NASA CONTRACTOR REPORT

NASA CR-61276

April 1969

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AN ANALYSIS OF THE JIMSPHERE ASCENT RATE WITH A DISCUSSION OF VERTICAL MOTIONS IN THE WINDS ALOFT

Prepared under Contract No. NAS 8-5608 by

R. S. Wheeler

THE BOEING COMPANY

For

NASA-GEORGE C. MARSHALL SPACE FLIGHT CENTER
Marshall Space Flight Center, Alabama

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PREFACE

This document has been prepared by the Postflight Trajectories Group of The Boeing Company to satisfy the technical requirements specified by Data Requirement Description SE-667, Contract NAS8-5608, Schedule II, Section A, Task 8.1.7 (see Exhibit CC, DRL 049, Line Item 50). The task performed was in support of the Aerospace Environment Division, Atmospheric Dynamics Branch (R-AERO-YE), Aero Astrodynamics Laboratory, Marshall Space Flight Center, National Aeronautics and Space Administration. J. W. Kaufman, Chief of the Atmospheric Dynamics Branch, was the technical coordinator.

The author wishes to express his thanks to J. W. Kaufman and W. W. Vaughan, Chief Aerospace Environment Division, MSFC/NASA, for their valuable suggestions in accomplishing this task and preparing this final report.

The author also would like to express his gratitude to Mr. R. D. McCurdy, Supervisor Postflight Trajectories Group, for his guidance and advice in the preparation of this report.

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PREPARED BY:

The Boeing Company under NASA Contract NAS8-5608
for the Aero-Astrodynamics Laboratory, Aerospace
Environment Division, Atmospheric Dynamics Branch,
Marshall Space Flight Center, Alabama.

Contract Monitor: John W. Kaufman

ABSTRACT AND LIST OF KEY WORDS

Perturbations of relatively large wavelengths are observed in the ascent rates of Jimsphere balloons. These are shown to be indications of vertical motions in the atmosphere. High frequency noise introduced by the FPS-16 Radar tracking is also observed in the data but this can be eliminated effectively by means of low pass filtering. To evaluate perturbations of significant wavelength a mean rate of rise of the Jimsphere is determined from filtered individual rise rate profiles which are then compared with the mean rise rate to evaluate the perturbations. A discussion of probable relationships of these perturbations with features on the profiles of the horizontal winds is also presented. It is concluded that the FPS-16 Radar/Jimsphere Wind Measuring System detects the larger vertical motions of the atmosphere.

Data Editing
Digital Low Pass Smoothing Filters
Jimsphere Balloon
Ascent Rate
Meteorology
Winds Aloft
Wind Reduction Program
Wind Profiles
Mean Rise Rate

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ILLUSTRATIONS (Continued)

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TABLES

SOURCE DATA PAGE

The following listed government-furnished data has been used in preparation of this document release:

Exhibit FF Line Item Number	GFD	Date of Issue
AERO 25	FPS-16 Radar/Jimsphere Wind Data	
	One Magnetic Tape containing 16 wind runs	1/11/68
	Six Magnetic Tapes containing 36 wind runs	8/14/68
	Two Magnetic Tapes containing 29 wind runs	8/19/68
	One Magnetic Tape containing 14 wind runs	9/4/68

SECTION 1

INTRODUCTION

1.0 GENERAL

In December 1964, operational use of the FPS-16 Radar/Jimsphere Balloon Wind Measuring System (References 1 and 2) was initiated. Since that time, a large set of wind measurements determined by this system has been accumulated. Particular interest has centered on the high resolution profiles of wind direction, scalar speed, and the zonal and meridional components of the winds aloft obtained from this system's data. To date, the detail structure of these horizontal winds has been studied extensively (References 3, 4, and 5). Recently, the ascent rates of the Jimsphere balloon have been studied in an effort to determine vertical winds. These ascent rate data show both high-frequency perturbations and lower-frequency perturbations. The wave lengths of these lower-frequency perturbations are large enough to conclude that the perturbations are due to vertical atmospheric motions and are not characteristic of the Jimsphere balloon.

1.1 PURPOSES AND OBJECTIVES OF THIS STUDY

The high-frequency perturbations in the ascent rate are attributed mainly to noise in the measuring system. This is particularly true when the slant range to the Jimsphere is large and the FPS-16 radar elevation angles are small. This noise in the Jimsphere ascent rates obscures the short-wave perturbations and hinders analysis of long-wave perturbations that might show association with features in the profiles of the horizontal variables. The purpose of this study is to identify means (1) to obtain reduced Jimsphere rise rate data that are free of the effects of noise, (2) to show that the remaining perturbations are representative of atmospheric-induced vertical motions, and (3) to explain the existence of these perturbations.

SECTION 2

PROCEDURE

2.0 GENERAL

The procedure to free the ascent rate data from the effects of noise is to select a proper digital filter and use it to process the data. In order to study the perturbations, the filtered ascent rate data are subtracted from an unperturbed rate of rise. It is assumed in this study that the unperturbed Jimsphere rate of rise in still air is represented best by the mean rise rate obtained statistically from a sample of Jimsphere ascent data. A theoretical solution for the rate of rise would be desirable. However, the equations for the ascent rate, given in Appendix A, show the dependency of rise rate on the ambient density and the drag. Density data with height are available from reference atmospheres or from measurements by means of radiosonde techniques. However, the coefficient of drag can be determined only if the relative speed of the air to the balloon, which itself is a function of the ascent rate, is known. Therefore, no attempt at a theoretical solution for the rise rate is made. In References 6 and 7, mean rise rates have also been determined to represent the unperturbed ascent rate of the Jimsphere.

As will be shown, the mean rate of rise versus altitude is represented by a first degree linear least squares line of regression to an altitude of 15 kilometers. Above 15 kilometers the ascent rate of the 2.0 meter Jimsphere decreases more and more rapidly as the balloon approaches its floating altitude. A mean ascent rate above 15 kilometers loses significance, and no attempt is made to extend any curve above this height.

2.1 WIND REDUCTION TECHNIQUE AND ERROR ANALYSIS

Inasmuch as reduced horizontal winds and ascent rate data were received from Marshall Space Flight Center, Aerospace Environment Division, for this study, a brief review of the wind reduction technique and the assessment of errors is presented.

The wind reduction technique currently used on FPS-16 Radar/Jimsphere flights is that described in Reference 3. MSFC's wind reduction program first performs data editing in the following manner. The 0.1-second readings of slant range, elevation angle, and azimuth are fitted to a 9-point first degree equation by the method of least squares for editing the data. If the residual at the midpoint of the 9-point line is greater than three times the assumed RMS error. the data for the midpoint is replaced by the average value over the interval.

2.1 (Continued)

Then the 9-point line is extrapolated to the 10th point and if the difference between this predicted value and the observed value is greater than five times the assumed RMS error the observed value is rejected and replaced by the value given by the extrapolated line. This procedure is repeated for each 0.1-second step until all the data have been edited.

After data editing, the tracking data are transformed to the x, y, z coordinates for each 0.1 second. These position coordinates are then smoothed with a first degree polynomial curve fit over a 4-second time interval (41 points centered on the data at the time of the first vertical coordinate greater than the desired multiple of 25-m). The position coordinates at each 25-meter altitude interval are then determined from these polynomials. The wind components are determined from these smoothed coordinates using the time difference over a 50-meter altitude interval and printed out for each 25-meter interval.

In Reference 1, Scoggins shows that from dually tracked releases, the RMS error for the Jimsphere ascent rate averages less than 0.2 meters per second throughout the altitude range of the flight. These data are from relatively light wind conditions. The study done by Susko and Vaughan (Reference 8) covered a larger sample of dually tracked Jimsphere balloons which contained releases during light winds aloft conditions as well as very strong wind conditions. The overall average of the RMS error in ascent rate was 0.37 meters per second. In light wind conditions the RMS errors agreed in general with what Scoggins reported. However, in strong wind conditions as the elevation angles of the radars became less than 10 degrees and slant ranges approached 100 km the RMS errors in rise rate increased significantly to greater than 1.0 meters per second at the higher altitudes. These dually tracked Jimsphere balloons were reduced to wind velocity and rate of rise values by the wind reduction technique described earlier.

RMS errors of the magnitudes indicated in rate of rise should be random and independent of each other. Therefore, rise rate data should show that high frequency noise scatters adjacent data points. This is illustrated in Paragraph 2.3 in which unfiltered ascent rate data are presented. The filtering of rise rate data, discussed in Paragraph 2.3, rids the data of the high frequencies leaving perturbations in the ascent rate profiles with wave lengths of 300 meters or greater. Such wave lengths of significant amplitude indicate that these perturbations are due to vertical atmospheric motions.

2.2 THE DATA

The data furnished by Marshall Space Flight Center, Aerospace Environment Division, consisted of ten magnetic tapes, supplied over the period from January 11 to September 4, 1968, containing four horizontal variables and the ascent rate of FPS-16/ Jimsphere Wind Measurements made at Cape, Kennedy, Florida. The test numbers of the data used in this study (48 profiles) are listed in Table 2-I. Jimsphere release times and dates in Greenwich Meridian Time are also presented.

TABLE 2-I. LISTING OF CAPE KENNEDY, FLORIDA, JIMSPHERE WIND DATA STUDIED

ETR TEST NO.	DATE	TIME OF RELEASE (GMT)
3069 -1	October 24, 1966	1700
-2		2000
-3		2300
-4	October 25, 1966	0100
-5		0230
-6		0500
-7		0650
-8		0811
-9		0903
6476 -2	October 25, 1966	2000
-3		2300
-5	October 26, 1966	0230
-6		0500
-7		0650
-8		0755
-9		0910
0163 -1	January 13, 1965	1542
-3		1826
-4		1934
-6		2137
-7		2237
-9	January 14, 1965	0040
-10		0134
0870 -1	February 10, 1965	1305
-2		1428
-3		1530
-4		1645
-5		1802
-6		1915
-8		2150
-9		2305
-10	February 11, 1965	0035

2.2 (Continued)

TABLE 2-I. LISTING OF CAPE KENNEDY, FLORIDA, JIMSPHERE WIND DATA STUDIED (Continued)

ETR TEST NO.	DATE	TIME OF RELEASE (GMT)
1272 -1	February 24, 1965	1300
-2		1521
-4		2029
-5		2150
-7	February 25, 1965	0025
-8		0144
-9		0259
2272 -1	April 13, 1965	1200
-2		1415
-3		1530
-4		1700
-5		1806
-6		1921
-7		2055
-8		2210
-9		2325

2.3 DATA CONDITIONING, FILTERING, AND PLOTTING

The first operation on the MSFC Jimsphere wind profile data is to convert the IBM 7094 Binary Coded Decimal (BCD) format to an IBM 360 Systems Extended Binary Coded Decimal Interchange Code (EBCDIC) format. This operation is accomplished by the Tape Inspection Program which is also used to inspect the tapes by checking the byte, word, and record count for conformity in each file. In addition, it accomplishes "time" editing (the editing of the independent variable) and notes record gaps and missing data. The output tape is then merged with the other inspected tapes and reformatted for data editing and filtering by the Graphics Data Conditioning program which implements on-line engineering decision making. The decision making capabilities of the Graphics Data Conditioning program are realized through the use of the IBM 2250 Display System, a computer hardware component of the IBM 360 computer system. The display system consists of a cathode ray screen, an alphanumeric keyboard, function keyboard, and a light pen, plus associated buffering and computer interface electronics. The light pen, the function keyboard, and the alphanumeric keyboard provide the means by which the engineer is able to give instructions to the computer, select the desired program options, initiate the routine for obtaining hard copy of the graphics displays, or enter discrete numerical or alphanumeric values. After the

2.3 (Continued)

computer has received and acted upon an instruction, it immediately displays the results on the cathode ray screen for evaluation by the engineer. Thus, iterative operations and recovery from operational errors are rapidly accomplished by this on-line operation.

The modules of the Graphics Data Conditioning program include the following:

a. A data editing procedure to remove "wild points" in the dependent variables.
b. A linear interpolation procedure to fill in data gaps.
c. The generation of Martin constrained digital filters which are derived from Fourier integral theory.
d. The display of this filter's transfer function.
e. The display of the data after filtering.
f. The storing of these conditioned data in a data bank for subsequent generation of a magnetic tape of the conditioned data.

These options are used in this study and are only a few of those available to the engineer in the Graphics Data Conditioning program.

The filter module of the Graphics Data Conditioning program provides a wide selection of various Martin type filters (i.e. high pass, band pass, etc.). Any one of these filters may be generated by selecting the type needed and then specifying the filter parameters to the computer. For the low pass smoothing filter the parameters specified are the desired cutoff frequency and the number of weighting factors to be used.

The low pass smoothing filter rids the Jimsphere ascent rate data of the high frequency noise and gives ascent rate profiles wavelength characteristics comparable to the wave lengths of significant features on the profiles of the unfiltered horizontal wind variables. Many different filter parameters were tested. Some of these filters, with the results of the filtering and frequency responses, are shown in Appendix B. The results of filtering by each show that 25 filter weights give the best results.

Two 25 weight filters are presented in Figures 2-1 and 2-2, with their respective frequency responses shown. Their respective effects on the filtering of the rise rate data of Test No. 6476-2, 2000 GMT, October 25, 1966 at Cape Kennedy are shown in Figure 2-3. Slight differences are observed in the amplitudes of the smallest scale features but no significant differences exist in the larger scale features of the two profiles.

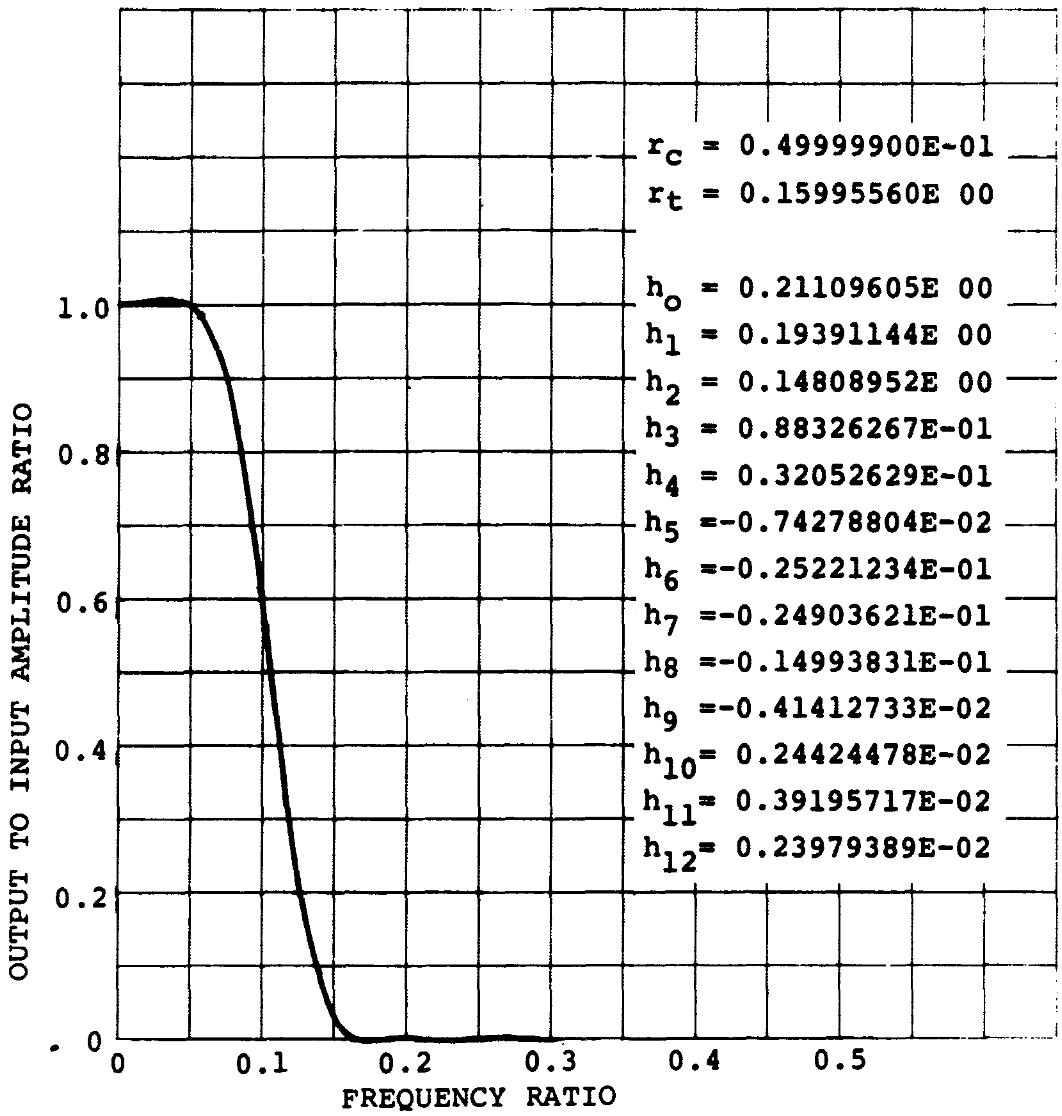


FIGURE 2-1 FREQUENCY RESPONSE OF 25-WEIGHT FILTER, CUTOFF FREQUENCY .002 CPM

	25 wt	13 wt	7 wt
Cutoff Frequency Ratio	r_c= 0.24999900E-01	r_c= 0.24999900E-01	r_c= 0.24999900E-01
Termination Frequency Ratio	r_t= 0.13495560E 00	r_t= 0.24491170E 00	r_t= 0.46482250E 00
h_0	0.15945514E 00	0.26684494E 00	0.48574217E 00
h_1	0.15110826E 00	0.22550301E 00	0.26208957E 00
h_2	0.12797914E 00	0.12968924E 00	0.44739948E-02
h_3	0.95214205E-01	0.38321815E-01	-0.94346499E-02
h_4	0.59643568E-01	-0.86413628E-02	
h_5	0.27821153E-01	-0.13899525E-01	
h_6	0.43313706E-02	-0.43956452E-02	
h_7	-0.91083830E-02		
h_8	-0.13544352E-01		
h_9	-0.11862507E-01		
h_{10}	-0.74886692E-02		
h_{11}	-0.32251127E-02		
h_{12}	-0.59624137E-03		

