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WIND PROFILE PARAMETERS IN THE GROUND LAYER
AND TROPOSPHERE AT MIDLATITUDES

by

O. M. Essenwanger

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13. ABSTRACT (Three sets of wind profiles (surface to 1, surface to 2, and surface to 10 km) have been derived for a pilot station from the midlatitudes (Chateauroux, France). These profiles were parameterized by establishing mathematical-stochastic models for further computer application, reducing the original input by a factor 1:1000. The coefficients for these computer models are given in this report by the individual month; six levels of probability (50, 68, 84, 95, 97.7 and 99 percent) have been computed for January and July as examples.			

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1. Introduction

In some previous articles, Essenwanger [1, 2, 3] has discussed new design criteria for wind based on the parameterization of surface to 25-km wind profiles. The newly developed techniques and selection of a characteristic wind profile coefficient are not only applicable to the set of surface to 25-km profiles but also for other layers of interest.

In the subsequent report, wind profiles for layers up to 2 km and surface to 10 km were treated with similar techniques. Data for the pilot station Chateauroux are included here. These data may be valuable for design problems when the lower layer profiles are of interest. It is evident that the threshold profiles, e.g. 90 percent exceedance, differ in both representations.

In addition, the correlations between surface winds and the profile characteristics in the first 2 km have been investigated. The inter-relationship between surface layer and surface to 10-km wind profiles was a further topic of research. As expected little correlation exists between surface wind and wind profiles in the first 2 km at midlatitudes. The displayed correlation between the data sets of surface to 1 km and surface to 2 km is spurious although not useless [4].

It should be stressed that the developed design data refer to the smooth wind profile as they would be obtained by averaging all small scale turbulence and gustiness. The superposition of the two phenomena on the smooth profiles will be treated in a forthcoming report.

Since the windshear for small increments is influenced by small scale fluctuations like turbulence and gustiness, the established wind profiles cannot be significant whenever the windshear parameter is of major importance. Other phenomena such as target displacement, etc. can be evaluated, however. The details of the methodology, derivation of results, and application will now follow, while some problems of the time relationship of wind profiles will be presented in a separate report by Billions [5].

2. Profile Statistics

The wind profile in the lowest 1- and 2-km layer as well as the surface to 10-km layer was of particular interest. These three subject matters will be treated separately first, and in the last section the interrelationship will be discussed.

The parameterization in general [1, 2, 3, 6] is based on the representation of the wind profile as a function of altitude h .

$$V(h) = \alpha_0 + \alpha_1 P_1 + \alpha_2 P_2 + \dots + \alpha_n P_n \quad (1)$$

where the α_i denote constants and the P_i symbolize polynomial terms as function of altitude h . A similar equation can be established for the wind direction profile

$$\theta(h) = \beta_0 + \beta_1 P_1 + \beta_2 P_2 + \dots + \beta_n P_n \quad (2)$$

with some provisions to prevent discontinuity at 360 degrees [7]. The β_i again are constants to be computed for the individual radiosonde data. The n is limited to the number of points (i.e., maximum $n = 11$ for the surface to 10 km profile at 1 km intervals) but in practical work fewer terms give a satisfactory approximation. In fact, three constants were sufficient for the wind profile in the lower 1 or 2 km and four for the surface to 10 km profiles.

The reduction to three to four coefficients provides still a multivariate distribution for statistical evaluation. It was proven [6] that the scheme can be further reduced to one variable (characteristic) parameter. In the case of the surface to 25-km profiles, the function of Equation (1) was a Fourier series which created some difficulties for the consideration of the phase angle in the reduction to one variable parameter and a set of monthly constants. In the case of polynomial representation no such difficulty exists.

The new parameterization then takes the form

$$V(h) = (X - \bar{X}) \left(\gamma_0 + \gamma_1 P_1 + \gamma_2 P_2 \right) + \bar{V}(h) \quad (1a)$$

and

$$\theta(h) = (Y - \bar{Y}) \left(\delta_0 + \delta_1 P_1 + \delta_2 P_2 \right) + \bar{\theta}(h) \quad (2a)$$

where the γ_i and δ_i are constants over a predetermined time period such as the month or the season. An annual combination is not advisable because the variable parameters X and Y follow a multimodal or mixed type of distribution form beyond the seasonal summary.

