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SOME PRACTICAL ACCURACY CONSIDERATIONS OF SMOKE TRAIL WIND PROFILE DATA

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ABSTRACT

Wind velocity profiles measured simultaneously by the smoke trail/photographic method by different camera pairs, and photographs reduced twice for the same trail are analyzed to determine the relative accuracy of the smoke trail wind data. Arithmetic means, standard deviations, and extremes are given for the differences between five pairs of profiles. Also presented are relative RMS errors in wind speeds, relative RMS errors in shears over height increments of 25, 50, 100 and 200 meters, and maximum shear differences for each case. The computed RMS differences in wind speeds are generally less than 1 meter per second, errors in wind shear vary to approximately 60 percent of the values used in vehicle design studies, and relative RMS errors in wind speeds range from approximately 0.1 to 0.7 meters per second. The sources of the errors are not isolated. These errors will probably be reduced as more experience is gained in data reduction and quality control procedures are improved.

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RESEARCH & DEVELOPMENT OPERATIONS

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SUMMARY

Wind velocity profiles measured simultaneously by the smoke trail/photographic method by different camera pairs and photographs reduced twice for the same trail are analyzed to determine the relative accuracy of the smoke trail wind data. Arithmetic means, standard deviations, and extremes are given for the differences between five pairs of profiles. Also presented are relative RMS errors in wind speeds, relative RMS errors in shears over height increments of 25, 50, 100 and 200 meters, and maximum shear differences for each case. The computed RMS differences in wind speeds are generally less than 1 meter per second, errors in wind shear vary to approximately 60 percent of the values used in vehicle design studies, and relative RMS errors in wind speeds range from approximately 0.1 to 0.7 meters per second. The sources of the errors are not isolated. These errors will probably be reduced as more experience in data reduction is gained and quality control procedures are improved.

SECTION I. INTRODUCTION

In the design and flight of vertically rising vehicles, the influence of horizontal winds must be considered. There are numerous methods for obtaining horizontal wind measurements. For the surface boundary layer, there are several wind measuring instruments which are considered reliable. However, for higher altitudes (above approximately 300 meters) wind measurements are harder to obtain and in many cases have larger errors. Many methods have been and still are being used in an attempt to accurately measure the higher altitude winds. Some examples of these are the smoke trail method, various balloon methods, dropsondes, etc. This report presents statistical information on the differences in the wind velocity profiles as measured by the smoke trail method using different pairs of cameras. These statistics presumably represent errors primarily in reading position coordinates from the film since at one location two cameras were used and the data reduced independently while other parameters did not vary.

The smoke trail/photographic method for obtaining upper altitude wind measurements seems to provide reasonably accurate wind data, but is restricted to clear daytime conditions. The errors inherent in this method have been discussed in a number of reports (Refs. 1, 2, 3, and 4). Junkin's report (Ref. 3) in particular discusses many error sources, and presents an analytical method for determining the accuracy of the measured wind data at discrete points on a given trail. It is not possible to compare directly his results with those presented in this report. Junkin is presently extending his analysis to provide statistics of the errors which will permit a direct comparison of the two methods.

The repeatability of a measuring system is related to its accuracy. In this report, repeatability (or lack of it) of the measurements, as determined from a comparison of the same wind profile measured from different camera pairs, provides information on the relative accuracy of the wind data. Discrete errors and error sources cannot be determined by the method discussed in this report.

The data for this wind profile comparison and wind shear study were obtained from four smoke trail tests made at Cape Kennedy, Florida, and one made at Wallops Island, Virginia. The trails were produced by expelling titanium tetrachloride into the atmosphere from a Nike Smoke Rocket. Photographs were made of the smoke trails at fixed time intervals by T-11 precision aerial mapping cameras (Ref. 2). Using these photographs, wind profile data were obtained by the procedure outlined in Reference 5.

For the wind data used in this report, two camera sites were used at Williams-Point to photograph the smoke trail. These sites, used in conjunction with the site at Patrick Air Force Base, Florida, make it possible for two wind profiles to be obtained for the same smoke trail by using different camera pairs. An indication of the repeatability and relative accuracy of the smoke trail method can be gained by comparing the wind profiles obtained from these sites. The smoke trail test from Wallops Island was from only one pair of cameras, but comparator readings were obtained by two different operators. This test provides information on the relative errors from reading position coordinates from film.

Although this report was originally prepared in the fall of 1964, publication was delayed in the interest of continuing the mutual exchange and critique of information concerning the smoke trail program. A great deal of agreement now exists among the participants in this program, but complete agreement on certain features of the trails (loops, superposition of elongated segments of the trails, etc.) and the accuracy of the wind profile data obtained for these cases has not yet been reached. Reference 6 and Section II of this report show some of the areas of agreement between Langley Research Center and Aero-Astrodynamics Laboratory, Marshall Space Flight Center.

SECTION II. A DISCUSSION OF THE STATISTICAL METHODS USED AND RESULTS OBTAINED

The differences in the wind speed profiles were computed using

$$\begin{aligned} \Delta u &= u_1 - u_2 \\ \Delta v &= v_1 - u_2 \\ \Delta V &= V_1 - V_2 \end{aligned} \qquad (1)$$

where u is the zonal wind speed component, v is the meridional component, and V is the scalar wind speed. In computing differences the algebraic sign is maintained. The subscripts 1 and 2 denote the camera pair,

Williams-Point North/Patrick Air Force Base (WP_N/PAFB) and Williams-Point South/Patrick Air Force Base (WP_S/PAFB), respectively. The subscripts will also denote readers 1 and 2, respectively, for the Wallops Island test.

The standard deviation of the differences σ_D was computed by

$$(\sigma_D)_x = \left(\overline{x^2} - \bar{x}^2\right)^{\frac{1}{2}} \tag{2}$$

where the x's represent either u, v, or V. The standard deviation of the differences for independent observations can be represented by (Ref. 7)

$$(\sigma_D)_x = (\sigma_1^2 + \sigma_2^2)^{\frac{1}{2}} \tag{3}$$

where σ_1^2 and σ_2^2 are the variances of the profiles from WP_N/PAFB and WP_S/PAFB, respectively. It is logical to assume that the two profiles have the same precision; thus,

$$(\sigma_D)_x^2 = 2\sigma^2 \tag{4}$$

or

$$\sigma = 0.707\ (\sigma_D)_x, \tag{5}$$

where σ is the root mean square (RMS) error associated with either profile.

Arithmetic means of the differences between profiles, standard deviations of the differences, extreme differences, RMS errors in wind speed, and wind shear information for each profile studied are given in Tables I through V. The tables show in general an increase with height in each of these parameters. The arithmetic mean of the differences was computed to determine whether or not there was a significant bias in the profiles; for a zero arithmetic mean, the profiles are not biased relative to each other. The means, presented in Tables I through V, are not zero, indicating that a bias is present. The reasons for the non-zero means are beyond the scope of this report. It should be noted, however, that they are a consequence of such things as the innate differences in the cameras, survey error, comparator operator bias, etc.

SECTION III. COMPARISON OF SIMULTANEOUS SMOKE TRAIL WIND PROFILE DATA

The profiles are compared in Figures 1 through 15. Figures 1 through 4 are the superimposed zonal wind speed profiles and their differences from the two pairs of cameras, WP_N/PAFB and WP_S/PAFB. Figure 5 is the superimposed zonal wind speed profiles and their differences for the Wallops Island smoke trail for different comparator operators. The meridional wind speed profiles and their differences are given in Figures 6 through 10; Figures 11 through 15 are the scalar wind values and their differences. Figures 6 through 15 correspond to Figures 1 through 5.

The standard deviations, extreme differences, and relative errors, associated with the component and scalar wind speed profiles increase with height. This increase with height is shown in Figures 1 through 15 and in Tables I through V. The variability is apparently not a function of the mean wind speed.

The smoke trail test having the largest standard deviation is test number 4019 (Table II). Also the variability in the profiles for this test is fairly constant for the entire trail (Figures 2, 7, and 12 and Table II). The converse of this is noticed in smoke trail test number 5233 (Figures 4, 9, and 14 and Table IV).

For smoke trail test LRC-9, all parameters were constant. Differences in these measurements are due primarily to film readings. In Figures 5, 10, and 15, relatively large RMS errors occur in the wind speed profiles between 11 and 12 kilometers. A comparison of Table V with Tables I through IV shows that RMS errors for this test are larger than some of those for the Cape Kennedy data where different camera pairs were used. Thus, it may be concluded that the errors shown for the Cape Kennedy data are due primarily to film reading.

In addition to the above, the results given in Table V can be compared to those given in an unpublished LRC report (Ref. 6). This report and the LRC report give the RMS errors obtained for smoke trail test LRC-9 in the same time interval; thus, the comparison is direct. The LRC report gives RMS errors of 0.2 and 0.4 for the zonal and meridional wind components, respectively, for the altitude intervals of 5.0 to 9.0 km; whereas, in Table V the corresponding values are 0.215 and 0.503. Further, for the altitude interval of 9.0 to 13.0 km, the LRC report gives RMS errors of 0.6 and 0.7 as compared to 0.669 and 0.670 of this report for the zonal and meridional wind components, respectively. No other direct comparison of accuracy could be made between the reports. In general, however, the two reports agree quite well with respect to RMS errors. An accuracy comparison could not be made with other error analysis reports, such as References 1 through 4 since they are concerned primarily with error sources rather than error magnitudes.

The extreme differences (Tables I through V) between the wind speed profiles given in this report but not in the LRC report are considered by the authors to be as important, if not more so, than the RMS errors because of the effect which these extreme differences have on the wind shears associated with a given smoke trail wind profile. If these extreme differences could be reconciled and good wind data obtained at the points of greatest interest (loops, etc.), then the smoke trail program would be greatly improved.

SECTION IV. ERRORS IN WIND SHEAR DUE TO ERRORS IN WIND SPEED

Wind shear is defined mathematically by

$$S_x = \frac{x_2 - x_1}{h_2 - h_1}, \qquad (6)$$

where x_2 represents either u, v, or V at the height h_2, and x_1 represents these variables at h_1. If the error in the altitude increment is assumed to be negligible, then the RMS error in wind shear σ_{s_x}, is approximated by

$$\sigma_{s_x} = \frac{\sqrt{2}}{\Delta h} (\sigma_D)_x, \qquad (7)$$

where Δh is $h_2 - h_1$, and $(\sigma_D)_x$ is defined by equation 2. The values of σ_{s_x} have been computed and tabulated (Tables I through V) for Δh values of 25, 50, 100 and 200 meters. The maximum differences in wind shear over the above altitude increments have also been computed and are presented in the tables. These maximum differences represent the maximum observed differences in the wind speeds divided by the altitude increment over which the differences occurred. Errors in the wind shear values are relatively large, and do not depend to any great extent on wind speed as shown in Tables I through V. The magnitude of the maximum scalar wind shear errors varies to approximately 60 percent of the magnitude of the extreme vector wind shear values quoted for vehicle design studies (Refs. 8 and 9). In reality, errors presented in this report are low due to the assumption of error free altitude measurements.

