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ANALYSIS OF CONJUNCTIVE ROCKETBORNE INFLATABLE SPHERE AND BEAD --ETC(U)
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ANALYSIS OF CONJUNCTIVE ROCKETBORNE INFLATABLE SPHERE AND BEAD THERMISTOR SOUNDINGS

MAY 1978

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US Army Electronics Research and Development Command
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White Sands Missile Range, N.M. 88002

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Please change paragraph 2, line 11, page 13 to read:

and 9,000 at Mach Numbers of .15 to .5 in increments of .05. This should

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19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Forty-nine conjunctive Robin/Datasonde soundings were analyzed to determine the compatibility of the temperatures and densities measured by both systems. The results of this analysis indicate differences between the two systems which at times exceed the expected noise error of either system. These large differences for any given sounding can be due to a variety of causes depending to some extent upon the altitude at which the differences occur. A portion of the difference in the altitude range of 38 to 56 km appears to be due to the calculation of the drag coefficient from the drag table. Additional measurements

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20. ABSTRACT (Cont)

and a different Reynolds number are required to better define the sphere coefficient of drag, eliminating the bias measurement between the two systems.

Errors in the pressure tie-on of the radiosonde data to the Datasonde can result in differences between the systems, and care should be taken to reduce the source of error. Another source of difference between the two measurements may be due to vertical motions. To compute densities the sphere technique assumes that the vertical motions are negligible and do not affect the density measurement. However, in making the sphere measurement compatible with the bead thermistor measurement, a method has been developed for computing verticle velocities that seems to give reasonable results compared to theory and measurements using other techniques. The average computed vertical motions varies from 0.4 m/s at 32 km to 4.9 m/s at 65 km.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

Two systems for determining the thermodynamic profile of the atmosphere for altitudes above ≈ 25 km on an operational basis are currently available. One of these, the Datasonde, telemeters data to a ground station which allows a computation of ambient temperature from approximately 25 to 70 km. The other, an inflatable falling sphere, or ROBIN, is a passive system, which when tracked by radar, allows a computation of density from approximately 95 to 30 km. When flown simultaneously, the two systems give redundant data in the altitude range from approximately 70 to 30 km. These redundant data may provide a unique source of information from which the behavior of the atmosphere might be better deduced. A brief description of each system follows:

DATASONDE

The Datasonde instrument package (sensor and transmitter), attached to a folded Starute decelerator placed within a dart vehicle, is carried aloft by a Loki-type rocket and when ejected is lowered by the inflated Starute. The instrument telemeters the temperature of the sonde to a ground station and a radar tracks the Starute. The sonde temperature data is used to acquire ambient temperature through a series of heat transfer equations which "correct" the sonde temperature. The "correction" terms are small at the low altitudes but increase sharply as the altitude approaches 70 km.

From this temperature profile and a knowledge of the pressure at a given altitude, a pressure profile can be obtained by

$$P_1 = P_0 \exp[-g(Z_1 - Z_0)/R'\bar{T}_0] \tag{1}$$

where P_0 is the pressure at height Z_0; P_1 is the pressure to be calculated at height Z_1; $R' = R/n$, the gas constant for dry air; $\bar{T}_0$ is the average temperature between levels Z_1 and Z_0; and g is the gravitational acceleration.

Density can be determined by

$$\rho = P/R'T \tag{2}$$

where T is the temperature at pressure level P.

The height of the pressure P_0 is normally determined from a radiosonde which is released within 3 hours of the overlap altitude of ≈ 25 km. Any inaccuracies in this tie-on pressure result in a constant percentage bias in both density and pressure. The inaccuracy can be due to an inaccuracy in the pressure reading of the rawinsonde and/or a time and space variability in the actual pressure. Kays and Avara [1] have shown that this bias can be as large as 8 percent.

A radar track of the Starute allows for a determination of the horizontal wind profiles and the altitude versus time of the datasonde.

ROBIN

The ROBIN system consists of a deflated metalized mylar sphere carried aloft in a Super-Loki rocket. The sphere, when expelled at ≈ 115 km (mean sea level) is inflated by isopentane and tracked by a precision radar from apogee to ≈ 30 km. The equations of motion for the sphere are

$$m\ddot{z} = mg - 1/2\rho\ C_dAv(\dot{z} - w_z) \qquad (3)$$

$$m\ddot{y} = -1/2\rho\ C_dAv(\dot{y} - w_y) \qquad (4)$$

$$m\ddot{x} = -1/2\rho\ C_dAv(\dot{x} - w_x) \qquad (5)$$

where m is the mass of the sphere, x and y the horizontal coordinates, and z the altitude. Dots over the coordinates indicate velocity and acceleration in that direction. ρ is the atmosphere's density, C_d the drag coefficient of the sphere, A its cross-sectional area, v the relative motion with respect to the air mass, and w the motion of the air mass relative to the earth. The parameters $\dot{x}$, $\ddot{x}$, $\dot{y}$, $\ddot{y}$, $\dot{z}$, and $\ddot{z}$ are obtained from the radar track; and therefore, these three equations contain four unknowns, ρ, w_x, w_y, and w_z. To solve this system, w_z is set equal to zero since $w_z << \dot{z}$ at all altitudes. Finally, ρ, w_x, and w_y are solved by the following.

$$\rho = \frac{2m\ (\ddot{z} - g)}{C_dAv\dot{z}} \qquad (6)$$

where

$$v = \sqrt{(\dot{x} - w_x)^2 + (\dot{y} - w_y)^2 + \dot{z}^2}\ , \qquad (6a)$$

$$w_x = \dot{x} - \frac{\ddot{x}\ \dot{z}}{z - g}\ , \qquad (7)$$

$$w_y = \dot{y} - \frac{\ddot{y}\ \dot{z}}{\ddot{z} - g}\ , \qquad (8)$$

Temperature and pressure are then determined by

$$P = P_0 - \int_{z_1}^{z_2} \rho g dz \qquad (9)$$

$$T(z) = \frac{1}{R'} \frac{P(z)}{\rho(z)}$$

where $P_0 = R'T_0\rho(z_0)$ and T_0 is a guess of the temperature at the altitude z_0.

ACCURACY OF THE TWO SYSTEMS

The expected noise error of the ROBIN system has been documented in a study by Luers [2]. The noise error computations are based on assumed errors in radar tracking and drag coefficients. The noise error as predicted by Luers has been shown to be acceptable in the 85 to 30 km range. The sonde temperature noise error has been well established in the 60 to 25 km range [3]. Above 60 km these correction terms increase in magnitude and are not as well established as the lower ones, but are nonetheless essentially correct. A more recent work by Naylor and Steffansen [4] thoroughly discusses the various sources of errors in utilizing a bead thermistor to measure upper atmosphere temperatures. However, it is not clear whether the sonde and ROBIN systems are free of systematic errors. This report is an attempt to determine the nature and effect of any systematic errors which may be present in either system.

COMPARISON OF THE TWO SYSTEMS

One of the most perplexing problems which arises when attempting to validate either system by comparing its data to the others is to determine what measurement(s) should be compared. The primary atmospheric measurement derived from the ROBIN is density, whereas the primary sonde measurement is temperature; therefore, these measurements cannot be compared directly. The variable which both systems compute is pressure. It therefore seems likely that if both systems compute the same pressure at all altitudes then both systems are free of systematic error. Consider the following argument.

