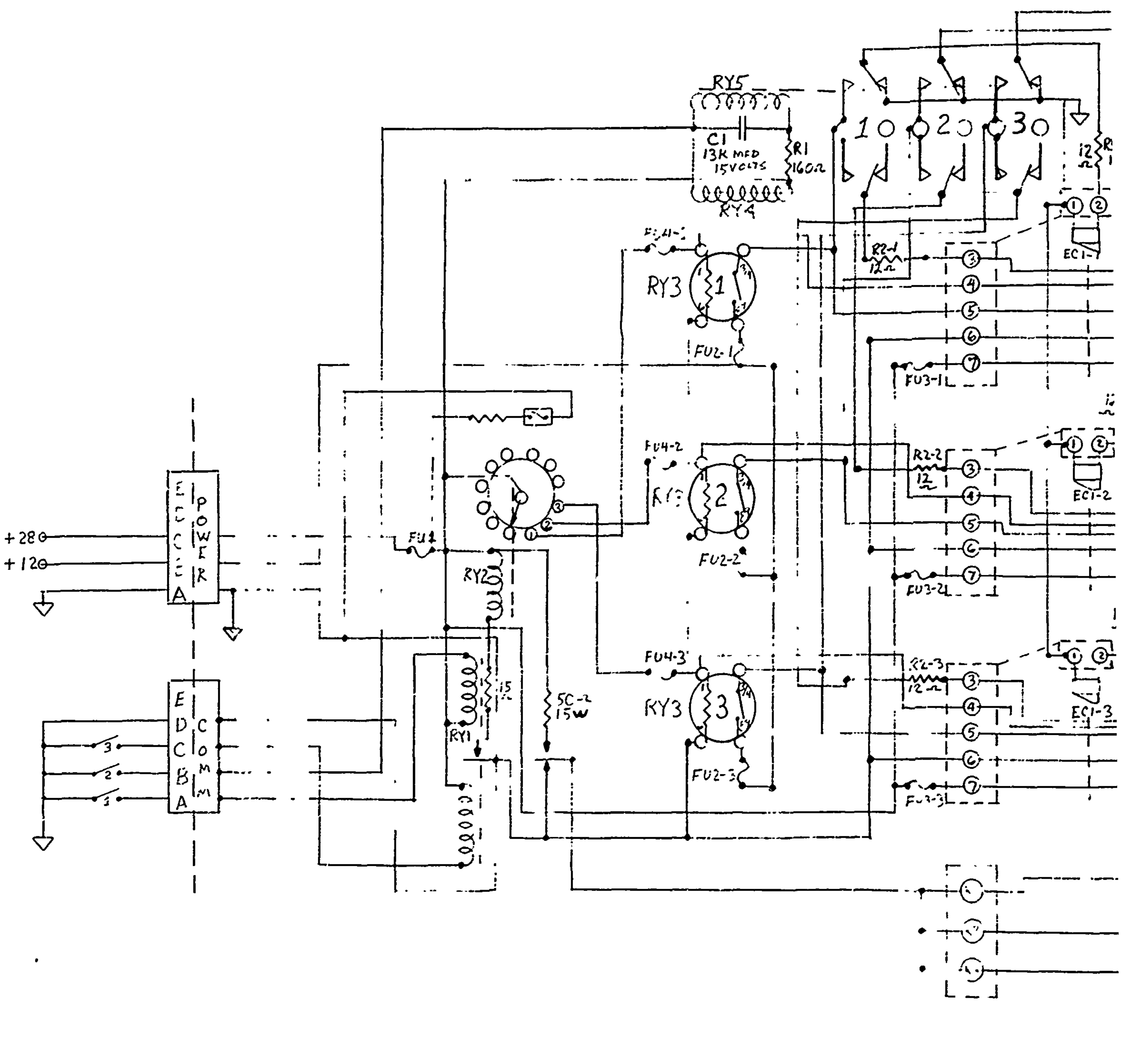
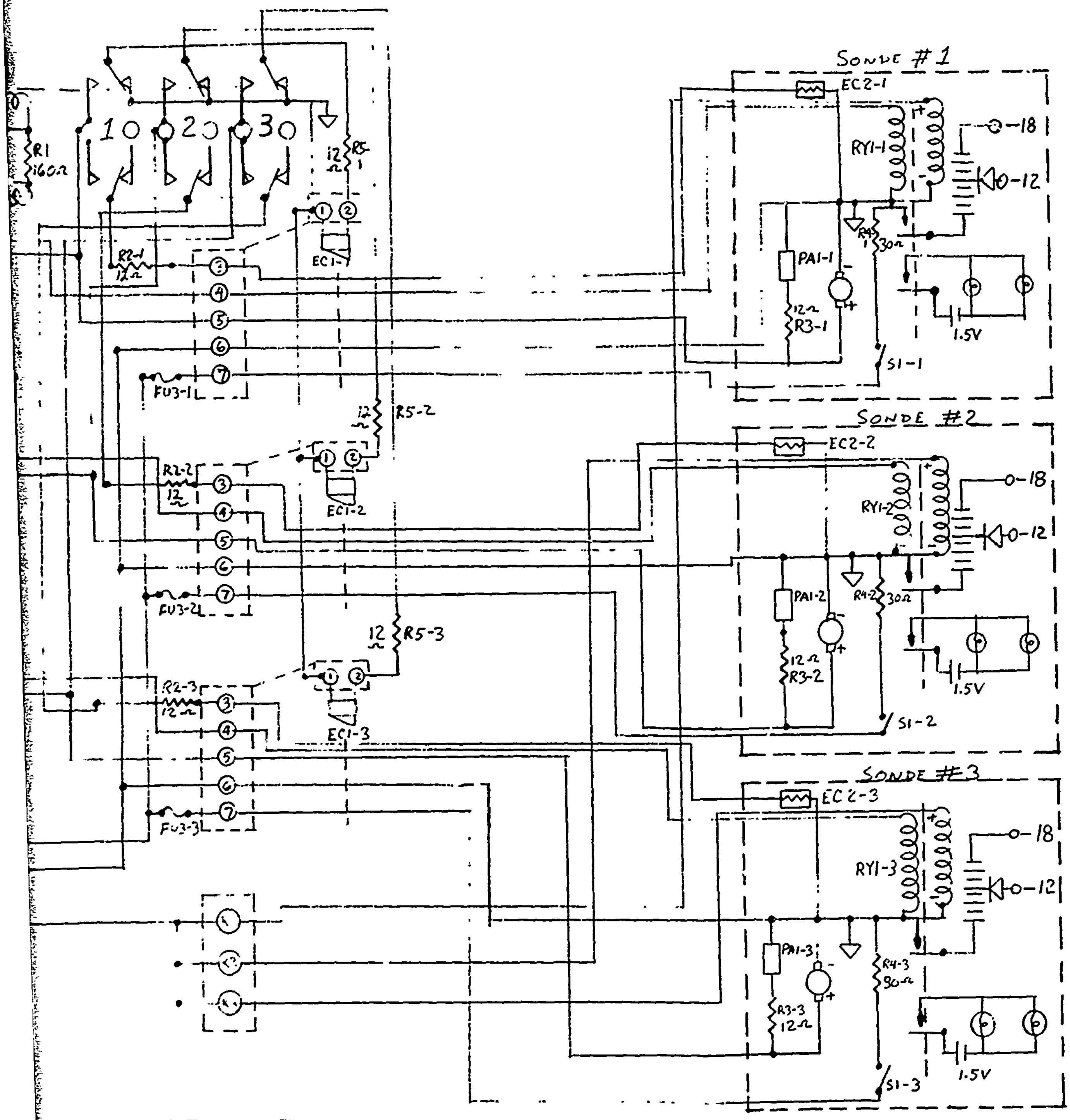


Figure 7. Schematic Diagram of Sonde Cutdown (

A



c Diagram of Sonde Cutdown Circuit

SECTION V
BALLOON FLIGHT TESTS

The first phase of the Windsonde flight testing consisted of dropping the sondes from a balloon. The sondes were released on White Sands Missile Range at altitudes ranging from 30,000 to 35,000 feet. In a typical flight sequence, the balloon was launched from an appropriate position such that all of the Windsondes could be dropped within range of the ground stations. A command signal from the ground started the sequence on the first sonde. This sequence allowed the air supply to reach the gyroscope's air bearing, started the transmitter, and started the spinup motor. After the desired rotor speed was reached, the spinup motor withdrew, uncaging the gyroscope. The sonde was then released. The remaining sondes were released in succession, and the dispensers and associated electronics parachuted to earth. Radiosonde runs prior to and after the release of the sondes were made to aid in determining initial conditions and in the data analysis.

NOVEMBER 1967 FLIGHT TESTS

Test Events

The first test drops occurred during the period 26 November through 2 December 1967. Three sondes were fabricated and taken to Holloman AFB, New Mexico, where final checks were made. These included supporting the gyroscope's rotor, testing the electronics, and assembling the sondes for the test drop. Two ground stations were used to record the data. The primary station was located at the Holloman GMD site with the secondary station at the Jallen GMD site. Both stations recorded the magnetic sensor's output and unprocessed signals from both pickoffs. In addition, the primary ground station was capable of reducing the pickoff data and recording the two components of the tilt angle. A number of problems involving lack of communications at the ground stations, road block leading to the Jallen site, etc., were overcome before the first drops occurred.

After two aborted attempts, the balloon was launched on 2 December 1967 from Truth or Consequences, New Mexico. Prior to the launch, each gyroscope was checked to ensure that it was caged and each transmitter was turned on and off. A beacon transmitter was used on the flight to enable the ground stations to locate the balloon easily. The launch was very smooth, causing no damage to the sondes.

About 3 minutes before the first drop, range radar reported an object falling from the balloon. As the countdown proceeded and the first sonde was released, the beacon signal failed to cut off, and range radar did not confirm that a drop had occurred. The second sonde's signal was also obliterated by the beacon. The third unit's transmitter frequency was sufficiently different from that of the beacon to allow data to be received.

Examination of the recorded data revealed, through the beacon signal, that all three of the sonde's gyroscopes had been spun up and that each sonde had been released on schedule.

Test Data

The first two sonde's signals were obliterated by the beacon, and the only data obtained was an indication that both gyroscopes had spun up properly and intermittent rotor spin-down rate. At least one of the two gyroscopes appeared to lose bearing support during the mission. The third unit yielded data from 32,300 feet to 23,000 feet. At this point, the gyroscope's rotor lost bearing support and no reliable information was obtained after that point.

For the first tests, the Windsonde data analysis was accomplished by feeding the tape-recorded tilt-angle and roll-position signals into a multichannel Honeywell Visicorder, obtaining a continuous graphic record.

Gyroscope pickoff angles were then scaled directly from the Visicorder chart. Roll position with respect to magnetic north was found by inspecting the roll sensor output trace. The magnetic sensor was aligned in such a way that a negative peak on the roll sensor trace occurred when pickoff "B" pointed north, and a positive peak occurred when it pointed south. Zero crossings corresponded to east or west orientations.

To ensure knowledge of the roll direction, deflectors in the launch fixture imparted a known initial roll to the sondes. Roll direction was chosen to be the same as the gyroscope rotor spin direction; as the rotor slowed down and transferred its angular momentum to the sonde body, it would tend to increase the roll rate slightly. An attempt was also made to maintain the roll rate throughout the flight by shaping the tail fins to give the effect of a small pitch angle. (The desired angle was calculated to be 0.15 degree.) Sonde data indicates, however, that an overall warping or misalignment of the tail fins overshadowed the effect of the pitch angle. The roll sensor trace shows that the roll rate decreased for the first few seconds, apparently stopping and then increasing again to approximately 1.5 rps. This behavior indicates that some aerodynamic property of the sonde (probably fin misalignment) caused it to reverse its roll direction during the flight.

Examining the gyroscope pickoff signals from sonde No. 3 on the Visicorder chart, we noted a strong correlation between the "A" and "B" pickoff outputs. If the tilt angle remains constant during a complete revolution, one would expect the pickoff waveforms to be two sinusoids of equal amplitude and frequency. However, they should be 90 degrees out of phase with each other because the pickoff axes are perpendicular to one another. In this case, the signals were nearly in phase with each other, which should occur only in the special case when the sonde is rocking in a plane bisecting the angle between the pickoffs. Faulty data transmission is the probable explanation here.

In laboratory tests, channel separation at the output of the ground station circuit had been excellent, but it appears that there was a severe crosstalk problem during the flight test. This probably resulted because, to obtain maximum signal-to-noise ratio, we were modulating the RCA transmitters with the greatest deviation allowed by the receiver bandwidth. However, if the receiver tuning was not precisely centered, the resulting distortion would lead to intermodulation and crosstalk between channels. In this case, it appears that serious distortion did take place to the extent that the subcarrier signal was masked by the direct modulation; in other words, both channels were dominated by signals from pickoff "B".

Fortunately, when the sonde is rolling one gyroscope pickoff is sufficient to determine the tilt angle. The disadvantages are that fine structure may be lost because the tilt angle must be averaged over some appreciable fraction of a revolution of the sonde, and the data readout cannot be readily automated.

Tilt angles used in the calculation of the wind profile for sonde No. 3 were hand computed, using a graphic technique. Instantaneous pickoff "B" angles were scaled from the Visicorder chart at 90-degree roll position increments and plotted as vectors on polar coordinate paper. Magnitudes and directions of the resultants of each pair of consecutive vectors were than tabulated. These tabulated values represented the sonde's average orientation during the respective time increments, and these were fed into the computer for calculation of the wind profile. Any number of intersections could have been derived if more data points had been desired, but selecting 90-degree intervals simplified the task and afforded the best accuracy in determining intersection points.

The radiosonde runs were made to obtain wind data for comparison. The first run was released from the Jallen site at 0930 MST and reached 30,000 feet at about 1000 MST. The second run was launched from the Holloman site at 1240 MST and reached 30,000 feet at about 1320 MST. Since the usable Windsonde flight was released at 1204 MST, the available wind data is 2 hours before and 1 1/2 hours after our test flight. The radar that was to have tracked the sondes as they fell was unable to locate them, and, as a result, the desired time-altitude-position information is not available.

The wind-speed data are plotted in Figure 8 along with the two radiosonde runs, while the wind direction is similarly shown in Figure 9. The Windsonde data agrees quite well with the radiosonde data, even though the radiosonde runs are separated both spatially and in time from the Windsonde drop. The sonde was clearly functioning and yielding wind information.