SECTION V. COMMENTS AND CONCLUSIONS

It has been shown in this report that the smoke trail procedure for obtaining wind profile data is repeatable within limits. From the wind profile data used in this report, no evidence was found of any persistent relative bias in the mean wind speed profiles. There were, however, large differences in the wind speed profiles in some cases. The largest standard deviation of these differences was found to be in excess of 1.0 meter per second. The larger differences in the scalar wind speed profiles range in magnitude up to 6.4 meters per second. No attempt was made to account for these large differences. The errors in wind shear were shown to vary to approximately 60 percent of the wind shear values used in design studies. Relative RMS errors in wind speeds range from approximately 0.1 to 0.7 meters per second.

It is emphasized that the magnitudes of the errors presented in this report are based on a small sample of data. The magnitude of the errors may decrease as more experience is gained in reducing the data and better quality control procedures are developed. Direct comparisons of the results presented in this report with those in Junkin's report (Ref. 3) are not possible and requires different interpretations.

Errors noted in the profiles used in this study may make a large contribution to what might be classified as turbulence. With reference to a steady state profile, similar to one measured by the GMD system, the variances of the errors in the smoke trail profiles discussed in this report contributed on the order of 10 to 30 percent to the total variance. In view of errors inherent in smoke trail measurements, the data must be used with caution in evaluating the response of vehicles to small scale wind variations.

TABLE I STATISTICAL DATA FOR SMOKE TRAIL TEST NUMBER 3564 (JUNE 7, 1963)

		Altitude Interval 5.0 - 8.975 km			Altitude Interval 9.0 - 13.0 km			Altitude Interval 5.0 - 13.0 km		
		u	v	V	u	v	V	u	v	V
Arithmetic mean of Differences (m/sec)		-0.002	0.023	0.001	0.098	0.137	0.140	0.048	0.080	0.071
Standard Deviation (m/sec)		0.184	0.401	0.226	0.272	0.498	0.481	0.238	0.456	0.382
Extreme Difference (m/sec)		-0.449	-1.241	-0.848	1.379	2.253	2.609	1.379	2.253	2.609
RMS Error (m/sec) of Wind Speed		0.130	0.283	0.160	0.192	0.352	0.340	0.168	0.322	0.270
Wind Shear (Δh = 25m) (1/sec)	RMS Error	0.007	0.016	0.009	0.011	0.020	0.019	0.009	0.018	0.015
	Maximum Difference	0.056	0.084	0.050	0.030	0.049	0.042	0.056	0.084	0.050
Wind Shear (Δh = 50m) (1/sec)	RMS Error	0.004	0.008	0.004	0.006	0.010	0.009	0.005	0.009	0.008
	Maximum Difference	0.023	0.043	0.018	0.028	0.030	0.040	0.028	0.043	0.040
Wind Shear (Δh = 100m) (1/sec)	RMS Error	0.001	0.004	0.002	0.003	0.005	0.005	0.002	0.004	0.004
	Maximum Difference	0.009	0.010	0.010	0.014	0.025	0.029	0.014	0.025	0.029
Wind Shear (Δh = 200m) (1/sec)	RMS Error	0.001	0.002	0.001	0.001	0.002	0.002	0.001	0.002	0.002
	Maximum Difference	0.007	0.009	0.006	0.006	0.011	0.026	0.007	0.011	0.026
Mean Wind Speed (m/sec)	WP_N/PAFB	2.580	-1.318	3.264	5.015	8.289	10.215	3.802	3.500	6.750
	WP_S/PAFB	2.582	-1.341	3.263	4.918	8.152	10.075	3.754	3.420	6.680

TABLE II STATISTICAL DATA FOR SMOKE TRAIL TEST NUMBER 4019 (JUNE 19, 1963)

		Altitude Interval 5.0 - 8.975 km			Altitude Interval 9.0 - 13.0 km			Altitude Interval 5.0 - 13.0 km		
		u	v	V	u	v	V	u	v	V
Arithmetic mean of Differences (m/sec)		-0.009	-0.100	-0.087	-0.087	-0.093	-0.177	-0.049	-0.096	-0.134
Standard Deviation (m/sec)		0.267	0.669	0.629	0.456	1.018	1.002	0.379	0.867	0.844
Extreme Difference (m/sec)		0.694	1.800	1.588	-3.772	-5.253	-6.414	-3.772	-5.253	-6.414
RMS Error (m/sec) of Wind Speed		0.189	0.473	0.445	0.322	0.720	0.708	0.268	0.613	0.597
Wind Shear (Δh = 25m) (1/sec)	RMS Error	0.011	0.026	0.025	0.018	0.040	0.040	0.015	0.034	0.033
	Maximum Difference	0.059	0.115	0.121	0.119	0.118	0.156	0.119	0.118	0.156
Wind Shear (Δh = 50m) (1/sec)	RMS Error	0.005	0.013	0.013	0.009	0.020	0.020	0.008	0.017	0.017
	Maximum Difference	0.028	0.070	0.065	0.074	0.067	0.089	0.074	0.070	0.089
Wind Shear (Δh = 100m) (1/sec)	RMS Error	0.003	0.006	0.006	0.004	0.010	0.010	0.004	0.008	0.008
	Maximum Difference	0.015	0.029	0.030	0.040	0.046	0.058	0.040	0.046	0.058
Wind Shear (Δh = 200m) (1/sec)	RMS Error	0.001	0.004	0.003	0.002	0.005	0.005	0.002	0.004	0.004
	Maximum Difference	0.007	0.015	0.014	0.019	0.026	0.032	0.019	0.026	0.032
Mean Wind Speed (m/sec)	WP_N/PAFB	4.651	4.863	6.866	2.971	5.782	7.250	3.781	5.339	7.065
	WP_S/PAFB	4.661	4.963	6.953	3.058	5.875	7.428	3.831	5.435	7.199

TABLE III STATISTICAL DATA FOR SMOKE TRAIL TEST NUMBER 4859 (JULY 26, 1963)

		Altitude Interval 5.0 - 8.975			Altitude Interval 9.0 - 13.0 km			Altitude Interval 5.0 - 13.0 km		
		u	v	V	u	v	V	u	v	V
Arithmetic mean of Differences (m/sec)		-0.017	0.015	0.014	0.057	0.214	-0.136	0.022	0.119	-0.064
Standard Deviation (m/sec)		0.134	0.281	0.155	0.284	0.793	0.492	0.228	0.613	0.379
Extreme Difference (m/sec)		0.586	-0.839	-0.652	-1.168	-3.241	2.621	-1.168	-3.241	2.621
RMS Error (m/sec) of Wind Speed		0.095	0.199	0.110	0.201	0.501	0.348	0.161	0.433	0.268
Wind Shear (Δh = 25m) (1/sec)	RMS Error	0.006	0.011	0.006	0.011	0.031	0.020	0.009	0.024	0.015
	Maximum Difference	0.021	0.035	0.019	0.038	0.083	0.055	0.038	0.083	0.055
Wind Shear (Δh = 50m) (1/sec)	RMS Error	0.003	0.006	0.003	0.006	0.016	0.010	0.004	0.012	0.008
	Maximum Difference	0.017	0.021	0.019	0.030	0.060	0.048	0.030	0.060	0.048
Wind Shear (Δh = 100m) (1/sec)	RMS Error	0.001	0.003	0.001	0.003	0.008	0.005	0.002	0.006	0.004
	Maximum Difference	0.006	0.013	0.008	0.016	0.032	0.027	0.016	0.032	0.027
Wind Shear (Δh = 200m) (1/sec)	RMS Error	0.001	0.001	0.001	0.001	0.004	0.002	0.001	0.003	0.002
	Maximum Difference	0.003	0.008	0.004	0.006	0.018	0.013	0.006	0.018	0.013
Mean Wind Speed (1/sec)	WP_N/PAFB	-4.479	0.298	4.733	-4.213	0.585	4.880	-4.342	0.448	4.809
	WP_S/PAFB	-4.462	0.283	4.719	-4.275	0.370	5.016	-4.364	0.328	4.874

TABLE IV STATISTICAL DATA FOR SMOKE TRAIL TEST NUMBER 5233 (AUGUST 7, 1963)

		Altitude Interval 5.0 - 8.975 km			Altitude Interval 9.0 - 13.0 km			Altitude Interval 5.0 - 13.0 km		
		u	v	V	u	v	V	u	v	V
Arithmetic mean of Difference (m/sec)		-0.017	-0.059	-0.014	-0.014	-0.016	-0.064	-0.035	-0.017	-0.024
Standard Deviation (m/sec)		0.100	0.263	0.167	0.079	0.206	0.138	0.090	0.236	0.153
Extreme Difference (m/sec)		-0.427	-0.855	-0.855	-0.273	-0.608	-0.480	-0.427	0.855	-0.855
RMS Error (m/sec) of Wind Speed		0.071	0.186	0.118	0.056	0.146	0.096	0.064	0.167	0.108
Wind Shear (Δh = 25m) (1/sec)	RMS Error	0.004	0.011	0.006	0.003	0.008	0.006	0.004	0.009	0.006
	Maximum Difference	0.027	0.044	0.045	0.012	0.034	0.020	0.027	0.044	0.045
Wind Shear (Δh = 50m) (1/sec)	RMS Error	0.002	0.005	0.004	0.001	0.004	0.003	0.001	0.005	0.003
	Maximum Difference	0.008	0.028	0.020	0.006	0.016	0.012	0.008	0.028	0.020
Wind Shear (Δh = 100m) (1/sec)	RMS Error	0.001	0.003	0.001	0.001	0.002	0.001	0.001	0.002	0.001
	Maximum Difference	0.004	0.012	0.008	0.004	0.008	0.007	0.004	0.012	0.008
Wind Shear (Δh = 200m) (1/sec)	RMS Error	0.001	0.001	0.001	0.000	0.001	0.001	0.001	0.001	0.001
	Maximum Difference	0.003	0.006	0.005	0.002	0.004	0.003	0.003	0.006	0.005
Mean Wind Speed (m/sec)	WP_N/PAFB	-4.117	2.421	5.323	-8.031	9.371	12.511	-6.080	5.907	8.928
	WP_S/PAFB	-4.099	2.480	5.337	-8.015	9.435	12.546	-6.083	5.969	8.953