The pressure at an altitude z, as measured by the ROBIN as it descends, is the integral of $\rho g dz$ plus an initial pressure, P_0. Thus the inflatable sphere technique adds small increments of pressure as the sphere descends. On the other hand, the pressure as measured by the sonde is $P_0 e^{-gz/R'T(z)}$ where P_0 is some pressure at a lower altitude as z increases. Thus the sonde method reduces the original pressure P_0 by this exponential function. Hence, the pressure as computed by the ROBIN and sonde is independent in the sense that the ROBIN is dependent upon the atmosphere above z, while the sonde is dependent upon the atmosphere below z. Hence, if the two pressures agree at a given z, it is certainly logical to assume that both the ROBIN and sonde were measuring the same atmosphere (within their respective noise error limits), above and below this z, respectively. If on the other hand the sonde pressure does not equal the ROBIN pressure at a given z, then one of them has accumulated over some z, a bias due to an improper measurement of either ROBIN temperature or density, or sonde density, the ROBIN from $Z_0 > z$, the sonde from $Z_0 < z$, where Z_0 implies the beginning altitude for that system.

Density and Temperature Differences from the Conjunctive Soundings

In an effort to validate both systems, 49 conjunctive ROBIN and Datasondes were analyzed for this study and are listed in Table 1.

A comparison of the temperature profiles of the ROBIN and sonde shows differences between the two systems which at times exceed the expected noise error of either system. These large differences for any given sounding can be due to a variety of causes, depending to some extent upon the altitude at which the differences occur. In this discussion, a distinction is made between a systematic error and a nonsystematic error. The latter type is discussed first.

Vertical motions of $|W_z| > 0$ will appear in the ROBIN computation as false temperature and density perturbations. Since the vertical wind W_z is an atmospheric phenomenon which can vary from day to day, the difference in temperature between the sphere and sonde due to this atmospheric phenomenon can properly be called a nonsystematic error. The error introduced to the ROBIN temperature due to $W_z > 0$ is $\frac{2W_z}{\dot{z}}$ where $\dot{z}$ is the vertical velocity of the sphere. This vertical velocity of the sphere is ≈ 225 m/sec at 60 km and decays exponentially to ≈ 20 m/sec at 30 km. Thus to explain a 5 percent discrepancy between sphere and sonde temperature at 60 km by W_z alone would necessitate a W_z of 5.6 m/sec while at 30 km the corresponding W_z would be 0.5 m/sec. However, in some instances the observed temperature discrepancy is > 10 percent at 30 km which necessitates a W_z of 1 m/sec. The possibility of such large vertical winds at these lower altitudes is not generally accepted; therefore, another reason for the difference in temperature at these lower altitudes must be found.

Another possible explanation of the temperature difference at the low altitudes (35 to 30 km) is that the sphere is beginning to "soften" as a prelude to collapse, thus leading to false temperatures because the sphere C_d no longer applies. This type of error must also be labeled nonsystematic since the balloon will both soften and collapse at somewhat different altitudes as studies have shown. Above 35 km the large difference can only be explained by vertical winds of considerable magnitude. Below 35 km the large differences can be attributed to either large vertical winds and/or a partial collapse of the sphere. Neither of the above can be proved conclusively due to the nature of the data. However, this report plus other studies made on both the ROBIN and sonde

TABLE 1

LOG OF THE CONJUNCTIVE DATASONDE AND ROBIN FALLING SPHERE SOUNDINGS AT THE WHITE SANDS MISSILE RANGE, N.M.

Flight No.	Date	Robin Time (Zulu Time)	Sonde Time (Zulu Time)
1	10/24/73	1315	1215
2	10/31/73	1845	1930
3	11/7/73	2000	1845
4	12/6/73	1030	930
5	12/12/73	1706	1755
6	1/14/74	1910	1700
7	1/16/74	1945	1854
8	3/27/74	1645	1545
9	4/10/74	1850	1845
10	5/1/74	1644	1639
11	5/17/74	1740	1745
12	6/12/74	1750	1745
13	6/19/74	1755	1750
14	6/26/74	1800	1755
15	7/3/74	1707	1702
16	7/17/74	1705	1717
17	7/24/74	1850	1845
18	7/31/74	1635	1630
19	8/7/74	1705	1700
20	8/14/74	1735	1730
21	9/4/74	1735	1730
22	9/11/74	1705	1700
23	9/25/74	1835	1830
24	10/9/74	2110	2105
25	10/30/74	1905	1900
26	11/6/74	1805	1800
27	11/6/74	1840	1835
28	11/20/74	1705	1700
29	11/20/74	1740	1735
30	11/27/74	1850	1845
31	12/13/74	2250	2245
32	12/13/74	2400	2355
33	12/16/74	2130	2030
34	12/18/74	1218	1210
35	1/8/75	1905	1900
36	1/15/75	1706	1700
37	3/5/75	1840	1830
38	3/26/75	1725	1718
39	5/14/75	1735	1725
40	6/18/75	2015	2025
41	6/25/75	1920	1936
42	7/2/75	1926	1936
43	7/9/75	1920	1930
44	7/16/75	1920	1930
45	7/23/75	1720	1730
46	7/30/75	1715	1725
47	8/13/75	1735	1745
48	8/27/75	1600	1610
49	9/10/75	1550	1600

indicate that there are no other contributing factors to the large discrepancies seen here. Further, the majority of the data (75 percent) tend to show the ability of both systems to respond to rapidly changing temperatures as shown in Figures 1 and 2. These figures illustrate rather conclusively that there are rapidly changing temperatures in the atmosphere to which both systems are responding. If this conclusion is valid, then any discrepancy in temperature above ≈ 5 km of balloon collapse must be due to vertical winds because of both the time needed to go from 35 to 30 km (4 min) and the pressure change between 35 and 30 km (6 mb).

The above discussion centers upon nonsystematic errors. There are also present in the data systematic errors in the altitude range of 60 to 40 km. The following section addresses this problem.

Statistical Method Used to Show Temperature and Density Bias

All 49 conjunctive flights were processed to determine the average ROBIN temperature and density as well as the average sonde temperature and density as a function of altitude. In addition to the above data, the C_d's that the ROBIN encountered were also averaged. The results are shown in Figure 3. Curve 1 of the figure represents the average values of C_d for all flights. Curve 2 represents the average temperature bias of the 49 conjunctive White Sands flights as a function of altitude, and curve 3 represents the same type of data for 48 flights from Point Mugu and Barking Sands.

The remarkable similarity between curves 2 and 3 leads to the belief that the bias is real and due to some systematic error in one of the systems. Further, the shape of the average C_d curve, especially in the altitude range of 56 to 38 km leads one to suspect that the values of C_d in that region are likely candidates for the systematic error. The similarity between the two bias curves substantiates the findings by Quiroz and Gelman [5] who reported the bias in the Point Mugu data, when compared to sonde data.

Drag Coefficients

The values of C_d versus Mach and Reynolds Numbers used in the ROBIN system were measured by A. B. Bailey and J. Hiatt [6] of ARO, Incorporated. Figure 4 is a three-dimensional plot of the C_d versus Mach and Reynolds Numbers with the axis as marked. The trajectory of the ROBIN in the Mach and Reynolds domain is shown. The numbers parallel to the Reynolds Number of 3162 are the corresponding ROBIN altitude in kilometers. The thick lines drawn parallel to the Reynolds Number axis indicate the approximate values of Reynolds Number for which there has been a measurement of C_d. It is of particular interest to note that in the altitude range of 55 km down, measurements have only been made at a Reynolds Number of 5,000 and 10,000, and in general the measurements are