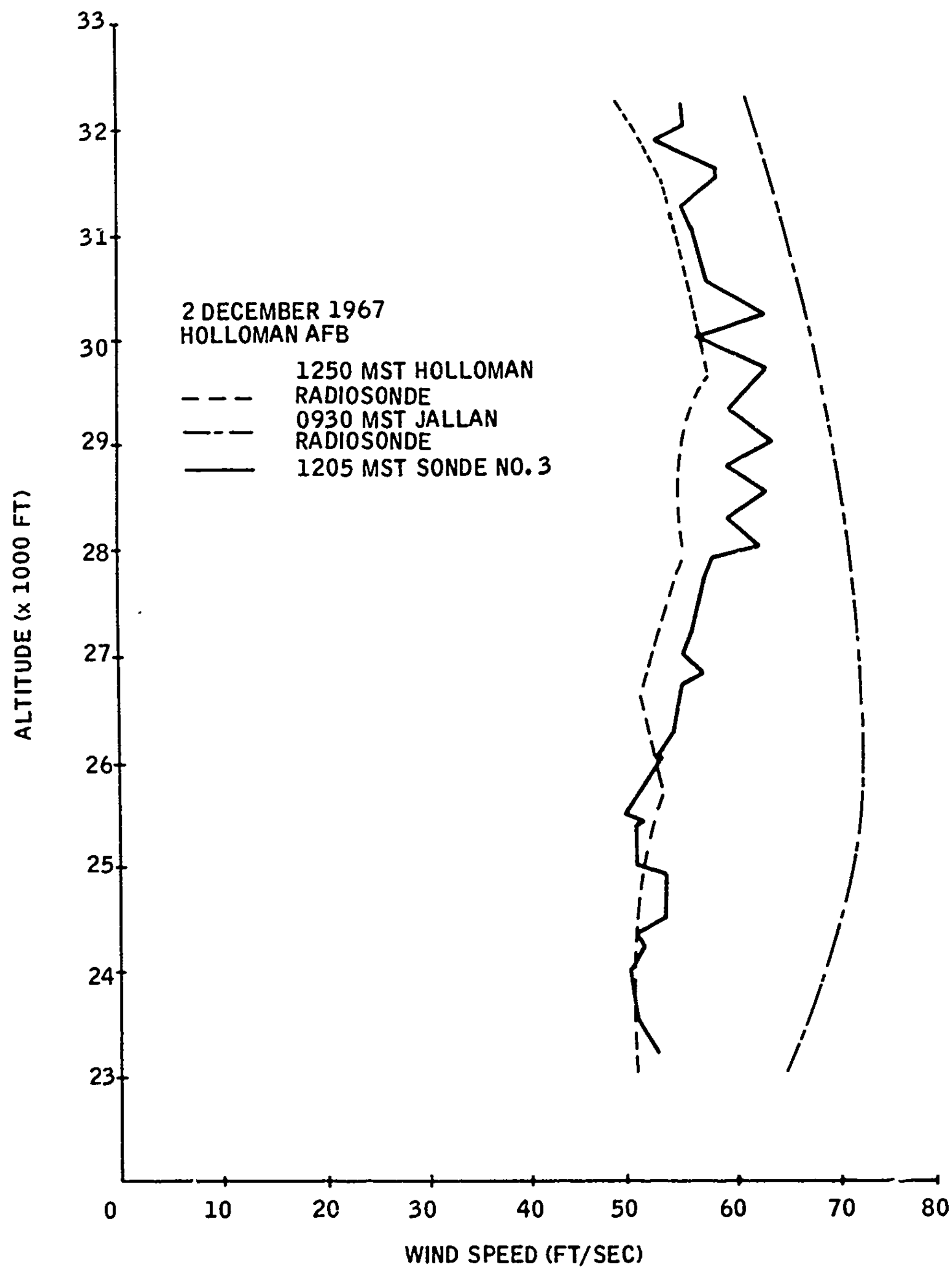


Figure 8. November 1967 Windsonde Test Results - Wind Speed

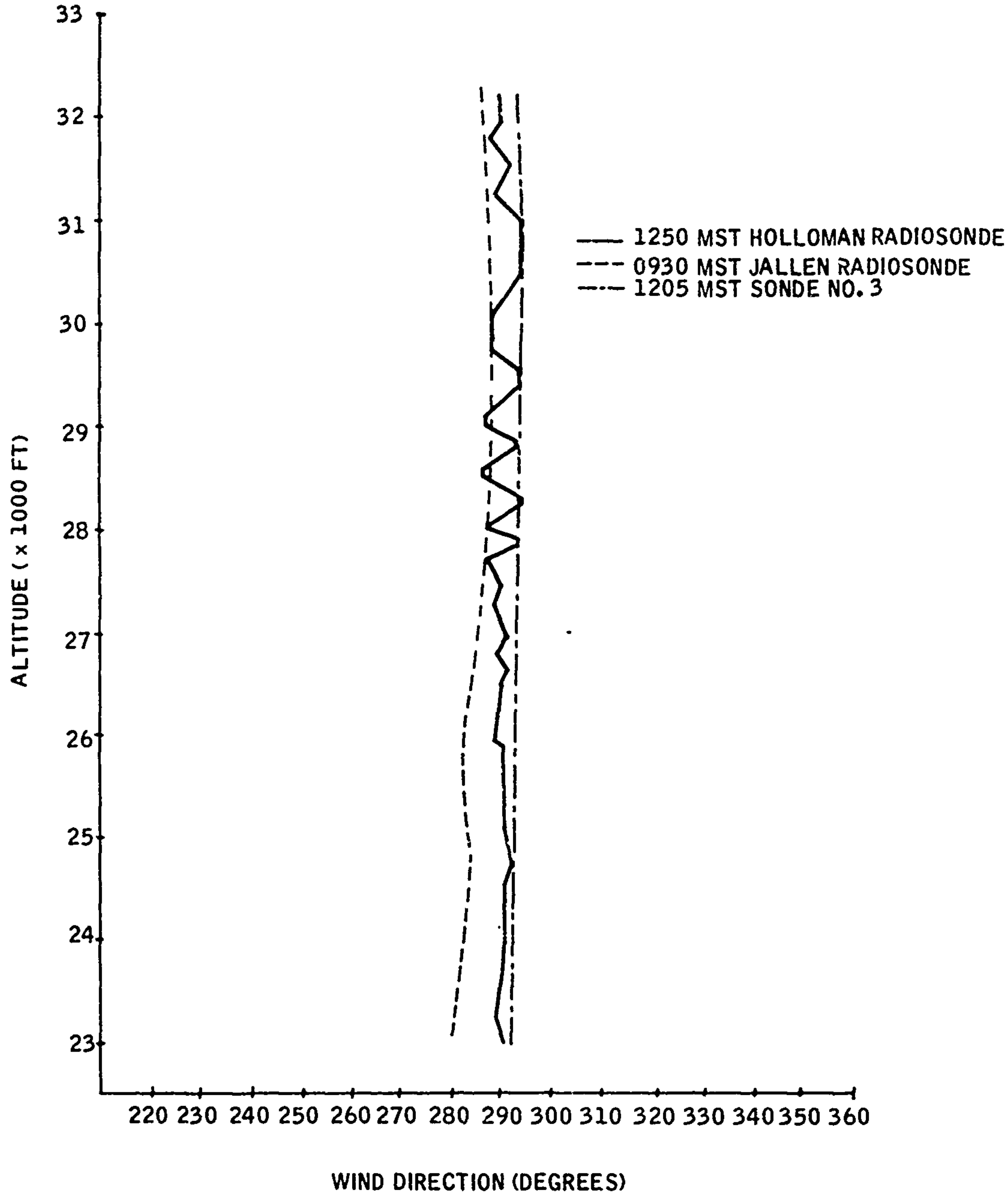


Figure 9. November 1967 Windsonde Test Results - Wind Direction

Post-Flight-Test Analysis

Aside from the failure of the beacon transmitter to cut off, difficulties with the data-transmission technique were minor. The major problems were the intermodulation between data channels and the required tracking of the balloon and sondes. With a balloon launch, the drop area cannot be fixed exactly, and the ground stations must be separated to ensure that one of them will be in range of the sondes. The narrow beamwidth of the GMD receivers required that the antenna be slewed. If the signal strength is low, the chance of loss of data is increased.

All three gyroscope rotors appeared to be spinning down at the expected rate, but each one appeared to lose bearing support earlier than anticipated. A test program was run investigating the gas bottle filling process and the question of bearing failure at resonance.

Using a programmed gas supply and an environmental chamber, simulated Windsonde tests were made. These tests indicated that the gas supply should have been adequate if the bottles had been filled properly. Since some of the gyroscopes have slighly higher flow rates than others, and since the gas bottles are structrually over-designed, it was decided that in the future each gas bottle would be filled to a minimum pressure of 4000 psi and would be cooled with Freon during the filling process.

Also included in the chamber tests were changing the rotor start speed and bearing support pressure. These tests showed no resonance problems in the expected operating range.

The results of these tests imply that the probable cause of the gyroscopes not fulfilling their mission was insufficient support gas. This was compensated for in the next units in two ways: The gas bottles were filled to 4000 psi, and the rotor spinup time was slightly shortened.

APRIL 1968 FLIGHT TESTS

Test Events

The second flight test program consisted of two flights with four sondes on each flight. The drop procedure was the same as on the earlier test, and basically the sondes were the same as those used on the first flight test. The major change reduced the gain in the pickoff circuits in an attempt to reduce the intermodulation between data channels. The tail surfaces were changed slightly as well. To maintain the roll direction and attempt to keep it uniform, ailerons were added to one pair of fins on each sonde.

The first test drop was scheduled for 29 April and the second for 1 May 1968. To reduce the field time, the sondes had been prepared as much as possible before going to Holloman AFB, New Mexico. The sondes were rechecked and prepared for launch while the equipment for the two ground stations was checked out.

The Holloman and Jallen GMD sites were again used as ground stations to receive Windsonde data. Although plans were to use one portable ground station for this drop-test series, it was felt that adequate signal-to-noise ratios would not be obtained beyond a range of about 15 miles. This decision was reached after observing signals from a number of radiosondes launched at the Holloman site several days before the Windsonde tests. The uncertainty in predicting the balloon trajectory is great enough so that a receiving range of at least 25 miles is desired.

Some serious liaison problems occurred, but they did not significantly affect the outcome of the tests. Arrangements had been made for intercoms in the radomes at both the Holloman and Jallen GMD sites to allow direct communication with the balloon control center. The Jallen intercom was installed, but the primary ground station at Holloman had no intercom for the 29 April tests. Communication with the control center was via a telephone in a building some distance from the radome. A hold in the countdown before the first drop was not relayed to the ground-station operator, so the sonde drops did not occur at the times he expected. Because of the unannounced hold in the countdown, the recorder ran out of tape just before the fourth drop occurred, and data were recorded only for the first three sondes. Signal-to-noise ratios were rather poor at the Holloman station because the balloon did not follow the expected trajectory, and the drop area was nearly 40 miles away. Fortunately, the Jallen station received and recorded signals from all four sondes.

The launch site for these test drops was the Truth or Consequences, New Mexico, area. Each sonde was checked to be sure its gyroscope was caged and that the transmitter worked. The first four sondes were placed in the Windsonde dispenser, and it was attached to the load bar. The winds at launch were quite light. However, when the launch truck started up it caused the sondes and dispenser to swing violently. The effects of this will be shown later. The launched flight train is shown in Figure 10.

The Windsonde dispenser was recovered, examined, and found to be in good condition. It was taken, along with a battery supply and balloon cutdown system, back to Truth or Consequences in preparation for the next launch.

During the prelaunch procedure on 1 May, one sonde transmitter was found to have a very low output. It was decided to place this unit in the fourth drop position, hoping that it would then be near the primary ground station at the time of its drop. All else went smoothly up to the launch; the ground winds were again very light. However, at launch the sonde dispenser was again given a violent shock. The drop sequence proceeded as planned.

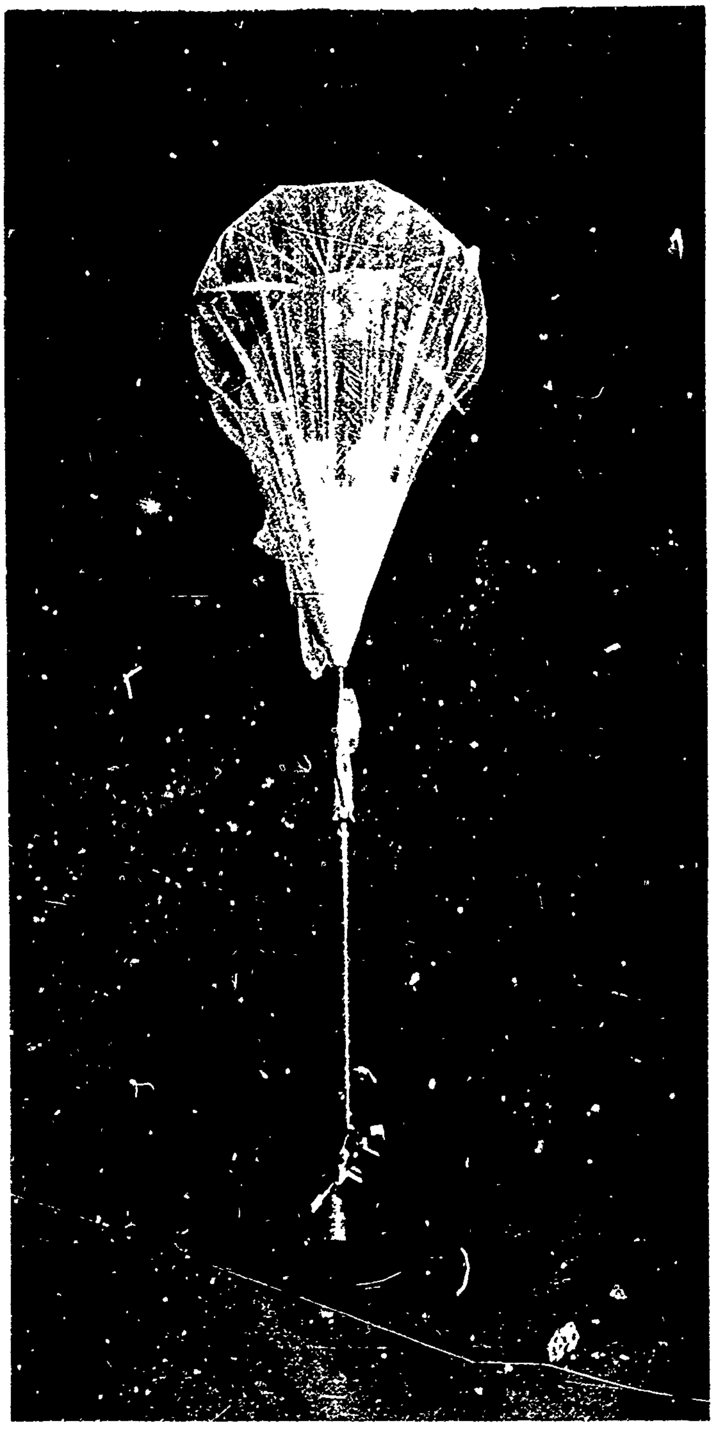


Figure 10. Flight Train for April 1968 Flight Test

All equipment was set up in the radome at the Holloman GMD site but, unfortunately, the intercom, telephone and master control switches for the station were inside a locked building and were not turned on until just prior to the first drop. Signals from the first three sondes were received and recorded, but no trace of signal was detected from the fourth sonde. The signals indicated that the first sonde did not drop, and it was found inside the container when recovered.

The rough launches on both flights slammed the cannister containing the sondes against the launch truck as it started up, causing some problems in the sondes. Specifically sonde No. 2 on 29 April did not spin up; it is quite likely that the spinup motor was uncaged during the rough balloon launch. Similarly, sonde No. 1 on 1 May was not released. The tie cord was broken when the sonde was found in the dispenser, and it must have occurred during the launch. The gyroscope in sonde No. 3 of 1 May started to spin up and then spun down. This could have been caused by spinmotor failure or by a partial uncaging of the motor at launch.

Noise and transmitter/electronics problems also caused a loss of data. The received signal from sonde No. 4 on 29 April was broken, and noise masked both pickoff "A" and the rate signal after 4 seconds. Sonde No. 4 on 1 May had a weak transmitter when tested just before launch. Some faint traces of signal were heard, but it is uncertain whether they came from the sonde.

Of the three remaining sondes, two had pickoff "A" only. Sonde No. 3 of 29 April had a very high noise level, and the roll information was good only from 13 to 35 seconds into the flight, while the "A" channel yielded data from 13 to 47 seconds. Sonde No. 2 of 1 May had data from "A" and the roll signal from 2 to 40 seconds into the flight; it was then lost in the noise. Sonde No. 1 of 28 April had both channels present for 42 seconds of the flight. However, the roll signal was not usable until 18 seconds after the drop. Examination of the data showed that some intermodulation was again evident.

Test Data

Data from three of the sondes were reduced. Since sonde No. 1 of 29 April had shown signs of intermodulation, the data was reduced using the "B" pickoff only. Because the roll signal was not usable until 18 seconds into the drop, some assumptions concerning the fall position, sonde drift, initial wind, etc. had to be made. The result is shown in Figure 11.

Although the data agreed within about 10 ft/sec with the radiosonde run (and two radiosonde runs may differ by more than that), and although assumptions had to be made about the start conditions, an attempt to improve the data was made. With the rough balloon launch it was possible that units other than those described above could have had their support cords cut. If this occurred, the sonde could be uncaged while not hanging vertically, and a bias angle would be added to the data.