The $\bar{V}(h)$ and $\bar{\theta}(h)$ represent the monthly (seasonal) mean profiles. In most cases

$$\bar{V}(h) \sim \bar{X}(\gamma_0 + \gamma_1 P_1 + \gamma_2 P_2) \quad (1b)$$

and

$$\bar{\theta}(h) \sim \bar{Y}(\delta_0 + \delta_1 P_1 + \delta_2 P_2) \quad (2b)$$

If this approximation can be made, the parameterized equations take the final form for the individual wind profile

$$V(h) = X(\gamma_0 + \gamma_1 P_1 + \gamma_2 P_2) \quad (1c)$$

and

$$\theta(h) = Y(\delta_0 + \delta_1 P_1 + \delta_2 P_2) \quad (2c)$$

In this equation or form of (1) and (2a) only one variate appears, viz. X or Y. The establishment of a probability distribution is now reduced to the one-dimensional case.

Although various types of distribution could be utilized, one of the most flexible form is the Weibull distribution. It is a well-established fact that the X for the windspeed profile does not follow the Gaussian distribution law.

The Weibull distribution provides a good tool for uniform treatment of windspeed and direction analysis. We write the cumulative distribution

$$F(x) = 1 - \exp\left\{-\left[\frac{(x - \gamma)}{\theta}\right]^\beta\right\} \quad (3)$$

and the inverse for any threshold x_{th}

$$x_{th} = \theta \left[-\ln(1 - F(x)) \right]^{1/\beta} + \gamma \quad (4)$$

The maximum likelihood fit for the three-parameter Weibull distribution is too complicated and costly for computer solution of an extended number of samples. A moments fit was suggested by Essenwanger [8] which is sufficient for descriptive purpose in practical application. The three parameters γ , β , and θ will be listed in the subsequent section of the individual layer representation. (Note: the γ and β are not related to the set of constants in Equations (1) and (2)).

Although the choice of polynomials is arbitrary, for reasons of convenience and simplicity Tchebycheff orthogonal polynomials have been utilized in the subsequent representations.

a. The Wind Profiles in the Surface to 1-km Layer

Although many discussions on the wind profile in the boundary layers exist, the representation at hand has a different purpose. The major goal is the establishment of a statistical distribution to derive profiles for a given probability threshold to be exceeded in a certain number of times. Since the profile in the lowest 50 ft is a negligible part of the total profile no particular emphasis will be placed on the special features of the wind in this boundary layer. Further, the Ekman spiral representation in the boundary layer or a sophisticated modification thereof is also of secondary interest.

The wind profile as a function of altitude follows Equations (1) and (2). We write

$$V(h) = A_0 + A_1\phi_{1h} + A_2\phi_{2h} \quad (5a)$$

and

$$\theta(h) = B_0 + B_1\phi_{1h} + B_2\phi_{2h} \quad (5b)$$

where the ϕ_{ij} denotes five points Tchebycheff orthogonal polynomials at 250 m intervals (Appendix). The parameterized form can then be written as

$$V_h = (A_1 - \bar{A}_1) (a_0 + \phi_{1h} + a_2\phi_{2h}) + \bar{V}_h \quad (6a)$$

and

$$\theta_h = (B_1 - \bar{B}_1) (b_0 + \phi_{1h} + b_2\phi_{2h}) + \bar{\theta}_h \quad (6b)$$

The mean profiles \bar{V}_h and $\bar{\theta}_h$ follow by substituting the mean of the coefficients into Equations (5a) and (5b).

The constants have been calculated from linear regression technique which provides

$$a_0 = r_{A_0 A_1} \cdot \frac{\sigma_{A_0}}{\sigma_{A_1}} \quad (7a)$$

$$a_2 = r_{A_2 A_1} \cdot \frac{\sigma_{A_2}}{\sigma_{A_1}} \quad (7b)$$

$$b_0 = r_{B_0 B_1} \cdot \frac{\sigma_{B_0}}{\sigma_{B_1}} \quad (7c)$$

$$b_2 = r_{B_2 B_1} \cdot \frac{\sigma_{B_2}}{\sigma_{B_1}} \quad (7d)$$

Table 1 lists the respective parameters by month, including the statistics for the Weibull distribution. The means are listed in Table 2. The midlatitude conditions have been chosen as a pilot station because they should approximate a global average, although true global average conditions can only be evaluated from combination of wind data of several climatic regimes.

The low values of the mean slope for the speed are expected. They correspond to an average 7 m/sec increase of the windspeed from surface to the 1-km altitude level. It should be noted that the maximum increase* is approximately 25-26 m/sec in winter with a seasonal decrease to approximately 16 m/sec in summer, running parallel with the reduction of the mean. It should also be noted that profiles exist with negative A_1 at which the windspeed diminishes with height. Although this average minimum negative slope indicates a lower windspeed at 1-km altitude of approximately 4-6 m/sec, in May one profile appeared with double that amount.