TABLE V STATISTICAL DATA FOR SMOKE TRAIL TEST NUMBER LRC-9 (APRIL 6, 1961)

		Altitude Interval 5.0 - 8.975 km			Altitude Interval 9.0 - 13.0 km			Altitude Interval 5.0 - 13.0 km		
		u	v	V	u	v	V	u	v	V
Arithmetic mean of Difference (m/sec)		-0.051	-0.300	- 0.064	-0.071	-0.595	-0.012	-0.060	-0.446	-0.038
Standard Deviation (m/sec)		0.304	0.712	0.316	0.946	0.948	1.044	0.699	0.850	0.768
Extreme Difference (m/sec)		-1.206	-3.158	-1.107	3.535	-3.546	4.109	3.535	-3.546	4.109
RMS Error (m/sec of Wind Speed		0.215	0.503	0.223	0.669	0.670	0.738	0.494	0.601	0.543
Wind Shear (Δh = 25m) (1/sec)	RMS Error	0.012	0.028	0.013	0.038	0.038	0.042	0.028	0.034	0.030
	Maximum Difference	0.048	0.115	0.042	0.132	0.082	0.141	0.132	0.115	0.141
Wind Shear (Δh = 50m) (1/sec)	RMS Error	0.006	0.014	0.006	0.019	0.019	0.021	0.014	0.017	0.016
	Maximum Difference	0.040	0.083	0.037	0.067	0.036	0.065	0.067	0.083	0.065
Wind Shear (Δh = 100m) (1/sec)	RMS Error	0.003	0.007	0.003	0.009	0.009	0.011	0.007	0.008	0.008
	Maximum Difference	0.019	0.036	0.011	0.049	0.022	0.048	0.049	0.036	0.048
Wind Shear (Δh = 200m) (1/sec)	RMS Error	0.001	0.004	0.001	0.005	0.005	0.005	0.004	0.004	0.004
	Maximum Difference	0.006	0.016	0.007	0.020	0.013	0.022	0.020	0.016	0.022
Mean Wind Speed (m/sec)	WP_N/PAFB	53.810	1.113	54.000	71.176	-2.300	72.181	62.383	-0.572	62.975
	WP_S/PAFB	53.861	1.413	54.064	71.247	-1.705	72.193	62.444	-0.126	63.014

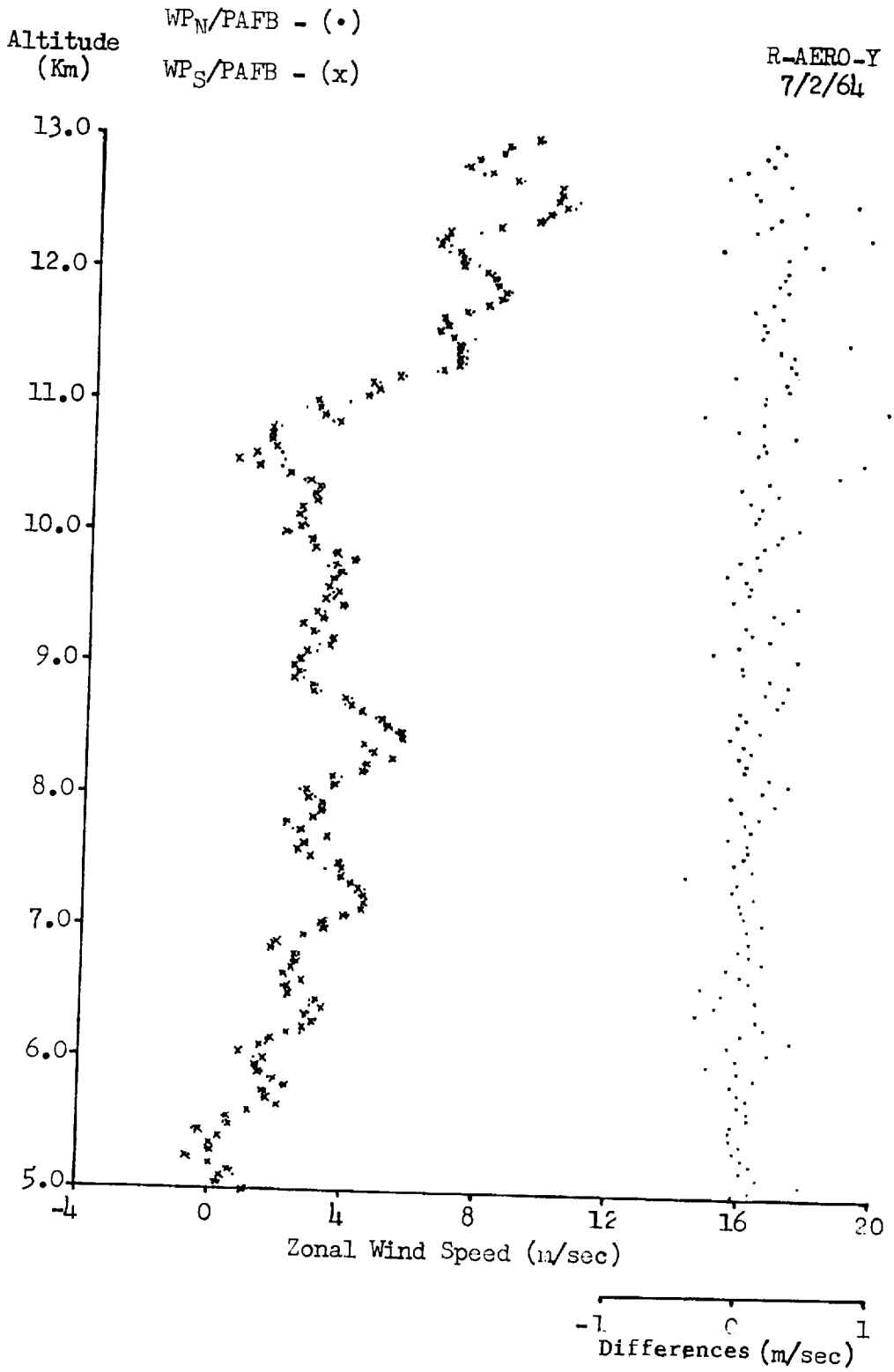

Figure 1. Zonal Wind Speed Profiles and Their Differences Obtained from Smoke Trail Test Number 3564 (June 7, 1963)

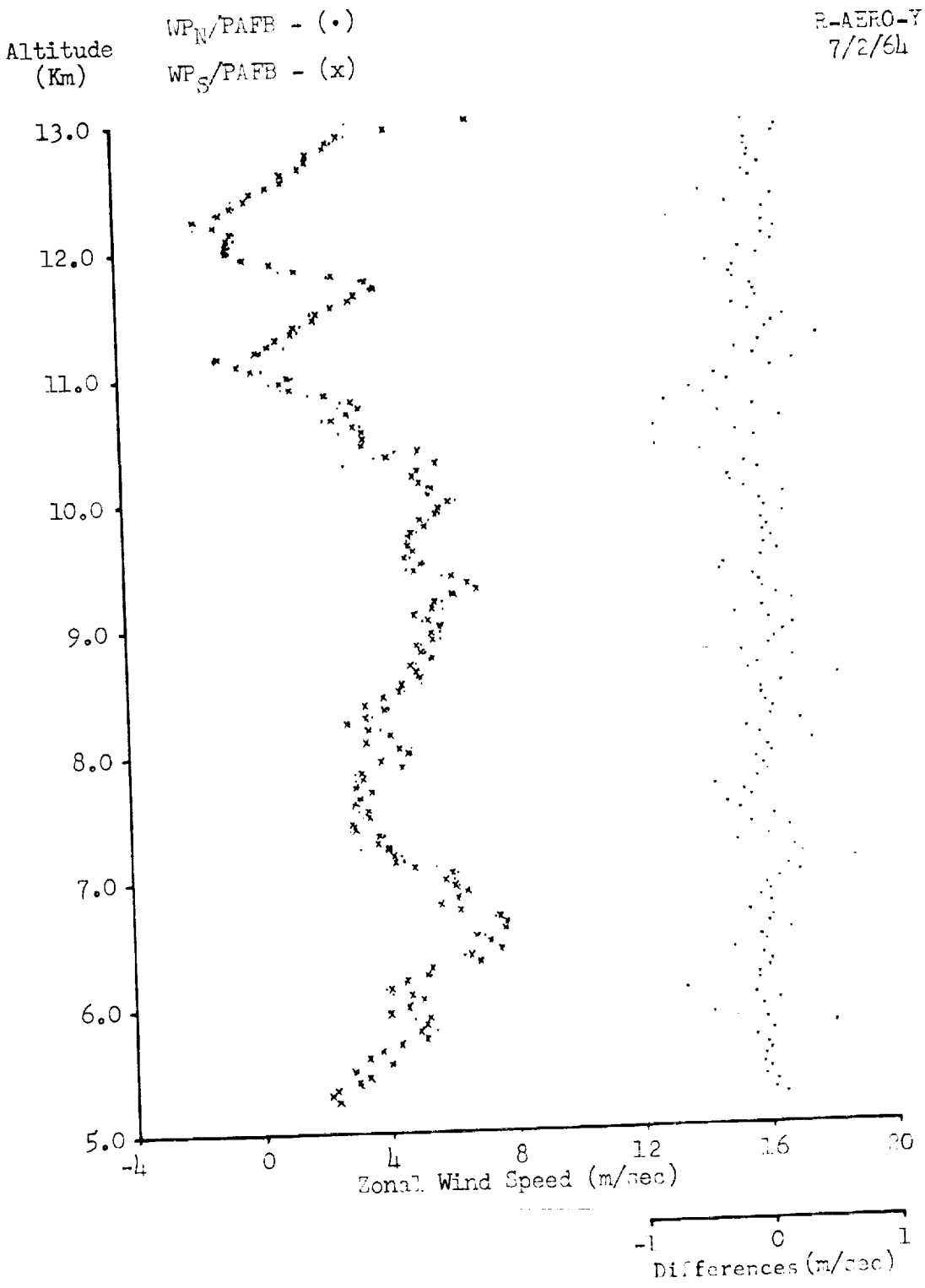

Figure 2. Zonal Wind Speed Profiles and Their Differences Obtained from Smoke Trail Test Number 4019 (June 19, 1963)