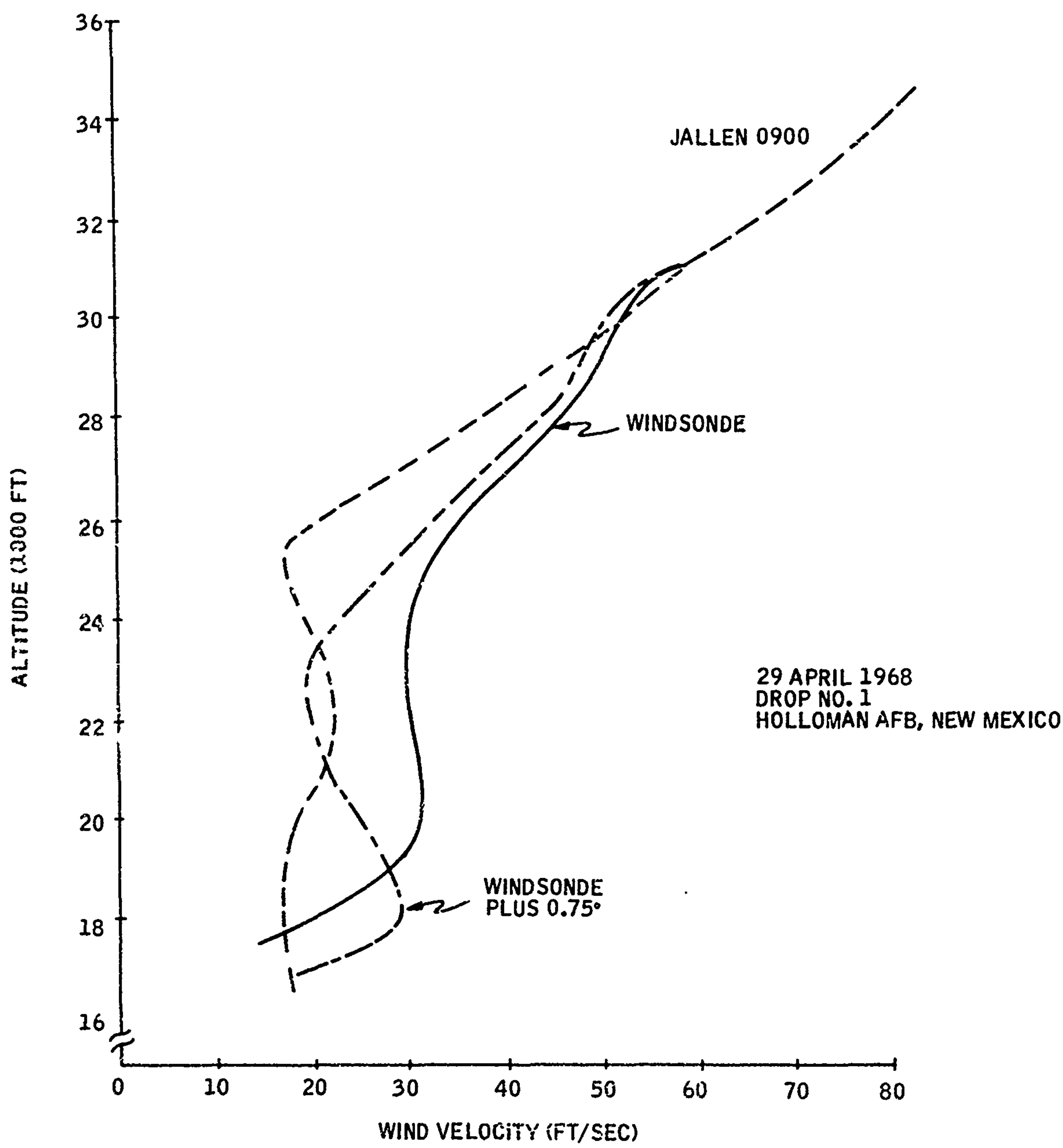


Figure 11. April 1968 Windsonde Flight

To determine what tilt angles should have occurred, the wind profile and sonde characteristics can be taken and the angle determined analytically. Since the only wind information available was the 0900 Jallen radiosonde run, this information was used. The result indicated that a 0.75-degree angle should be added to the data. This reduced the deviation between the Windsonde and radiosonde data. However, with all the uncertainties concerning the initial conditions, the validity of this correction is uncertain.

Although the data from sonde No. 1 of 29 April had showed channel intermodulation and sonde No. 3 of that same day had only channel "A" information which would probably be similarly affected, the data was reduced. Since there was no data for the first 13 seconds, start condition assumptions had to be made. The reduced wind data tended to remain too high, and no easy correction can be made that significantly improves it. The likely problem is the intermodulation by the noise of channel "B".

Sonde No. 2 of 1 May appeared to have good data for 40 seconds of the flight. However, a curve of rotor speed versus time showed a sharp slope change at 15 seconds, indicating that the rotor had been touched by the bearing or a piece of foreign matter. A correction was again required since the actual tilt angles and computed tilt angles disagreed. After adding the correction the data agreed quite well with the radiosonde data until the point of rotor speed slope change, where they diverged rapidly.

Post-Flight Test Analysis

It appears that the data transmission was a major problem. As previously mentioned, the signals were very noisy and required additional filtering to make them usable. Pickoff "B" signals, which directly modulate the transmitter, were in some cases not transmitted because of some undetermined component failure.

This left only the Pickoff "A" signal which, along with the magnetic sensor output, was present on the subcarrier signal. A considerable amount of interaction between the pickoff and roll signals is possible when the signal-to-noise ratio is poor, as it was on the drops. When the noise level is high, the angle-decoding circuit becomes sensitive to the amplitude of the pickoff signal, and this amplitude can be affected by roll in two ways. The received radio-frequency signal fluctuates as the sonde rolls because of asymmetry in the antenna pattern. If there is not enough incoming signal to produce limiting in the f-m receiver, the detected pickoff signal level is seriously affected by changes in the carrier amplitude. Also, since the overall bandpass of the system is not completely flat, the subcarrier frequency swing produced by the magnetic aspect sensor also induces some change in detected subcarrier amplitude, which again reflects in the pickoff "A" signal.

Even though the degree of interaction is small, it seriously affects the derived wind profile because the resulting in-phase errors in the tilt and roll angle readouts lead to a cumulative wind-velocity error when integrated. Other random signal fluctuations resulting from multipath transmission, and "jerky" antenna tracking contributed to the noise problems.

BALLOON TEST SUMMARY

Although the amount of data received from the balloon-dropped Windsonde tests was limited, the results did indicate that the Windsonde responds to wind shear as it falls. It was difficult to determine response time and accuracy of the system with the data obtained and the supporting information supplied since the radar was unable to track any of the sondes. As a result we could not correlate indicated sonde motions with actual events and estimate errors. On the first flight test, the radiosonde runs yielding wind information that were available for comparison differed both spatially and in time from the Windsonde and one another. They also showed a 12- to 22-ft/sec difference between each other and a 12-degree shift in direction. The Windsonde data fell in between the two radiosonde profiles.

During the first flight test, the gyroscope gas supply was found to be deficient. This was changed, and it proved adequate during the second flight test. Intermodulation of data channels also proved to be a problem on the first tests. The attempt to improve this situation was not successful as there was still some intermodulation during the second tests.

We were unable to check the Windsonde's response time because of the lack of a rapid-response wind-measuring technique for comparison. Radiosonde data is smoothed over 2000-foot intervals and therefore offers no hope of checking the predicted delay distance of the Windsonde.

SECTION VI

AIRCRAFT WINDSONDE DESIGN

With the results of the balloon-dropped tests indicating that the concept would work, the redesign of the Windsonde for aircraft deployment was undertaken. Modifications were required in the physical structure, electrical wiring, gyroscope spinup and vertical reference system, and retardation and release mechanism.

RETARDATION AND RELEASE SYSTEM

The aircraft-launched sonde must be retarded to remove the aircraft-induced horizontal velocity the sonde has at ejection. The sonde must be slowed to some known speed with respect to the local air speed in a relatively short time. This is essential so that the sonde does not fall much below the aircraft's altitude where the true wind velocity is measured, yielding initial conditions. After consideration of several alternatives, it appeared that the best method of slowing the sonde was by using a parachute. Although there was a large difference of opinion between manufacturers in what would be required, the best approach appeared to be a 2.7-foot-diameter slotted parachute. The maximum force that should be applied with this parachute was 35 g's, occurring as it opened. As designed with the 4000-psig gas supply, the gyroscope was capable of withstanding 50 g's 20 seconds after the gas bottle opened.

Shackle Release Mechanism

One approach for the release from the parachute was a spring-loaded shackle. The initial shock as the parachute deployed was expected to shear a safety wire and compress an interior spring. As the package slowed down the relative force caused by the parachute's drag decreased, releasing some of the stored energy in the spring. When the drag force reached about 1.1 g's on the parachute, the spring force had moved a piston inside the shackle to a position that released the sonde. This occurred within a few seconds of release, allowing the sonde to begin free-fall near the altitude where the wind velocity was determined.

On 1 October 1968, two dummy sondes were prepared for ejection from a C-130 to test the shackle retardation and release scheme (see Figure 12). Both sondes were quite similar to actual Windsondes physically. The plane was depressurized and flown at 30,000 feet off the east coast CONUS. Just as the first

Figure 12. Dummy Windsonde Models for Shackle Test

test sonde was being pitched out, the turbulence in the cargo area whipped the parachute around. In doing so the tail boom was bent and the shackle was pulled, shearing the wire and releasing the parachute.

The second sonde was taken to the rear of the plane, and while the parachute was held in the same hand as the body of the sonde, it was pitched out rapidly. This one cleared the airplane easily, but the forces on it were insufficient to shear the safety wire. The sonde did not drop from the parachute.

The results of these tests warned us of high turbulence in the cargo area of the C-130 with the cargo door open and indicated that a different means of release would be required on the first aircraft-deployed sonde tests.

A third dummy sonde was prepared and taken on the next flight tests to test a modification to the shackle. The safety wire that was cut on the earlier sondes was replaced by a spring. When the retarding force applied tension to the shackle, the piston compressed a spring as before. However, instead of shearing a wire, a wire spring that served the purpose of the safety wire was released. The sonde was ejected over White Sands Missile Range from 25,000 feet. Although it functioned satisfactorily, it appeared to release almost immediately, before the sonde had slowed down.

Pyrotechnic Release Mechanism

A second approach to the release of a Windsonde from its retarding parachute was the use of pyrotechnic cutter. Such a device has a fixed time delay between its initiation and the actual firing of the cutter. When fired, a cutting surface is forced across an opening, severing the support cord. Motion pictures of the dummy sonde test indicated that the sonde was apparently hanging vertically from the parachute 5 seconds after ejection from the plane. To allow for arming and ejection, a pyrotechnic cutter with a time delay of 10 seconds would be adequate.

Choice of Release Mechanism

Although the shackle release system appeared to have several desirable features, there was not sufficient time to develop it for the Windsonde tests. As a result a 10-second pyrotechnic cutter that was easily armed was chosen to release the Windsondes from their parachutes.

GYROSCOPE SPINUP TABLE

The spinup mechanism required for aircraft deployment was much different from that used on the balloon sonde. On the balloon models the sonde was held vertically, and the spinup motor was built into the system. This approach required nearly 40 seconds to spin up the rotor. The higher g-loadings, (30 to 35 g's) as the parachute opened required that the sonde be decelerated within 20 seconds. This required a much faster spinup method. As a result, a "sawhorse" was built that would allow the sensor to be spun up at right angles to the center line of the sonde body. Thus the sonde was laid in the airplane in a horizontal position, and a remote spinup motor was used. The spinup motor entered through a hole in the side of the sonde, passed through a hole designed into the side of the gyro, and into the rotor itself. The sawhorse was built in such a way that its top could be placed horizontal to the earth's surface, allowing the spinup motor to be vertical with respect to the earth's surface, achieving a vertical spin axis for the gyroscope.

The spinup system consisted of a 110-volt, 400-Hz motor, with a Sprague clutch on the end of the shaft. The clutch on the shaft extended inside the gyroscope rotor. When the voltage was applied to the motor, the shaft would start to rotate. The rods that made up a portion of the clutch would roll out the inclines and obtain purchase on the inside of the hole in the gyroscope's rotor. The spinup motor, along with the gyroscope's rotor would reach 12,000 rpm within 4 seconds. When the gyroscope rotor was at the same speed as the motor's synchronous speed (12,000 rpm), a pin was pulled which allowed the motor and drive clutch to drop free. With both the rotor and the spinup motor running at the same speed, the clutch would slide freely out of the rotor without causing any tilt to the spin axis. In this way the spin axis could be accurately set, depending upon the attitude of the aircraft and the settings of the sawhorse as they were adjusted during flight in the plane. To be certain that no damage occurred to the gyroscope rotor, a switch was placed on the side of the sawhorse. This was a rotary switch in which the first position applied no voltage to any portion of the sonde. The next position applied voltage to the squib on the gas bottle which allowed gas to support the rotor. The last position turned on power to the spinup motor.

The base of the table consisted of a 6-inch-wide aluminum channel 63 inches long supported about 33 inches high on aluminum angle struts. At each end, the struts were attached to a base 36 inches wide. The top of the table was a second 6-inch aluminum channel attached at the front by pins that acted as a hinge. A slotted clamp at the rear allowed the top of the table to be leveled regardless of the aircraft pitch attitude. The sonde supports and spinup motor were attached to the table in a manner that placed the center line of the sonde approximately 48 inches above the floor (see Figure 13).

A typical spinup sequence follows: The sonde was placed on the table with the spinup motor clutch inserted into the gyroscope's rotor. A plug was inserted

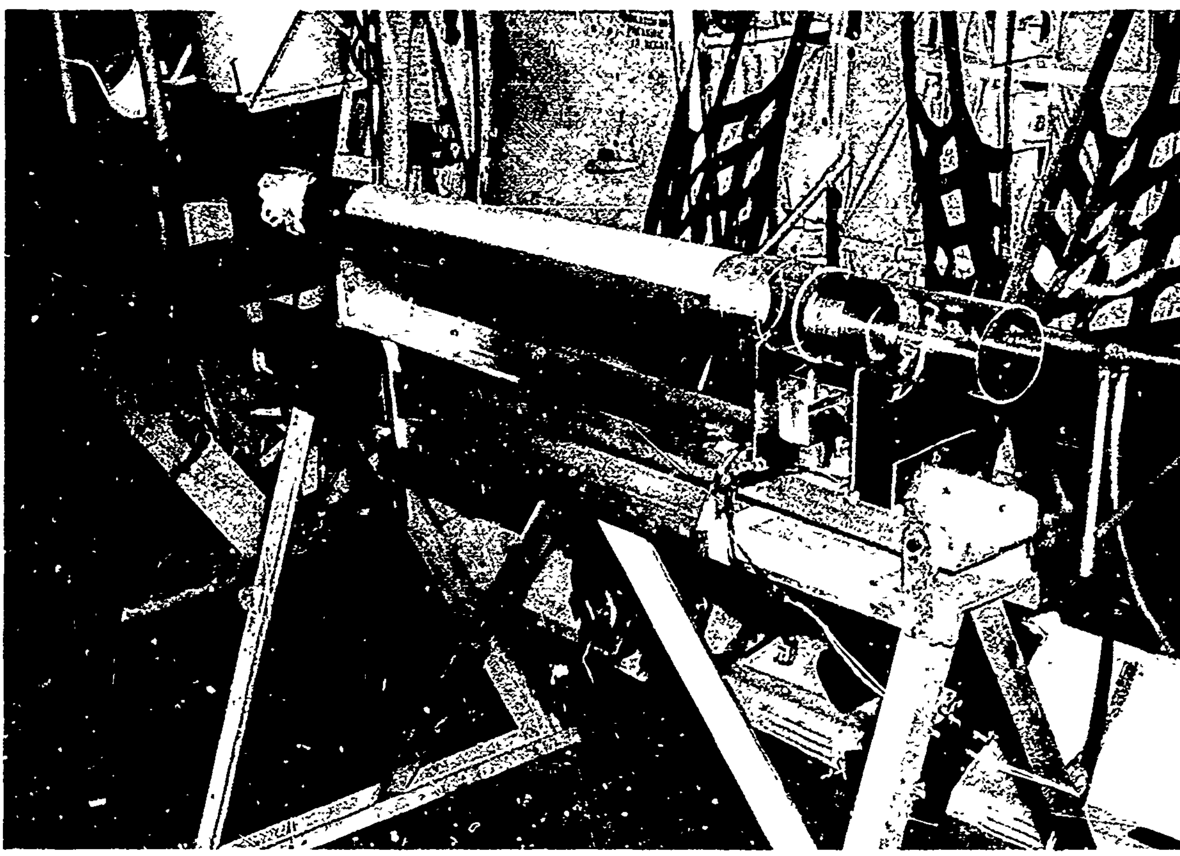


Figure 13. Spinup Table With Dummy Sonde

into the sonde turning on its internal batteries, transmitter and electronics. At the appropriate time, the three-position switch was moved to the second position, opening the gas bottle; then the switch was moved immediately to the last position, turning on the spinup motor. Four seconds later the spinup motor was disengaged, the electrical leads to the gas bottle removed and the sonde lifted from the table. The pyrotechnic cutter was then initiated and the sonde ejected from the plane.