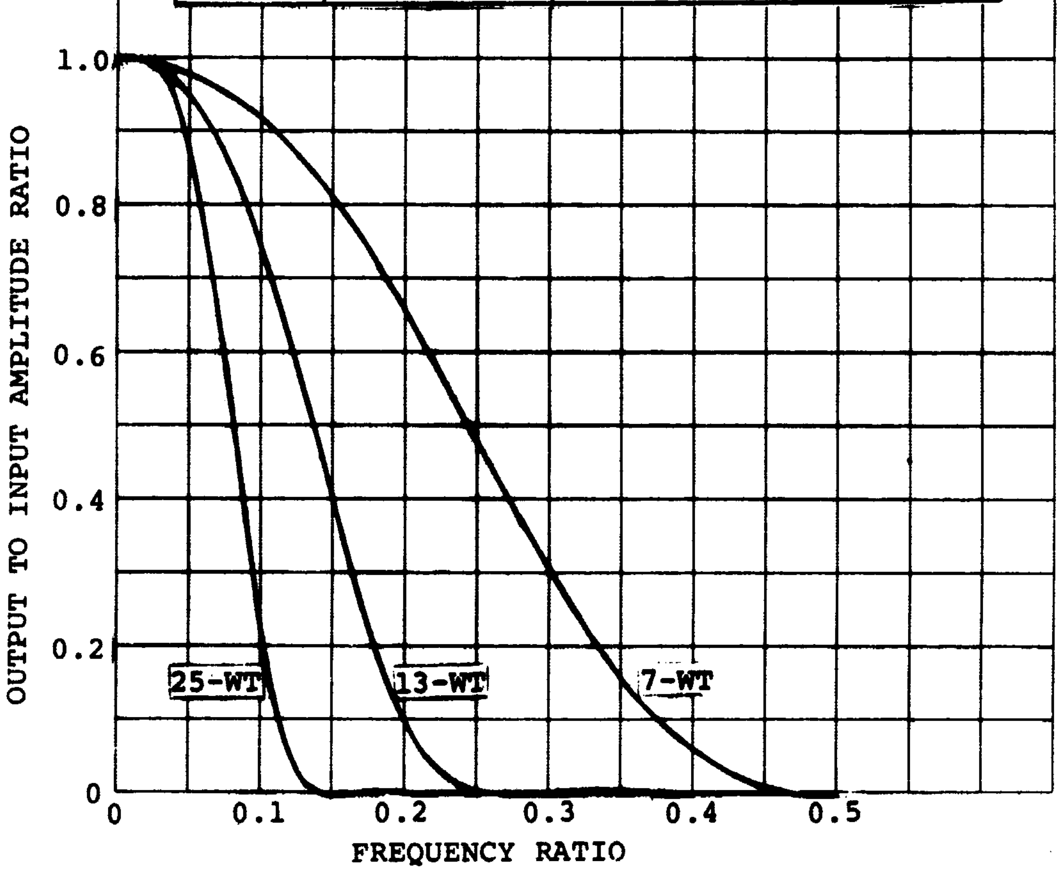


FIGURE 2-2 FREQUENCY RESPONSES OF 25-, 13- AND 7-WEIGHT FILTERS USED TO FILTER ASCENT RATE DATA, CUTOFF FREQUENCY .001 CPM

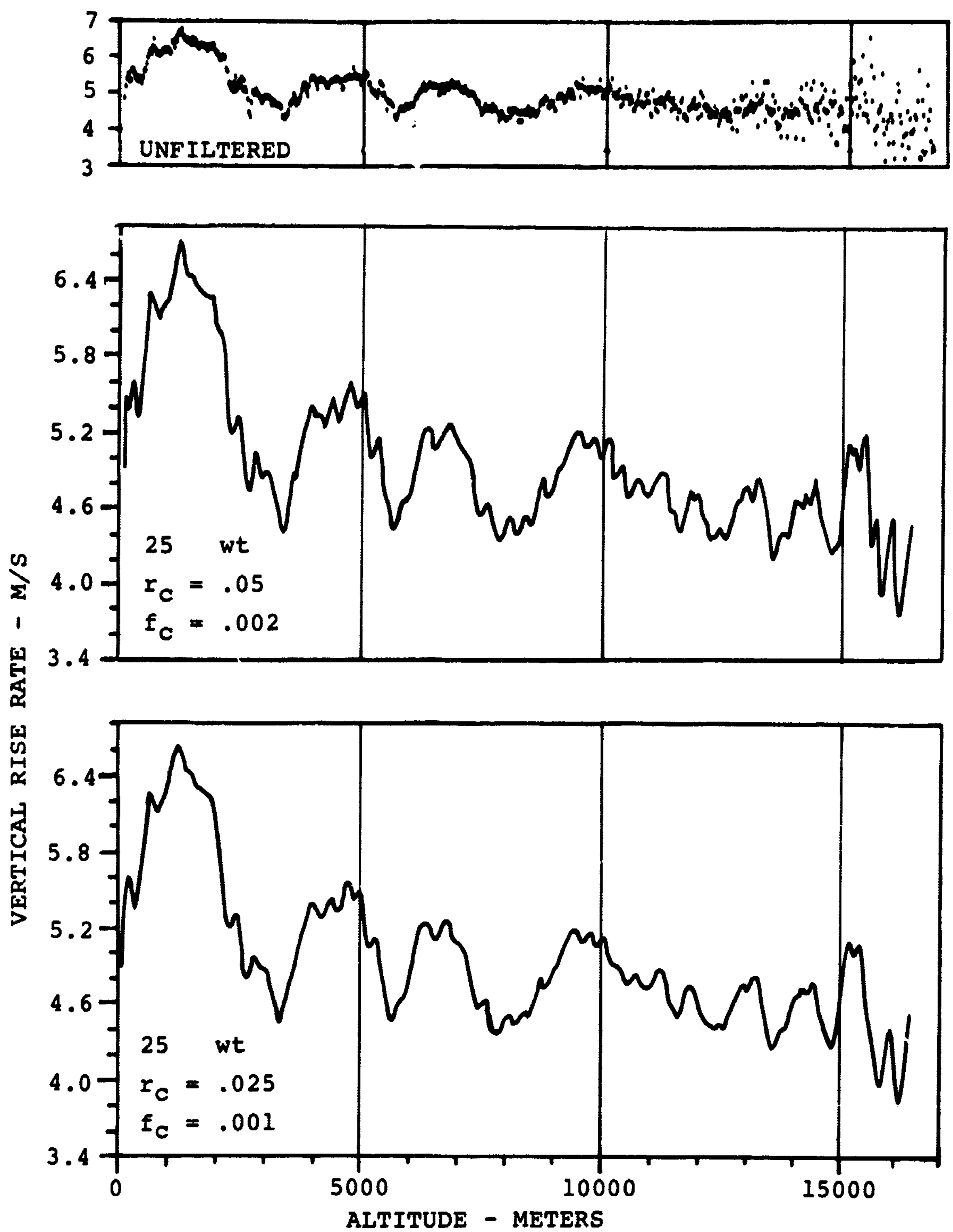


FIGURE 2-3 ASCENT RATE DATA FOR TEST 6476-2: UNFILTERED, FILTERED BY FILTER OF FIGURE 2-1, AND BY FILTER OF FIGURE 2-2

2.3 (Continued)

The lower frequency cutoff filter (Figure 2-2) is selected for use because it removes more of the high frequency noise from the ascent rate data. The significance of the 13- and 7-weight filters, also presented in this same figure with their frequency responses, is to demonstrate how the filter module operates to avoid the loss of data points at the beginning and at the end of the data file. The first three data points are presented unfiltered after which the 7-weight filter is applied to the next three. The seventh point through the twelfth are then filtered by the 13-weight filter after which all data up to the twelfth point from the end are filtered by the 25-weight filter. The reverse of this is then accomplished on the last twelve data points. Note that all three sets of filter weights depicted in Figure 2-2 have the same cutoff frequency. The rolloff interval is determined by the filter module of the Data Conditioning program and varies inversely as the number of filter weights specified.

2.4 THE MEAN RISE RATE DETERMINATION

The edited and smoothed data from the Data Conditioning program are stored in a Conditioned Data Bank from which a new data tape is written. This tape is then reformatted to become the input tape for a statistical program that is designed to compute a mean rate of rise and standard deviation at each altitude interval from the maximum sample of 48 conditioned Jimsphere ascents. The input tape is a single file tape, 800 records long, each record consisting of 241 words. The first word is the independent variable, height, and the other words are the 5 dependent variables from each of the 48 Jimsphere wind measurements used in this study. Program logic for determining the mean rise rate and the standard deviation of the perturbations is shown in Figure 2-4. Note that the IBM 360 computer interprets the IBM 7094 BCD coding for "blank" as a negative number. Hence, the test whether W_j is greater than zero determines whether the ascent rate value read by the computer is a significant value or a blank.

In Figure 2-5, the mean rate of rise (W), is depicted in four profiles, each plotted at 200 meter intervals; Profile A beginning at 450 meters, B at 500 meters, C at 550 meters, and D at 600 meters. The purpose of the four profiles is to demonstrate the goodness of fit of the linear first degree least squares curve, from near the surface to 15,000 meters. The regression line is given by the following equation:

$$W = 5.397 - .05667H$$

where W is the ascent rate, and height, H, is in kilometers.

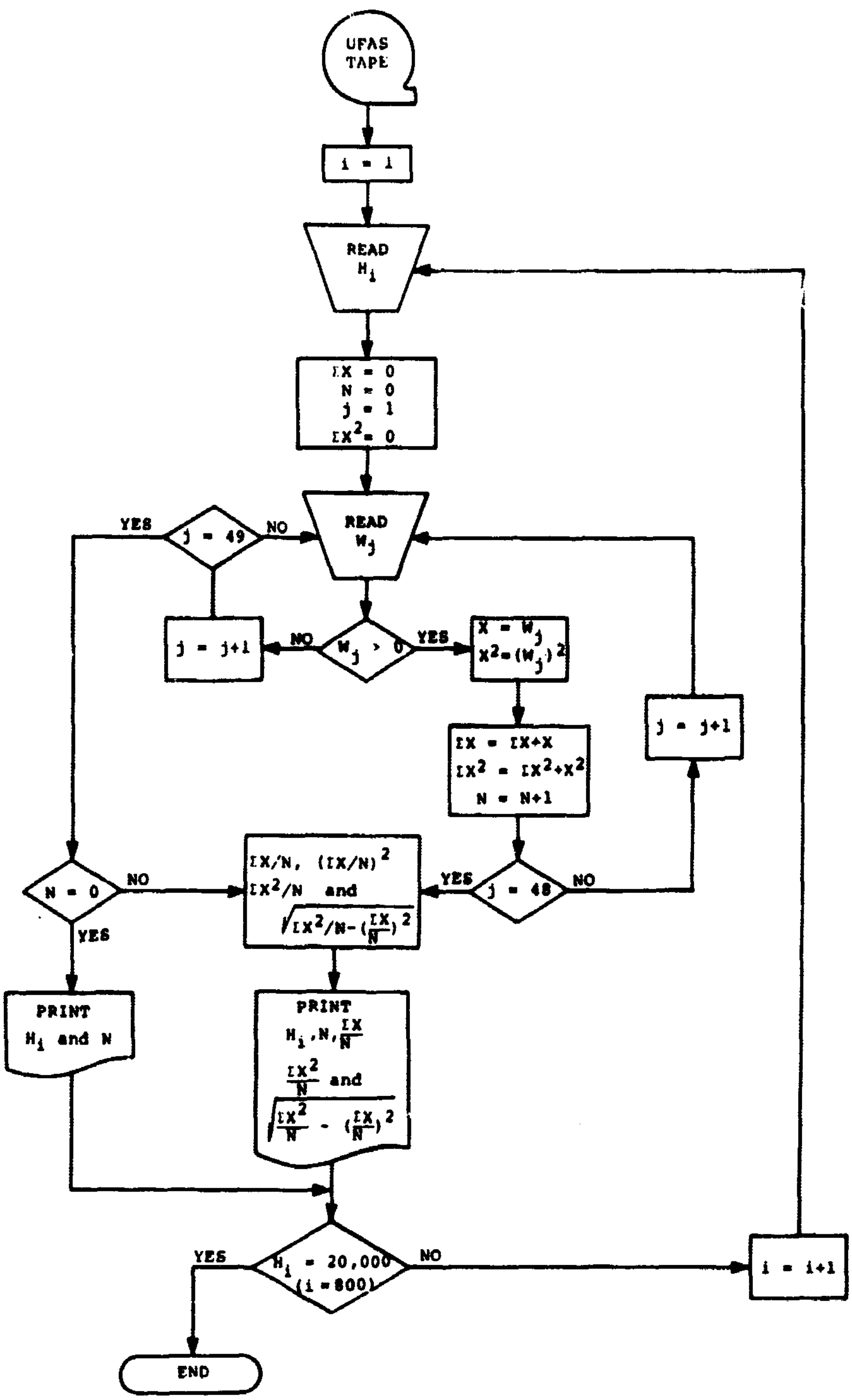


FIGURE 2-4 FLOW CHART FOR PROGRAM TO COMPUTE MEAN RISE RATE AND STANDARD DEVIATION

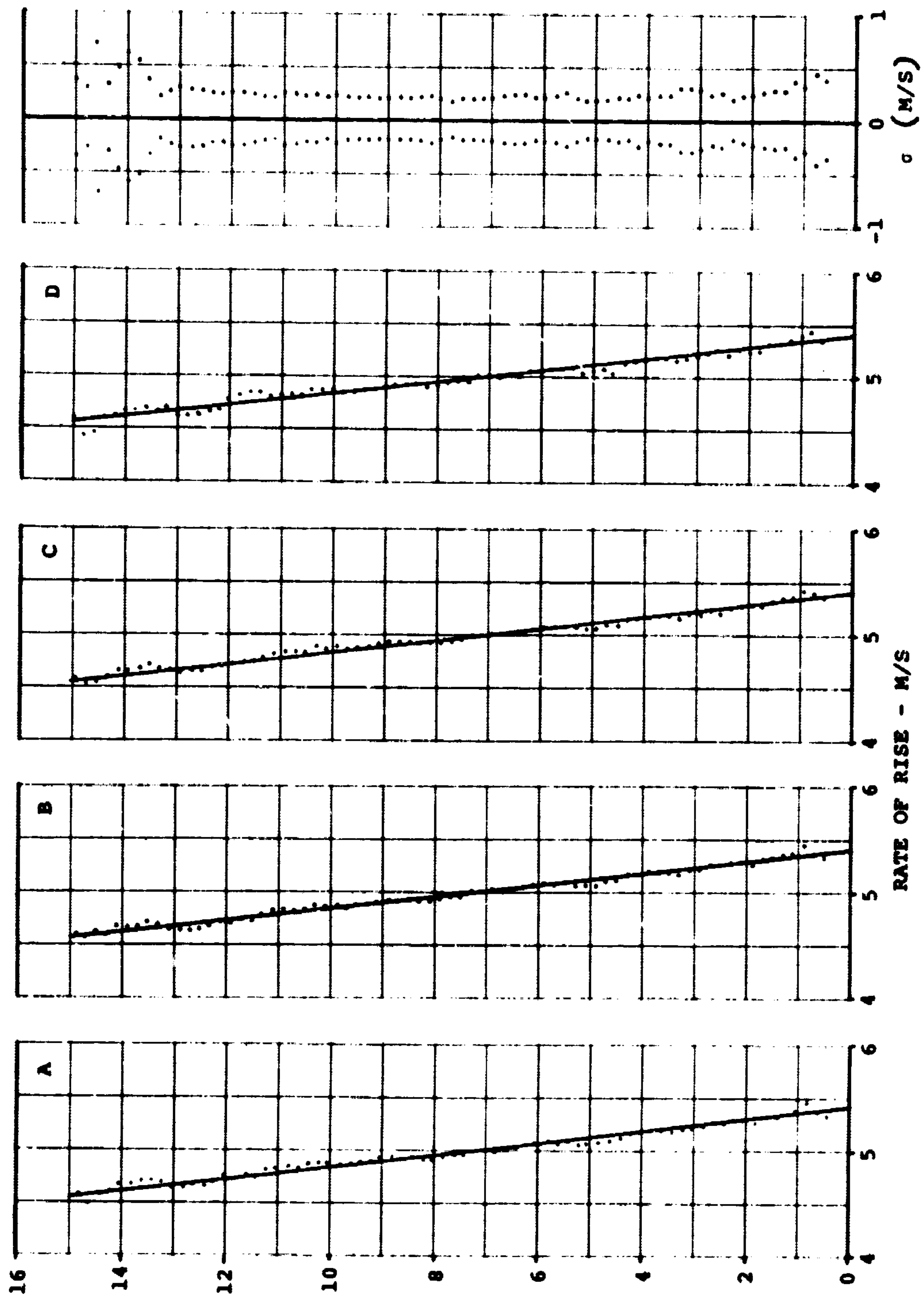


FIGURE 2-5 PROFILES OF MEAN RISE RATE WITH LINEAR LEAST SQUARES CURVE FIT AND PROFILE OF STANDARD DEVIATION

2.4 (Continued)

If at each 25 or 50 meter height interval, the W values are plotted on just a single diagram, the points would run together or show enough scatter to obscure the goodness of fit of the regression line. This linear first degree curve is used on the individual rise rate profiles to judge the degree of perturbations in the ascent rates. It is realized that from season to season there are small variations in the mean rate of rise and that from balloon to balloon the individual ascent rates in still air vary.