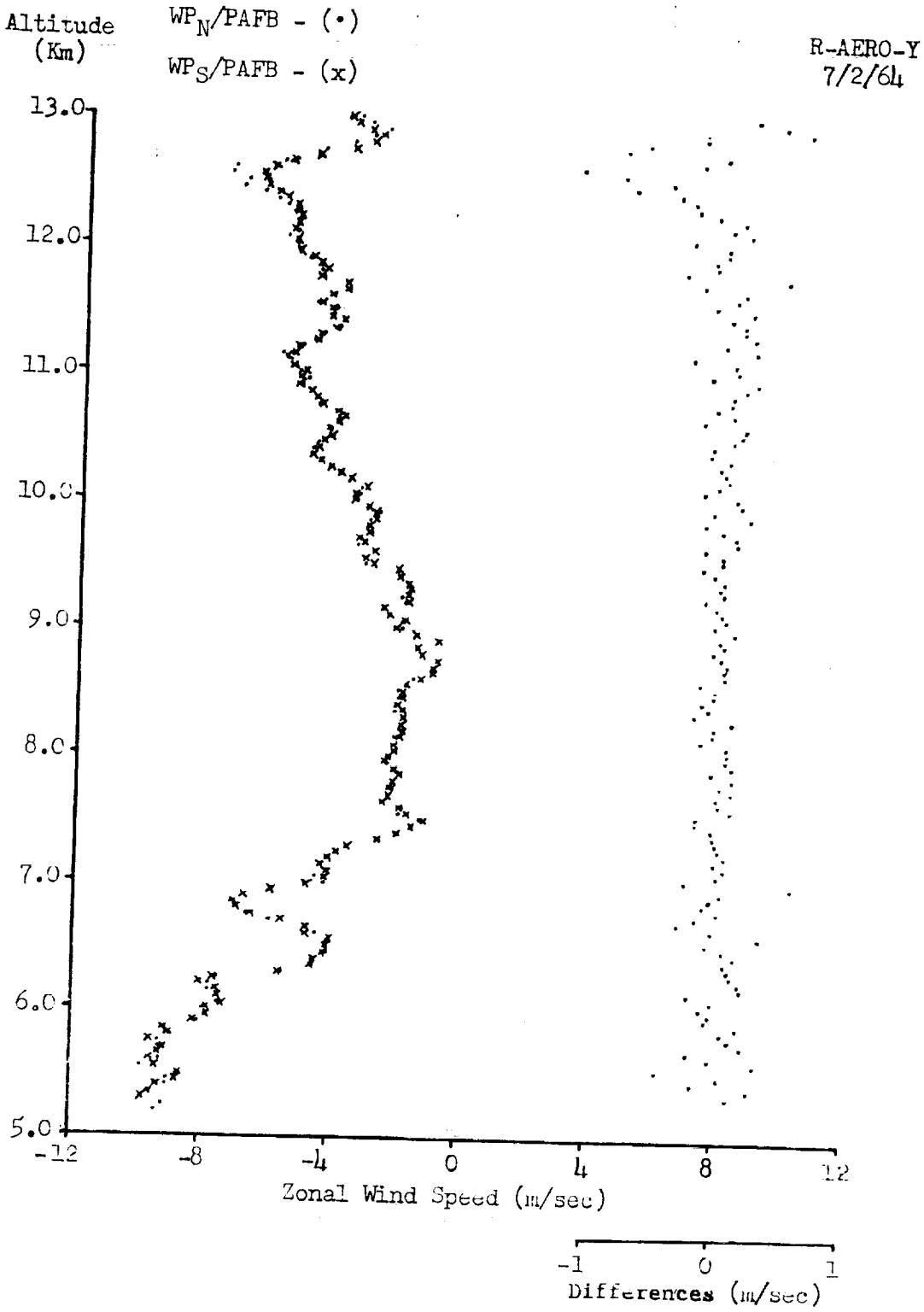

Figure 3. Zonal Wind Speed Profiles and Their Differences Obtained from Smoke Trail Test Number 4859 (July 26, 1963)

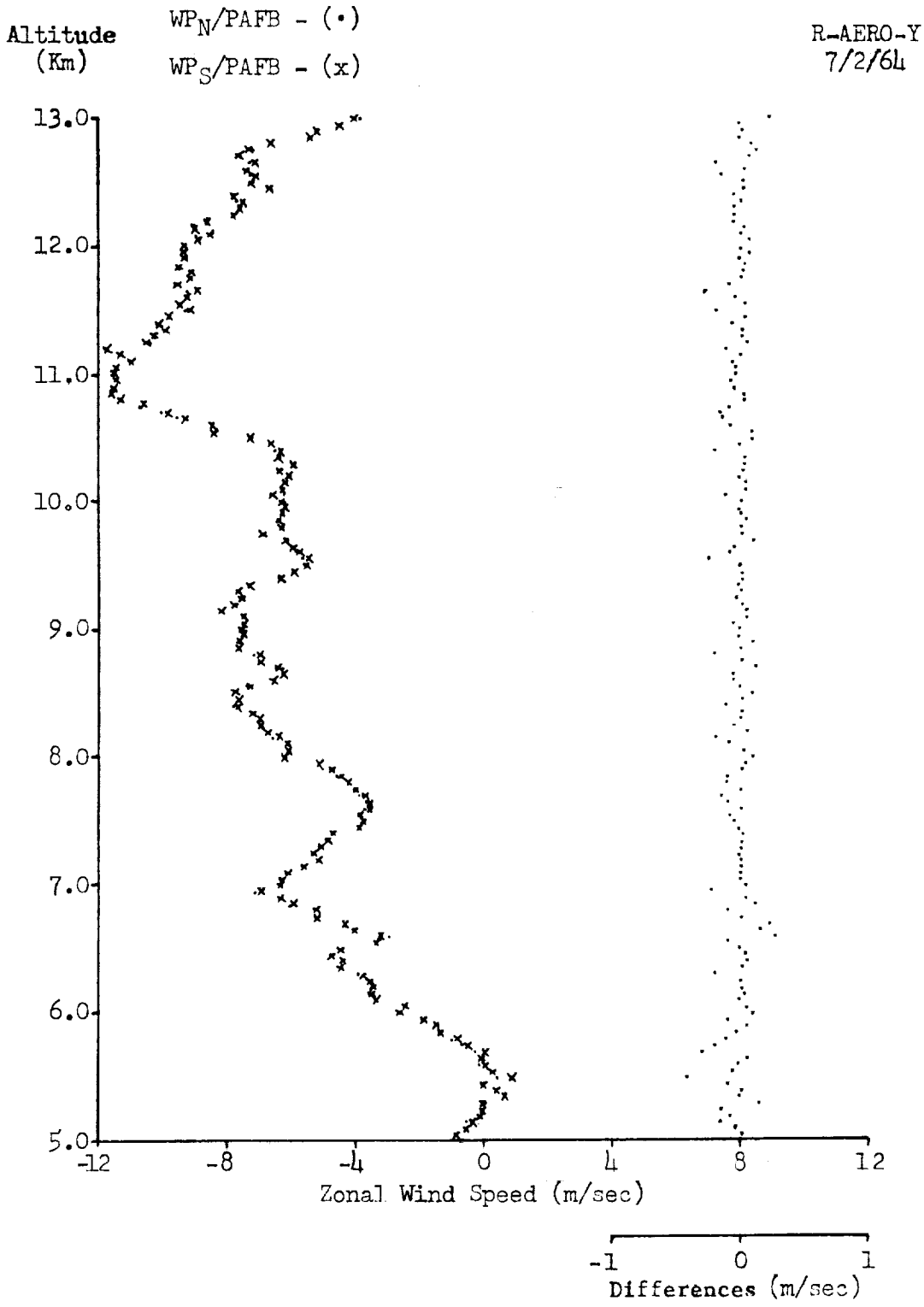

Figure 4. Zonal Wind Speed Profiles and Their Differences Obtained from Smoke Trail Test Number 5233 (August 7, 1963)