SONDE MECHANICAL MODIFICATIONS

There were two areas in which physical modifications were made to the Windsonde design that had been used for the balloon tests. The requirement for external spinup was one reason for placing the sonde horizontally on the spinup table. This required that a hole be cut in the outer cover of the Windsonde. The hole was slightly larger than the existing hole in the gyroscope and located such that the spinmotor would gain access to the rotor without touching any part of the sonde except the gyroscope.

The second modification came about as a result of the shackle tests. To reduce the possibility of the tail boom bending during the deployment process, as occurred on the first dummy sonde-shackle test, the main boom was made of thin-walled, stainless steel tubing. Two lengths of larger diameter tubing were added at the junction of the tail boom and forebody to give added strength during the apparent whipping of the sonde as it entered the windstream.

SYSTEM ELECTRICAL MODIFICATION

Low signal-to-noise ratios on the earlier drops resulted in a considerable loss of data. Ground-station operation was complicated by the necessity for manual adjustment of receiver output amplitude and roll-sensor d-c level. Even though a reduced transmitter-to-receiver distance was expected for the aircraft-dropped sondes, an improved data-transmission technique was considered necessary. Improvements were made in three areas -- the magnetic sensor for roll position, channel separation to eliminate intermodulation, and in the ground receiving stations.

Magnetic Field Sensor

Since we had decided to use a voltage-controlled oscillator as a subcarrier for one pickoff, it was no longer necessary to use the magnetic sensor which generated a frequency-modulated subcarrier. Instead a thin-film magnetometer that had been developed independently was examined. This thin-film magnetic sensor was much more sensitive than necessary for aspect sensing in the earth's magnetic field. However, when its sensitivity was reduced for this application, it was very stable under conditions of varying temperature and supply voltage.

The relationship between applied field and the rest position of the magnetization vector in thin films is the basis of the thin-film magnetometer. Variations in the component of magnetic field along the sensitive axis modulated the amplitude of the sense-coil signal. When operated in this manner, the sensor output served as a modulated subcarrier signal.

An experimental sensor was constructed to determine applicability of the technique to the Windsonde program. Operating at 14 kHz, 50 percent modulation of the subcarrier amplitude resulted from a 1.0-oersted peak-to-peak variation in applied magnetic field. Carrier amplitude was stable within ± 5 percent over the temperature range +35 to -60°C, and the frequency variation over the same temperature extremes was ±2 percent. A 10 percent supply-voltage variation produced a carrier amplitude change of less than 15 percent.

Sonde Electronics

Throughout the balloon flight test program, intermodulation of the data had created serious problems. We attempted to minimize this problem in several ways. Reducing the post-detection bandwidth of the receiving system resulted in a considerable reduction of the noise problem. Previously, we had used a 25-kHz low-pass filter to isolate the direct-modulated signal from the subcarrier. However, the gyroscope pickoff waveform was not significantly distorted if the filter cutoff frequency was reduced to 10 kHz. To isolate the second pickoff signal from the roll-sensor output, two separate subcarrier frequencies were used. The magnetic sensor used for roll aspect sensing produced a modulated 14-kHz output signal. A voltage-controlled oscillator operating at 22 kHz was modulated by the second gyroscope pickoff signal. Onboard processing decoded the second pickoff signal before it was transmitted, drastically reducing the required bandwidth. We still transmitted one raw pickoff signal, however, to facilitate analysis if some failure occurred.

Onboard angle decoding of the second pickoff channel was accomplished by amplifying and clipping the pickoff signal, then a-c coupling the clipped waveform to a diode-resistor network which compared the positive and negative peak voltages. At the output of the network, the average voltage was proportional to the pickoff angle. This voltage was filtered and used to control a 22-kHz voltage-controlled oscillator. We intentionally did not filter all of the "ripple" on the angle readout, because the ripple signal could be used to determine the gyroscope spin rate if the direct modulation failed. A schematic diagram of the sonde electronics is shown in Figure 14. and a photograph appears as Figure 15.

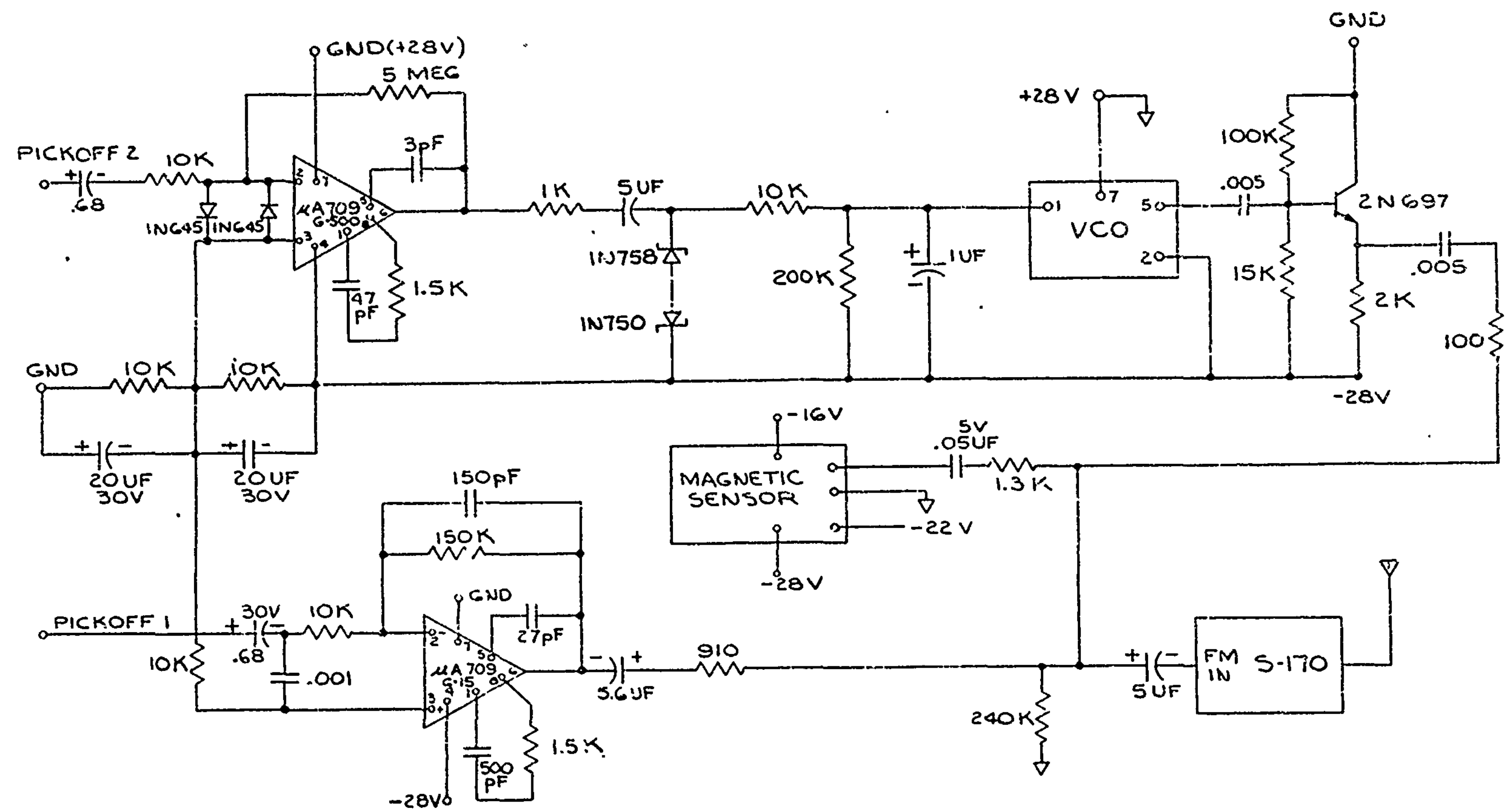


Figure 14. Schematic of Windsonde Electronics

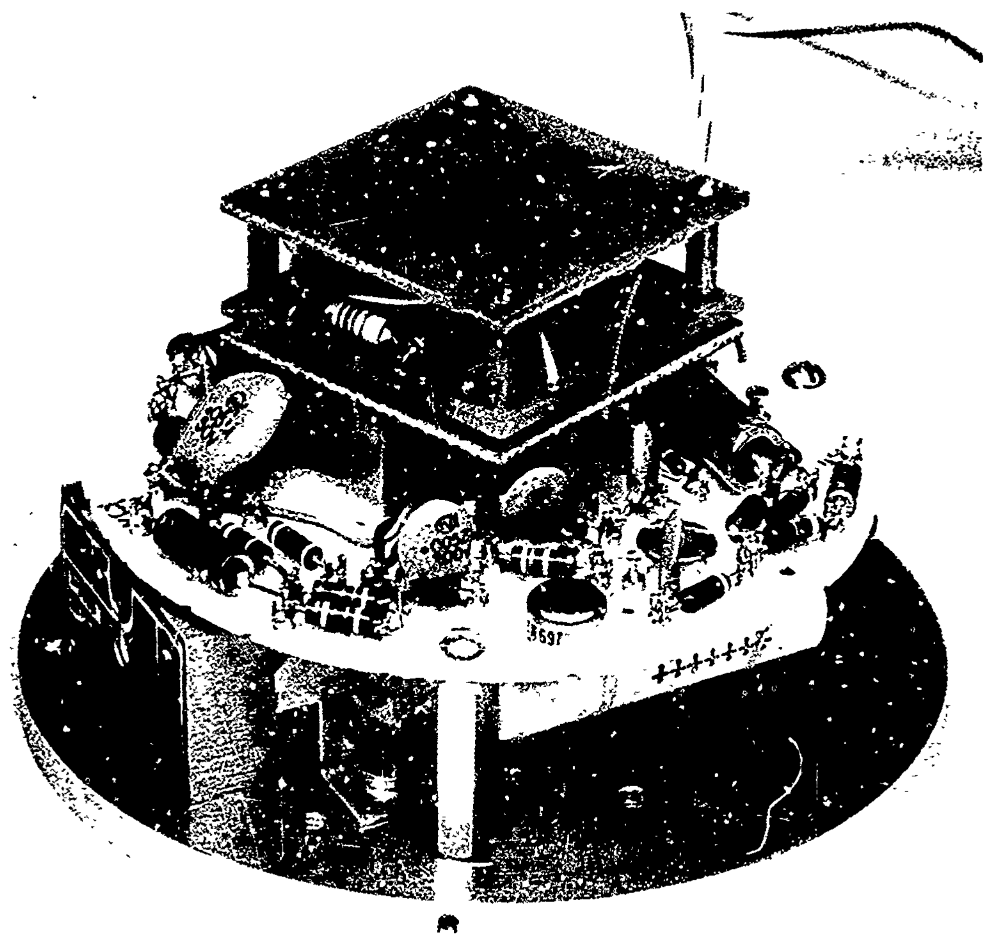


Figure 15. Win'sonde Electronics and Magnetometer

An arrow was scribed on the magnetometer to mark the sensitive axis and was used for alignment with respect to the gyroscope pickoffs. A number of different antennas were tested in the laboratory to determine whether a better antenna system could be used. These all proved that the system that we had been using, a quarter-wave stub using the hemispherical surface of the sonde itself as a ground plane, was as good as any other that was readily available.

Ground Station Electronics

At the ground stations, Nems-Clarke telemetry receivers were again used in conjunction with the GMD equipment. Receiver outputs were fed simultaneously to a 10-kHz low-pass filter, a 14-kHz bandpass filter and an a-m detector, and a 22-kHz telemetry subcarrier discriminator. Outputs of these three devices (the pickoff "1" signal, roll-sensor output and pickoff "2" angle, respectively) were recorded. A block diagram of the receiving schemes is shown in Figure 16 and Figure 17 is a photograph of the ground station.

A slight modification of the ground-station data-recording system was made possible by the acquisition of two tape recorders which had two direct-record channels. The wideband recording capability made it possible to record the Nems-Clark receiver output directly without further processing. With these recording facilities, it was unnecessary to build two complete data-processing systems for the ground stations.