Regarding balloon variations, Eckstrom (Reference 6) gives the average weight of the uninflated Jimsphere as 407.9 grams with a standard deviation of 3.9 grams. Eckstrom also shows a range of values of drag coefficient at each Reynolds number. Slight variations will exist in the performance of the pressure release valves and in the volume and cross-sectional areas of each Jimsphere. Each of these factors affect the rise rate, albeit slightly. By comparing the mean rise rate shown in Figure 2-5 with other studies (References 6, 7, and 8) it is estimated that the unperturbed rise rate is known within two or three percent.

The profile in the right portion of Figure 2-5 presents the standard deviations (versus altitude) of the perturbations in the data from which the mean rate of rise is determined. The standard deviations are fairly constant throughout most of the altitude interval averaging about 0.25 meters per second. Below about 1500 meters and above 13 kilometers the standard deviations increase significantly. Near the surface, convective instability of the atmosphere causes large amplitude variations in the rise rates which increase the standard deviation. Above 13 kilometers the tracking errors become significantly greater with increasing slant ranges and decreasing elevation angles. The size of the sample also is decreased at either end of the calculation of mean rise rate because tracking data do not begin or end at the same altitudes.

SECTION 3

DISCUSSION

3.0 GENERAL

Some of the atmospheric phenomena that produce vertical motions in the atmosphere are convective activity, gravity waves, thermodynamic instability layers, and turbulence. Transitory stacked and paired longitudinal vortices (Reference 3) also have vertical components of motion. Some of these vertical motions will be too small or too transitory to be observed on the profiles of the filtered Jimsphere ascent rate data. Other vertical motions persist over a considerable altitude interval with sufficient amplitude to be seen readily. It will be extremely interesting in more specific studies to determine the degree of variation of rise rate because of such atmospheric factors.

3.1 COINCIDENT PROFILES OF COMPONENTS

In Figures 3-1 through 3-17 the 17 sets of profiles of the four horizontal variables of the winds are presented with the ascent rate profiles. The scale of the rise rate is expanded significantly and it should be noted that the scales of the graphs of this parameter are not uniform from profile to profile. These profiles are reproductions from hard copy of the displays on the IBM System/360-2250 Graphics Console.

The profiles of consecutive runs from the Test No. 0870 series made on February 10, 1965 are presented in Figures 3-1 through 3-5. This entire series of runs shows a remarkable persistence of the features in the horizontal components. In particular, a large increase in wind speed between 11 and 12 kilometers is noted and is accompanied by a sizable veering of the wind direction with altitude. No similar persistence of the variability features of the ascent rate appear. This implies that the perturbations in the rise rate are quite transitory even though the associated horizontal variables have persistent features. In Figure 3-1, a relatively large positive ascent rate perturbation is shown at 11 kilometers with associated large increase of horizontal wind speed. In Figure 3-2, this feature has disappeared but an equally large perturbation appears at 12 kilometers above which there is a sizable negative perturbation. Since these phenomena appear within the maximum wind layer, they may be an example of the transitory paired and stacked longitudinal vortices. In Figures 3-3, 3-4, and 3-5, the most significant features appear to be the large variation in rise rate below 2 kilometers. This variation is probably due to convective activity near the surface.

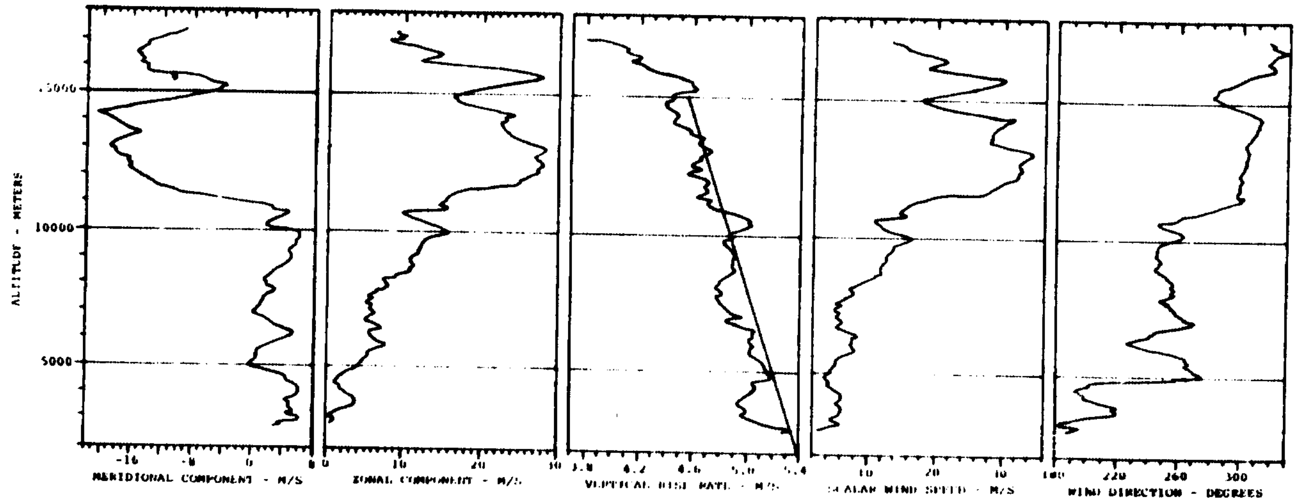


FIGURE 3-1 COMPONENT WIND PROFILES, TEST 0870-2, 1428Z, FEB 10, 1965

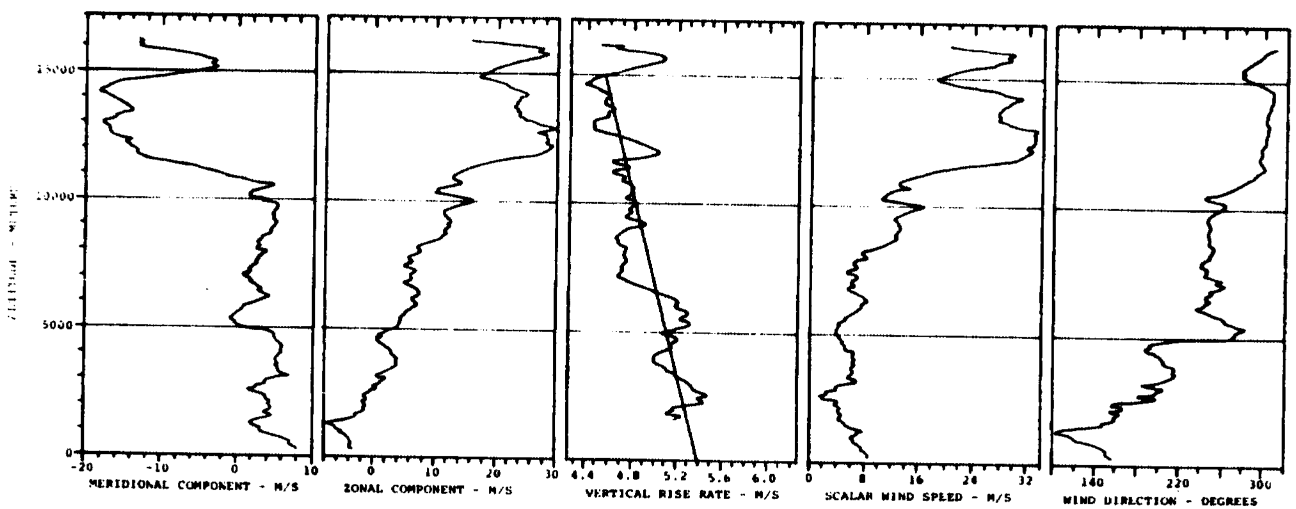


FIGURE 3-2 COMPONENT WIND PROFILES, TEST 0870-3, 1530Z, FEB 10, 1965

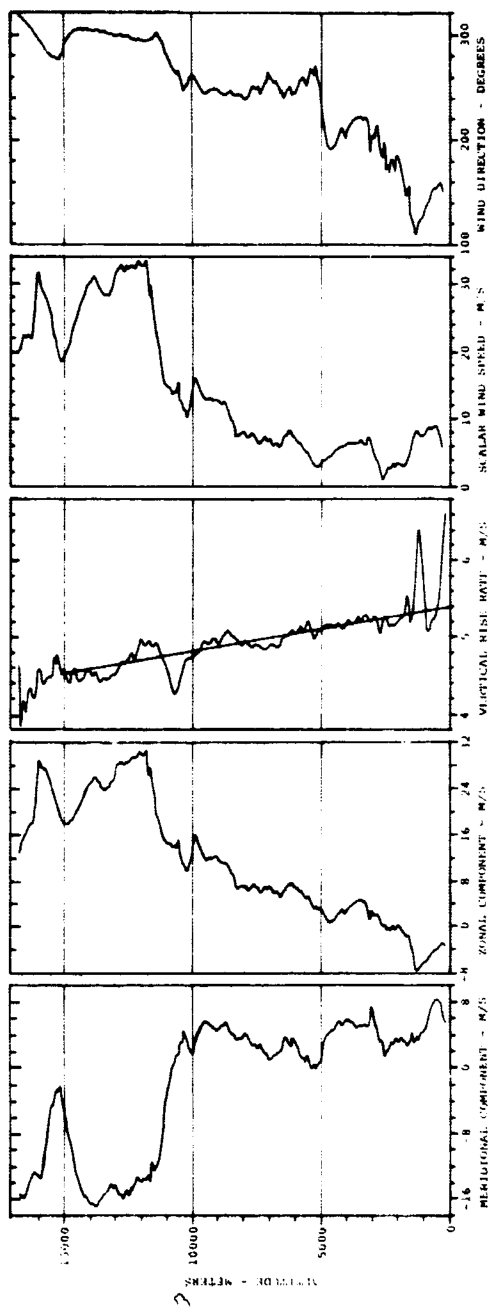


FIGURE 3-3 COMPONENT WIND PROFILES, TEST 0870-4, 1645Z, FEB 10, 1965

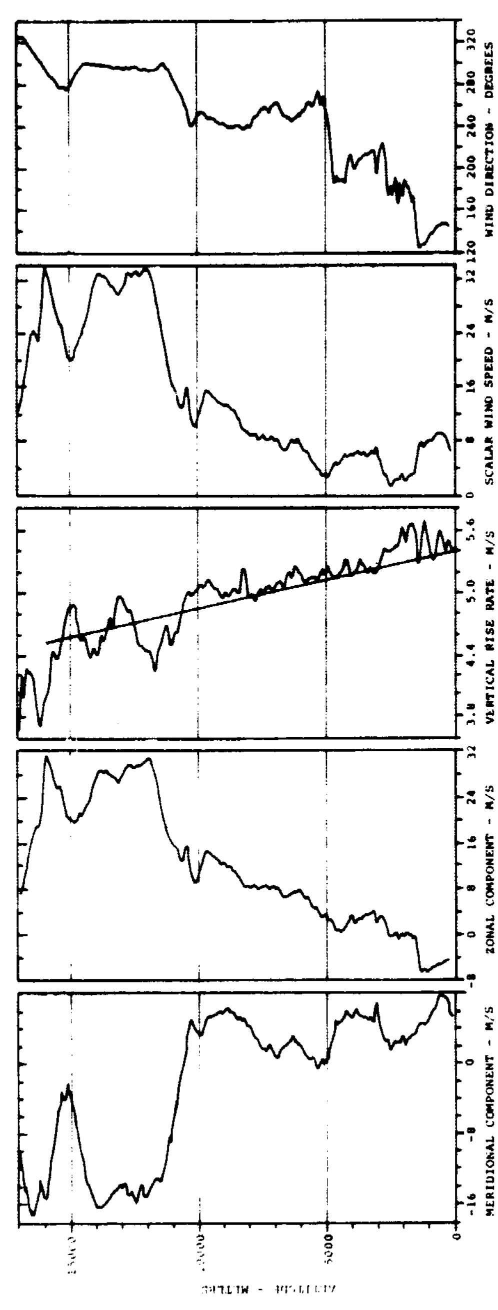


FIGURE 3-4 COMPONENT WIND PROFILES, TEST 0870-5, 1802Z, FEB 10, 1965

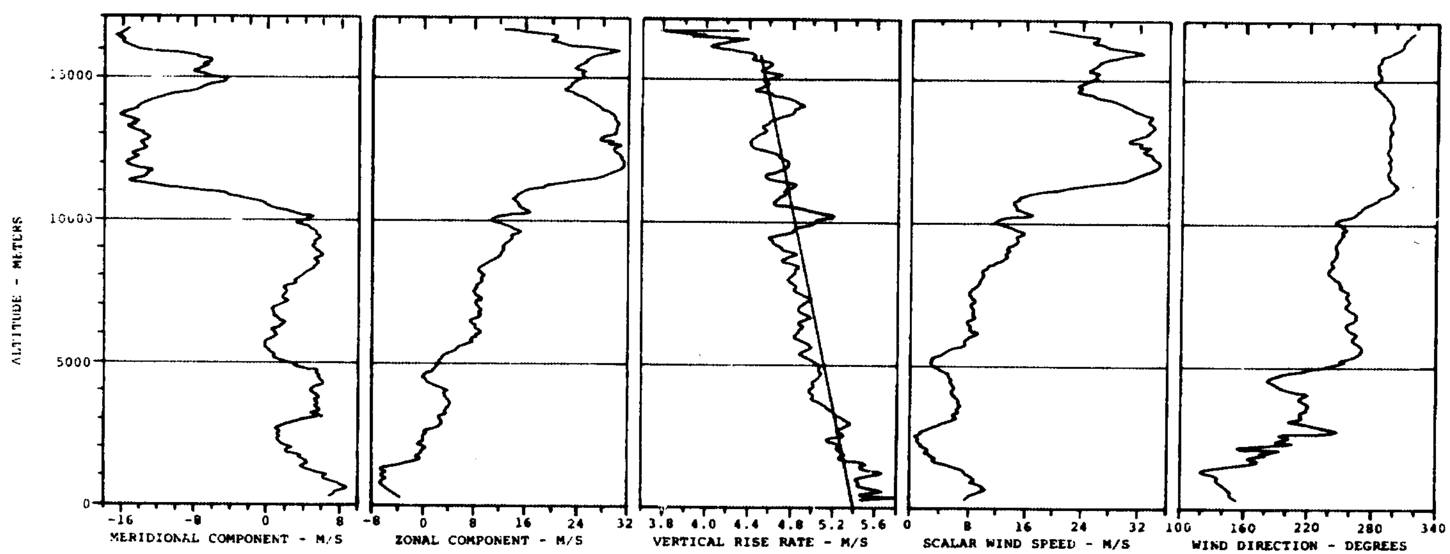


FIGURE 3-5 COMPONENT WIND PROFILES, TEST 0870-6, 1915Z, FEB 10, 1965

3.1 (Continued)

The Test No. 1272 series of Jimsphere winds shown in Figures 3-6 through 3-10, were made on February 24, 1965, a day of considerable cloudiness. The synoptic weather for that day shows a weak wave or a front to the north of the station. The station and the surrounding area lie in the warm sector which signifies that this is an area of convergence. From the generally large perturbations in ascent rate at all levels in these profiles, it can be deduced that there is increasing instability in the air mass.