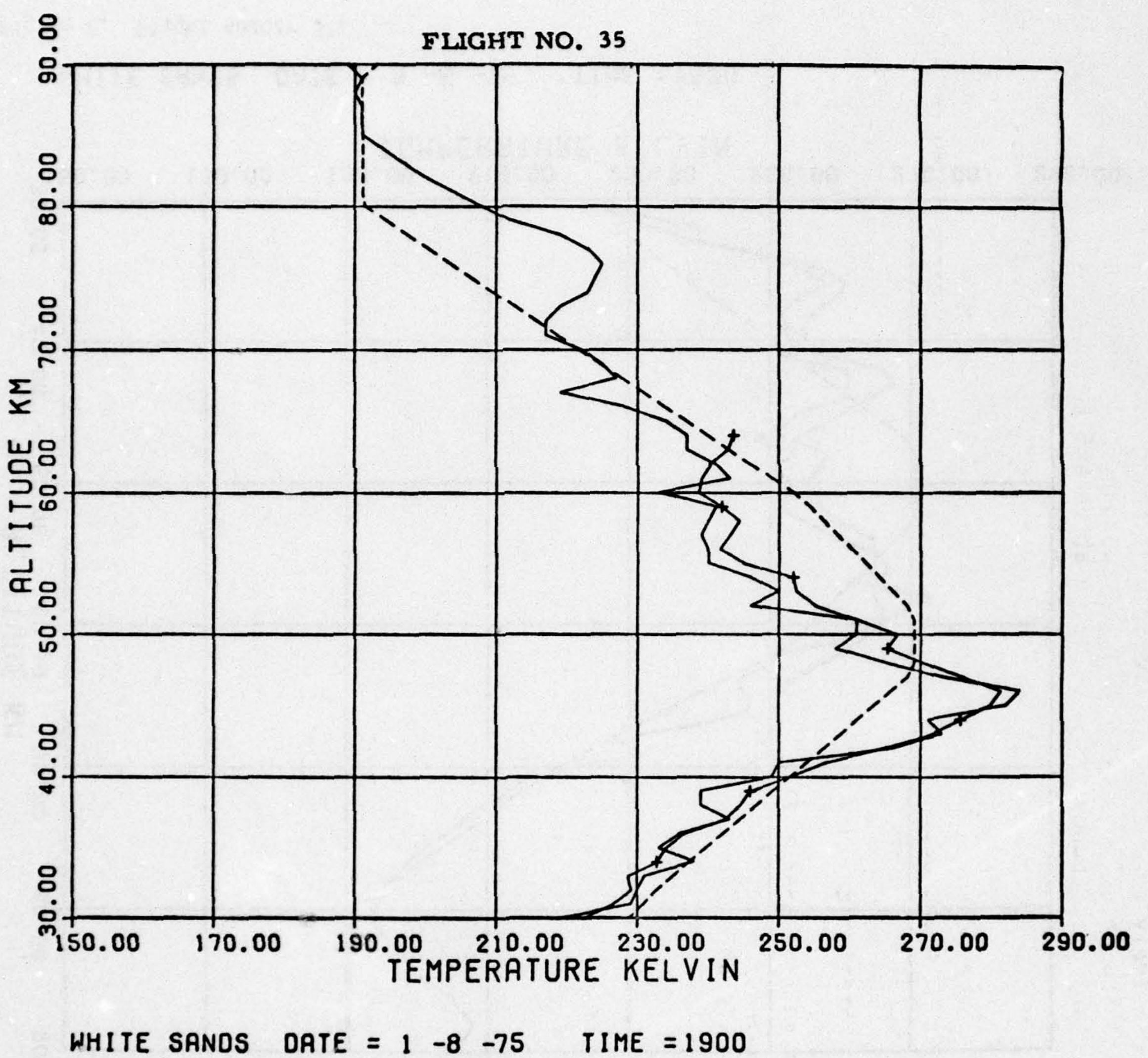


Figure 1. Flight number 35.

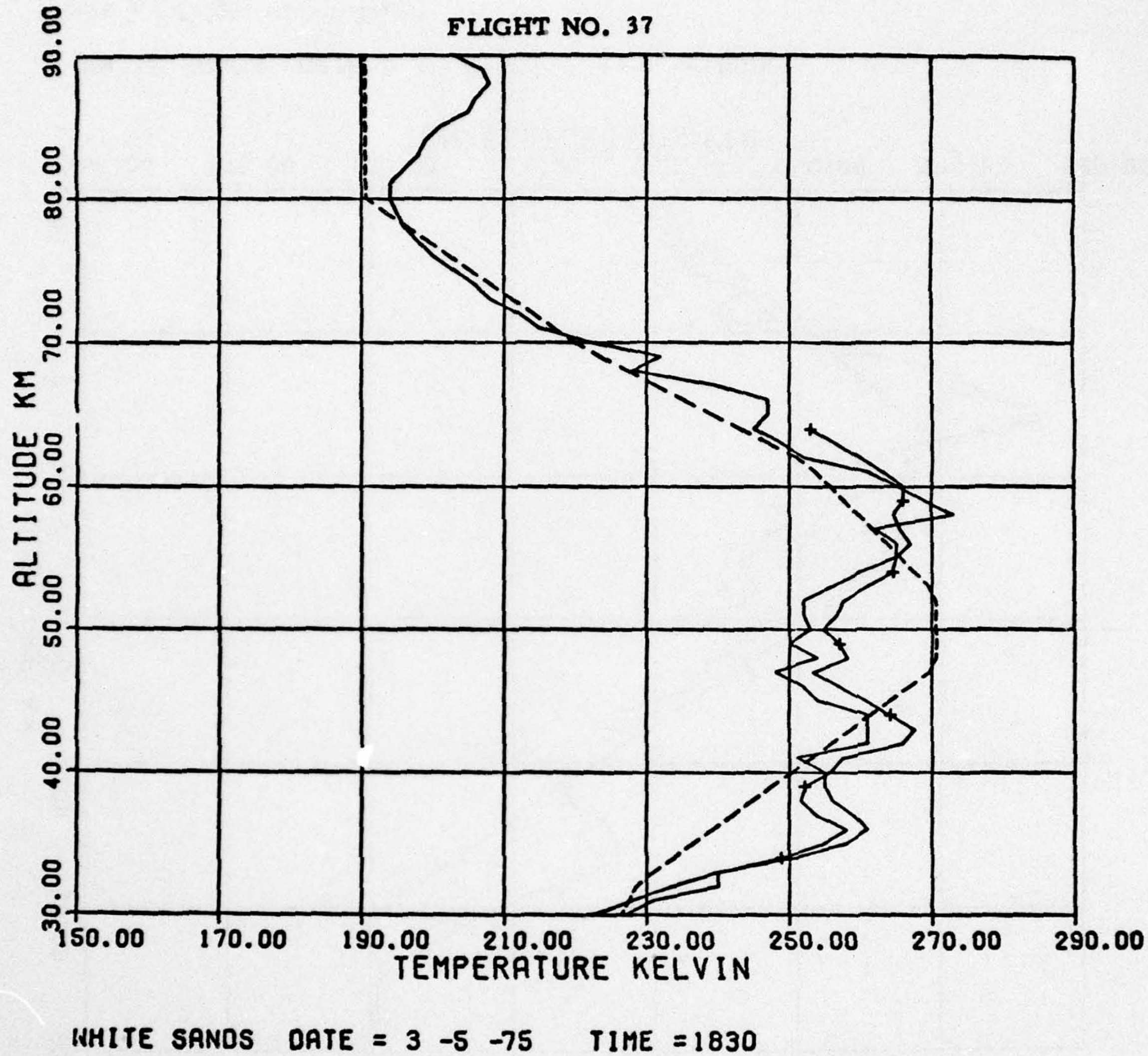
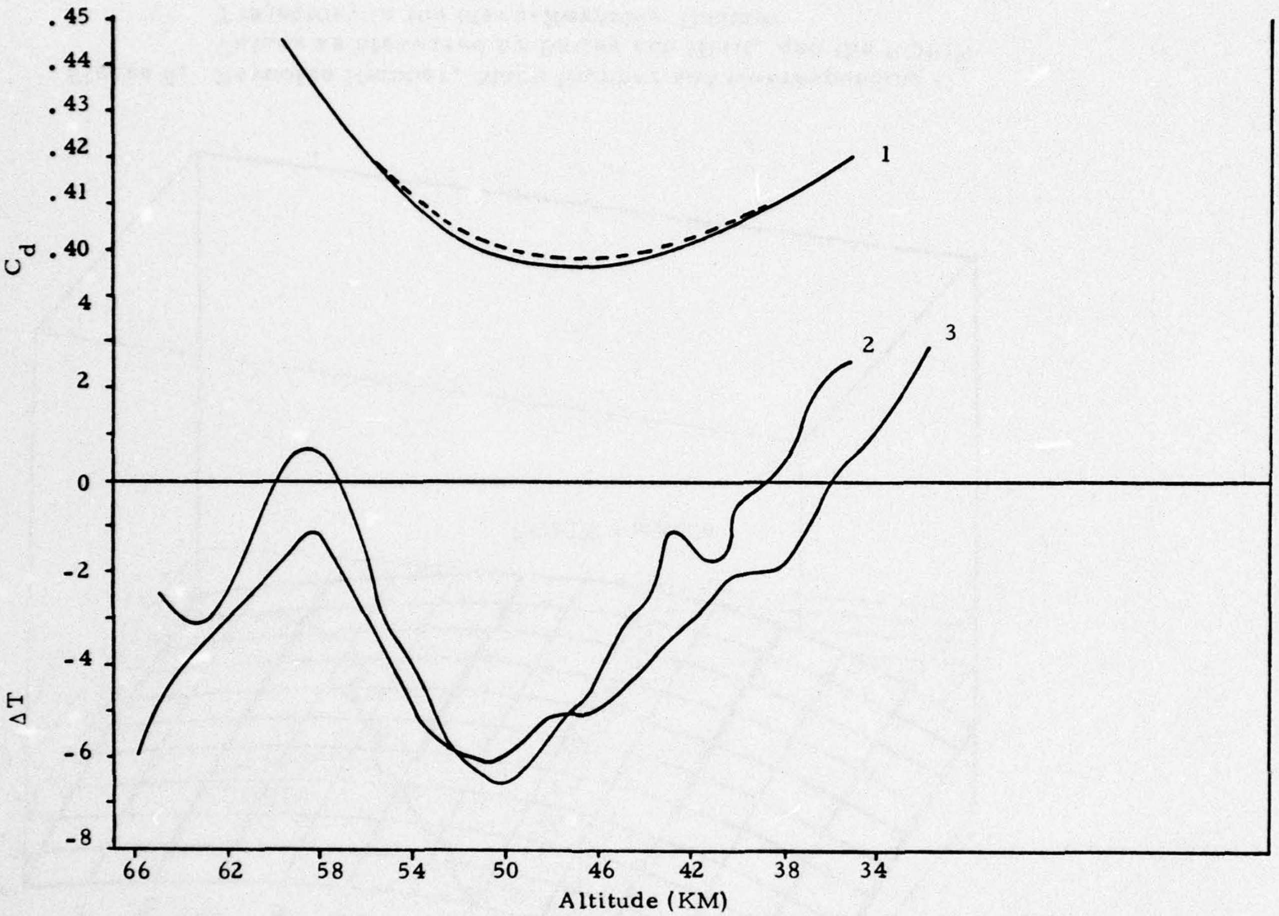