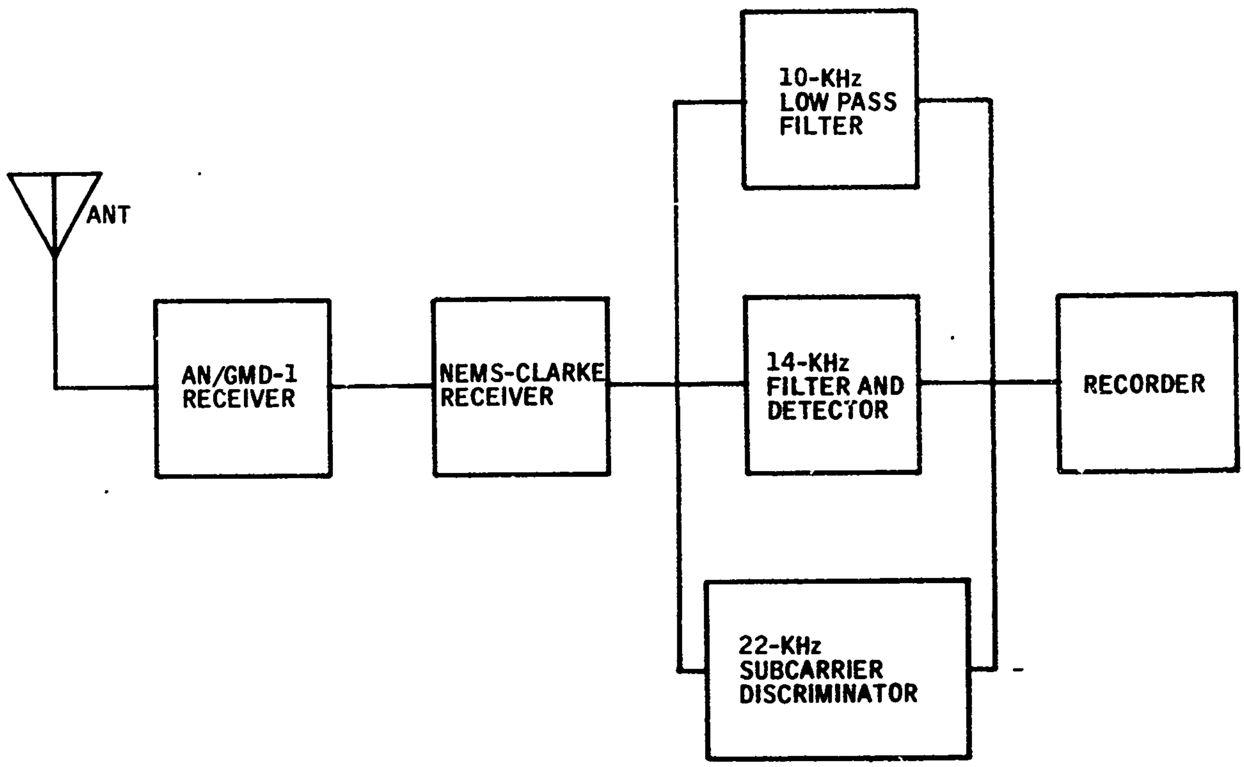


Figure 16. Ground Station Block Diagram

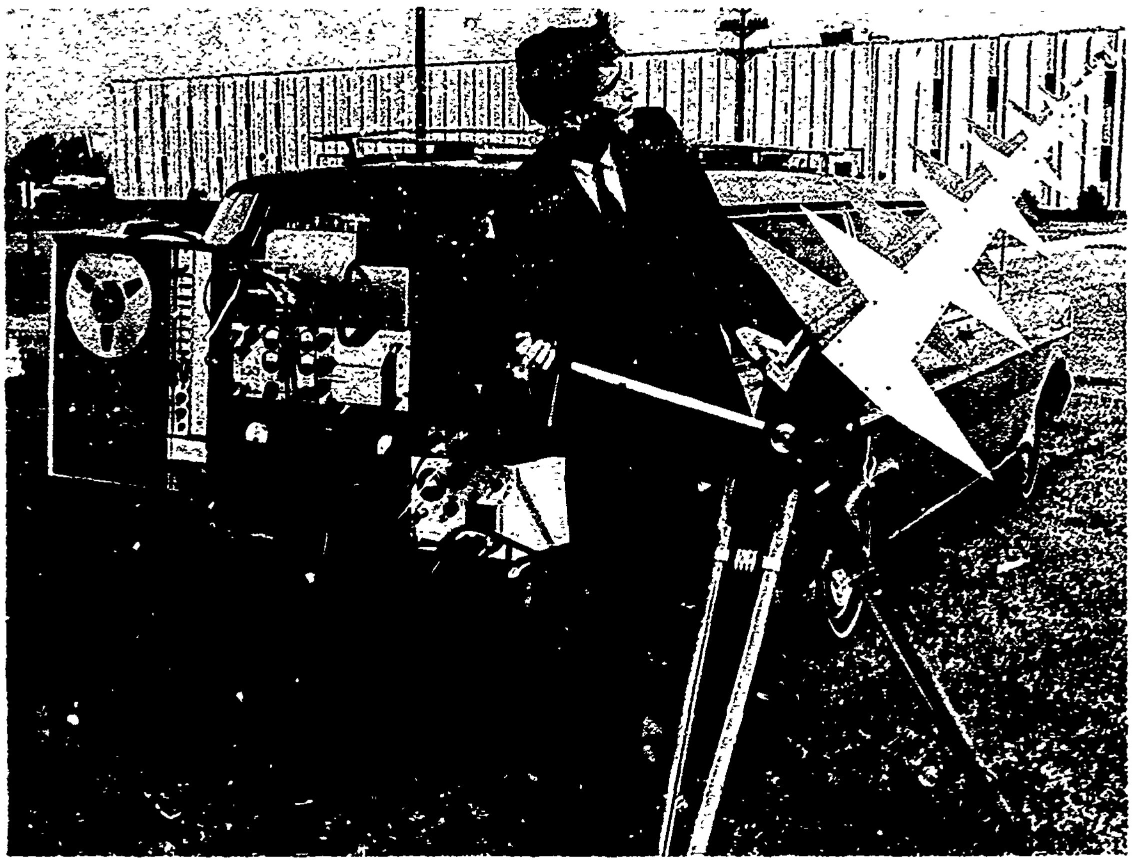


Figure 17. Windsonde Aircraft Test Ground Station

SECTION VII

AIRCRAFT FLIGHT TESTS

The aircraft-deployed Windsonde tests were scheduled in two phases, the first consisting of four sondes with the second having five sondes. In this way any problems that occurred during the first test would be corrected before the second. A typical flight went as follows. The aircraft would fly a straight and level path while the spinup platform was adjusted. The plane was depressurized and two minutes before the drop the sonde was momentarily turned on and checked to be certain it was transmitting. One minute prior to the drop the sonde was turned on for the final time. Fifteen seconds before the drop the rotary switch was rapidly moved through its two positions, opening the gas bottle and turning on the spinup motor. Ten seconds before the drop the motor was released, the switch turned off, the leads to the gas bottle squib removed, and the Windsonde picked up. With five seconds to go the pyrotechnic cutter was initiated, the sonde carried to the rear of the plane and ejected. All of this occurred with the airplane depressurized and the crew on walk-around oxygen.

NOVEMBER 1968 FLIGHT TESTS

Test Events

The flights were scheduled during the week of 3-9 November 1968. The Air Force C-130 that was to deliver the equipment to Holloman Air Force Base and be used on the flight tests developed mechanical troubles with its nose wheel. As a result, other arrangements were made to get the equipment and Honeywell personnel to Holloman AFB while the Air Force attempted to get the nose wheel repaired. Upon arriving at Holloman Air Force Base, we discovered that, due to some mixup, no Operations Directive had been filed for this flight test. The Operations Requirement, which had been carefully prepared and sent through as a preliminary document, had not been answered. The primary result of this was that there was no range time allotted to us for that week. Many discussions were held, and with the assistance of Mr. Hines of the White Sands Missile Test Range, we finally were able to obtain one hour of time on Thursday and one hour of time on Friday, 7 and 8 November, for our tests.

We found that repairs on the C-130 were not going to be made in time for us to fly during that week. With the AFCRL airplane from Bedford, Massachusetts unavailable for use in our tests, we attempted to find an aircraft at Holloman. With the help of Mr. Milford Brown of AFCRL, Holloman Balloon Test Facility, we were able (after much cutting of red tape) to obtain a C-130 aircraft that was flying out of Holloman. We were also able to obtain a local flight crew to use on this flight. Arrangements were made to get our spinup system established on the plane and to locate power to use for the spinup motor.

Personnel arrived from AFCRL, Bedford approximately one and one-half hours before the first flight was scheduled on 7 November. A procedure was established for the test drop at this time with the assistance of the people at King 1, the radar control of the mission.

Two ground stations were again used. One was established at the Jallen GMD site approximately 12 miles north of the drop area. This station contained the primary ground station which was similar to the balloon test ground stations with two exceptions: there was a 14.7- kHz discriminator at this station, and the data was recorded both on f-m and direct channels, allowing us to record the raw data for later processing. The backup station was established at SW-50 site on the range approximately 5 miles from the drop area. The station was established on top of a building used for camera coverage by Land-Air. Both stations were provided with a communications system that enabled them to talk with the aircraft overhead and reasonably well with each other and King 1. Messages that were unable to go directly could be relayed through the aircraft. The backup ground station was similar to the primary one with the exception that the 14.7- kHz discriminator was not used, and the angle processing was not done at the ground station. This data was recorded directly as raw data and was then available to be fed into the ground station once we were back in the laboratory.

On 7 November at 10:30 a.m. the aircraft made its first pass over the drop site. The flights were scheduled to be at a pressure altitude of 25,000 feet, which was the limit of the C-130 aircraft being flown out of Holloman. On the countdown, the dummy sonde using a pyrotechnic release scheme was ejected. The ejector and release appeared to function properly. On the next pass the first live sonde was ready. Twelve seconds before the drop zone was reached, the gas-bottle squib was fired and the spinup motor started. Five seconds later the spinup motor was withdrawn from the sonde and the sonde picked up. At this time the pin was pulled that started the 10-second delay on the cutdown squib. The beacon transmitter, which was allowing the ground stations to track the aircraft as it approached the drop zone, was then turned off. At T = 0, the sonde was pitched out of the aircraft tail first.

Once the sonde was ejected from the airplane, two things were discovered: first, the gyroscope rotor had not been spun up, and second, the cutdown did not release as the sonde fell on the parachute. Between the second and third drops, the aircraft was forced to remain out of the pattern due to another airplane over the target area. As a result the plane was open for a much longer period than had been anticipated and the temperature in the compartment dropped much lower than anticipated. On the third drop, the second live Windsonde was prepared and ejected, and it appeared to function properly. The gyroscope was spun up, and we could hear it spinning down as we recorded it at the ground station. However, this unit was not released from the parachute either.

Back in the laboratory, a debriefing was held to determine what had caused the malfunctions on the two live Windsondes. It appeared that, on the first unit, the activating pin did not come out although it had been pulled. Since there was no rotor spinup, this had little consequence. In fact, what it did do was provide data on the terminal velocity of the sonde on the parachute. Since the sonde will have reached terminal velocity by the time it is cut loose, this is essential to know in determining initial conditions.

On the second sonde, the pin was definitely pulled loose. However, the turbulence in the back of the aircraft caused the parachute to wrap around the fins, and it was apparent that, although the squib did fire and sever the line attaching the parachute to the sonde, release did not occur. This sonde then gave us no wind data. However, it did tell us that there was sufficient gas bottle supply and sufficient gyroscope spin life to function for a full 30,000-foot drop.

Movies taken onboard the aircraft of the actual sonde ejections showed two things: first, they confirmed that the parachute shroud lines did in fact entangle themselves around the tail fins on the second live Windsonde during deployment. They also showed that, even though the parachute and tail fins were pitched into the airstream first, the sonde still fell and turned into a nearly vertical position before the chute inflated. This caused a severe torquing of the sonde about its center of gravity. However, despite this we found that the gyroscope did not bottom out. Since there appeared to be a severe buffeting of the sonde causing it to strike the airplane when ejected in a tail-first attitude, we decided to eject the next units nose first. We felt that this way the sonde might clear the aircraft before the parachute inflated.

The radar during the first day was able to track the aircraft properly, and give us its position as it approached the drop zone. However, it did not track any of the sondes that were ejected from the plane.

On 8 November, two sondes were again ejected. The first sonde hit the aircraft as it was ejected, and one of the fins containing an aileron broke off and flew back inside the plane where it was recovered. The second sonde, although buffeted, did not appear to strike the aircraft as it was ejected. The received data implied that both sondes were functioning properly. Radar was able to see each sonde as it left the aircraft and tracked one of the sondes to the ground. However the DIGS had not been turned on and no record was available. Figure 18 shows the sonde hitting the aircraft as it was ejected.

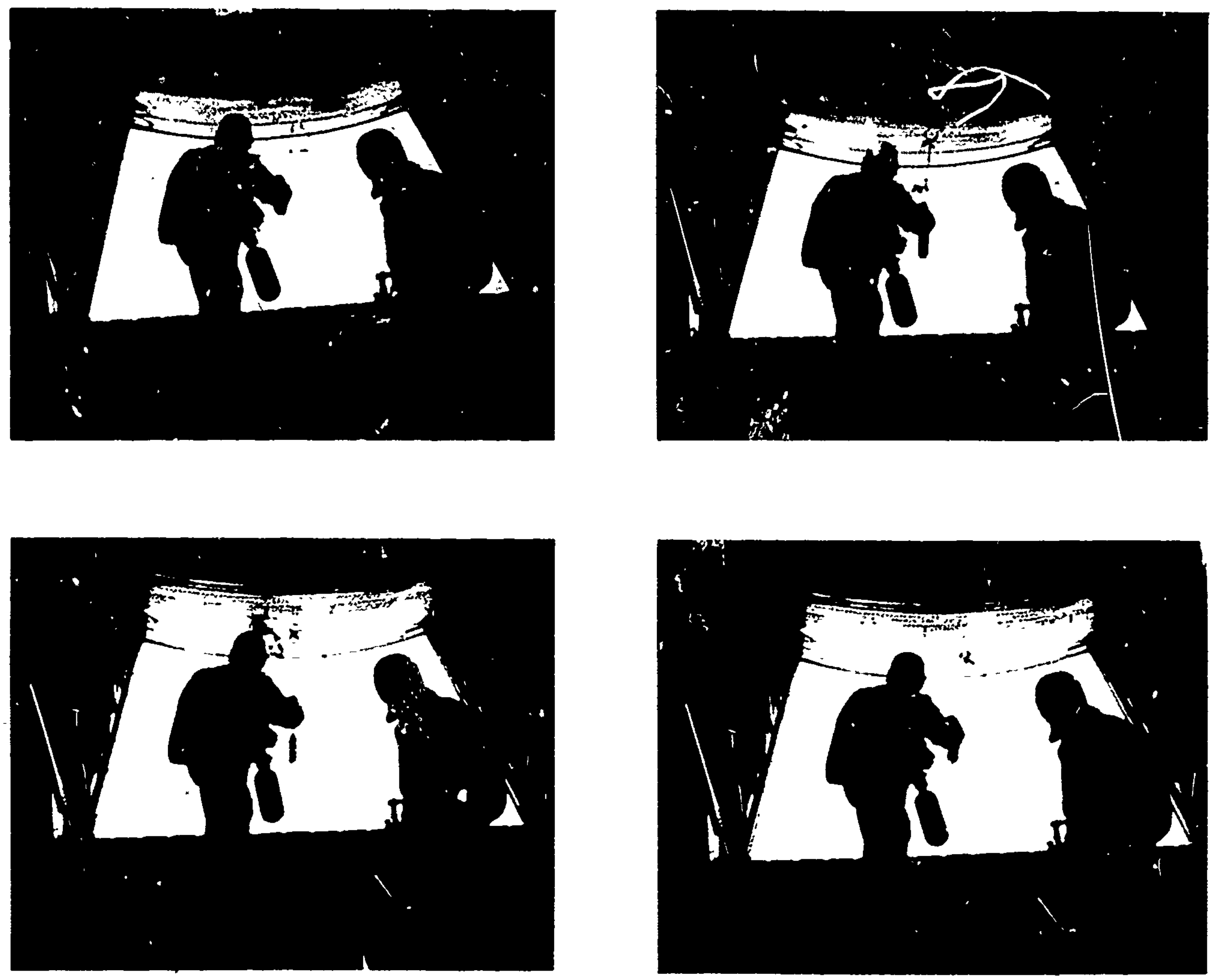


Figure 18. Sonde Ejection Sequence for November 1968 Flight (Showing Sonde Hitting Aircraft)

Test Results

Neither of the first two sondes was released from its parachute. However, some information was gained from each unit. The first unit did not have a gyroscope signal but yielded terminal velocity information of the sonde-parachute combination -- approximately 80 ft/sec. The second sonde's parachute was entangled in the Windsonde fins, not allowing it to fully inflate, and, as a result, it fell faster. However, it did let us know that the gyroscope survived the ejection and ran long enough for a 30,000-foot drop.

The third sonde indicated that its gyroscope was capable of being spun up, of withstanding the shock of ejection from the aircraft, and of making the free fall without losing bearing support. However, since this sonde had its tail fin broken off, it tended to act somewhat erratically. It did not roll as planned. It tended to wobble about some angle, rather than continue in a corkscrew rolling action as it fell. Although data was received, it was not reduced since the aerodynamics of a broken-fin sonde and the erratic roll behavior invalidated this sonde's data.

Due to the severe turbulence directly behind the aircraft and the problems concerning hitting the aircraft and the resulting odd roll rate, the first step in analyzing the data from the fourth sonde was to examine its roll rate. The sonde was designed with ailerons in the fins to roll it clockwise when looking down the tail of the sonde. These ailerons kept it rolling between one and two revolutions per second as the sonde fell. In addition, as the gyroscope rotor slowed down it transferred momentum to the body of the sonde, also tending to keep it rolling clockwise. The sonde started out with a counterclockwise roll rate of about 1/2 rps which increased to nearly 1 rps. The maximum counterclockwise rate occurred at about 15 seconds into the drop. At this point the sonde started to decrease its roll rate toward zero and reached that point at about 30 seconds into the drop. It then remained not rolling for 7 seconds before it started to roll in the proper direction.