In the series given in Figures 3-11 through 3-17, some persistence of variations in ascent rate can be observed, but there are no clear cut associations with the features in the horizontal components of the wind. In other words, when a rise rate perturbation appears in one figure, at the same level as features in the horizontal flow, it may be absent on the next Jimsphere flight or may be reversed in sign. An example of this is in the lowest five kilometers of the Test No. 2272 series of April 13, 1965. In this series, the data to 5 kilometers are characterized by relatively large changes in wind direction. On that day there was considerable cloudiness, but there were no fronts near the station. The perturbations in the ascent rates are also relatively large but are randomly distributed in this lower altitude interval and do not appear to be uniquely associated with any single characteristic of the change in wind direction or speed. In Figures 3-14, 3-15, and 3-16, prominent long wave undulations in the ascent rate profiles appear between 2 and 10 kilometers altitude. These are persistent over the period but do not quite stay in phase with each other. Only the zonal component profile in Figure 3-14 shows similar undulations which may be associated with those in the ascent rate profiles. The ascent rate variabilities are probably associated with atmospheric motions, variations in thermal structure moisture, etc.

In Figures 3-18 and 3-19 the vertical rise rate profiles for two series of wind runs are shown on unexpanded scales. In order to better present them for comparisons with each other, height is displayed as the abscissa. All of the rise rates (Test No. 0870 Sequence) presented in Figure 3-18 show persistent variability below 3 kilometers. These variations can probably be accounted for by lower atmospheric instability. Figure 3-19 is another montage of vertical rise rate profiles from the Test No. 3069 series of October 25 and October 26, 1966. The upper two profiles are very similar, showing some persistence of the predominant features. The synoptic weather indicated a weak frontal surface over the station. No rawinsonde at this time was available to determine the height of this frontal surface, but apparently it was approxi-