Figure 2. Flight number 37.



Curve 1 - **Average values of C_D for the White Sands flights**

Curve 2 - **Average values of $T_S - T_R$ for the White Sands flights**

Curve 3 - **Average values of $T_R - T_S$ for the Barking Sands - Pt. Magu flights**

Figure 3. Average Values for 49 Conjunctive Robin-Rocket Sonde Flights Flown at White Sands in 1973-74-75 and 40 Flights at Point Mugu and Barking Sands in the Same Years

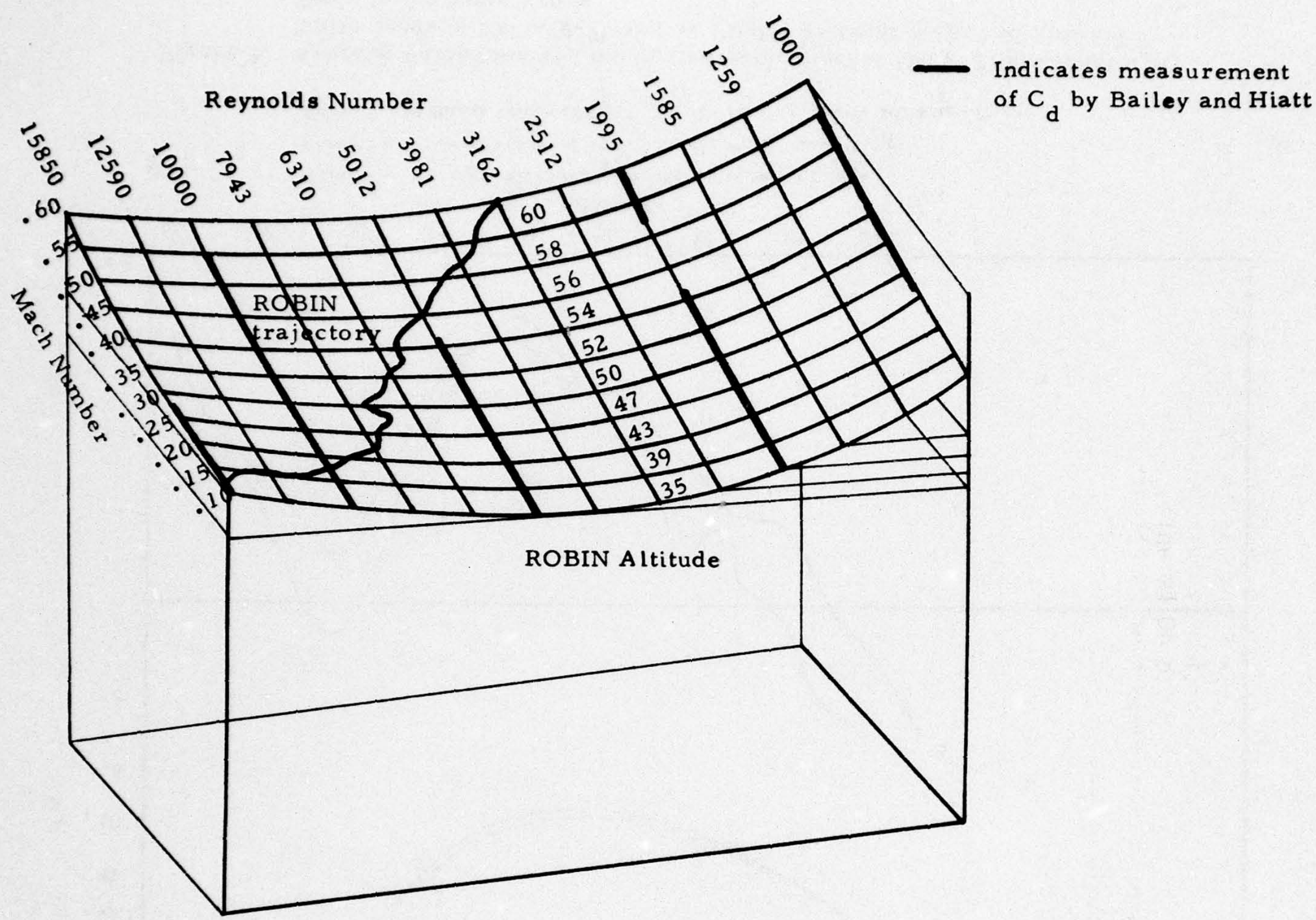


Figure 4. Reynolds Number, Mach Number and Corresponding C_d Values as Measured by Bailey and Hiatt, and the ROBIN Trajectory in the Mach-Reynolds Domain

not too helpful in pinpointing exact values of C_d for Mach Numbers < .6 and > .2 which comprise an altitude range for the ROBIN of 60 to 40 km.