There were three forces that would tend to affect the roll rate of the sonde. The first was the aileron force which tended to roll the sonde in a clockwise direction if it were acting as designed. The second was the transfer of momentum due to the decaying of the gyroscope rotor's speed. The third was the damping force of the air on the sonde which tended to slow it down, regardless of which direction it was trying to roll. The initial roll rate of counterclockwise rather than clockwise could have been imparted due to the rotation of the sonde and parachute combination after it was released from the plane. However, the increase in the sonde's roll rate as it fell can only be due to an additional effective aileron force on the sonde in the opposite direction to the designed aileron. At the point where the sonde changed direction, some effect to negate this undesired aileron force must have taken place, such as a cracked or damaged fin being released from the sonde.

The stoppage of the sonde as it reached the zero roll rate position was unusual, and one possible explanation is as follows. If the sonde was damaged upon being ejected from the aircraft, as one might expect from pictures of the other sondes, it was likely that the tail boom was bent. With this bent tail boom, it was possible that as the sonde reached the zero roll rate condition, it would try to "fly." In this condition the sonde would not roll. This would be a quasi-stable condition which could be changed by an additional torque acting on the sonde as it fell. Such a torque could be a change of the wind speed or direction, which did occur, according to the radiosonde runs, as the sonde fell through this altitude range. Once it was disturbed out of this quasi-stable state, it continued to roll in the direction of the remaining torques. This explanation requires both that the sonde tail boom be bent and the tail fin itself be damaged as it was ejected from the plane. Movies of the other sondes indicated that they did strike the plane as they went out, and the recovery of a piece of a tail fin from the sonde No. 3 shows that it also struck the underside of the plane as it was ejected. Thus this explanation is plausible.

The lack of actual wind information was disappointing, although the tests were quite valuable. First, the gyroscope was able to successfully survive the g forces that it encountered during the sonde's ejection, the turbulence at the rear of the plane, and striking the plane as it was ejected. In addition, the parachute release mechanism appeared to function properly when not tangled in the fins. The data transmission and reception were very good, and there was no difficulty with the electronics onboard the sondes. The data that was reduced showed no indication of cross modulation between the pick-offs as there had been in the early portion of the program. It appeared that the only real problem that remained was the safe ejection of the sonde from the aircraft.

WINDSONDE MODIFICATIONS

Three areas required some attention before the last series of flight tests could be completed. The sonde had to be protected until it was clear of the turbulent zone around the deploying aircraft. The tail fin was strengthened in case it was struck during deployment. The proper initial roll had to be imparted to the sonde as it was released.

Sonde Protection

The protection of the sonde during deployment was approached in two ways. The sonde was placed in a protection tube 5-1/2 feet long. Six inches from the top of the tube was a plate. The sonde was attached to the bottom of the plate inside the tube with a reefing line cutter ready to release it from the plate. Above the plate was the packed chute (see Figure 19). As the sonde

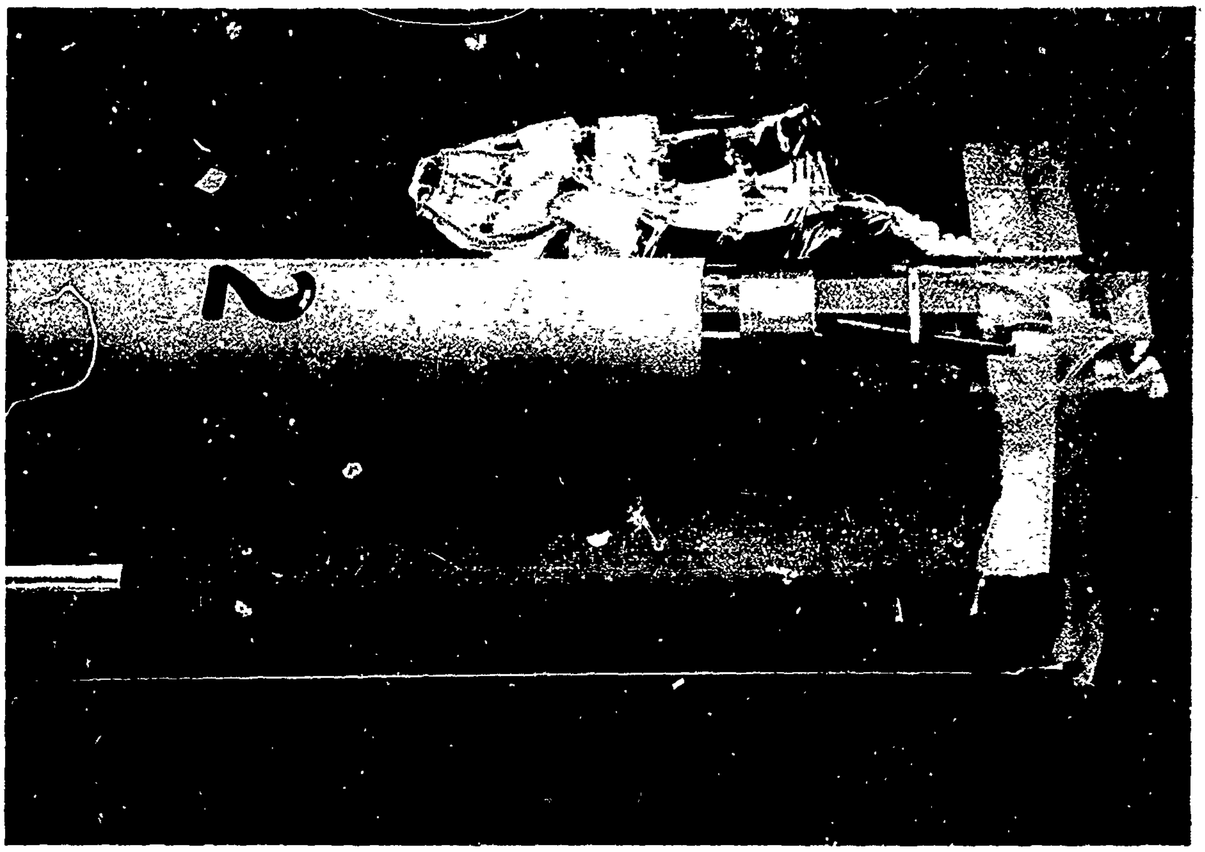


Figure 19. Aft End of Sonde Protection Tube

was ejected, a light, static line pulled the parachute out of the tube, inflating it. The parachute remained attached to the tube until it impacted. When the reefing line cutter released the sonde from the tube, the sonde began its wind measurement.

A "sugar scoop" was made to assist in safely ejecting the sondes from the aircraft. The scoop was 5 - 5/8 inches in diameter and 106 inches long. The rear half of the bottom 66 inches of the tube was cut away, allowing the sonde to eject cleanly. As the sonde in its protection tube fell through the ejection tube, it was at one point entirely in the half-cylinder area. As the bottom part of the sonde-tube reached the airstream, it was blown out of the half cylinder toward the rear of the plane without striking the ejection tube or becoming entangled in it. The sonde package was 1 foot below the aircraft at that time. The ejection hole was approximately 3 feet from the hinge of the ramp on the back of the C-130, and thus clear of the severe turbulent area (see Figure 20).

A number of discussions were held with the Airborne Engineering Group at Hanscom Field concerning the "sugar scoop". A test was made at Hanscom proving that the scoop could be safely inserted and removed.

Sonde Tail Fin

Since it appeared that the tail fins and booms were being damaged as they exited the aircraft, the tail fins were modified. The cruciform fin with a 6-inch span was replaced by a 4-inch-diameter ring tail. The cruciform shape remained to support the ring tail. In this way we effectively had the same lift as before, when the sonde was at an angle of attack. The steel tubing that made up the ring tail was heavier than wanted but strong enough to reduce the possibility of breakage.

Initial Roll Rate

Several methods for giving the sonde an initial roll were examined. The best approach was to put a small pin in the side of the sonde. This pin fit into a slot cut in the protection tube. As the sonde fell from the tube, the pin slid down the slot. The moments of inertia of the sonde and tube were nearly the same. The slot was cut to uniformly accelerate the sonde twice as fast as desired, since the reaction force would counterrotate the tube (see Figure 21).

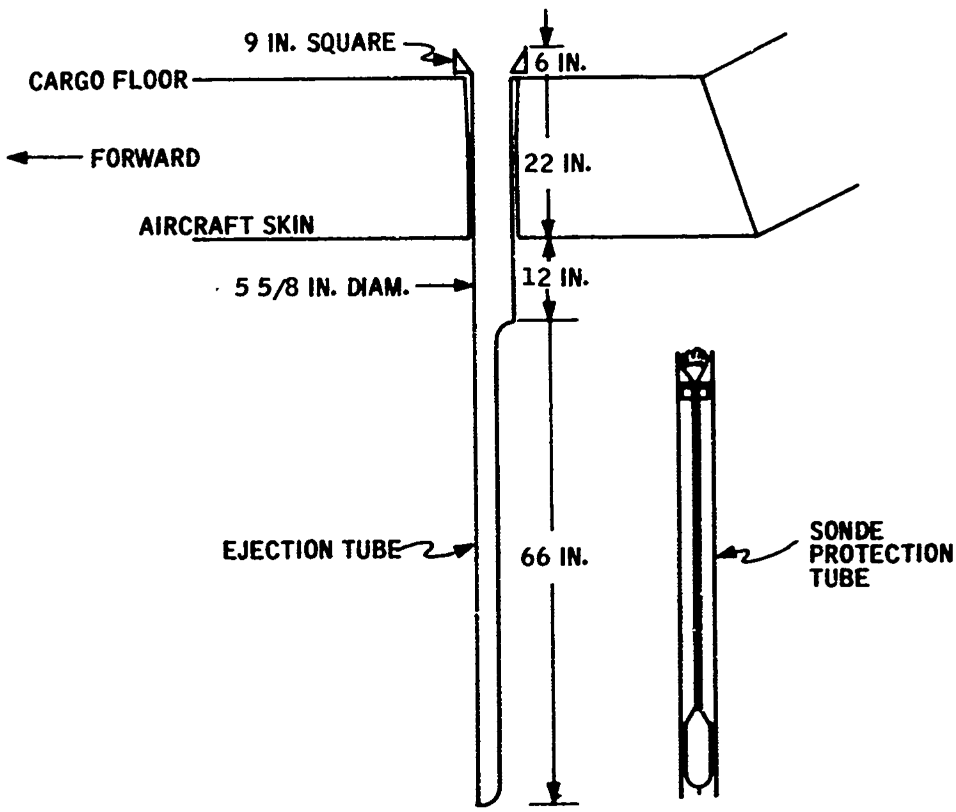


Figure 20. Windsonde Ejection Method

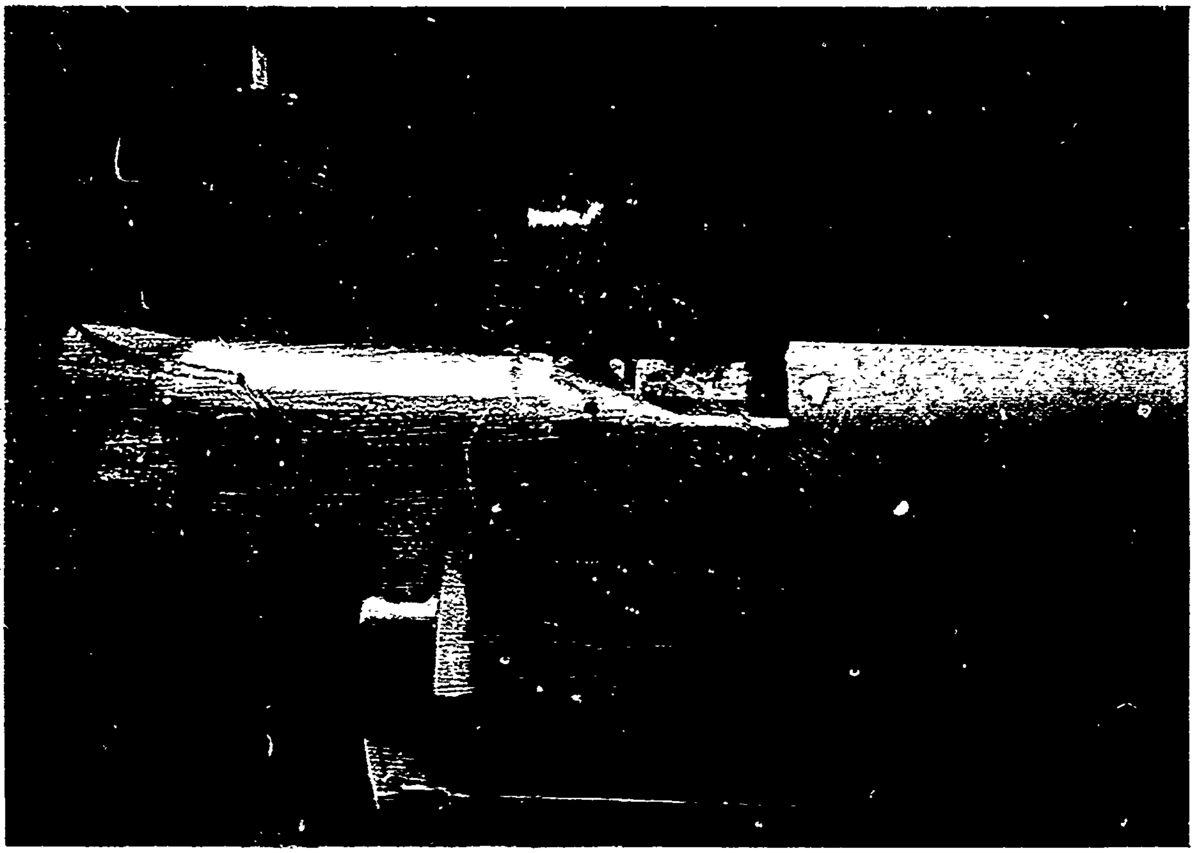


Figure 21. Roll-Inducing Mechanism in Forward End of Protection Tube

APRIL 1969 FLIGHT TESTS

Test Events

Preparations for the April 1969 flight tests were much better than for the November flight tests. The Operations Directive and its modifications had been taken care of, and the scheduled air time was available for us. Since a new approach was being used on the ejection of the sondes, a dummy flight test was scheduled. For this test we had a camera plane flying slightly below and to the rear of the C-130. This plane was able to photograph the sonde as it fell in its protective container from the sugar scoope. In addition Col. Church was to photograph the sonde as it trailed behind the airplane.

On Monday, 21 April, the aircraft took off to make the dummy sonde drop. This sonde consisted of a weight attached in a tube that matched the weight distribution of a real sonde. Shortly after taking off, the C-130 aircraft was forced to return to the base, because of an apparent generator failure in the number 3 engine. This problem was repaired, and the aircraft again took off for the mission. The plane flew at 25,000 feet over the White Sands Missile Range with the camera plane flying slightly behind it. The camera plane developed radio trouble and nearly caused a second aborted flight. However, just prior to the drop time he was able to make intermitent radio contact with the C-130. In order to be certain that the camera plane knew when the drop took place, the C-130 rocked its wings 30 seconds before the sonde ejection.

The procedure for dropping the dummy sonde was identical to that for the subsequent dropping of live sondes. The dummy sonde was placed on the spin table as the countdown reached the proper start point. The sequence was simulated, and the sonde was carried to the ejection tube in the floor of the aircraft. At the proper point it was allowed to drop out of the tube. The 10-foot length of monofilament line was attached to the inside of the aircraft and to the top of the parachute. As the sonde fell out of the tube, the line deployed the parachute.

The camera plane and the camera onboard the C-130 obtained photographs of the dummy sonde as it was deployed. Radar was able to track the aircraft and vector it over the Salt Target area and was able to locate the sonde and parachute combination as it came out of the plane. However, they did not have the DIGS operating at the time so we could not get any information concerning the sonde's fall rate. The movies of the ejection indicated that the tube did not strike the aircraft at all and the tube was not subjected to turbulence. The parachute deployed nicely and the entire system functioned well.

On Tuesday sondes No. 3, 4 and 5 were given their final checkout. The ground stations had their tape recorder levels set. The parachutes and their static lines were attached to the sonde tubes. Since one of the transmitters, (unit No. 2), appeared to be malfunctioning, a spare transmitter was obtained. This transmitter was installed on the following day and appeared to work properly.