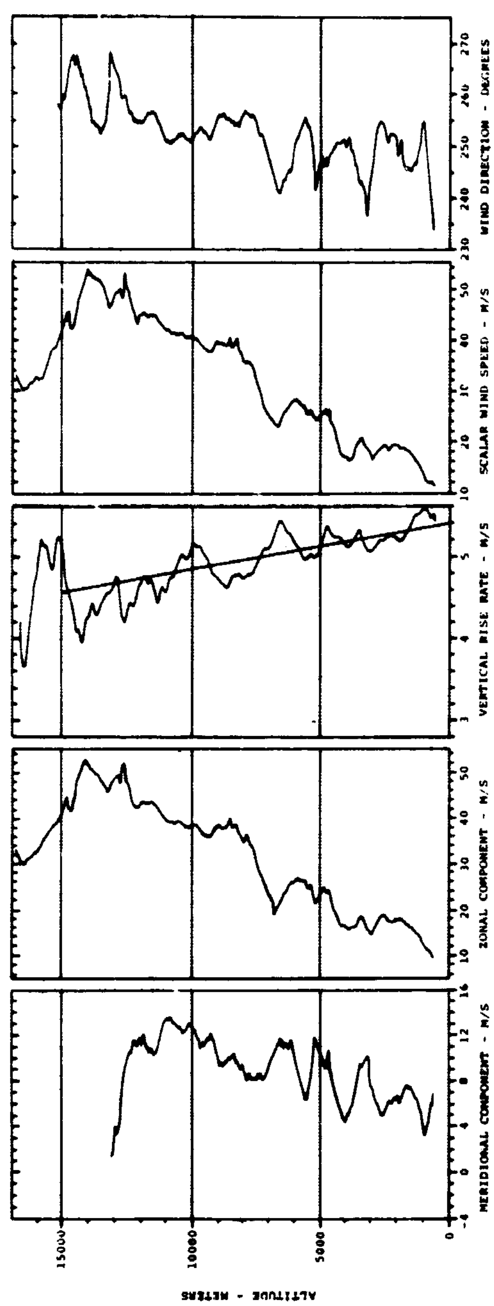


FIGURE 3-6 COMPONENT WIND PROFILES, TEST 1272-1, 1300Z, FEB 24, 1965

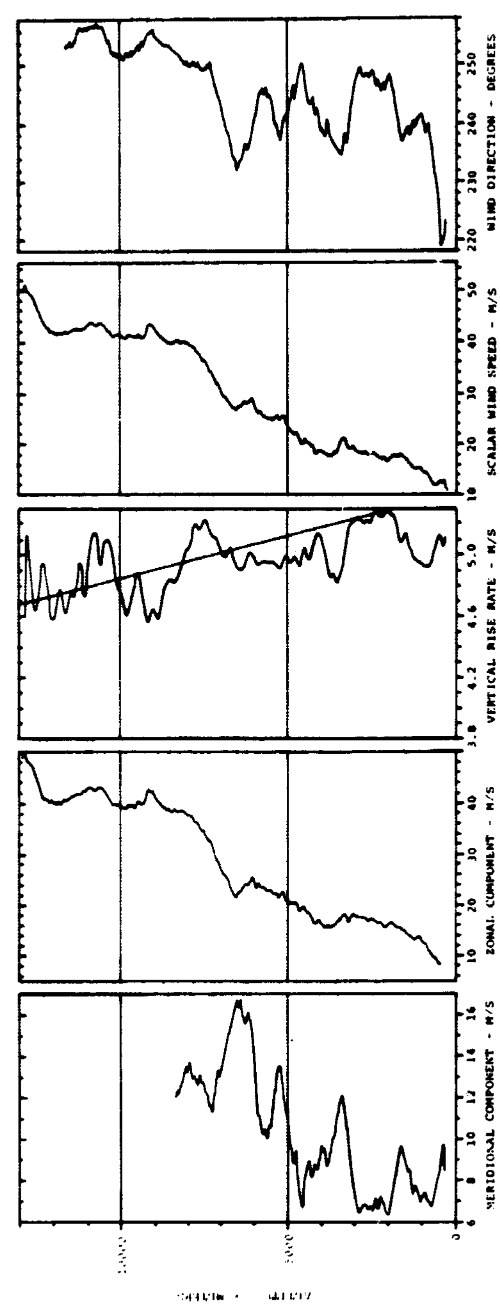


FIGURE 3-7 COMPONENT WIND PROFILES, TEST 1272-2, 1521Z, FEB 24, 1965

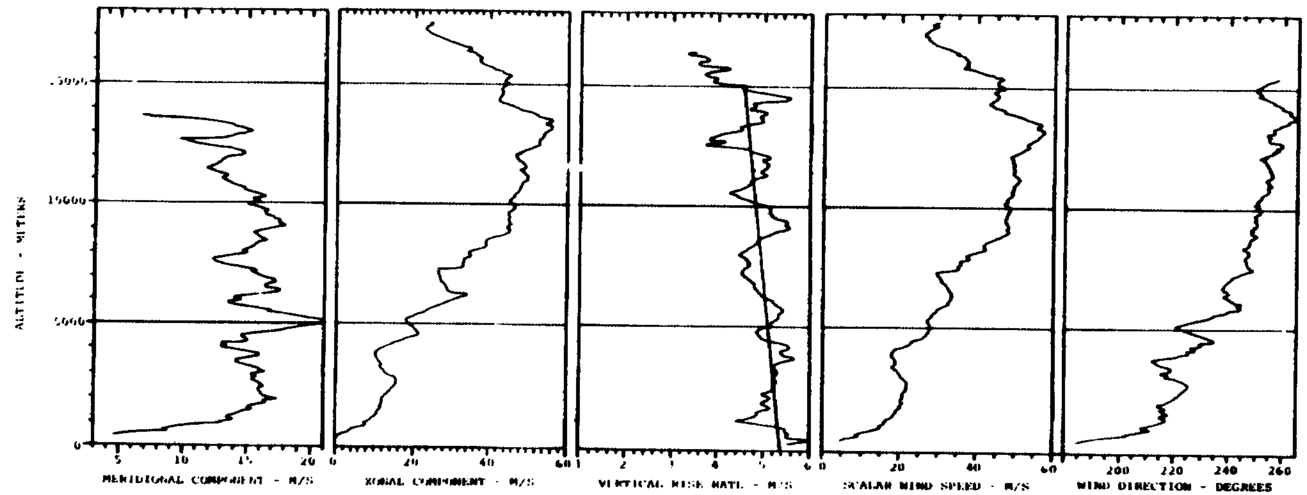


FIGURE 3-8 COMPONENT WIND PROFILES, TEST 1?72-5, 2150Z, FEB 24, 1965

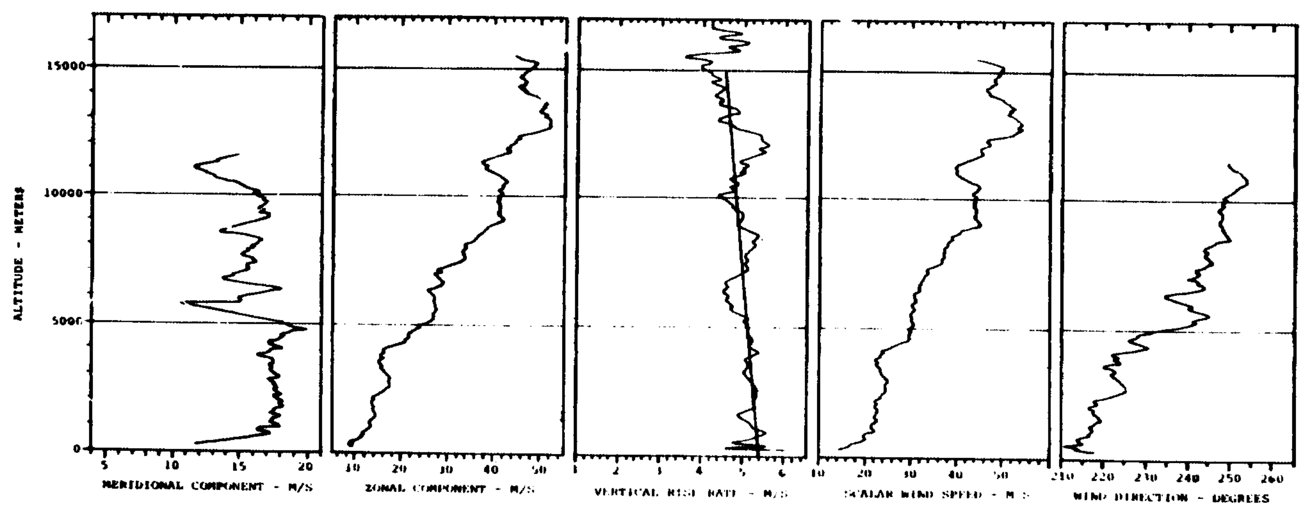


FIGURE 3-9 COMPONENT WIND PROFILES, TEST 1272-7, 0025Z, FEB 25, 1965

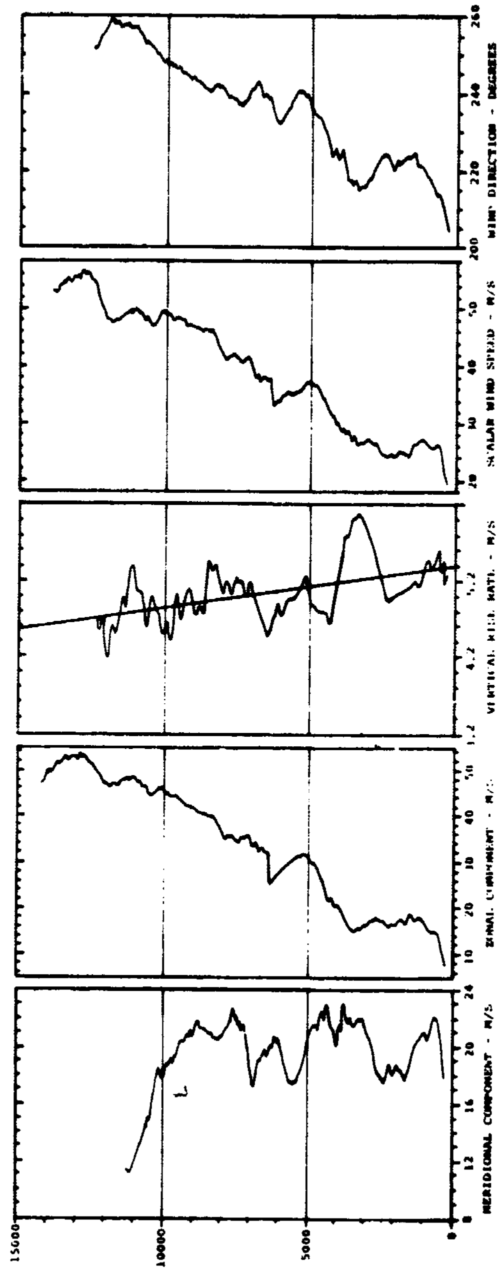


FIGURE 3-10 COMPONENT WIND PROFILES, TEST 1272-9, 0259Z, FEB 25, 1965

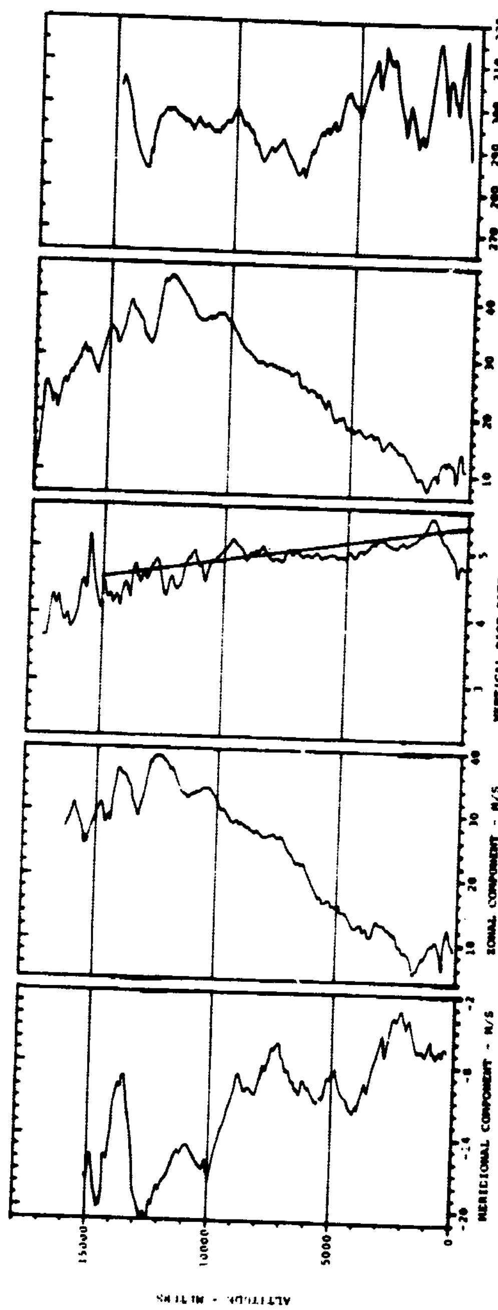


FIGURE 3-11 COMPONENT WIND PROFILES, TEST 2272-1, 1200Z, APR 13, 1965

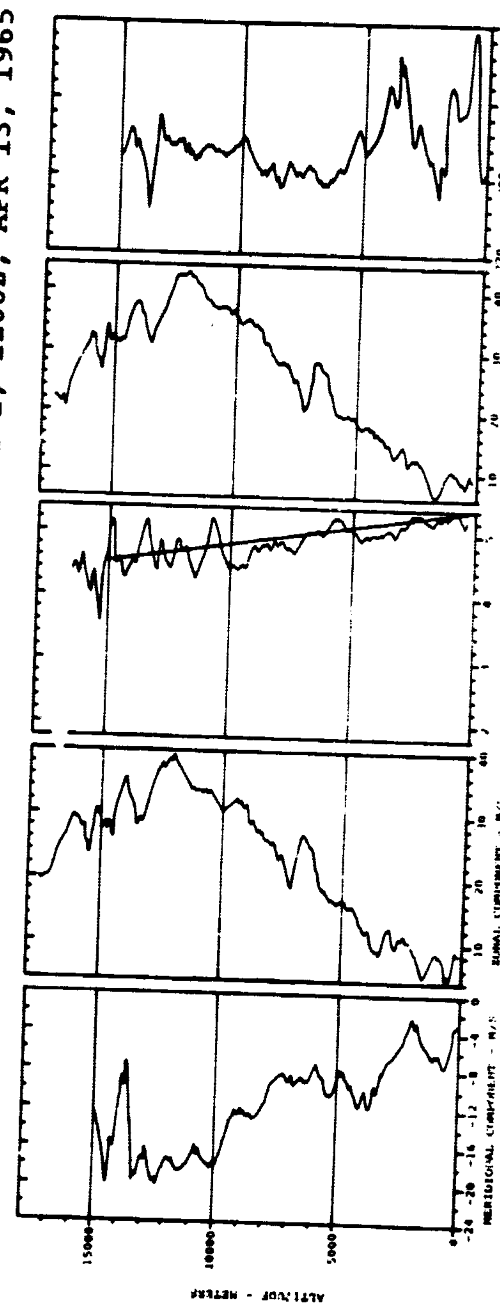


FIGURE 3-12 COMPONENT WIND PROFILES, TEST 2272-2, 1415Z, APR 13, 1965

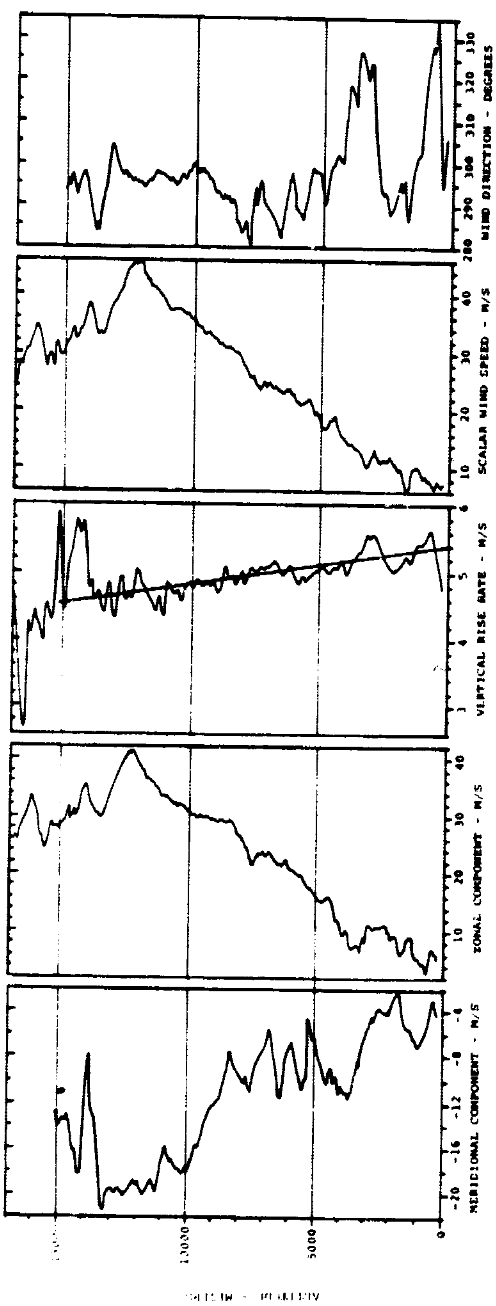


FIGURE 3-13 COMPONENT WIND PROFILES, TEST 2272-3, 1530Z, APR 13, 1965

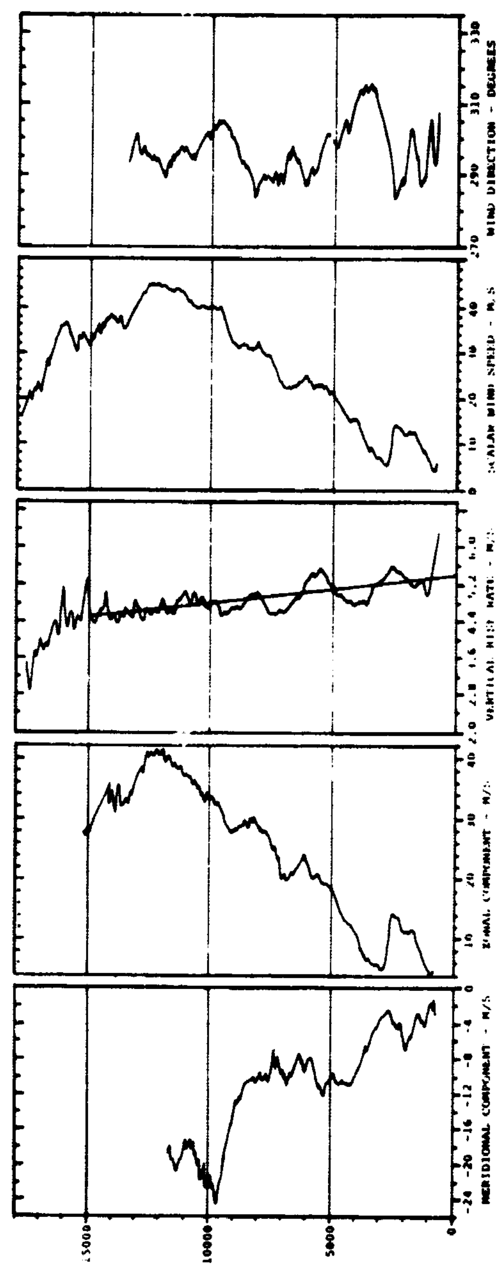


FIGURE 3-14 COMPONENT WIND PROFILES, TEST 2272-5, 1806Z, APR 13, 1965

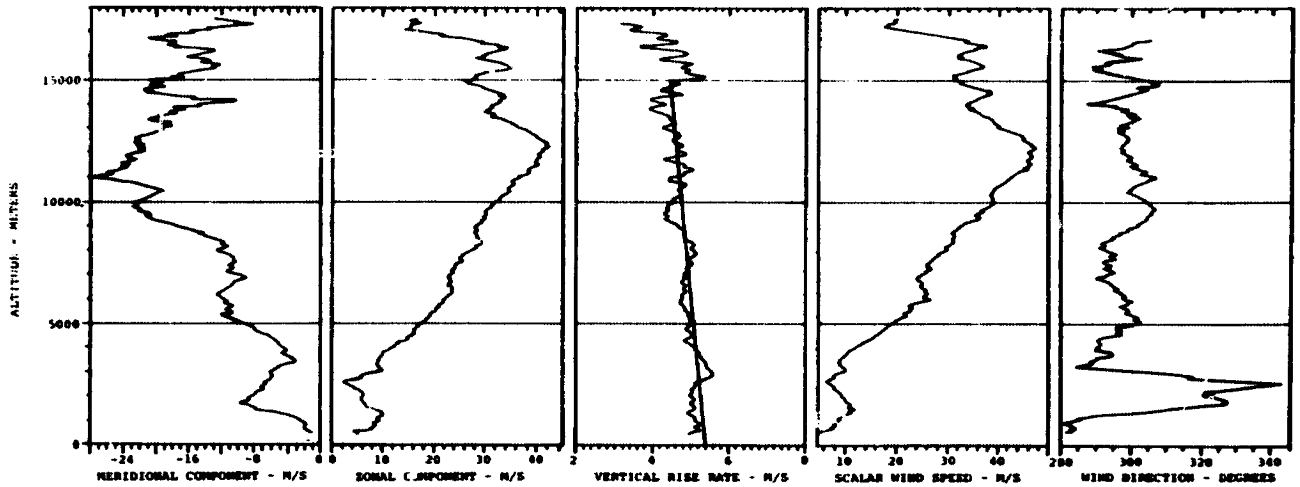


FIGURE 3-15 COMPONENT WIND PROFILES, TEST 2272-7, 2055Z, APR 13, 1965

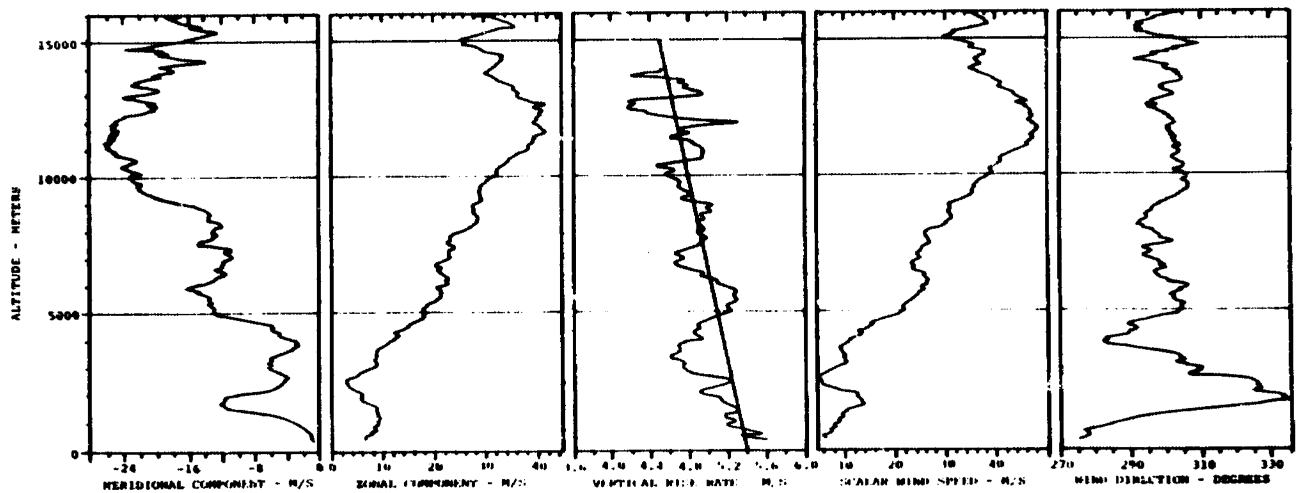


FIGURE 3-16 COMPONENT WIND PROFILES, TEST 2272-8, 2210Z, APR 13, 1965

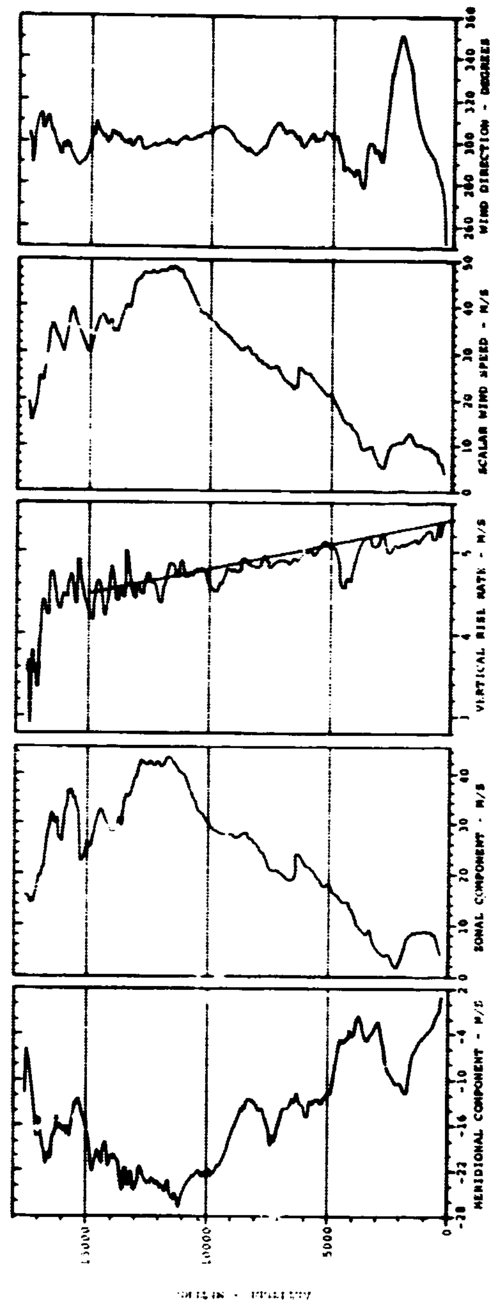
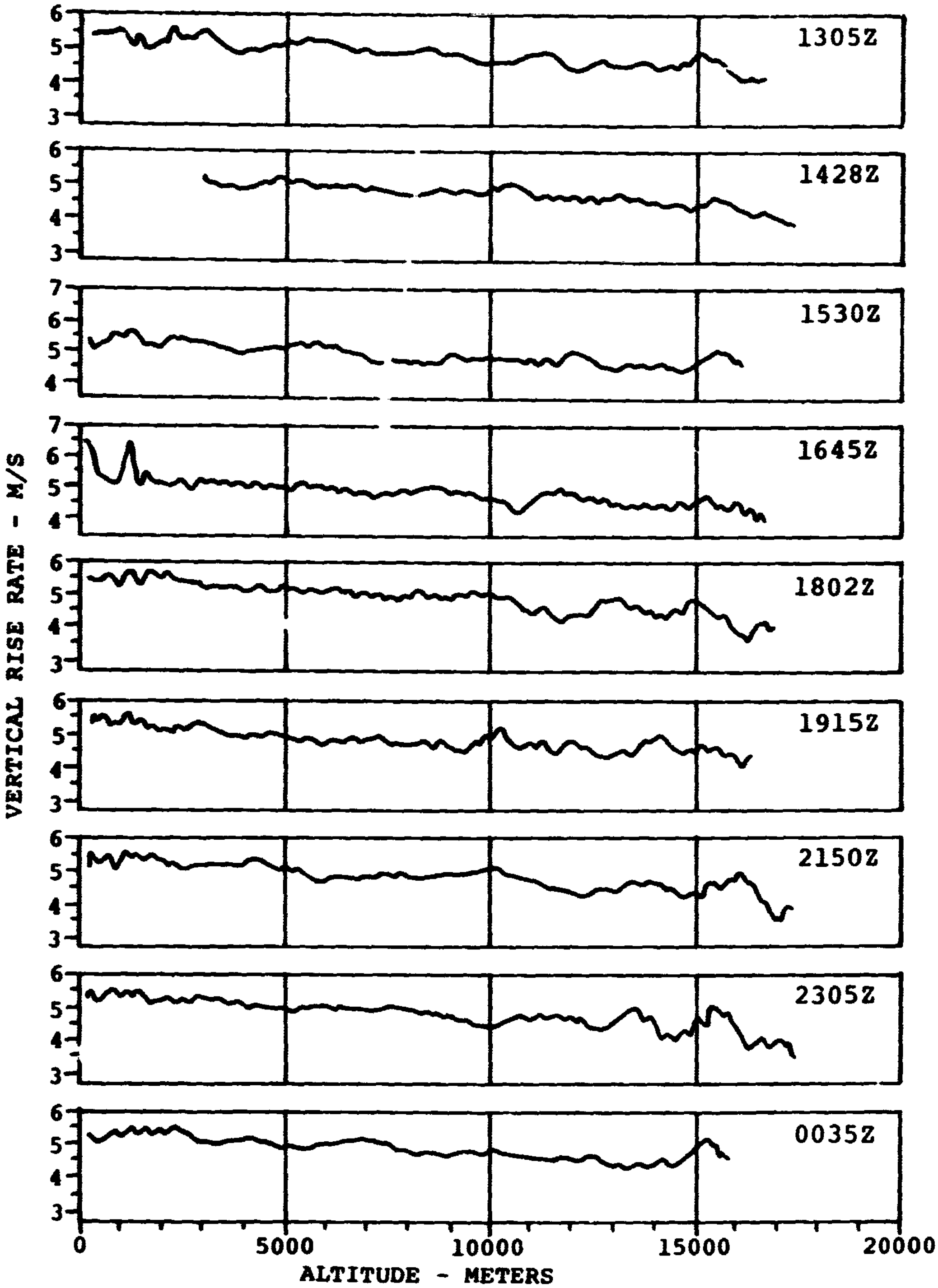


FIGURE 3-17 COMPONENT WIND PROFILES, TEST 2272-9, 2325Z, APR 13, 1965



FEB. 10 and 11, 1965

FIGURE 3-18 ASCENT RATE PROFILES, TEST SERIES 0870, FEB 10-11, 1965

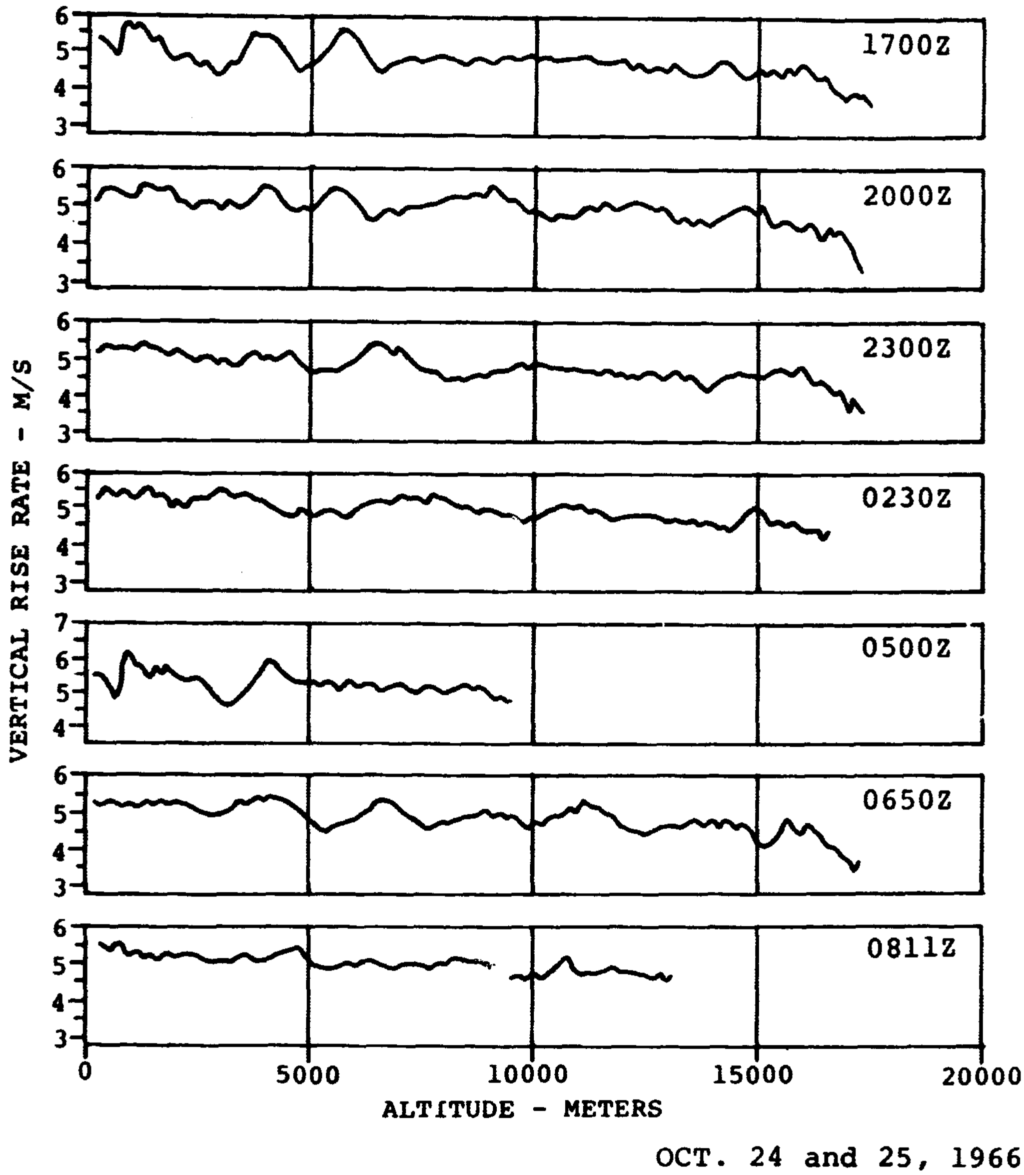


FIGURE 3-19 ASCENT RATE PROFILES, TEST SERIES 3069, OCT 24-25, 1966

3.1 (Continued)

mately at 4500 meters. The predominant fluctuations in the rise rate between 3 and 7 kilometers are very likely associated with the frontal surface and may represent the vertical components in gravity waves. The winds back from east-northeast near the surface to a westerly direction at about 4500 meters, and then remain fairly uniform from this direction to near the top of the wind profile. From single-station analysis techniques this is evidence that the frontal surface is close to the level at which the winds stop backing with height. Throughout the subsequent profiles of this series, the perturbations, so dominant on the first two, tend to disappear, and others form at different levels. Apparently the frontal surface is dissipating and the subsequent perturbations are due to other causes.