Figure 5 is a portion of the curves furnished by Bailey and Hiatt. Notice the crossover of the 5,000 and 10,000 Reynolds Number curves at Mach .76. The shaded portion of this figure represents an altitude range of the ROBIN of 55 to 40 km which is the major portion of the bias. With no measurements of C_d between Reynolds Numbers of 5,000 and 10,000, it is impossible to determine the precise value of C_d at Reynolds Numbers of 6,000, 7,000, 8,000 and 9,000, the Reynolds Numbers that the ROBIN encounters in going from 55 to 40 km. Hence, until C_d measurements are made in this area of Reynolds Numbers, the cause of the temperature bias between the sonde and ROBIN cannot be proven. Yet from the evidence presented here, it is more than speculation to suggest that the cause of the temperature bias between the ROBIN and sonde in the altitude range of 56 to 38 km is the inaccurate shape of the C_d curve. If the shape were changed as the dotted C_d line of Figure 3 indicates, the bias would disappear.

A study of Fig. 3 suggests a probable bias in the ROBIN data from about 56 to 38 km due to the drag table. This bias in either temperature or density can be corrected by the following expression:

$$K = -.8213 + 3.520 \times 10^{-2}z - 3.667 \times 10^{-4}z^2 \tag{11}$$

where z is the altitude in kilometers between 56 and 40 km and K is the correction temperature. Table 2 gives the percentage correction in temperature that should be applied to the ROBIN temperature as a function of altitude. This should be considered as only a temporary correction. The only way to realistically determine if the bias is due to C_d is to make measurements of C_d at a Reynolds Number of 4,000, 6,000, 7,000, 8,000 and 9,000 at Mach Numbers of .15 to .5 in increments of .05. This should determine the precise shape of the C_d curve and locate accurately the minimum value of C_d.

USE OF CONJUNCTIVE FLIGHTS TO DETERMINE W_z

The previous discussion concerning the validity of the two systems referred to the vertical winds as a phenomenon affecting the temperature and density profile of the ROBIN's measurement but not that of the sonde. A method of using conjunctive data to extract vertical wind data is yet to be determined.

A falling sphere such as the ROBIN will obey Newton's laws of motion, and the following equation can be derived for the true density. As before,

$$\rho_T = \frac{2m(\ddot{z} - g)}{C_d A v'(\dot{z} - W_z)} \quad . \tag{12}$$

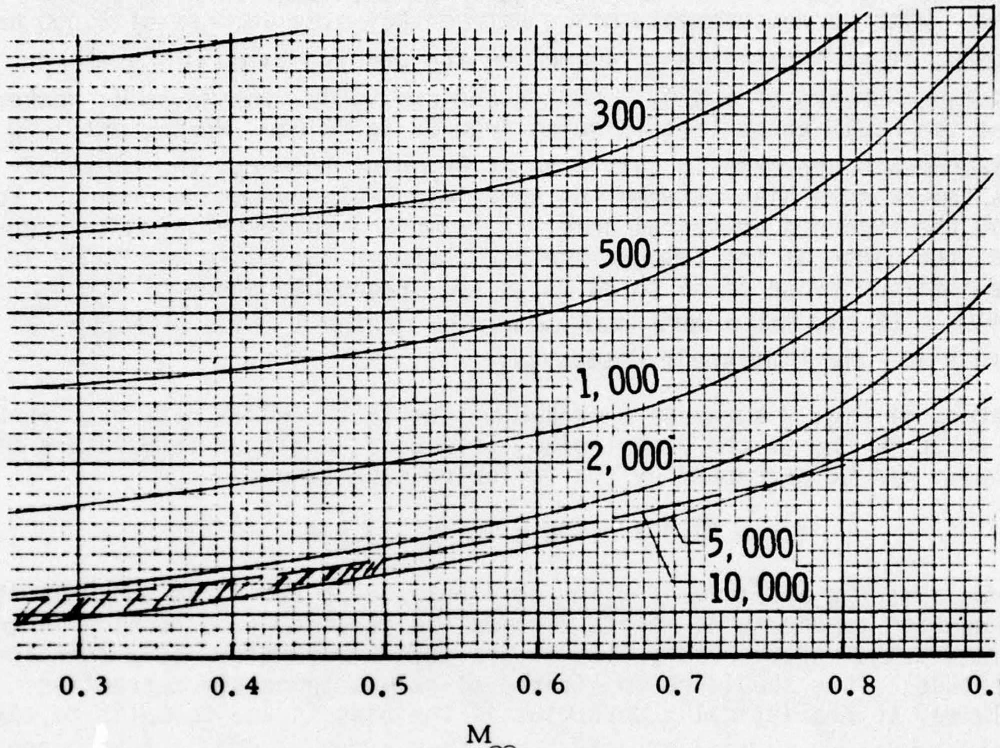


Figure 5. Values of C_d vs. Mach Number for Given Reynolds Number taken from Bailey and Hiatt

TABLE 2

CORRECTION IN ROBIN TEMPERATURE VERSUS ALTITUDE TO ELIMINATE BIAS

Altitude (km)	Percentage Change in Temperature	Absolute Change* in Temperature
56	0	0
55	0.5	1.3
54	1.0	2.7
53	1.4	3.8
52	1.8	4.9
51	2.0	5.4
50	2.2	5.9
49	2.3	6.2
48	2.3	6.2
47	2.3	6.2
46	2.2	5.9
45	2.1	5.5
44	1.8	4.7
43	1.4	3.6
42	1.0	2.6
41	0.5	1.3
40	0	0

*Calculated using 1962 US Standard Atmosphere.

The density as computed from the ROBIN data is

$$\rho_S = \frac{2m\,(\ddot{z} - g)}{C_d A v \dot{z}} \tag{6}$$

where W_z has been set to zero and

$$v = \sqrt{(\dot{x} - W_x)^2 + (\dot{y} - W_z)^2 + \dot{z}^2}$$

$$v' = \sqrt{(\dot{x} - W_x)^2 + (\dot{y} - W_z)^2 + (\dot{y}_z - W_z)^2}\ .$$

If we further assume that there are no erratic wind shears so that $\dot{x} = W_x$ and $\dot{y} = W_y$ then

$$v = \dot{z} \text{ and } v' = \dot{z} - W_z\ .$$

Under these conditions

$$W_z = \dot{z}\left(1 - \sqrt{\frac{\rho_S}{\rho_T}}\right). \tag{13}$$

This expression could be used to determine W_z if ρ_T, the <u>true</u> density, were known. Since the sonde's density ρ_R is unaffected by vertical winds, the first impulse is to equate ρ_R to ρ_T and use it in Eq. (13) as

$$W_z = \mathring{z}\left(1 - \sqrt{\frac{\rho_S}{\rho_R}}\right). \tag{14}$$

However, as pointed out previously, ρ_R is subjected to a bias resulting from an initial pressure error and hence its use in Eq. (14) would bias W_z if ρ_R were biased.

A similar expression can be derived for W_z by comparing temperatures.