The pattern for the wind direction is somewhat more complex. While the average turn (positive turn is veering with height, i.e., a right turn of the wind with height) shows only 12 degrees in July, its seasonal

*In the 5-point Tchebycheff polynomials, the linear term ranges from -2 to +2, which provides a value of 4 times the slope (A_1 or B_1) between highest (1 km for positive A_1 or B_1) and lowest windspeed or direction.

TABLE 1. CHATEAUROUX, SURFACE TO 1-km WIND PROFILE DATA
(1956-1964)

Month	Profile Parameters				Weibull			A_1		N
	\bar{A}_1	a_0	a_2	σ_{A_1}	γ	β	θ	Max	Min	
1	1.61	2.67	-0.61	1.24	-0.83	2.05	2.75	6.3	-1.8	359
2	1.49	2.59	-0.06	1.49	-0.76	2.06	2.54	5.5	-1.6	383
3	1.24	2.19	-0.08	1.03	-0.59	1.84	2.06	4.7	-0.8	420
4	1.09	2.01	-0.08	0.97	-0.65	1.86	1.96	4.3	-0.9	401
5	0.95	1.78	-0.15	0.89	-0.85	2.12	2.03	4.2	-2.3	418
6	0.88	1.99	-0.09	0.96	-0.12	1.05	1.02	4.3	-1.3	335
7	0.95	2.04	-0.04	0.95	-0.39	1.42	1.47	6.2	-0.8	369
8	0.93	1.63	-0.05	0.90	-0.73	1.93	1.87	4.0	-1.3	423
9	0.99	2.00	-0.11	0.98	-0.40	1.45	1.53	5.5	-0.8	410
10	1.30	2.46	-0.05	0.98	-0.35	1.73	1.85	5.2	-1.1	418
11	1.53	2.78	-0.05	1.26	-0.71	1.84	2.51	6.8	-0.8	345
12	1.65	2.53	-0.14	1.31	-0.77	1.93	2.74	6.4	-1.3	419

Units: A_1 , σ_{A_1} , γ , Max, Min, and V_h in m/sec

	\bar{B}_1	b_0	b_2	σ_{B_1}	γ	β	θ	B_1		R_{B, A_1}
								Max	Min	
1	10.3	1.46	0.002	13.4	-13.9	1.87	27.2	72.2	-41.1	-0.02
2	9.1	0.46	-0.052	10.4	-18.7	2.89	31.1	44.1	-30.5	0.02
3	7.2	0.75	0.004	11.6	-24.6	2.99	35.6	62.4	-39.9	0.11
4	4.6	0.32	-0.041	11.2	-82.5	9.29	91.7	53.5	-62.1	0.14
5	5.0	0.32	0.063	12.7	-38.0	3.78	47.6	60.3	-61.8	0.12
6	4.7	0.92	0.061	13.4	-17.6	1.72	25.1	70.0	-46.8	0.05
7	3.2	-0.59	-0.045	12.6	-17.8	1.73	23.7	88.4	-48.1	0.08
8	4.5	-0.65	-0.005	12.4	-22.4	2.29	30.3	86.7	-51.9	0.07
9	6.7	0.35	-0.017	14.9	-30.1	2.66	41.4	78.9	-56.8	0.00
10	6.2	0.66	-0.032	13.2	-66.4	6.41	78.0	65.5	-63.1	0.06
11	8.9	0.82	0.007	11.5	-13.7	2.07	25.6	71.7	-29.0	-0.04
12	8.6	1.50	0.007	11.6	-24.5	3.12	37.0	59.7	-47.6	-0.07