SECTION 4

CONCLUSIONS AND RECOMMENDATIONS

4.0 CONCLUSIONS

Both high and low frequency perturbations are observed in the reduced Jimsphere ascent rates. High frequency perturbations are mainly noise in the tracking data which is still present in the reduced ascent rate data. Noise in the tracking data generally increases in amplitude with altitude of the Jimsphere as shown in Figure 2-3, because of increasing slant ranges and smaller elevation angles, and is attributable chiefly to noise in the measurement of elevation angles (References 9 and 10). The smoothing filter selected to remove the effects of this noise in the ascent rate data is the one whose frequency response and filter weights are shown in Figure 2-2. It effectively eliminates the effects of noise from the ascent rate data yet allows the passage of perturbations of wavelengths comparable with those of significant features in the profiles of the horizontal components.

In the long wavelength perturbations the amplitudes rarely exceed one meter per second and are generally considerably less. Nevertheless, this amounts to a variation of from 10 to 20 percent of the mean ascent rate of the Jimsphere balloon. Deviations of the Jimsphere ascent rate due to aerodynamically induced oscillations, irregular venting of the super-pressure release valves, extreme changes in density, or changes in drag because of wind shears will not perturb the rate of rise in excess of two or three percent of the mean rise rate.

It is shown in Reference 7 that an extreme change in density of the atmosphere causes less than one percent change in the ascent rate. Also, the change in drag because of a wind shear of 0.28 sec^{-1} is shown to affect the ascent rate by about three tenths of one percent.

The RMS errors of the tracking system in measuring ascent rates, based on the reduction scheme used for the Jimsphere, may be of the same order of magnitude as the amplitudes of long-wave perturbations but RMS errors produce only high frequency perturbations. Therefore, they are suppressed by the filtering process on the ascent rate data. The long-wave perturbations, therefore, are at least a qualitative measure of vertical motions of the atmosphere. Because the unperturbed ascent rates of individual Jimspheres differ slightly, quantitative evaluations of detected vertical motions of the air are of limited accuracy and can be assumed to be only within ±30 or 40 percent of the real vertical motion.

4.0 (Continued)

In general, the vertical motions in the atmosphere appear to be transitory. It is noted that in the example of persistence pointed out in Figure 3-19, the prominent rise rate perturbations in the neighborhood of the frontal surface are found only on the first two of the series of profiles. They are not identifiable as the same perturbations on the profiles of wind runs measured within the next few hours. Where perturbations in the ascent rate are located, their existence can generally be associated with one or more of the characteristics of the horizontal flow. The persistence of these characteristics however does not insure the presence of a similar perturbation on the succeeding runs. Nevertheless, successive Jimsphere ascents do not follow the same paths through the same portion of the atmosphere. Therefore, it is unlikely that evidence of vertical winds will be observed with much persistence.

APPENDIX A

THE JIMSPHERE BALLOON AND ITS RATE OF RISE

1.0 GENERAL

The Jimsphere balloon is a constant volume mylar balloon two meters in diameter with roughness elements on the surface to provide stability of the airflow at supercritical Reynolds numbers. (References 6 and 12.) The roughness elements are 3-inch cones formed into the mylar and are kept rigid by an overpressure of 5 millibars of the helium used to inflate the Jimsphere. The pressure differential is maintained by release valves which vent the helium as the balloon rises. The nature of the venting, whether sporadic or fairly constant, is unknown. It is estimated, however, that thrust provided by the venting is negligible.

1.1 EQUATIONS OF MOTION OF THE JIMSPHERE RISING IN STILL AIR

The measured ascent rates of the Jimsphere in the real atmosphere are observed to vary in a nonsystematic manner and it is felt that the excursions from the systematic change of its rise rate with height are due to vertical motions of the atmosphere. It would be ideal, then, to be able to determine the systematic rise rate of the balloon as it should be in still air; and then by subtraction from the observed rise rate derive a measure of the vertical motions of the atmosphere.

The forces acting on the balloon in still air are (1) buoyancy, (2) drag, and (3) the weight of the balloon and its gas (References 6 and 7). The force of buoyancy, B, is equal to the weight of the air displaced by the balloon:

$$B = \rho g V \qquad (A.1)$$

where ρ is the ambient density of the air, g the acceleration of gravity, and V the volume of the Jimsphere. The ambient density decreases with altitude, so it is easily seen that the buoyancy force is eventually just equal to the weight of the balloon and its gas. At that altitude the ascent rate is zero and the Jimsphere floats. The weight or gravitational force, G, is given by

$$G = -g(m_b + m_H) \qquad (A.2)$$

where m_b represents the mass of the uninflated balloon and m_H represents the mass of the helium gas enclosed. As long as $G < B$, the Jimsphere ascends producing the third force of drag,

1.1 (Continued)

D, which varies directly as the square of the relative speed of the air to the balloon. In still air this relative speed of the air to the balloon is of course the ascent rate, W. The drag force is given by

$$D = -\frac{1}{2} C_D \rho W^2 A \tag{A.3}$$

where C_D is the coefficient of drag and A is the cross-sectional area of the balloon. After release, the Jimsphere rapidly reaches a steady state where the buoyancy is just balanced by the gravitational and drag forces. Thus, vertical acceleration of the balloon vanishes and

$$B + G + D = 0 \tag{A.4}$$

or

$$\rho g V = g\ (m_f + m_H) + \frac{1}{2} C_D \rho W^2 A \tag{A.5}$$

In Equation A.5 the acceleration of gravity, g, can be considered constant within the altitude ranges achieved by the Jimsphere; the volume, V, is constant; the mass of the uninflated balloon is constant; and the cross-sectional area of the balloon is constant. Of the other parameters, the ambient density decreases with altitude, the mass of the helium gas in the balloon decreases with altitude, and the ascent rate decreases systematically with altitude. If the coefficient of drag were a constant, Equation A.5 would provide a means of solving for the ascent rate because ambient density can be determined from independent measurements or from climatological data. The mass of the helium gas within the balloon can be determined from the equation of state for helium at the pressure in the Jimsphere (5 millibars greater than ambient pressure) and at a nominal temperature greater than ambient temperature. The equation of state for the helium is given by,

$$\rho_H = \frac{P_H}{R_H T_H} \tag{A.6}$$

where ρ_H is the density of the helium gas and more definitively is

$$\rho_H = \frac{m_H}{V} \tag{A.7}$$

Therefore,

$$m_H = \rho_H V = \frac{P_H V}{R_H T_H} \tag{A.8}$$

1.1 (Continued)

The pressure of the helium, P_H, is 5 millibars greater than the ambient pressure of the atmosphere; R_H is the gas constant for helium, or approximately 7.25 times the gas constant for dry air, R. T_H is the temperature of the helium in the balloon, not more than 10 degrees C above the ambient temperature of the atmosphere. The expression for m_H can be expressed in terms of ambient pressure and temperature. Let

$$P_H = P + \delta P \quad \text{(A.9)}$$

where P is the ambient pressure and δ_P is the overpressure in the Jimsphere.

Furthermore

$$P = \rho RT = \frac{\rho R_H T}{7.25} \quad \text{(A.10)}$$

and

$$T = T_H - \delta T \quad \text{(A.11)}$$

where δT is the temperature difference between the gas in the Jimsphere and the ambient atmospheric temperature. Then after substitution and collecting terms

$$m_H = \frac{\rho V}{7.25}\left(1 - \frac{\delta T}{T_H}\right) + \frac{V \delta P}{7.25 R T_H} \quad \text{(A.12)}$$

Combining A.5 and A.12, and rearranging terms, gives

$$\frac{C_D W^2 A}{2g} = V\left(1 - \frac{1}{7.25}\right) - \frac{1}{\rho}\left(m_b + \frac{V \delta P}{7.25 R T_H}\right) + \frac{V \delta T}{7.25 T_H} \quad \text{(A.13)}$$

DeMandel, et al., (Reference 2) show that the two terms on the right in A.13 containing T_H are about two orders of magnitude smaller than the other terms. Hence, they can be neglected with only a very small sacrifice of accuracy. A simple expression for the ascent rate can then be expressed in terms of C_D and ρ. After evaluating the constants in A.13 for the 2.0 meter Jimsphere balloon and substituting, the ascent rate is

$$W \cong \left[\frac{1}{C_D}\left(2.26 \times 10^5 - 25.5\rho^{-1}\right)\right]^{1/2} \quad \text{(A.14)}$$

Eckstrom (Reference 6) did wind tunnel tests on a model of the Jimsphere to determine the variation of the coefficient of drag with Reynolds number, and found remarkably constant values for Reynolds numbers greater than 10^5. However, in determining

1.1 (Continued)

variation of C_D on flight tests of full scale Jimspheres, Scoggins (Reference 1) as well as Eckstrom found that the values of coefficient of drag were nearly double the values determined on the model and that there was considerable range of values with Reynolds numbers greater than 10^5. Unfortunately, the Reynolds number is a function of the relative speed of the air with respect to the balloon and therefore a function of ascent rate.

It has been shown that the ascent rate W is a function of the coefficient of drag. The coefficient of drag is a function of the Reynolds number which itself varies with the ascent rate. Therefore, it is impractical, without independent determinations of C_D, to utilize equation A.14 to determine the unperturbed rise rate of the Jimsphere in still air.

APPENDIX B

THE FILTER FOR JIMSPHERE RATE OF RISE DATA

1.0 GENERAL

The ratio of noise to the Jimsphere ascent rate data is of an order of magnitude greater than the ratio of noise to the scalar wind speeds and the other horizontal components. Noise from the tracking system which is partially smoothed in the wind reduction process is hardly observable in the horizontal component winds because of their relative magnitudes. However, the rise rate of the Jimsphere averages only about 5 meters per second so that the effects of noise are much more severe in scattering adjacent data points. For this reason, low pass filtering of the ascent rate data is necessary to distinguish the perturbations which are of the same wavelengths as features in the profiles of the horizontal winds. The most efficient digital filter to perform this is the Martin constrained filter. (References 13 and 14.) The Ormsby filter (Reference 15) with a linear rolloff between the cutoff and termination frequencies would be ideal except for the violent oscillations known as the Gibbs oscillations that occur in the filter response function at both ends of the rolloff interval. To suppress these oscillations completely the Ormsby filter would require an infinite number of weights. The Martin filter is a modification of the Ormsby filter and employs a sine rolloff between the cutoff and termination frequencies. The Martin filter can be constrained to keep the Gibbs oscillations within reasonable bounds.

1.1 THE CONSTRAINED MARTIN DIGITAL SMOOTHING FILTER

The constraint on the Martin smoothing filter is chiefly in the number of filter weights required to give a desired rolloff interval without Gibbs oscillations exceeding one percent in the gain of frequencies below the cutoff nor exceeding one percent in gain of the frequencies greater than the termination frequency. The number of weights is given by an empirical formula

$$N = \frac{0.42\pi}{r_t - r_c} \tag{B.1}$$

or, since all factors in the numerator are constant

$$N = \frac{1.3295}{r_t - r_c} \tag{B.2}$$

where N is the number of weights on one side of the symmetrical numerical filter, not counting the central weight; r_t is the

1.1 (Continued)

ratio of the termination frequency to the sampling frequency; and r_c is the ratio of the cutoff frequency to the sampling frequency.

The total number of filter weights, N_T, is given by

$$N_T = 2N + 1 \qquad (B.3)$$

The rolloff interval, h, is defined as one half the difference between the termination frequency ratio and the cutoff frequency ratio, or in other words:

$$h = \frac{r_t - r_c}{2} \qquad (B.4)$$

With these definitions, the central weight, h_o, is defined by

$$h_o = 2(r_c + h) = r_c + r_t$$

and the filter weights numbered from the central weight, h_o, are given by:

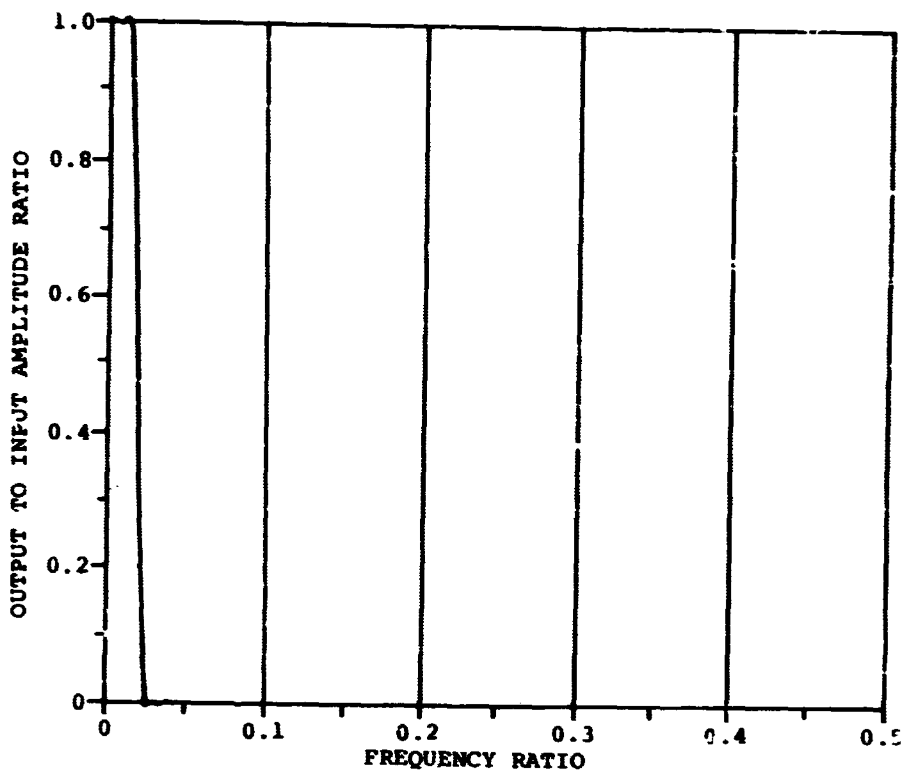
$$h_k = \frac{\sin(\pi k h_o)\cos(2\pi k h)}{\pi k(1-16k^2h^2)} \qquad (B.5)$$