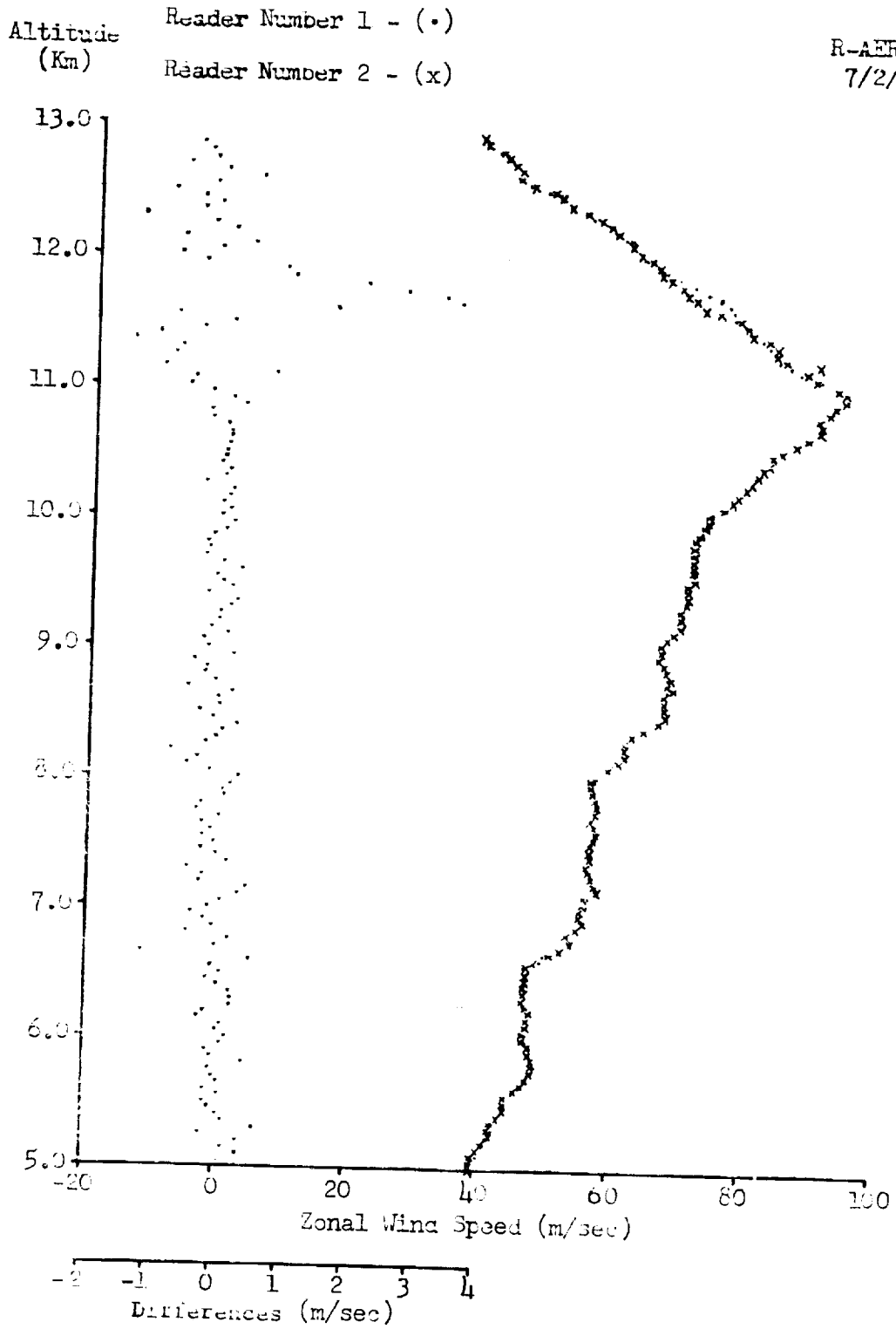

Figure 5. Zonal Wind Speed Profiles and Their Differences Obtained from Smoke Trail Test Number LRC-9 (April 6, 1961)

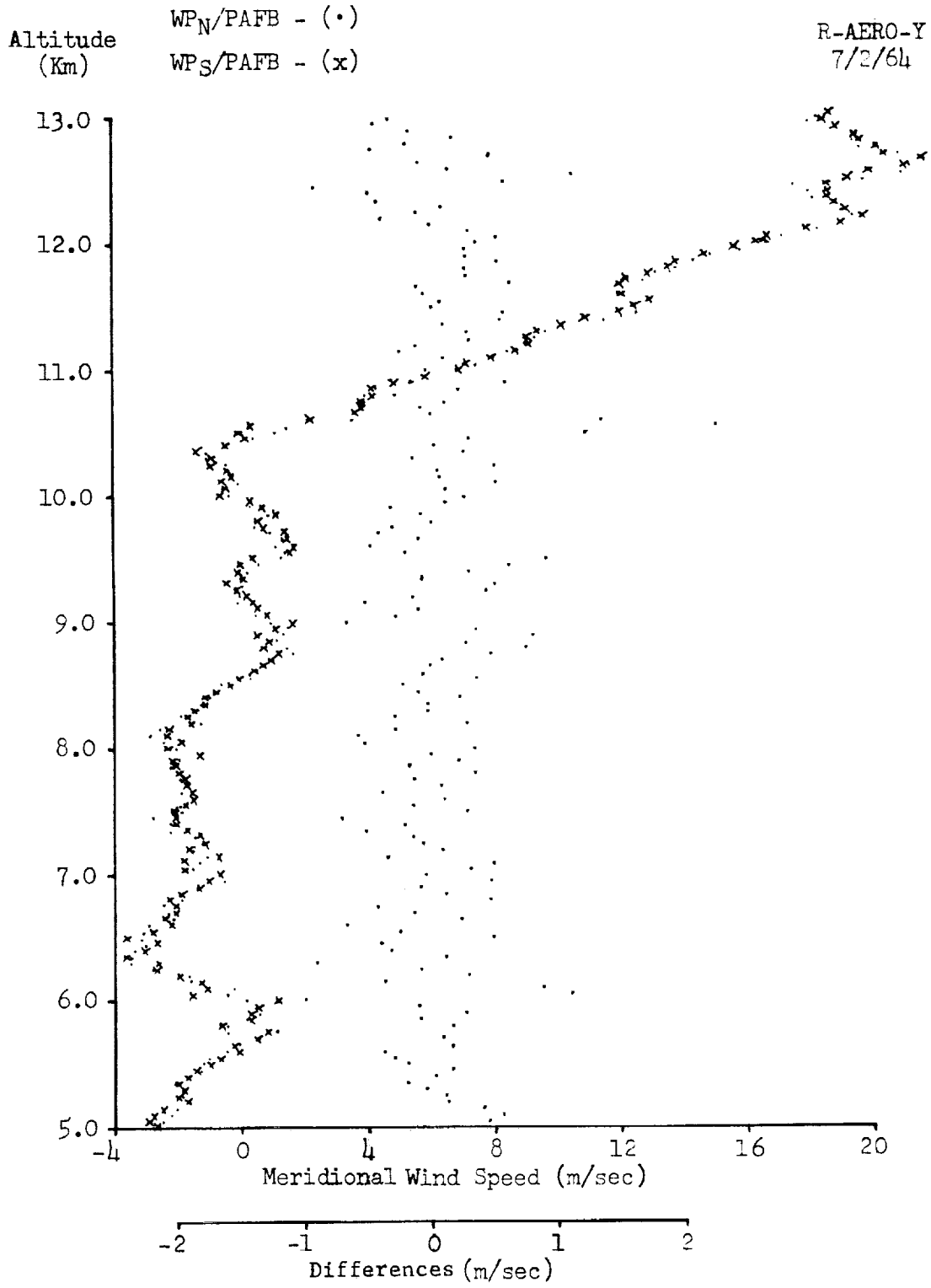

Figure 6. Meridional Wind Speed Profiles and Their Differences Obtained from Smoke Trail Test Number 3564 (June 7, 1963)

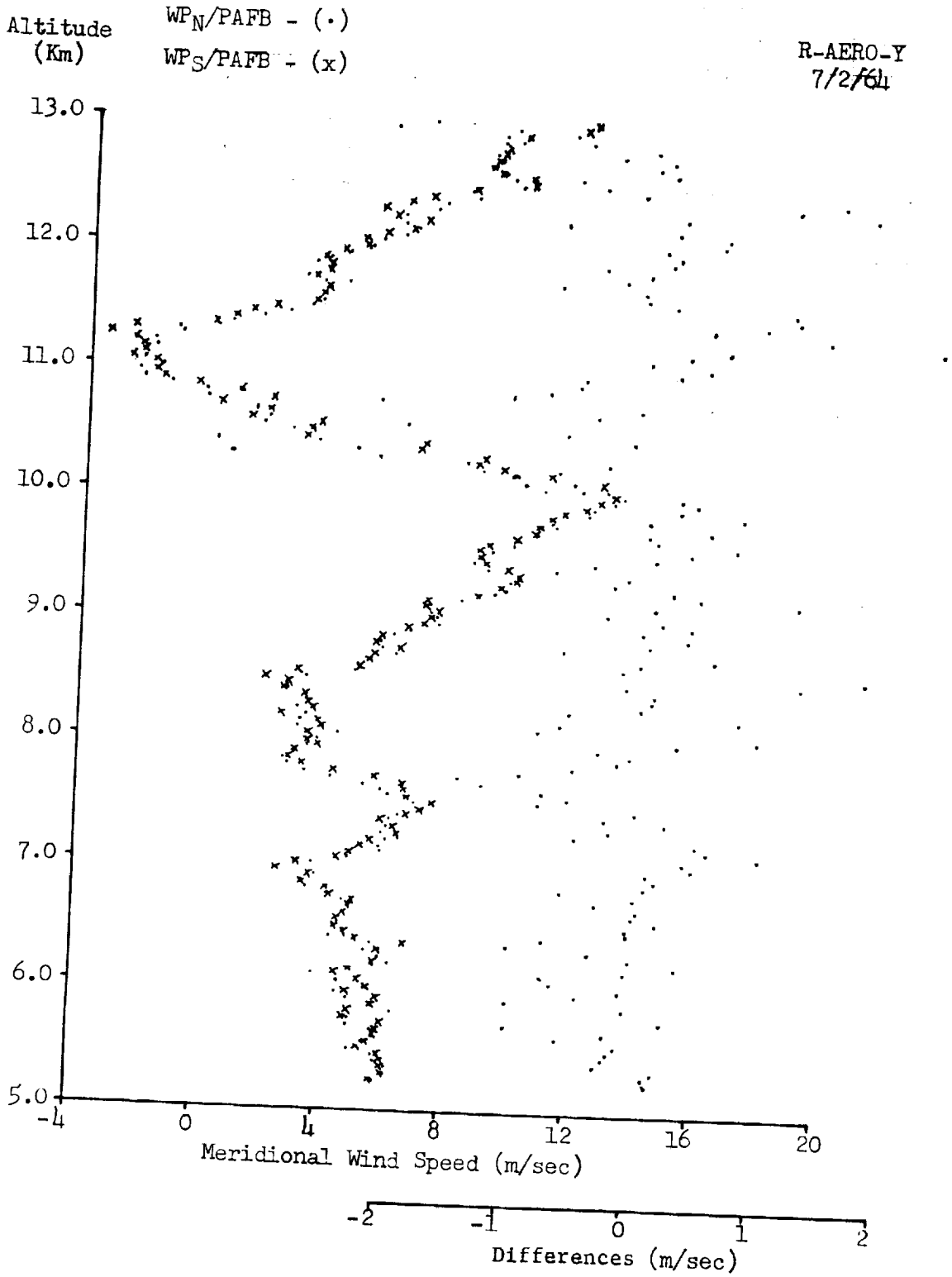

Figure 7. Meridional Wind Speed Profiles and Their Differences Obtained from Smoke Trail Test Number 4019 (June 19, 1963)