Two ground stations were established in the vicinity of the Jallen GMD site.

Each of the sondes was placed on the spinup table to be sure that the spinmotor could make contact with the gyroscope rotor. The spin table was installed in the aircraft and the electrical connections checked to be certain that everything would function properly.

On Wednesday, 23 April, three drops were scheduled. Fifteen minutes prior to the first drop, the photo plane pilot reported that his camera was not working. Five minutes later he had managed to repair it. We had decided to go ahead with the drops without the photo plane if necessary, since the pictures of the dummy sonde had showed all was well.

Although we had the range for our mission, another plane was flying in the same airspace. As a result, the C-130 had to climb from 23, 500 feet to the drop altitude of 25, 000 feet just prior to the actual drop. At 4 minutes to the drop, we were informed that there would be no radar tracking of the falling sondes. After much discussion, this problem was resclved, and we were able to get permission for the DIGS to track the sondes as they fell. The permission came approximately 2 minutes before the first drop.

Each of the three drops went off successfully (see Figure 22). On the first drop, the radar was able to track the parachute as it left the plane but was unable to see the sonde fall from the parachute. On the second drop, sonde 4, the radar saw the parachute as it left the plane and was able to follow the sonde as it fell to the ground. On sonde No. 5, the radar was unable to locate the sonde, and only tracked the parachute. Sonde No. 3 had no gyroscope signal; the other two units appeared to have good data all the way. Permission was obtained from mission control personnel allowing the ground station operators to look for the sondes. However, they were unable to find either the sondes or their parachutes and protective tubes.

On Thursday, 24 April, sondes 1 and 2 had their final deviation levels established, and the ground stations were checked out. Both units were then placed in their protective tubes, and the parachutes and static lines were attached. With the slight problem of the lack of DIGS on the Wednesday flight, we made certain of getting tracking on the next day.

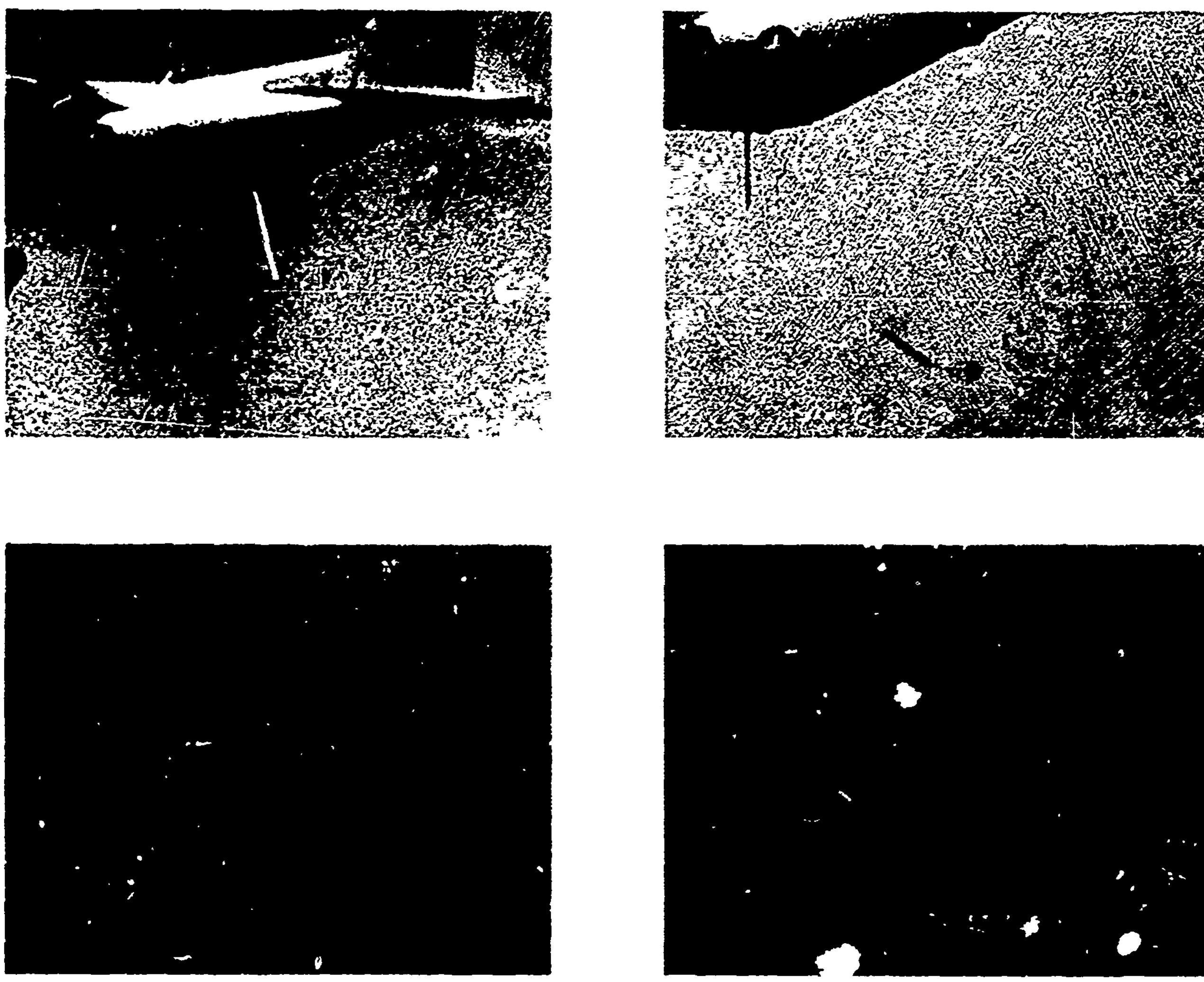


Figure 22. Sonde Ejection Sequence for April 1969 Flight

In viewing the films from the Wednesday flight, we found the chase plane on the first drop slightly out of position. However, the films taken onboard the C-130 and those taken from the chase plane for the other two drops showed that each of the units performed well. On one unit you could actually see the sonde drop out of the tube. The wing tank of the chase plane obscured the camera's view just as the sonde was becoming vertical. As a result we requested that the pilot make a shallow turn as the sonde passed him to obtain longer coverage. This was scheduled for the Friday flight.

On Friday, 25 April, two sondes were ejected from the C-130. On both drops the radar again tracked the parachutes and was unable to find the sondes. However, both sondes appeared to give good information. Upon landing, we discovered that the roll-inducing portion of sonde No. 1's protective tube had been broken off. As a result this sonde did not get its initial roll.

Again the ground station operators attempted to find the sondes or their parachutes, but again were unable to find any portion of the unit. It appeared that a low-flying helicopter would be the only way to locate the pieces.

The two ground stations were located within a few hundred yards of one another at the Jallen GMD site. This is approximately 15 to 20 miles from the Salt Target, the area where the sondes were dropped. Radiosonde runs were made before and after our mission from the Holloman site. This is 25 to 30 miles in the opposite direction from the Salt Target Area. The ground winds in the various areas were quite different, and, as a result, the comparison data at low levels should be expected to be different.

For the first time we were able to have radar track one of our sondes as it fell to the ground. Unfortunately there were three problems with the radar data. First, the data as it tracked the plane indicated that the aircraft was changing altitude quite drastically. Those onboard the plane implied that this did not occur. Second there was a gap in the data during the time period when the sonde was going out of the plane. Apparently as the radar switched from the plane to the sonde-parachute combination, the data was too random to use. On the one sonde that was tracked as it fell, there was again a gap in the data which occured at the time when the sonde was released from the parachute. These gaps are both on the order of 5 to 6 seconds.

The primary use of the radar data was to give us the horizontal and vertical velocities of the sonde-parachute combination at release. A secondary effect would be to give us position, horizontal and vertical velocities and accelerations of the sonde as it fell through the wind profile. In this way we would be able to determine how the sonde was responding. The indicated actions of the free-falling sonde as presented by the radar track are not consistent with what one would expect. For example there are positive and negative acceleration changes of 38 ft/sec occurring within a 2-second time frame. On a free-falling sonde this is not possible. The result is that the radar data, while helpful, was not sufficient and quite disappointing in aiding our system analysis.

Test Data

All five of the sondes were released from their parachutes and data received at the two ground stations. On sonde No. 1 there was no roll information at the beginning of the drop. This was due to the loss of the front end of the protection tube as discussed earlier. The roll rate increased as the sonde fell. During the period when the sonde was not rolling at the proper rate, it was difficult to determine the sonde's position. As a result there is some uncertainty in the early points of sonde No. 1. However good data was obtained. Sonde No. 2 had no roll problems. This sonde appeared to perform satisfactorily all the way to the ground.

On sonde No. 3 there was no gyroscope signal. Apparently, the spinup motor was not engaged in the gyroscope's rotor with the result that the gyroscope was not spun up. However, all other parts of the data transmission functioned properly on this unit. The roll rate did change as the sonde fell. This was probably due to the lack of the gyroscope rotor's transfer of angular momentum as it slowed down. Sonde No. 4, the unit that was tracked by radar to the ground, had pickoff 2 only. The VCO signal was not present at all. This could be due to the failure of the pickoff, or some component in that part of the circuit.

As has been shown in the past, it is possible to reduce the data with only one pickoff. This was done on unit 4. Number 5 appeared to have no difficulties. Data from both pickoffs were received, and the information appeared good all the way to the ground.

The radar on four of the five units did not switch from the sonde-parachute combination to the sonde itself as it was released. It was able to find only sonde 4. In each case, the radar data at the time when the sonde was released was incomplete. The result was that we are uncertain of the sonde's relative velocity at the moment of release. This information is essential to reducing the data. Although the aircraft attempted to fly a straight-and-level path, we are uncertain as to its attitude at the instant of release. The sawhorse was positioned sometime before the release point and could easily be off by a degree. In addition, if the plane had been in a shallow bank on the order of 1 degree, the appearance onboard the aircraft would be that it was flying level. This gave us the problem of knowing whether the gyroscope had uncaged while vertical.

Two radiosonde runs were made from the Holloman site on each of the days that we had Windsonde drops. There was a difference between the two runs of 10 to 20 ft/sec and 20 to 60 degrees in direction.

The first attempt at reducing the data did not take into consideration the unknown initial velocity of the sonde. The data was compared with the radiosonde data. There appeared to be a difference in the data that increased as the sonde's altitude decreased. This implied a fixed vector difference between the computed data and the radiosonde data. If so, a fixed vector added to all of the data points should correct for this uncertainty. This vector would be a sum of any errors in the initial tilt angle and of the uncertainties in the sonde initial velocity.

At specific points in the drop, the average of the two radiosonde runs was plotted on polar graph paper. The Windsonde information was then plotted for similar points. Vectors were drawn between the two data points. In general, the vectors increased with time as one would expect if the error was indeed due to the initial uncertainties. One would expect that the uncertainties would be different for each sonde since the ejection time was different for each sensor, and the uncertainty of the plane's attitude and that of the spinup table would not necessarily be the same each time. The expected ballistic parameter of the sondes indicated that either the start altitude was lower than indicated or the impact area was higher than at the Holloman site. If not, the sonde's ballistic parameter had to be considerably lower than anticipated. The data were calculated using a compromise ballistic parameter.

The wind speed data for sondes 1 and 2 are shown in Figure 23, and wind direction data is given in Figure 24. Similarly, sondes 4 and 5 are shown in Figures 25 and 26. The data as shown for the radiosonde runs were smoothed by the operator over 2000-foot intervals. The data from the Windsondes has been smoothed over approximately 200-foot intervals.

Looking first at Figure 23, we find that the wind speed information between the two sondes agrees quite well until the low altitudes are reached. Of interest are the strong similarities between the two curves at approximately 14,000, 13,000, and again in the 9,000-to 10,000-foot range. The wind speed as indicated by the Windsondes decreases more rapidly than that shown by the radiosonde runs. If the ballistic parameter was as low as indicated by the one radar track data, then the curves essentially should be pulled down such that the peaks at the 10,000-foot level are about 1,000 feet lower. This would have little bearing on the high-altitude data. If, however, the data started at a somewhat lower altitude, then the entire curves would be shifted downward. The wind direction information as shown in Figure 24 shows the same effect. The wind directions agree very well until we get into the 8,000- to 9,000-foot altitude where the Windsonde starts to change before the radiosonde does. However, at this point there is approximately 80-degree difference between the 10 and 12.00 o'clock radiosonde runs.

Figure 25 indicates that the two Windsondes, 4 and 5, agree with one another better than the two radiosonde runs do. However they all tend to agree with one another quite well. Again the similarities in the shape of the Windsonde