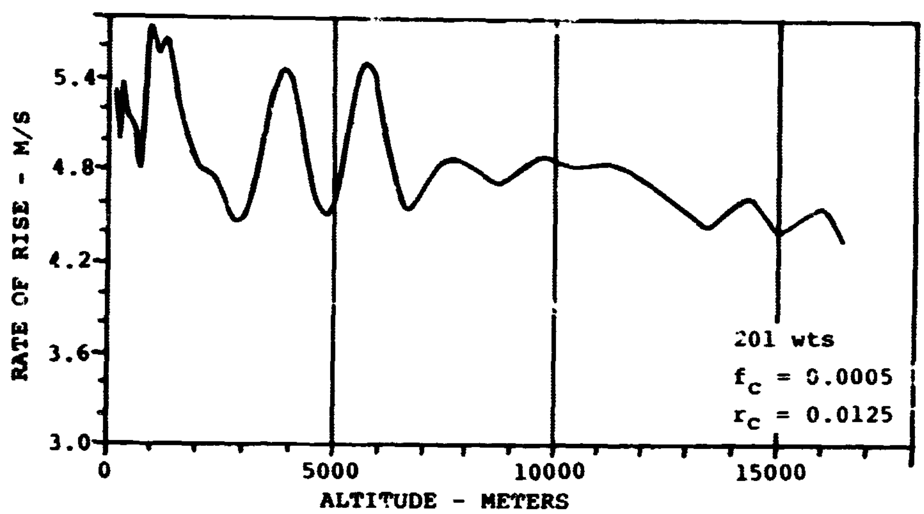
where k is the subscripted count of the weight from the central weight. Since the filter weights are symmetrical then

$$h_{-k} = h_k$$

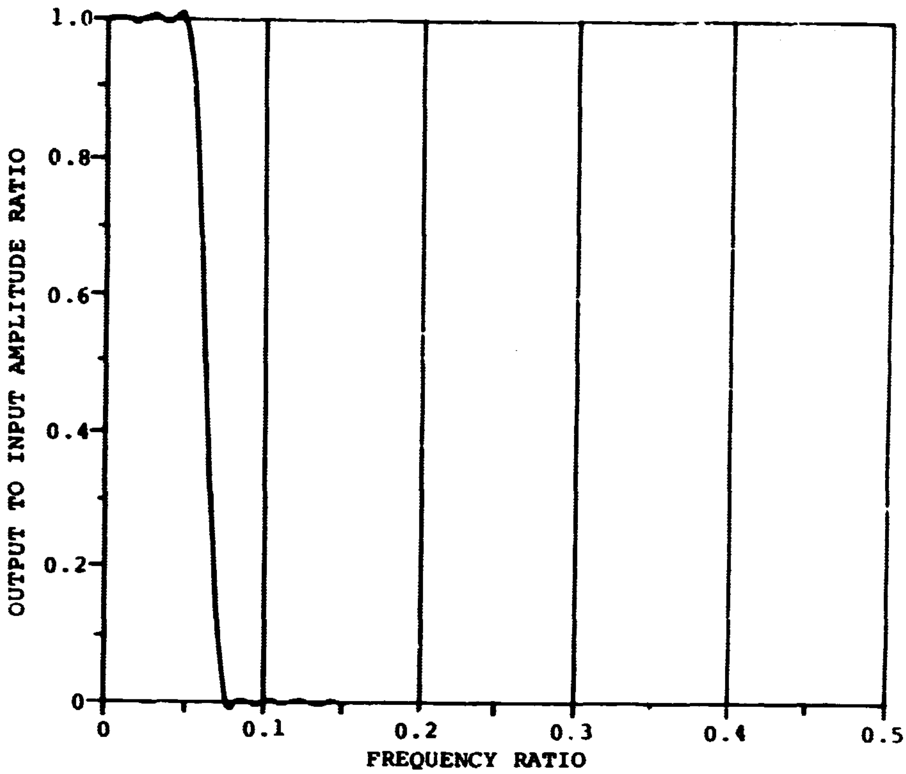
1.2 SELECTION OF FILTER PARAMETERS

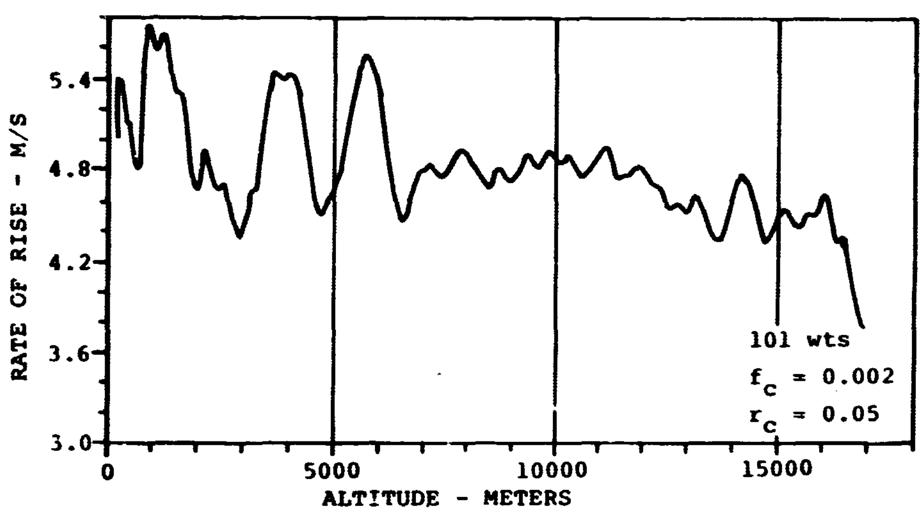
In the foregoing, it has been shown that a filter can be designed and utilized to process a given data set to achieve the response desired. The rise rate data of the first run of the 3069 series of runs made October 25, 1966 was filtered with several filters of different specifications to help determine which filter was best for eliminating noise in the rise rate data. In Figures B-1 through B-5 some of the filters tested are shown along with the smoothing each produced on the rise rate data for Test No. 3069-1. Figures B-2 and B-3 may at first glance appear to depict the same filter. It should be noted however that they are not the same, in that they differ in cutoff frequencies. It is desirable to retain a resolution of the same order as is found in the profiles of the horizontal components and yet allow sufficient rolloff interval that the filtering will not require too many weights. On the basis of such tests and examination of the results, the filter shown in



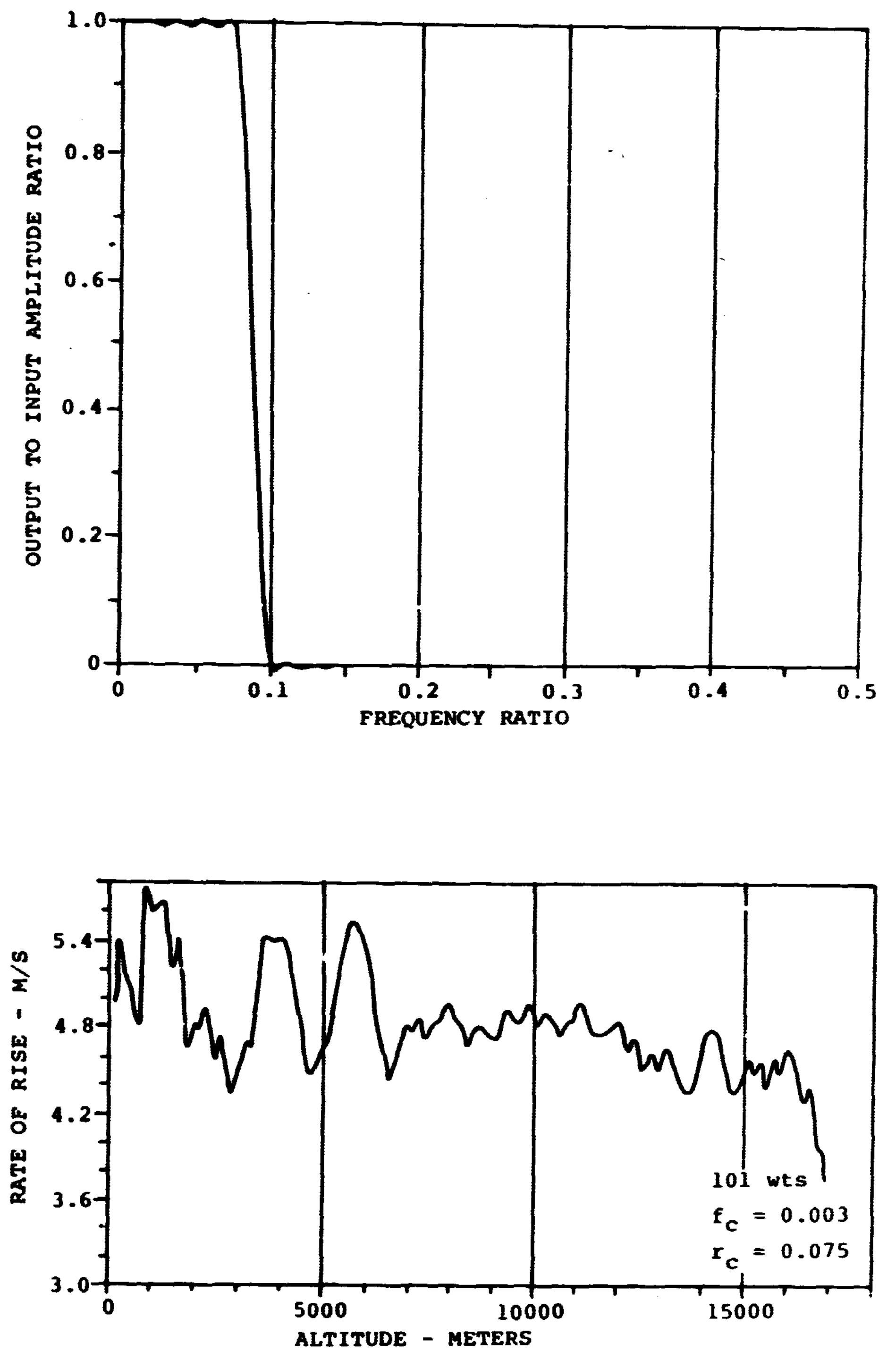


B-1 FILTER FREQUENCY RESPONSE AND FILTERED ASCENT RATE PROFILE (A)

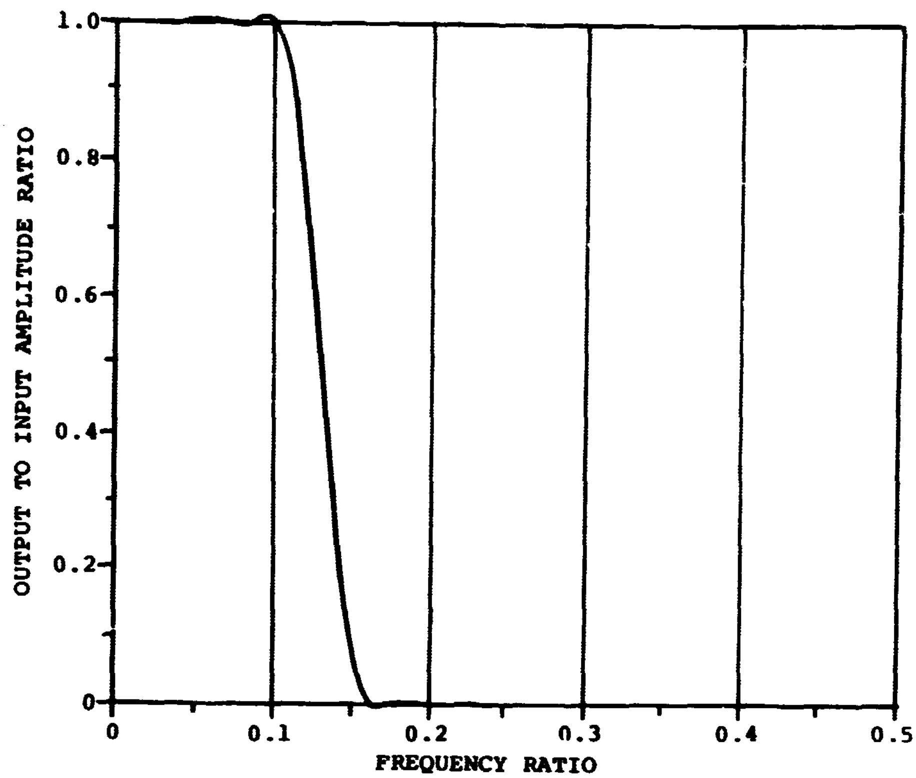


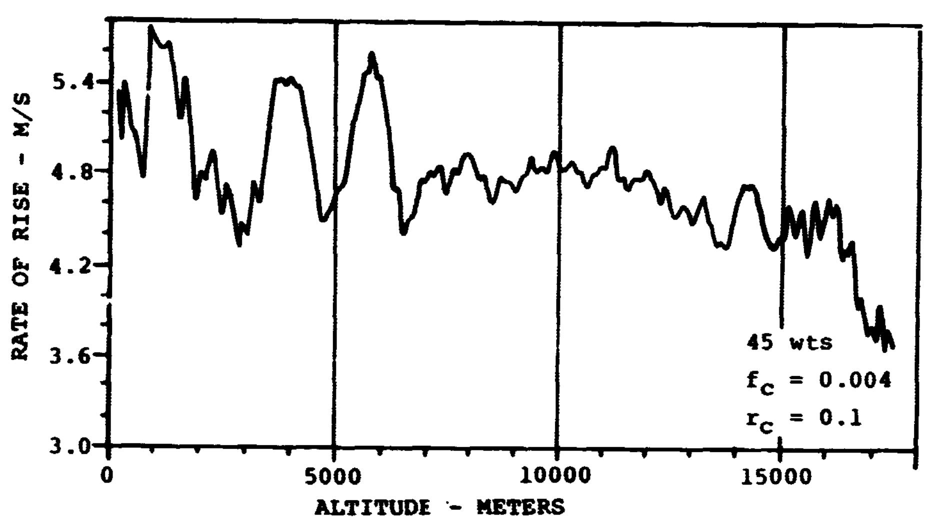


B-2 FILTER FREQUENCY RESPONSE AND FILTERED ASCENT RATE PROFILE (B)

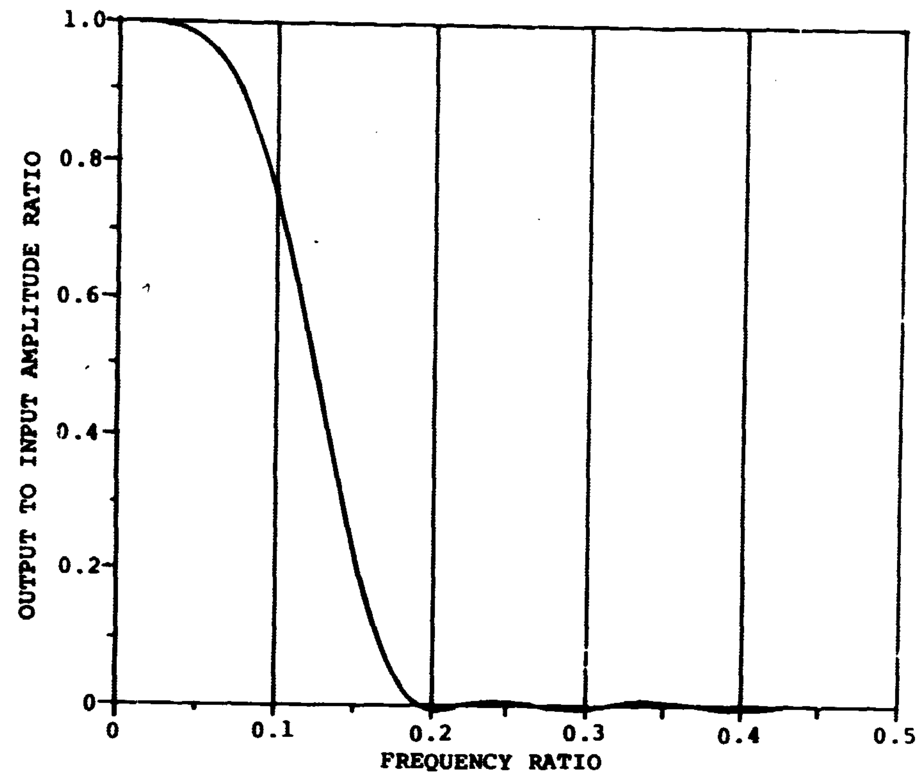


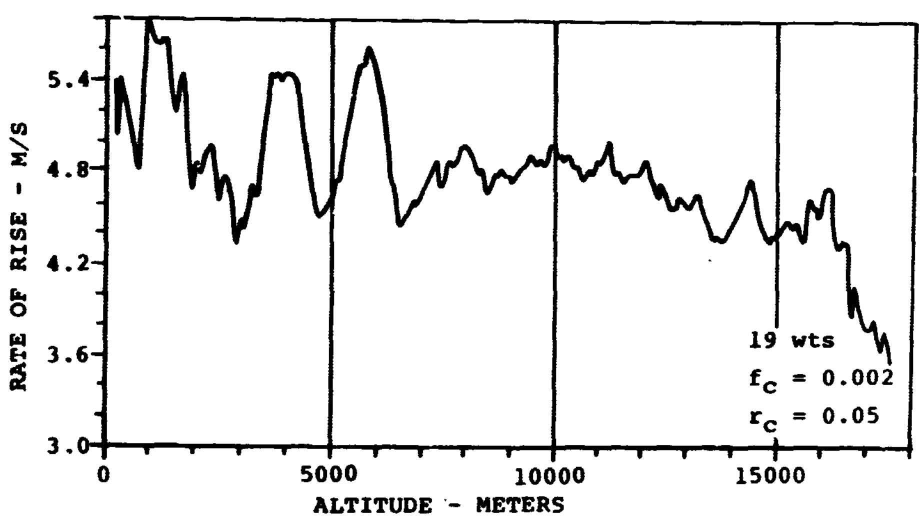
B-3 FILTER FREQUENCY RESPONSE AND FILTERED ASCENT RATE PROFILE (C)