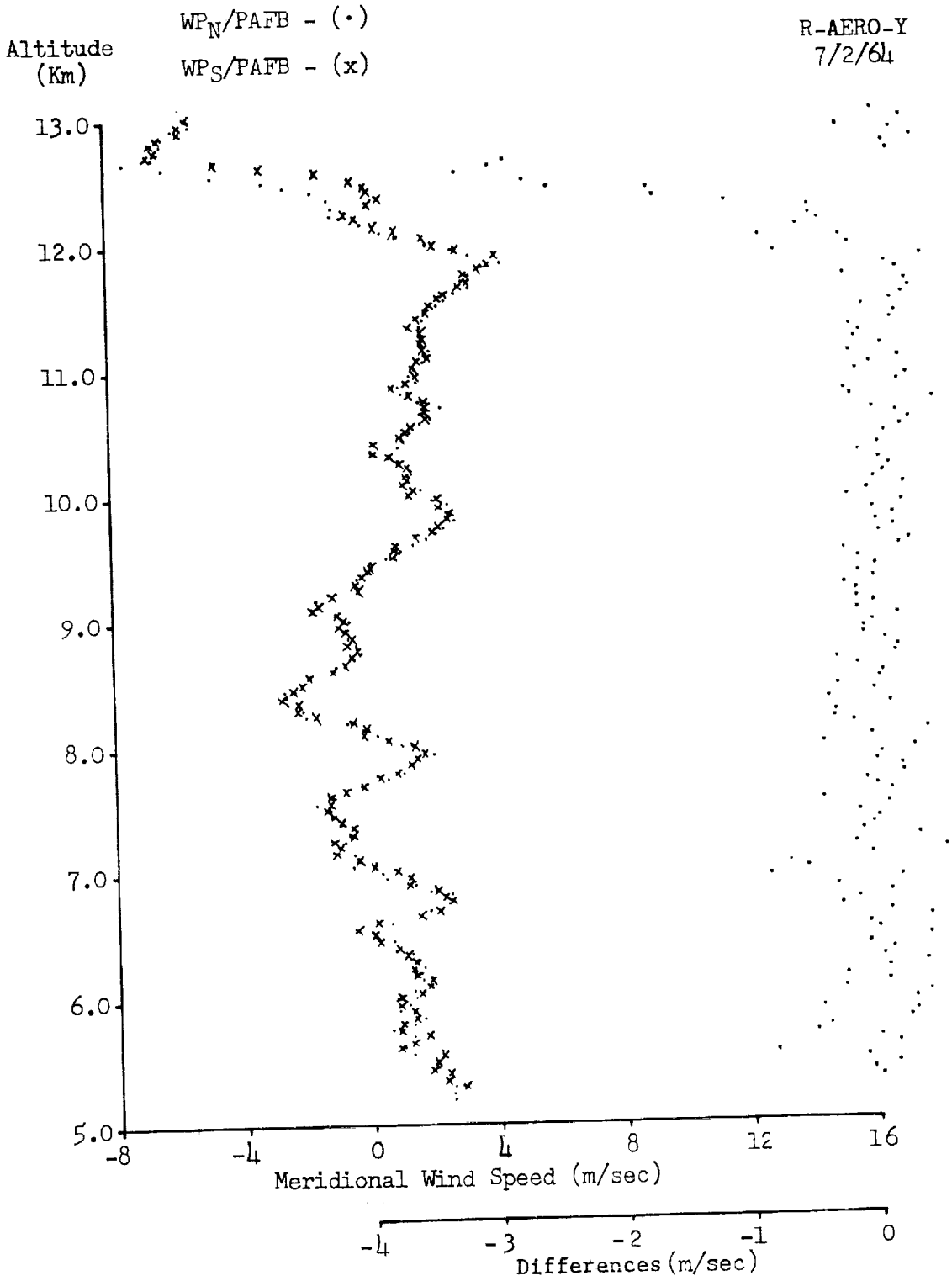

Figure 8. Meridional Wind Speed Profiles and Their Differences Obtained from Smoke Trail Test Number 4859 (July 26, 1963)

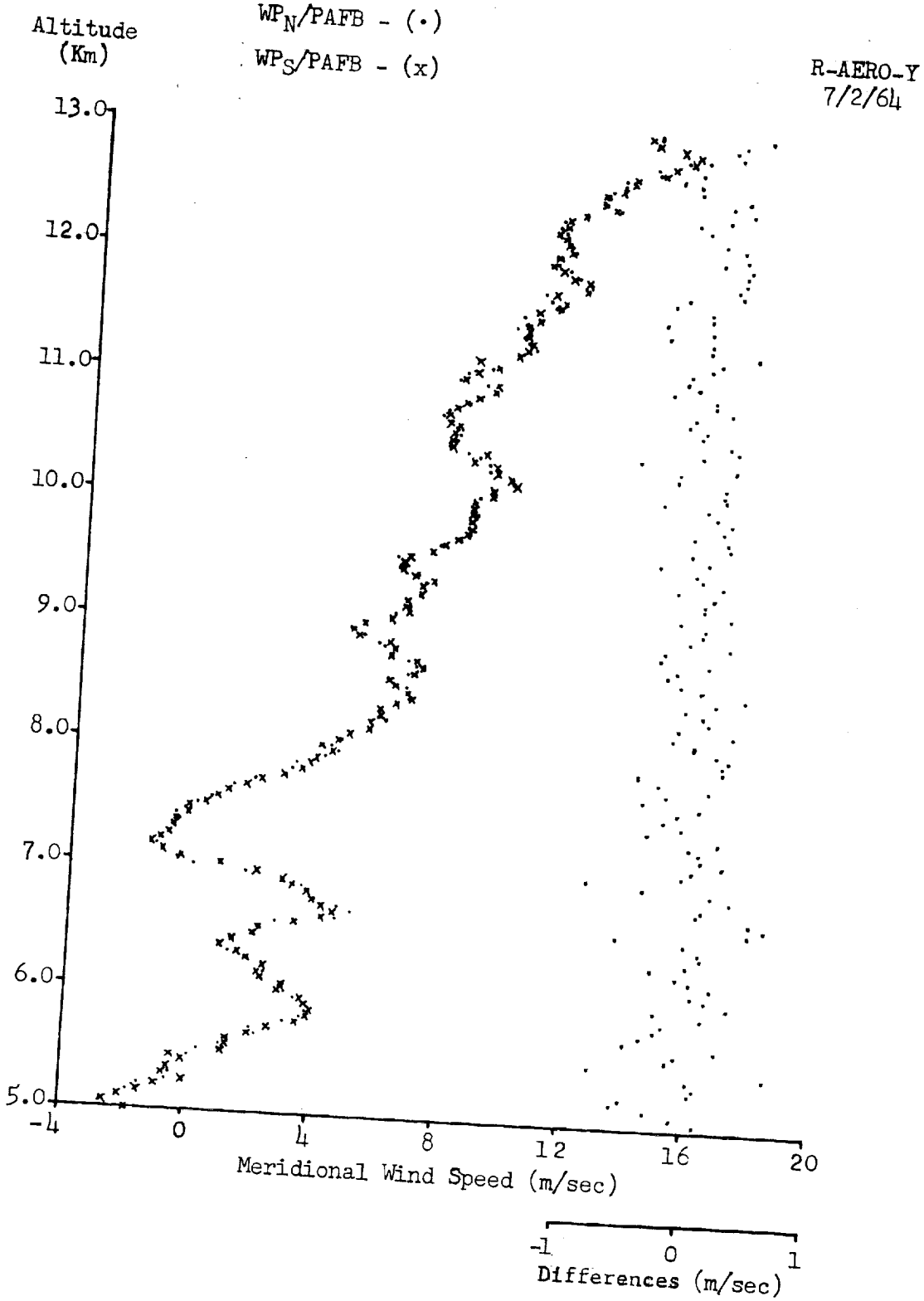

Figure 9. Meridional Wind Speed Profiles and Their Differences Obtained from Smoke Trail Test Number 5233 (August 7, 1963)

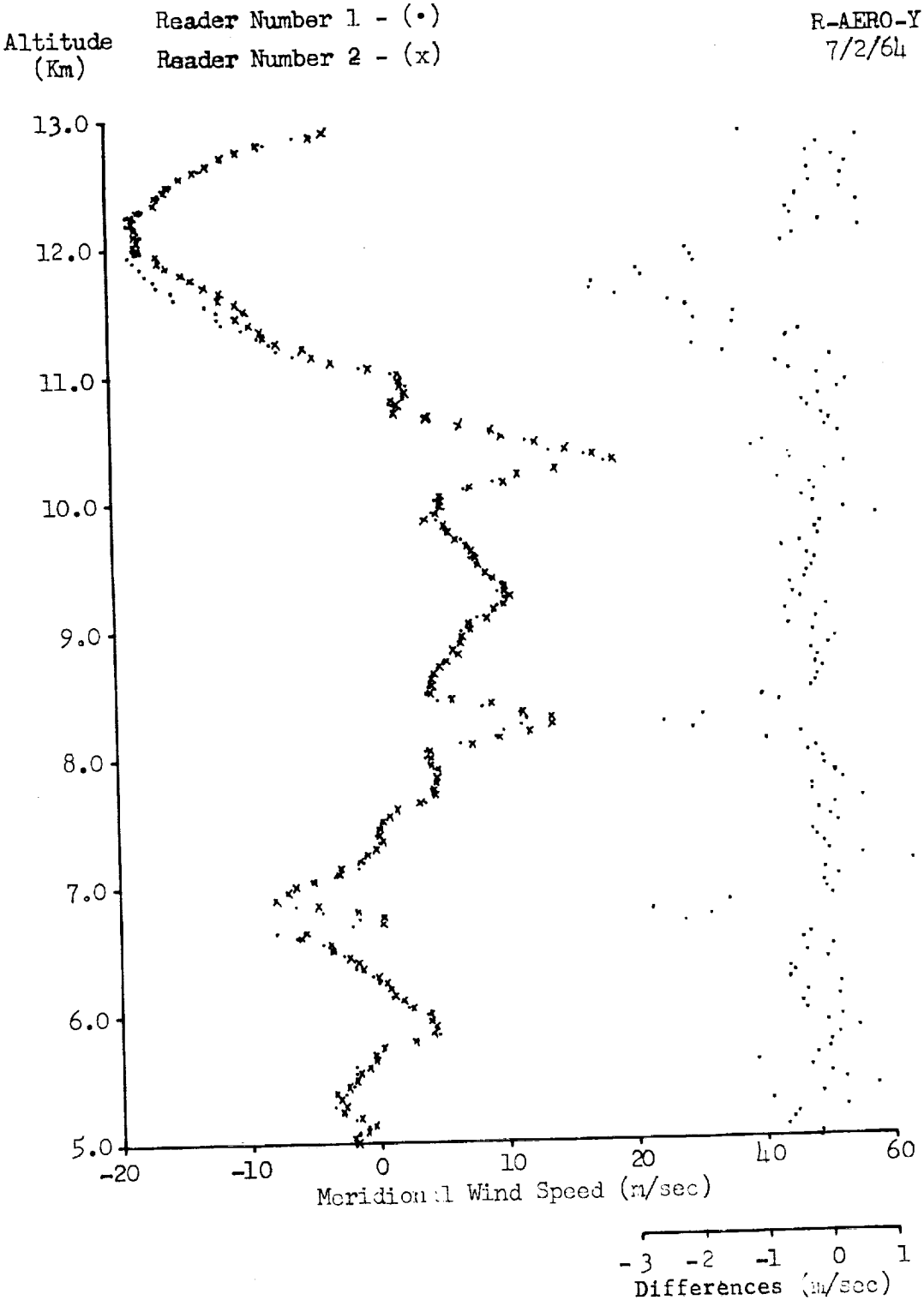

Figure 10. Meridional Wind Speed Profiles and Their Differences Obtained from Smoke Trail Test Number LRC-9 (April 6, 1961)