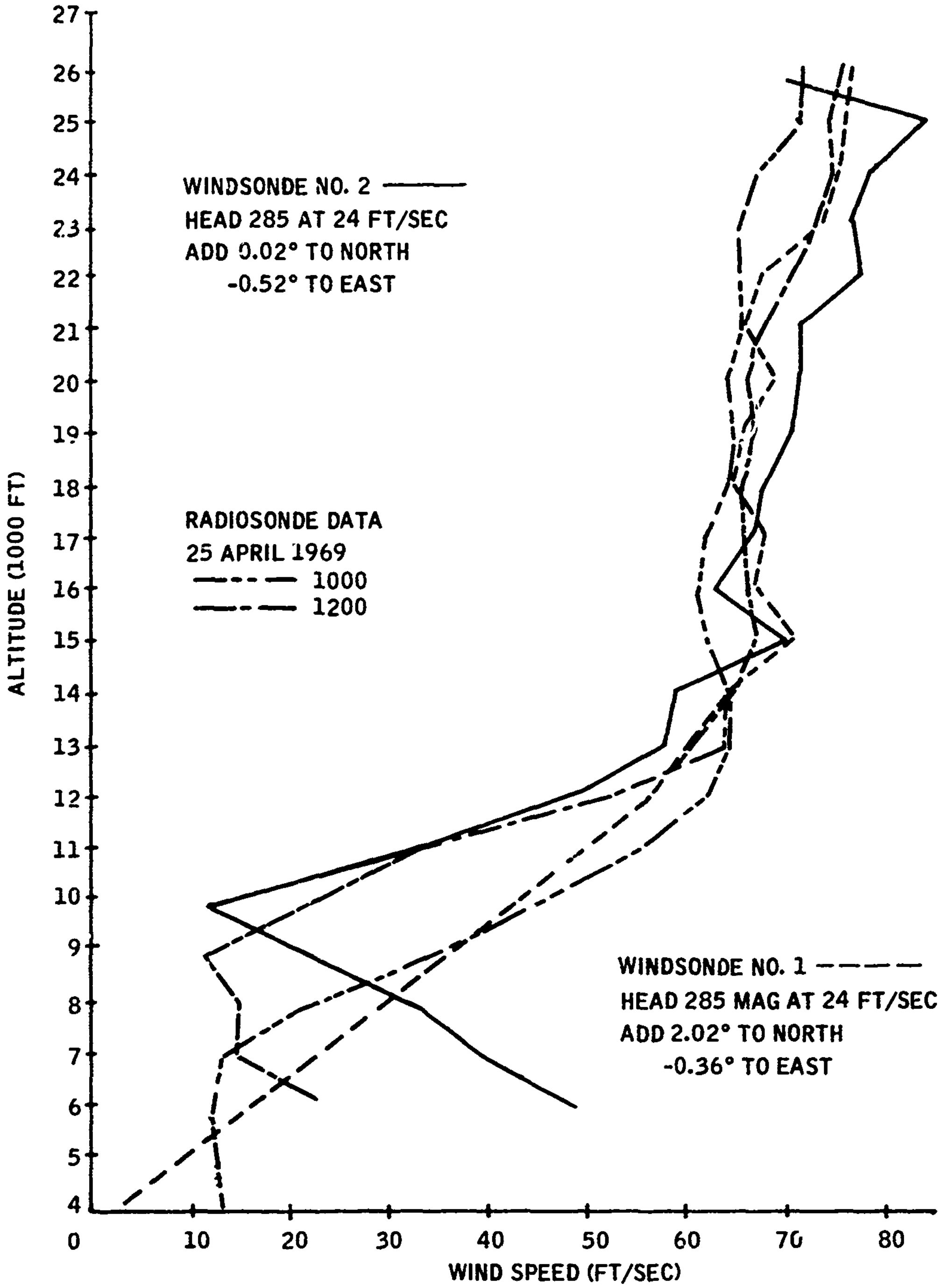


Figure 23. Wind Speed Data - Sondes 1 and 2

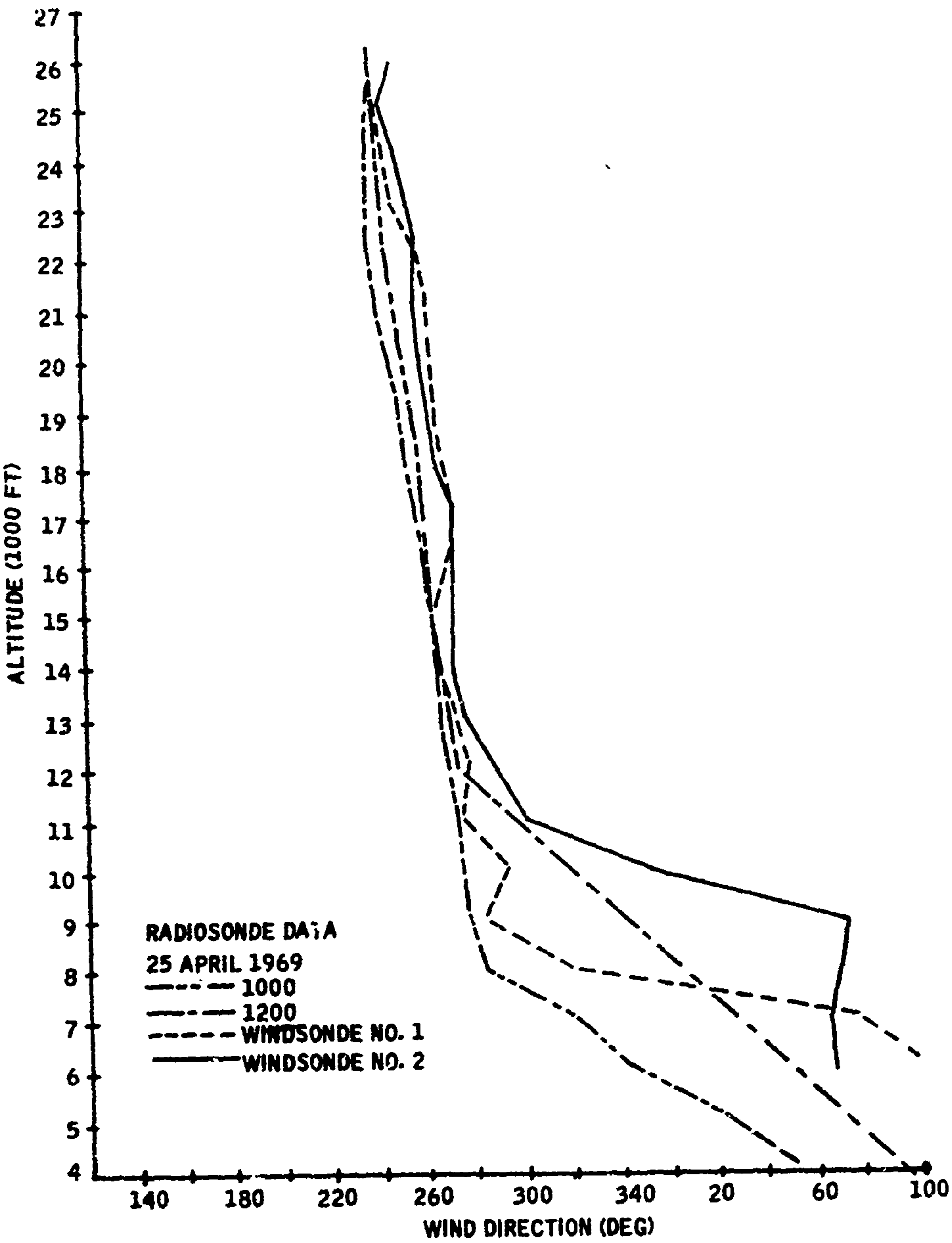


Figure 24. Wind Direction Data - Sondes 1 and 2

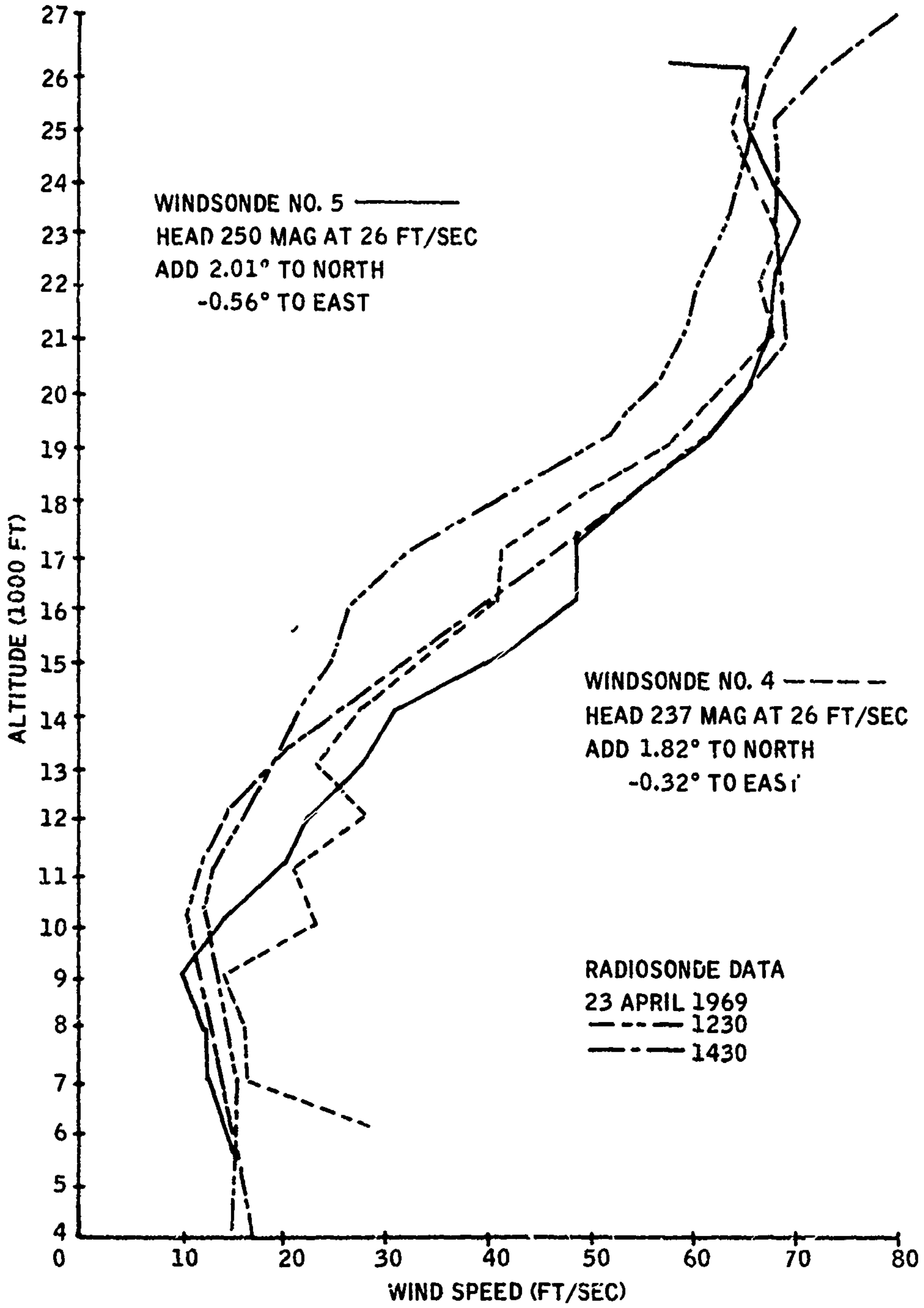


Figure 25. Wind Speed Data - Sondes 4 and 5

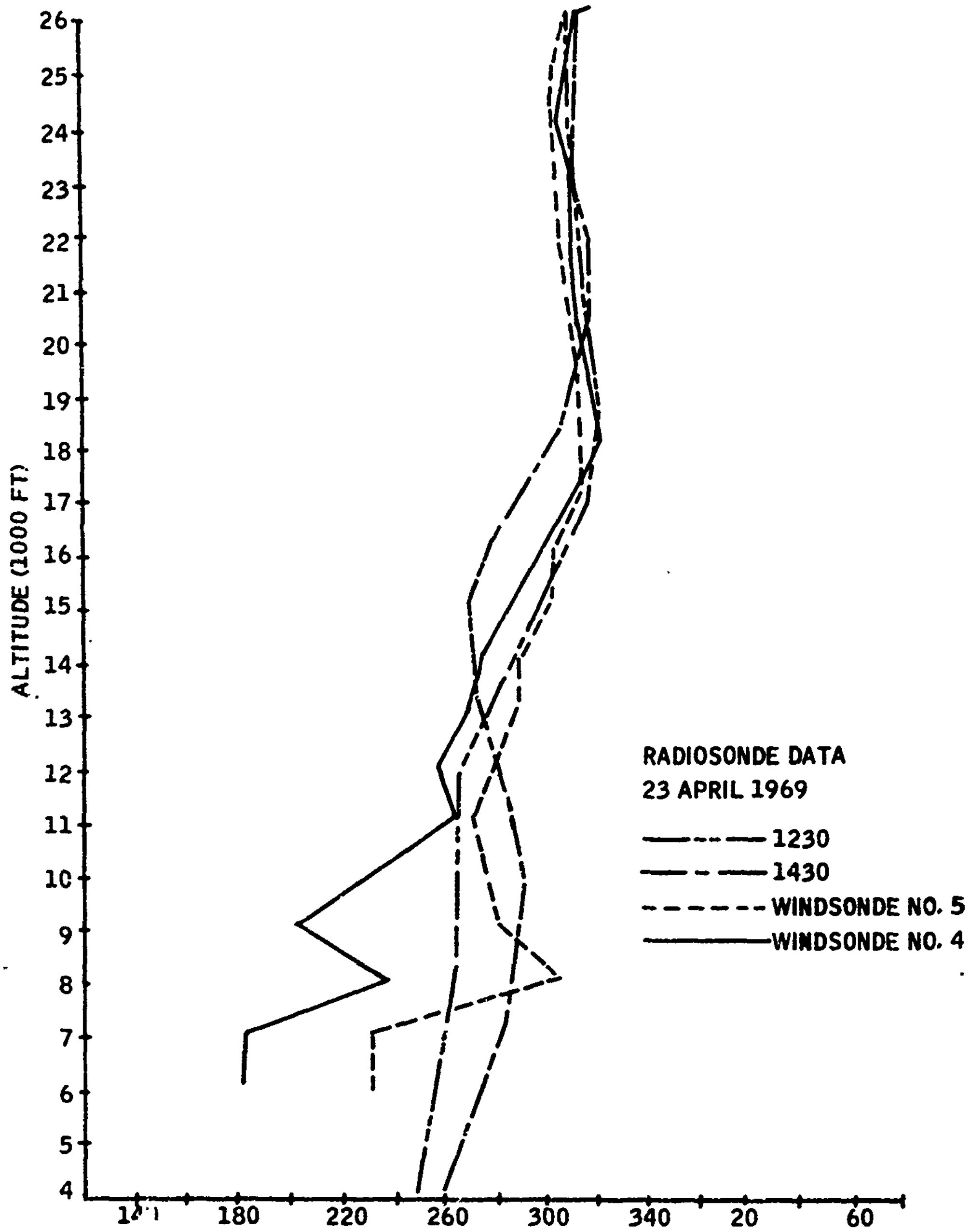


Figure 26. Wind Direction Data - Sondes 4 and 5

runs is evident at the 16,000-foot level and again at the 9,000-foot level. The "stretching" of the curves holds as before since the value chosen for the ballistic parameter was the same for all runs. The wind-direction information as shown on Figure 26 again implies that the sondes agreed quite well with the radiosonde data.

The corrections that were added to each of the sondes due to the initial-condition uncertainties were different for each unit. It should be noted, however, that these corrections were made to an average of the two radiosonde runs since that was the closest data we had to the actual drop time.

If we had corrected to either one of the radiosonde runs, rather than the average, we would have found a shift in the wind profiles. However, it is evident that the sondes are consistent with one another and in general agree quite well with the radiosonde runs of that day.

SECTION VIII

CONCLUSIONS

The results of the last aircraft Windsonde tests show that the arrowsonde approach to measuring winds is feasible. The sonde provides a vertical profile of winds that compares quite favorably between successively dropped sondes and other means of determining winds. Wind shear and perturbations are shown rather clearly. There are areas that require further improvements, in particular the problem of determining the initial condition of the sondes. This includes horizontal and vertical velocity at the moment of release, and wind at release altitude. The second area where work is needed is in determining the error bounds on the length of time between the sondes ejection from the aircraft and its release and on the determination of the wind at altitude to provide initial conditions.

It is evident that, with further development, the Windsonde will effectively describe vertical profiles of wind over areas that are not accessible to normal operations. The system as described meets the initial guidelines. It is able to give an accurate wind measurement, it does not require tracking, it does not require the aircraft to loiter, and the system should be inexpensive in quantity.

SECTION IX

MISCELLANEOUS

ACKNOWLEDGEMENTS

The success of this program was in part due to the excellent cooperation and assistance received from Air Force personnel. In particular, both Lt. Col. James Church and Lt. Col. Robert Cowne assisted in the field tests and handled interface problems with dispatch. Sergeants John Bowers and Robert Evers also assisted capably in the field tests. The cooperation of the AFCRL Balloon Branch at Holloman AFB, New Mexico, and Mr. M. Brown of that group and of the White Sands Missile Range was also greatly appreciated.

PROJECT PERSONNEL

Personnel working on the project included: John Ballinger (deceased 30 October 1968), Stephen Rohrbough, Lyle Koehler, Paul S[illegible]stad, and William Volna.

Assistance fromthe Technical Laboratory included: Jim Vaughn, Ron Jiracek, Carl Heinen, Roy Floody, and Jerry Thielen.

PUBLICATIONS

A paper entitled "An Air-Launched Windsonde" by S. F. Rohrbough, L. E. Koehler, and J. G. Ballinger was presented at the Fourteenth International ISA Aerospace Instrumentation Symposium, 3-5 June 1968, at Boston, Mass.

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12042-QR9	15 September 1968
12042-QR10	15 December 1968
12042-QR11	15 March 1969
12042-SR1	July 1969

TRAVEL

During the contract period, 38 man trips were made that directly concerned the program. These included four flight tests and one coordination trip to Holloman AFB, New Mexico, and Lyle Koehler, Paul Senstad, and Jim Vaughn traveling to Ellsworth AFB, South Dakota, to complete the Physiological Training Course. Dummy sonde test drops from Hanscom Field at Bedford, Massachusetts, and at Camp McCoy, Wisconsin, are also included.

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13. ABSTRACT

An air-dropped, instrumented sonde for measuring wind profiles has been developed. It requires no tracking, no aircraft loitering, and is relatively inexpensive. The instrument is essentially an arrow-shaped sonde that remains at zero angle of attack during descent. Wind direction and velocity are inferred from orientation of the sonde axis with respect to vertical and magnetic north. An air-bearing gyroscope and a magnetometer are used to measure this orientation.

Performance of the sonde has been verified through both balloon-launched and aircraft-launched test series. Balloon launchings provided preliminary test results indicating that the concept was viable and also indicating areas of improvement required to eliminate intermodulation problems within the sonde electronics. Aircraft launchings provided wind data that compared favorably with concurrent radiosonde measurements.

The results of the study indicate that a further development effort aimed toward providing better knowledge of conditions at launch is required.

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Wind Shear						
Acceleration						
Gyroscope						
Dropsonde						

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AIR-LAUNCHED WINDSONDE
Final Report

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