B-4 FILTER FREQUENCY RESPONSE AND FILTERED ASCENT RATE PROFILE (D)





B-5 FILTER FREQUENCY RESPONSE AND FILTERED ASCENT RATE PROFILE (E)

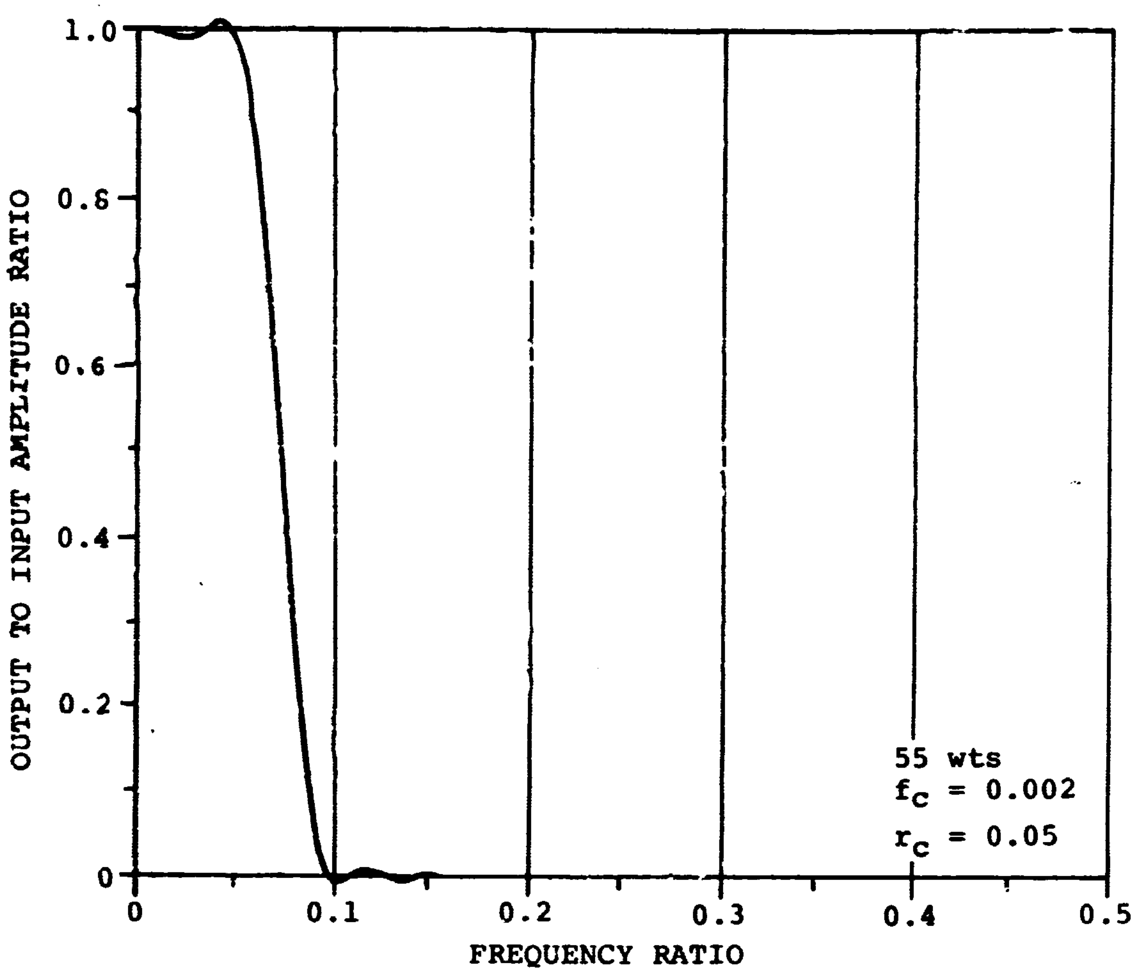
1.2 (Continued)

Figure 2-2 was selected for use in this study on all rise rate profiles.

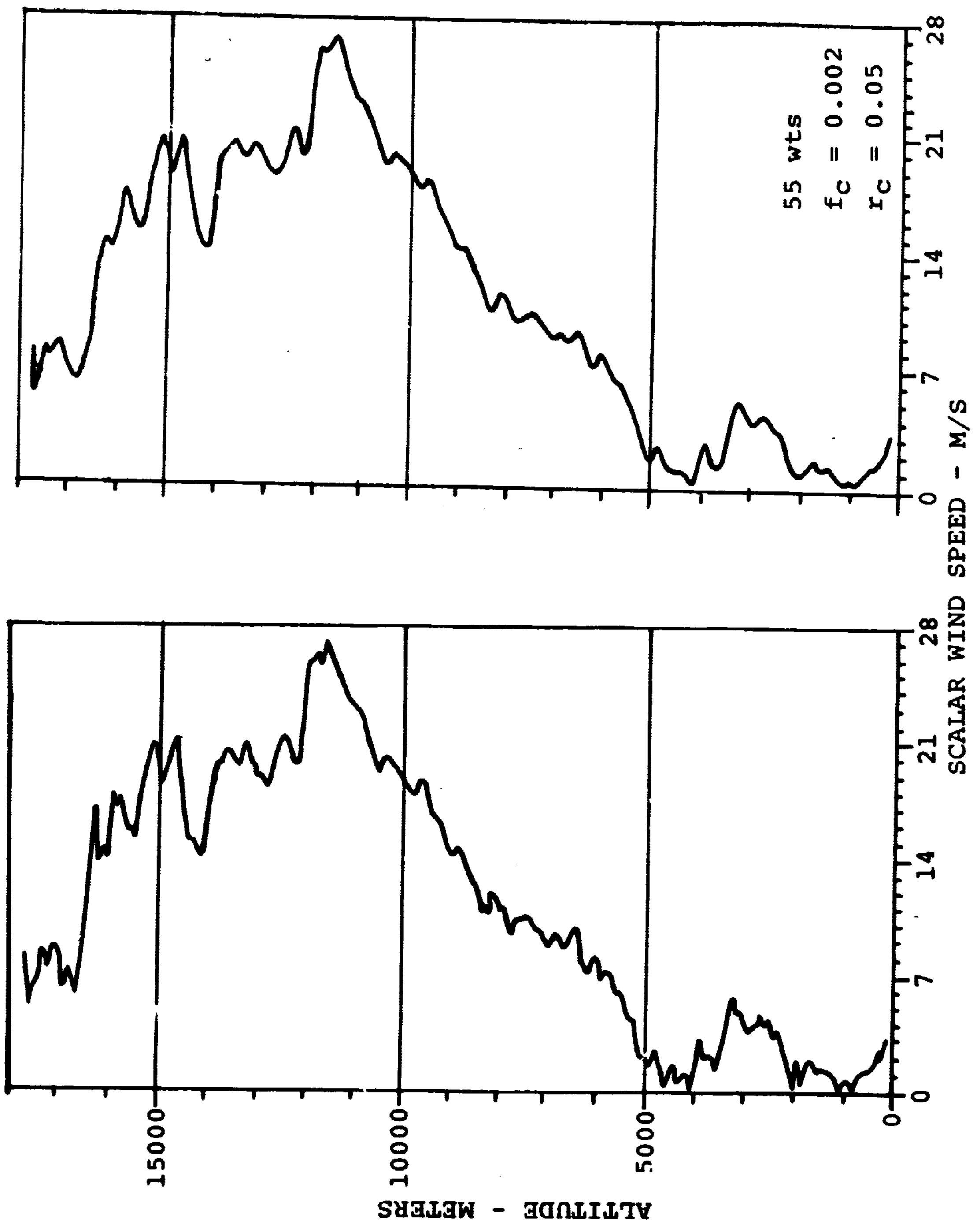
Figures B-6 and B-8 give the frequency responses of two filters that were applied experimentally to the profile of the scalar wind of Test 3069-1. The resulting filtered profiles are shown in Figures B-7 and B-9 along with the profile before the filtering was accomplished. It will be noted that with the severe filtering by the filter in Figure B-8, the resultant profile in Figure B-9 shows a profile of the scalar winds very similar to that which would be observed by rawinsonde. Unfortunately, no rawinsonde data close to the time of the Jimsphere Test 3069-1 was available for comparison of the respective profiles.

In all the figures that depict the frequency response functions of the filters, the abscissas are scaled off with respect to frequency ratio. Frequency ratio, r, is the ratio of any frequency to the sampling frequency. Jimsphere wind and ascent rate data are given at altitude intervals of 25 meters; hence, the sampling frequency is 0.04 samples per meter. The highest frequency which can be recognized in digital data is the Nyquist or "folding" frequency which is one half the sampling frequency. However, the highest meaningful frequency in Jimsphere wind data is 0.01 cycles per meter. All other frequencies in the data are lower and therefore of longer wavelengths.

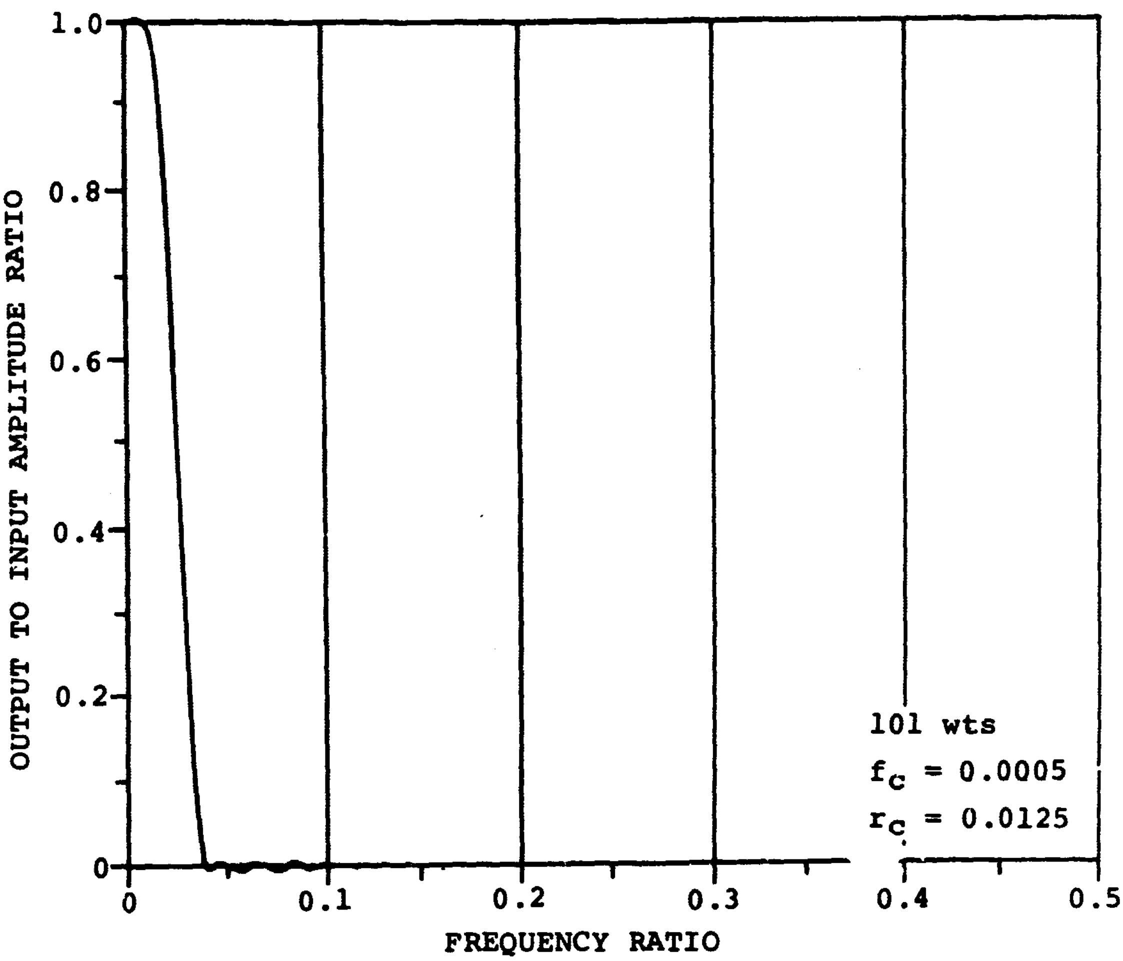
Wavelength is the inverse of the frequency when frequency is given in the units of cycles per unit length. The wavelength content of Jimsphere wind data, then, includes wavelengths of 100 meters or longer. Frequency given in terms of cycles per unit length should be called "wave number" because frequency is usually given in cycles per unit time. However, the misuse of the word "frequency" has been consistent throughout this paper.



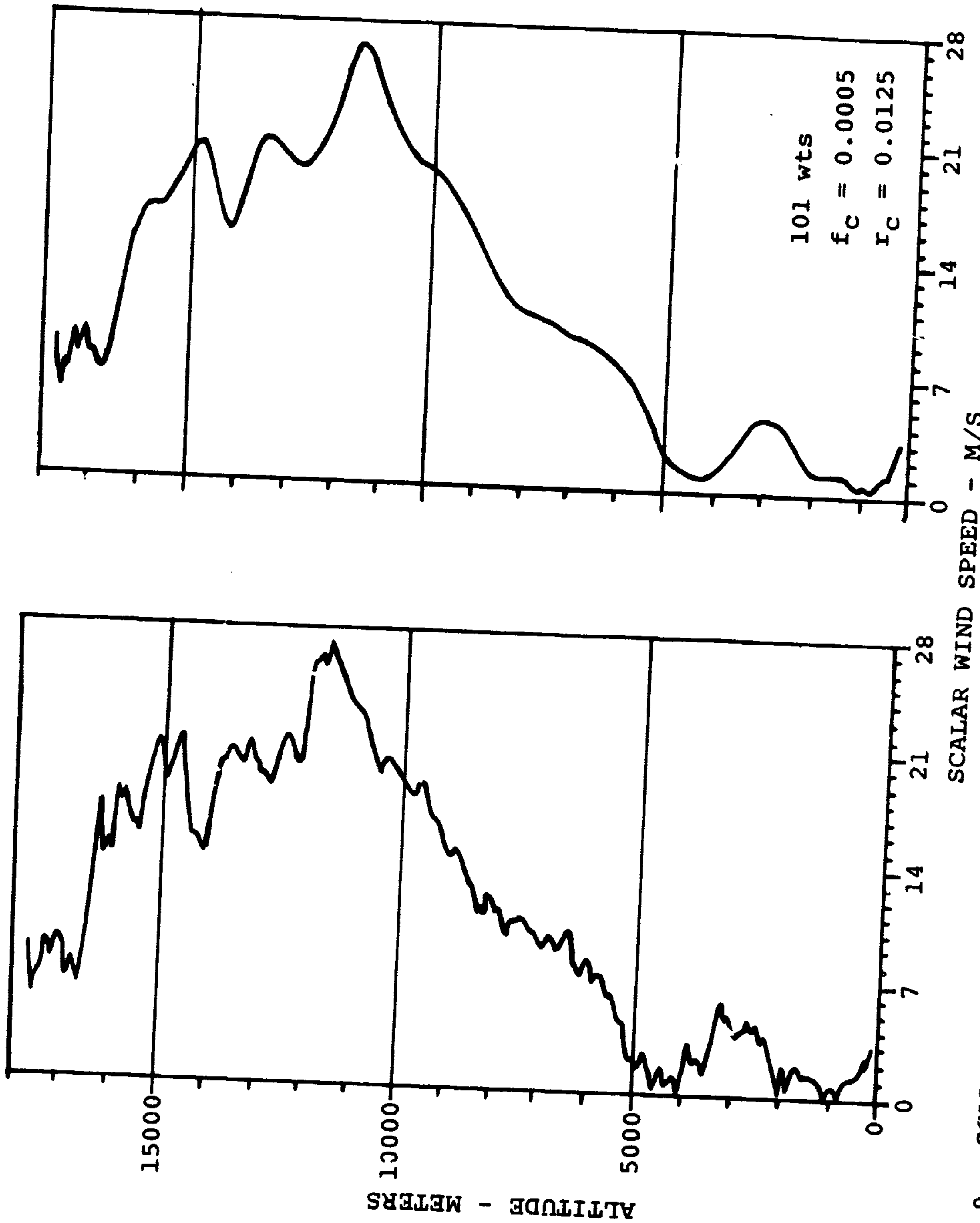
B-6 FREQUEN~Y RESPONSE OF 55-WEIGHT LOW PASS FILTER



B-7 SCALAR WIND PROFILE; UNFILTERED AND FILTERED BY 55-WT. FILTER



B-8 FREQUENCY RESPONSE OF 101-WEIGHT LOW PASS FILTER



B-9 SCALAR WIND PROFILE; UNFILTERED AND FILTERED BY 101-WT. FILTER

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