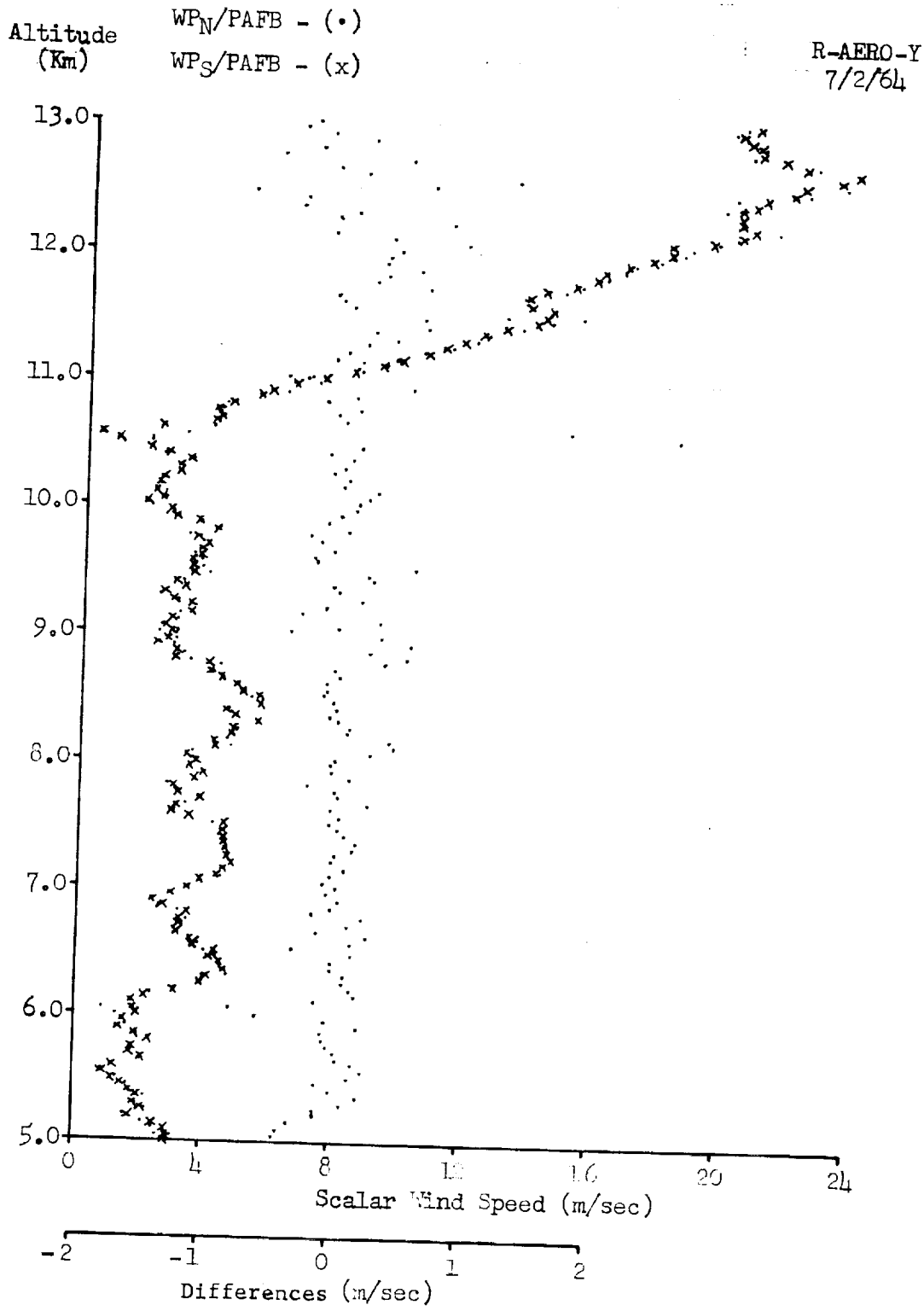

Figure 11. Scalar Wind Speed Profiles and Their Differences Obtained from Smoke Trail Test Number 3564 (June 7, 1963)

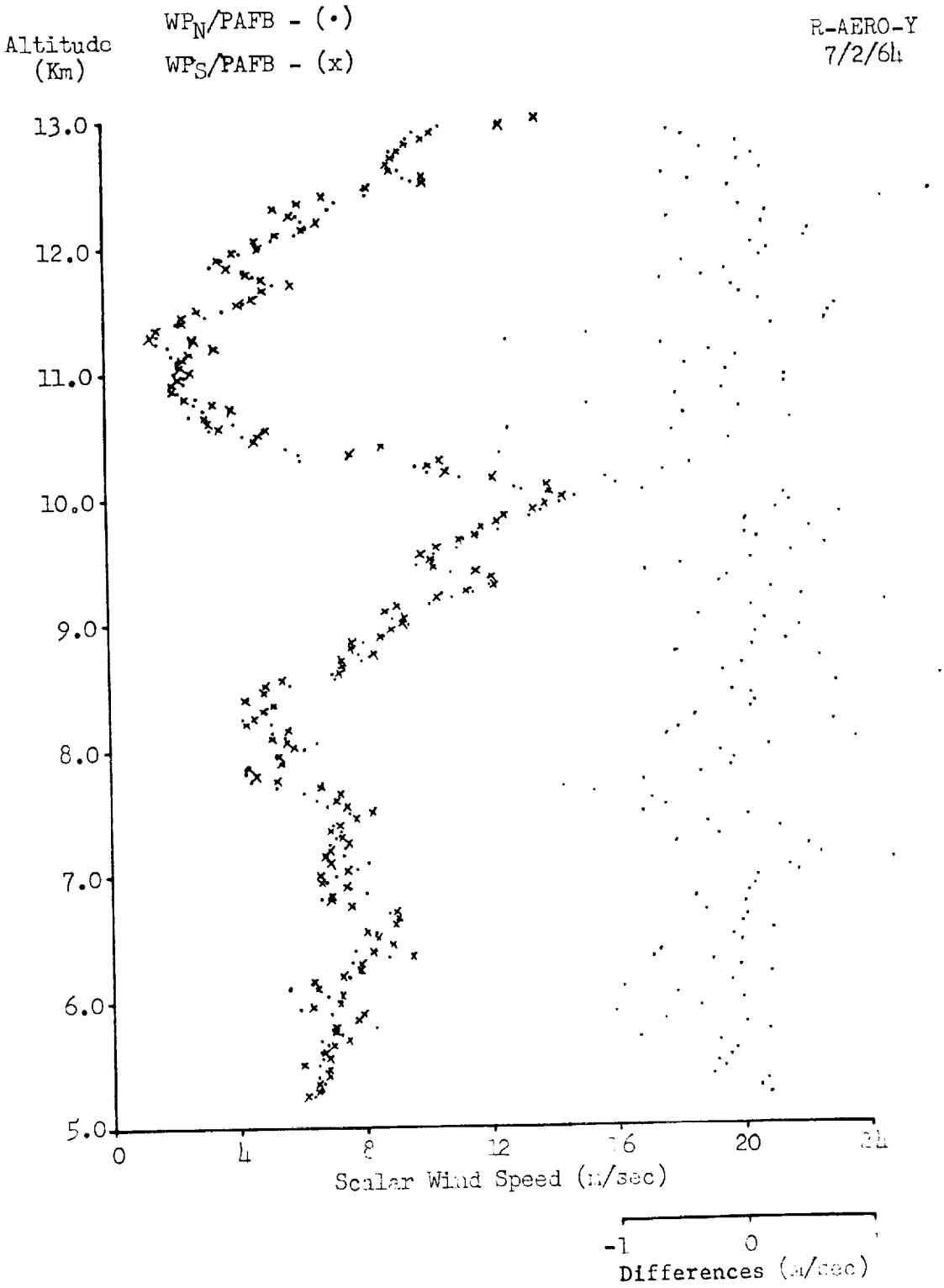

Figure 12. Scalar Wind Speed Profiles and Their Differences Obtained from Smoke Trail Test Number 4019 (June 19, 1963)