The ROBIN's temperature can be written as

$$T_S = \frac{KP_S}{\rho_S} \text{ (ROBIN).} \tag{15}$$

and the true temperature can be written as

$$T_T = \frac{KP_T}{\rho_T}\ . \tag{16}$$

Substituting (15) and (16) in (13) yields

$$W_z = \dot{z}\left(1 - \sqrt{\frac{P_S T_T}{P_T T_S}}\right). \qquad (17)$$

Now, if we assume that $P_S = P_T$ and $T_T = T_R$, then it follows that

$$W_z = \dot{z}\left(1 - \sqrt{\frac{T_R}{T_S}}\right). \qquad (18)$$

Note that Eq. (14) can be in error due to bias in ρ_R, whereas Eq. (18) can be in error due to a bias in T_S and/or P_S. (The assumption that $T_R = T_T$ is probably quite valid, especially at altitudes below 50 km.)

Eqs. (14) and (18) will yield identical results only when the datasonde pressure equals the ROBIN's pressure. From previous arguments the assumption can be made that if the two pressures are equal, they are true. If this is a valid argument, then W_z should also be true.

To study the relationship between ROBIN and sonde data to determine if there are any true W_z values, each conjunctive flight was processed to yield P_S/P_R, ρ_S/ρ_R, $T_S - T_R$ and W_z from Eqs. (14) and (18), both of which were corrected by Eq. (11).

Figure 6 shows the data from a conjunctive sounding on 18 December 1974. The data show an almost perfect example of $P_R = P_S$ throughout almost the entire flight and of the resulting vertical winds. Unfortunately, this flight is the only conjunctive sounding where $P_R = P_S$ for a significant altitude range, but the figure does show almost conclusively the presence of vertical winds and their expected amplitude.

Other valid W_z data can also be recovered from those flights for which $P_R \neq P_S$, provided the error in W_z is significantly less than the expected W_z. To show this, the expected error in W_z when $P_R/P_S \neq 1$ is plotted in Fig. 7. The figure shows that for $|P_R/P_S - 1| > .005$, the error in W_z versus altitude is almost as large as the expected W_z. Hence, if the W_z data is limited to only those data points for which $|P_R/P_S - 1| < .005$, many values of W_z which have an expected error of less than 1 m/sec can be extracted from the conjunctive sounding data. Figure 8 is a composite plot showing these values of W_z from the conjunctive flights. The values of W_z shown in Fig. 8 were computed by using Eq. (18) rather than (14). Apparently the sonde temperature is quite accurate and the possibility of bias in pressure is less for the ROBIN than the sonde. Hence Eq. (18)

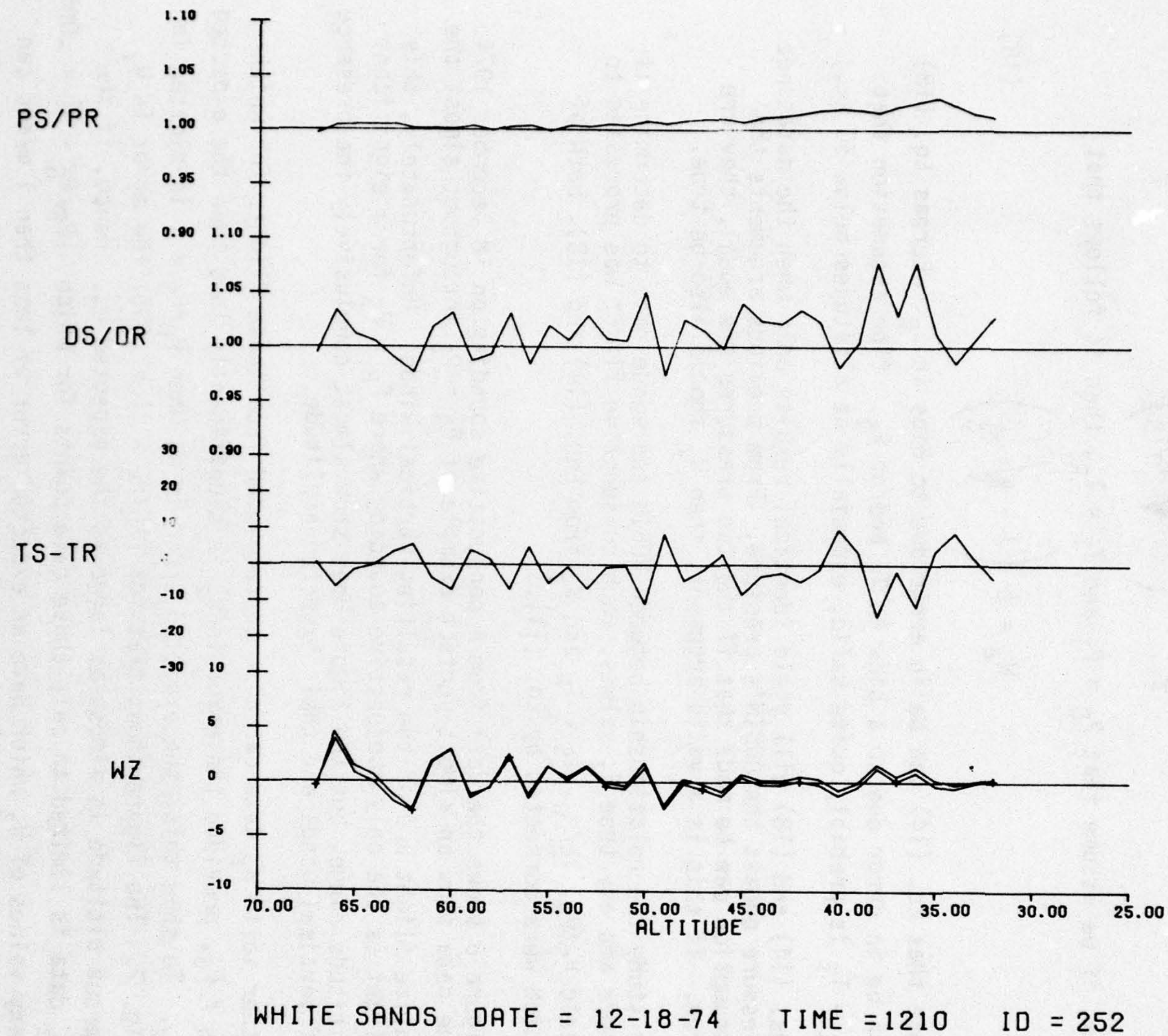


FIGURE 6. FLIGHT NUMBER 34.