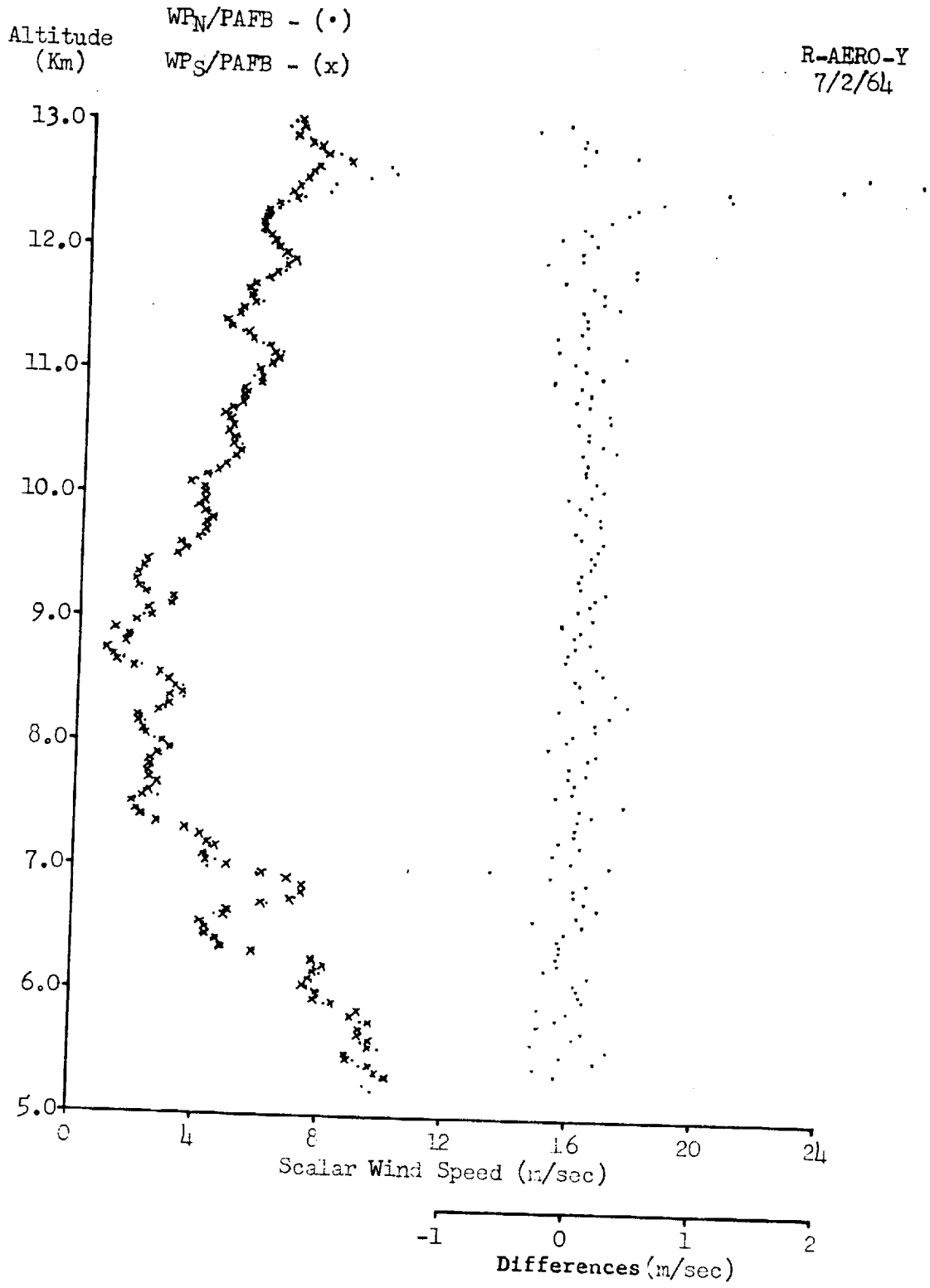

Figure 13. Scalar Wind Speed Profiles and Their Differences Obtained from Smoke Trail Test Number 4859 (July 26, 1963)

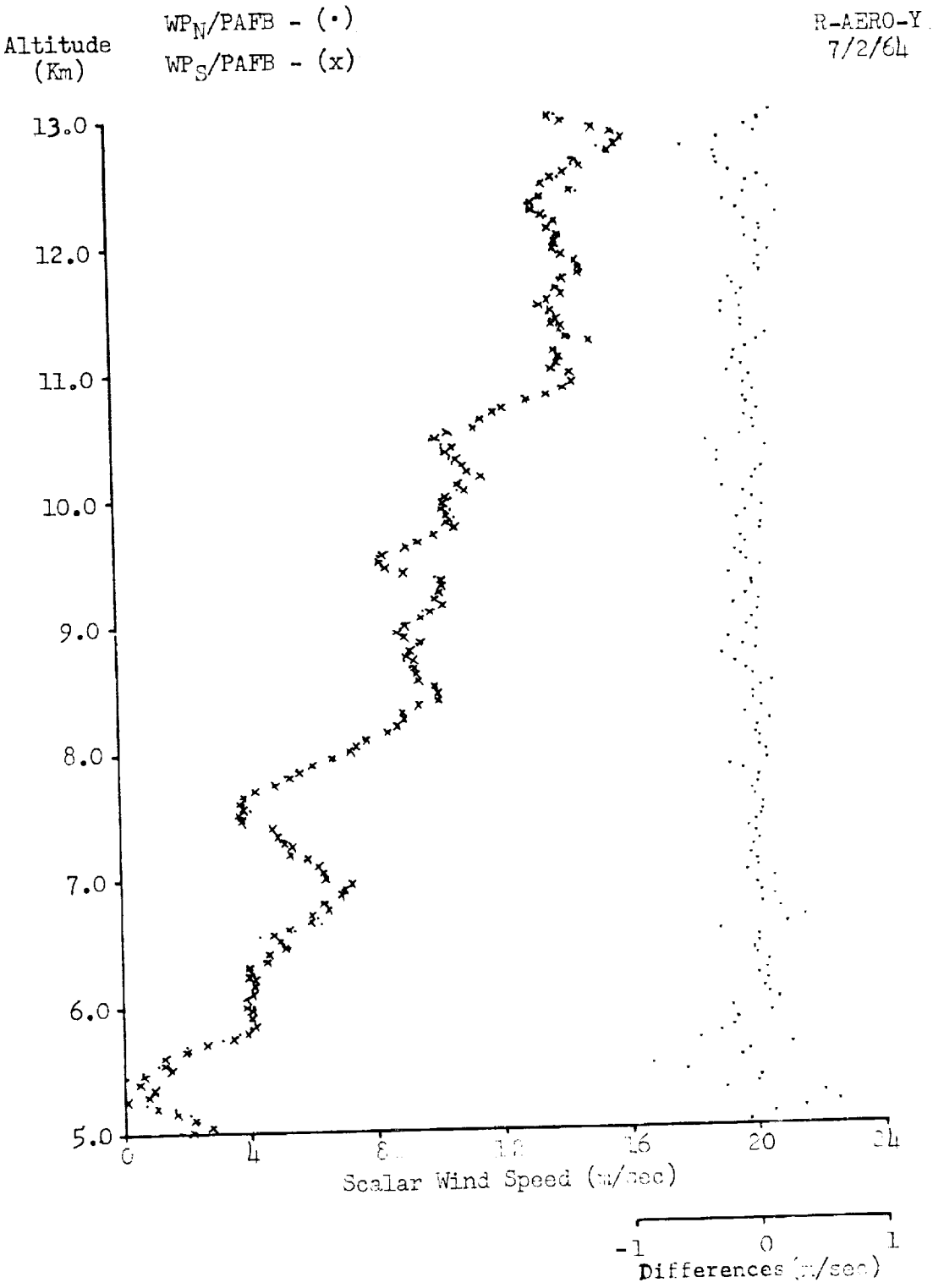

Figure 14. Scalar Wind Speed Profiles and Their Differences Obtained from Smoke Trail Test Number 5233 (August 7, 1963)

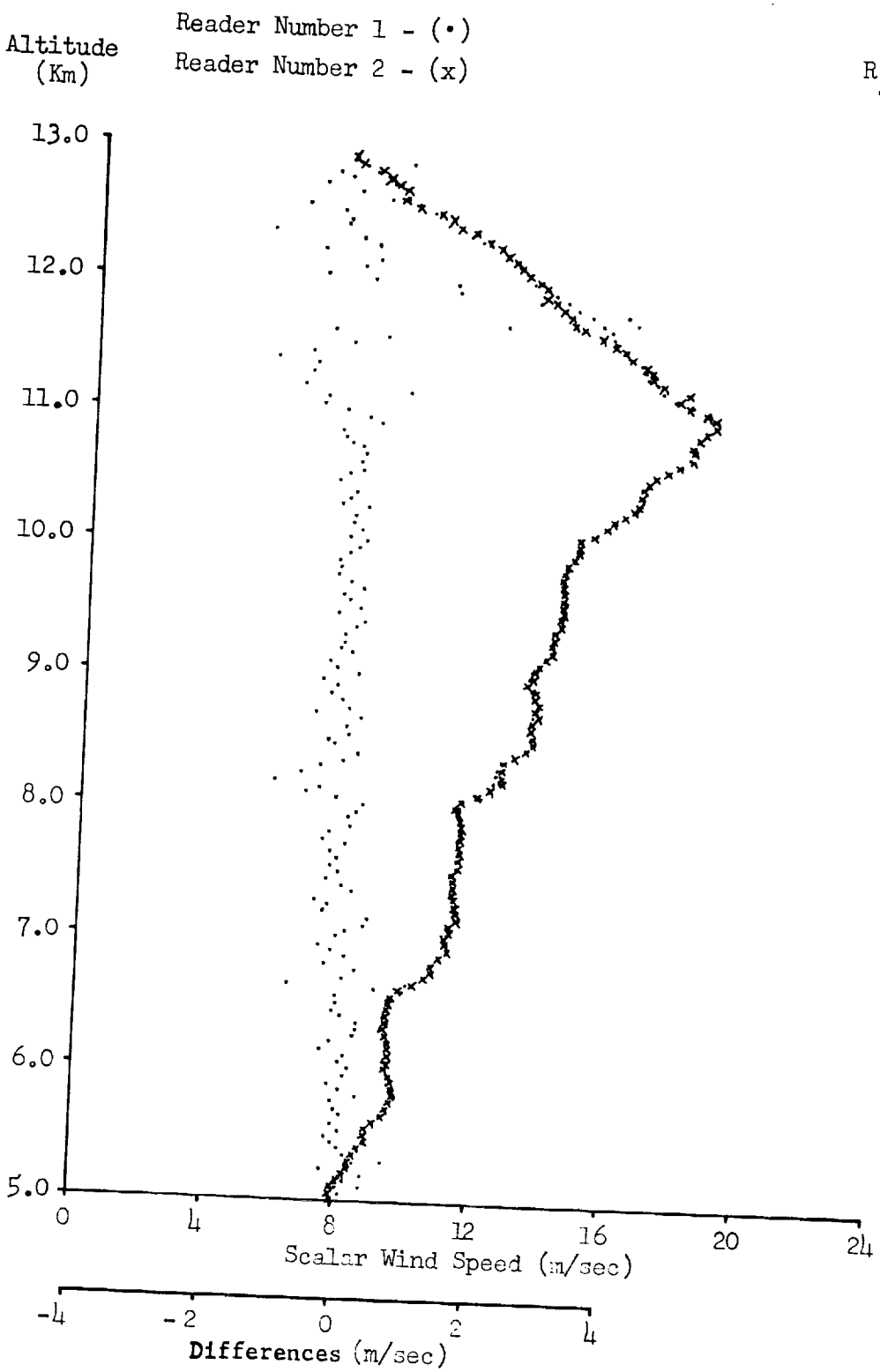

Figure 15. Scalar Wind Speed Profiles and Their Differences Obtained from Smoke Trail Test Number LRC-9 (April 6, 1961)

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SOME PRACTICAL ACCURACY CONSIDERATIONS OF SMOKE TRAIL WIND PROFILE DATA

By Dennis W. Camp and James R. Scoggins

The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Office. This report, in its entirety, has been determined to be unclassified.

This document has also been reviewed and approved for technical accuracy.

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