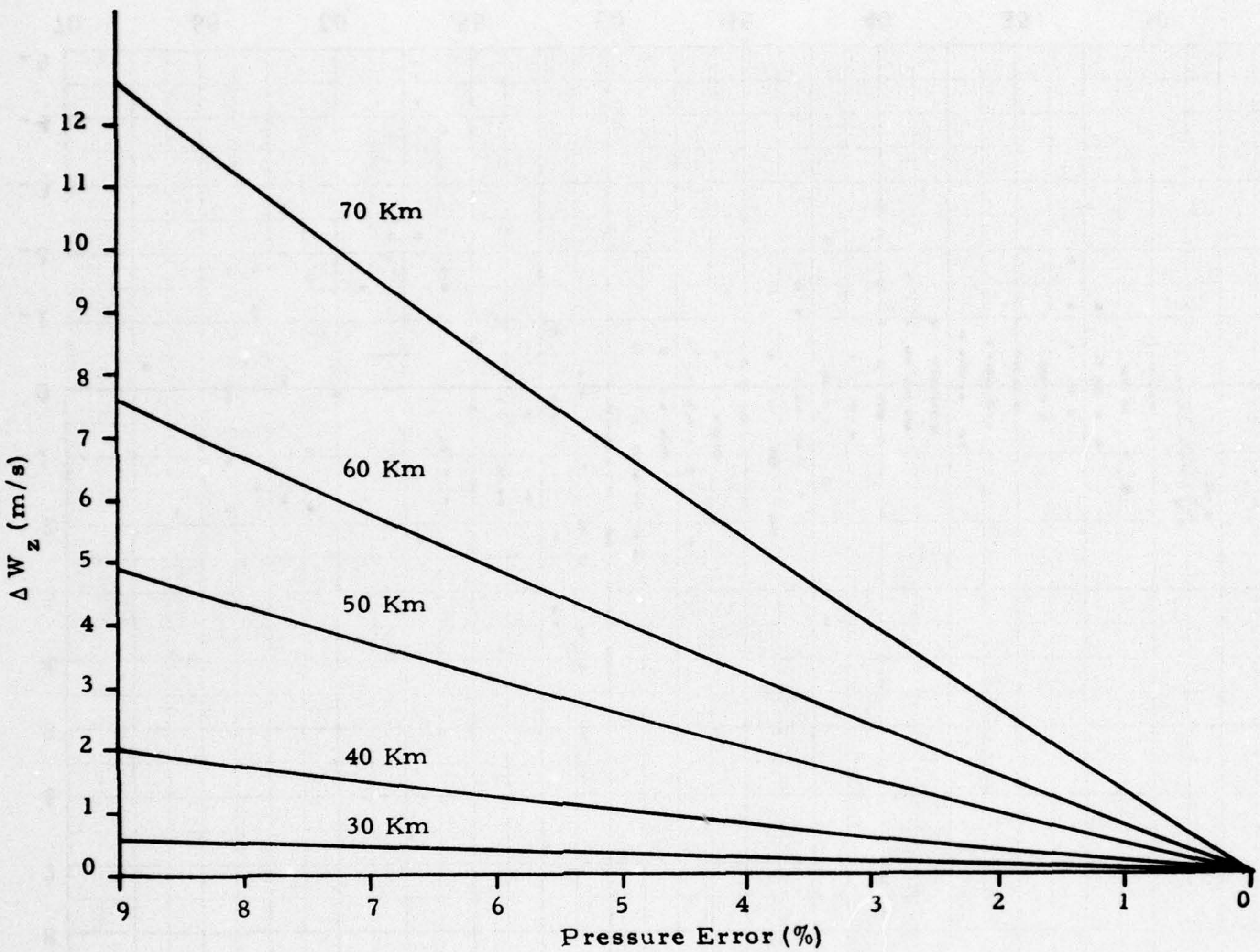


Figure 7. Error in W_z as a Function of Pressure Error Between Sensors for a Given Altitude

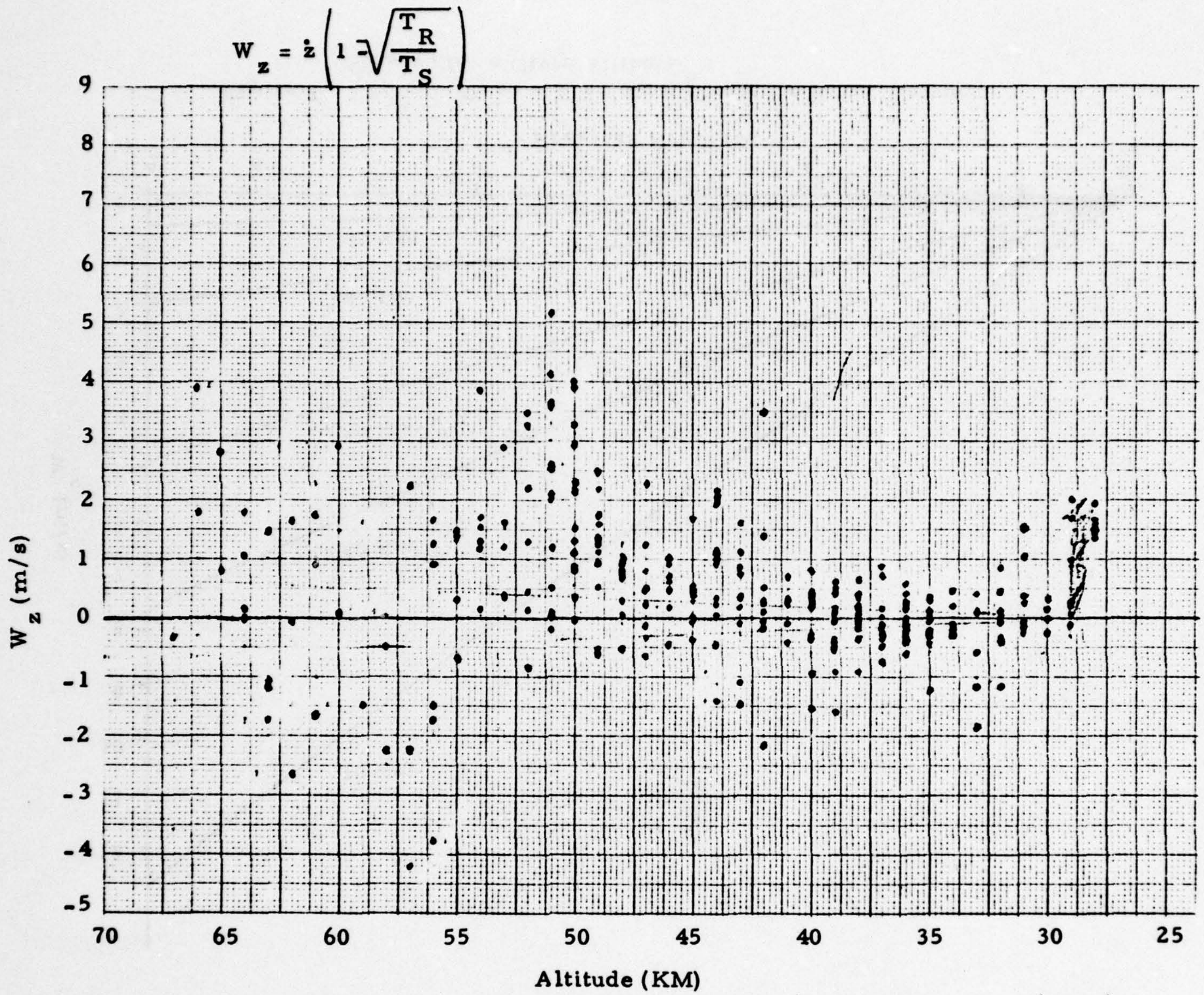


Figure 8. W_z vs. Altitude for all Flights when $|P_S/P_R - 1| \leq |.005|$

will yield more probable values of W_z than Eq. (14). Finally, the absolute value of W_z was averaged at those altitudes where the pressure deviation was less than 1 percent. These numbers are plotted versus altitude in Figure 9.

CONCLUSIONS

This method of computing vertical winds seems to give reasonable results, compared to theory and measurements using other techniques. In Reference 2 the vertical motion in the 10-35 km region was of the order of .1 m/sec, and in the 55-80 km region 2 m/sec. These data agree well with the data of Figs. 2 and 5. The vertical motion as reported in Reference 1 ranges from 11 to .5 m/sec over an altitude range of 65 to 30 km. The time between the ROBIN and sonde (5 minutes) may be causing some error in measurement. In the future, it would be better if the ROBIN and sonde were fired so that they were at the same altitude at the same time. This is possible by firing the ROBIN first and letting it fall with the sonde. As Fig. 2 illustrates, great care must be taken in using this technique. Generally, Eq. (6a) gives more reliable vertical winds than does Eq. (6). This is true because the pressure measurements of the ROBIN are generally more reliable than the pressure measurements of the sonde. However, when the pressure bias is greater than 1 percent, W_z cannot be computed at any altitude. We intend to study the method of computing the pressure from the sonde in an attempt to eliminate the bias between the ROBIN and sonde. If this can be done, then better measurements of W_z can be made.

RECOMMENDATIONS

To obtain maximum information from both the ROBIN and sonde, they should always be fired as close together in time as possible.

Greater care should be taken when obtaining the tie-on pressure value for the sonde. Some better way of determining the pressure altitude should be devised.

The values of C_d in the region of Reynolds Number from 10,000 to 5,000 for Mach Number between .5 and .1 should be better established.

To obtain better information on the possible softening effect, controlled chamber experiments should be done, photographing the sphere as the altitude decreases from 40 to 30 km. A study should also be made of the return radar signal in this altitude range because of the possibility of increase in noise to signal ratio as the balloon loses its rigidity. Another way would be to fly ROBINS with different amounts of isopentane, thereby varying the altitude at which the balloon should collapse.

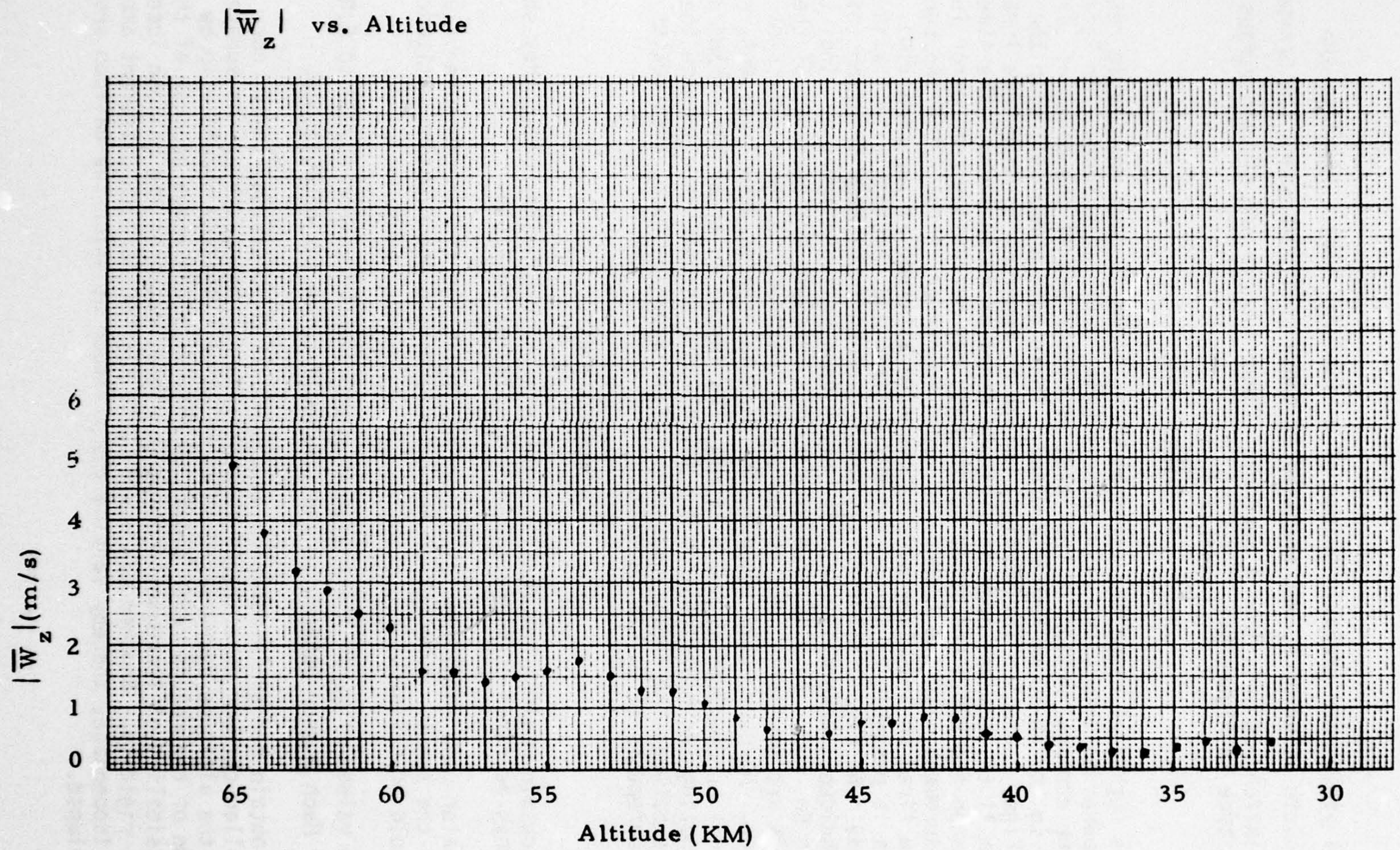


Figure 9. Average of the Absolute Value of W_z vs. Altitude

To verify the results obtained in this report, an experiment such as the one designed below should be done.

SUGGESTED EXPERIMENT

The most critical part of the experiment is to fly ROBINS of different diameters as close as possible in time. ROBINS with different diameters will have different Mach and Reynolds Numbers at a given altitude, and the vertical winds effect will differ because of different fall velocities. Hence, ROBINS of different sizes will yield information regarding both problems encountered in this report, C_d and W_z. The pattern of flights is somewhat important too, but not critical. The best way would be to fly a ROBIN of 1 m diameter followed by a sonde followed by a sphere of 1/2 m diameter. If these could be fired within 20 minutes and each ROBIN dual tracked, the resulting data would yield important information. If this pattern were repeated approximately six times in 24 hours, then the resulting data could be used for the following:

1. A better understanding of C_d as a function of Reynolds and Mach Numbers for the ROBIN.

2. A better understanding of the effect of vertical winds on ROBIN temperatures.

3. A better understanding of the magnitude of vertical winds as a function of altitudes.

4. A more complete description of the reasons for the differences in ROBIN and sonde temperature profile.

REFERENCES

1. Kays, Marvin, and E. P. Avara, April 1970, "Errors Associated With Meteorological Data Above 30 km," R&D Report, ECOM-5295, Atmospheric Sciences Laboratory, US Army Electronics Command, WSMR, NM.

2. Luers, James K., July 1970, "A Method of Computing Winds, Density, Temperature, Pressure, and Their Associated Errors From the High Altitude ROBIN Sphere Using an Optimum Filter," Final Report AFCRL-70-0366 prepared for Air Force Cambridge Research Laboratories, Office of Aerospace Research, United States Air Force, Bedford, MA.

3. Krumins, M. V., and W. C. Lyons, June 1972, "Corrections for the Upper Atmosphere Temperatures Using a Thin Film Loop Mount," Naval Ordnance Laboratory, NOLTR 72-152.

4. Naylor, J., and F. Steffansen, September 1976, "Error Evaluation of a Rocket Meteorological Temperature Sounding System," NAS6-2627.

5. Quiroz, R. S., and M. E. Gelman, October 1975, "An Evaluation of Temperature Profiles from Falling Sphere Soundings," Journal of Geophysical Research, Vol. 80, No. 30.

6. Bailey, A. B., and J. Hiatt, March 1971, "Free-Flight Measurements of Sphere Drag at Subsonic, Transonic, Supersonic, and Hypersonic Speeds for Continuum, Transition, and Near-Free-Molecular Flow Conditions," AEDC-TR-70-291, Von Karman Gas Dynamics Facility, Arnold Engineering Development Center, Air Force Systems Command, Arnold Air Force Station, TN.

7. Marshall, J. C., 1969, "Behavior of Smoke Trails 30 to 70," Journal of Applied Meteorology, Vol. 3, No. 44.

8. Woodman, R. F. and A. Guillen, 1974, "Radar Observations of Winds and Turbulence in the Stratosphere and Mesosphere," Journal of Atmospheric Sciences, Vol.31, No. 2.

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