Units: $B_1 > \sigma_{B_1}$, γ , Max, and Min in deg

TABLE 2. CHATEAUROUX, SUPPLEMENTAL DATA OF MEAN COEFFICIENTS

Month	Windspeed (m/sec)						
	1 km		2 km		10 km		
	\bar{A}_0	\bar{A}_2	\bar{C}_0	\bar{C}_2	\bar{E}_0	\bar{E}_2	\bar{E}_3
1	8.05	-0.22	9.38	-0.68	15.47	-0.07	-0.008
2	7.74	-0.22	9.14	-0.56	15.49	-0.04	0.007
3	6.84	-0.24	7.93	-0.48	14.80	-0.01	-0.005
4	6.58	-0.18	7.68	-0.38	13.98	-0.01	0.004
5	5.61	-0.23	6.54	-0.32	13.95	0.02	0.002
6	5.15	-0.21	6.00	-0.29	11.70	0.004	0.012
7	5.58	-0.25	6.52	-0.31	13.75	0.02	0.015
8	5.82	-0.20	6.80	-0.30	14.83	0.01	0.012
9	5.63	-0.23	6.57	-0.35	12.90	-0.003	0.013
10	6.48	-0.28	7.56	-0.53	13.00	0.03	0.025
11	7.64	-0.22	9.12	-0.60	15.89	0.02	0.015
12	8.31	-0.24	9.79	-0.68	15.17	0.002	0.008
	Wind Direction (deg)						
	\bar{B}_0	\bar{B}_2	\bar{D}_0	\bar{D}_2	\bar{F}_0	\bar{F}_2	\bar{F}_3
	1	163	-0.69	176	-4.5	325	-0.42
2	177	-0.67	196	-3.2	288	-0.77	0.29
3	164	-0.43	292	-2.9	291	-0.39	0.21
4	307	-0.11	294	-1.4	284	-0.42	0.13
5	339	0.40	328	-1.4	283	-0.48	0.20
6	318	0.25	281	-1.2	276	-0.45	0.13
7	229	0.26	272	-0.5	274	-0.33	0.06
8	254	0.17	269	-1.1	277	-0.35	0.15
9	188	-0.29	200	-2.8	252	-0.27	0.12
10	178	-0.46	186	-2.8	301	-0.29	0.16
11	179	0.08	195	-3.1	280	-0.69	0.24
12	166	-0.52	180	-3.4	312	-0.66	0.19

trend displays an average of 40 degrees in winter. Attention is also called to the maximum or minimum slopes which express larger veering or backing.

The last column in the lower part of Table 1 displays the correlation between windspeed and direction slope. It is noticeable that virtually no linear correlation existed. This fact can be interpreted that the directional turn from surface to 1 km is by and large independent from the speed profile. In different terms it can be stated that the mean directional profile has the highest probability of being associated with any speed profile of any threshold. This simplifies the task for establishing design criteria.

b. The 2-km Profiles

It is of some interest how the wind profile behaves in the first 2-km profiles. The parameterization was, therefore, extended to include the first 2-km layer.

The wind profile as a function of altitude can be written

$$V(h) = C_0 + C_1\phi_{1h} + C_2\phi_{2h} \quad (8a)$$

and

$$\theta(h) = D_0 + D_1\phi_{1h} + D_2\phi_{2h} \quad (8b)$$

where again ϕ_{ij} denotes five points orthogonal Tchebycheff polynomials at 500 m intervals. The parameterized form becomes

$$V_h = (C_1 - \bar{C}_1) (c_0 + \phi_{1h} + c_2\phi_{2h}) + \bar{V}_h \quad (9a)$$

and

$$\theta_h = (D_1 - \bar{D}_1) (d_0 + \phi_{1h} + d_2\phi_{2h}) + \bar{\theta}_h \quad (9b)$$

Again, the mean profiles \bar{V}_h and $\bar{\theta}_h$ can be obtained by substituting the means of the coefficients into Equations (8a) and (8b).

The constants have been obtained from

$$c_0 = r_{C_0 C_1} \cdot \frac{\sigma_{C_0}}{\sigma_{C_1}} \quad (10a)$$

$$c_2 = r_{C_2 C_1} \cdot \frac{\sigma_{C_2}}{\sigma_{C_1}} \quad (10b)$$

$$d_0 = r_{D_0 D_1} \cdot \frac{\sigma_{D_0}}{\sigma_{D_1}} \quad (10c)$$

$$d_2 = r_{D_2 D_1} \cdot \frac{\sigma_{D_2}}{\sigma_{D_1}} \quad (10d)$$

The parameters for this 2-km wind profile set are exhibited in Table 3 by month. Again, Chateauroux was the pilot station for the midlatitude conditions.

We conclude from Table 3 that the seasonal variation for the C_1 coefficient is very weak but runs parallel to the 1-km profile. The range of the average slope is almost the same and it appears that the mean profiles would be almost the same as the 1-km profiles except that the profile is stretched through a 2-km altitude layer. This is factually the case for the mean profiles but the 90 to 99 percent cannot readily be evaluated by this first perusal.

One should remember that some dampening of the slope occurs for the 2-km layer, as not all profiles with extreme slope in the 1-km layer continue this extreme extension into the next km layer. If this were the case one could merely double the slope of the 1-km set and readily expand into the second km layer.

Although the average slope of the directional profile discerns veering with altitude, the maximum-minimum values indicate almost as much backing in the extreme case as veering.

The relationship between the directional and speed slope is virtually negligible again. This means that for practical purposes the average directional turn is the most likely to be associated with any of the windspeed profiles. Again, this makes computational efforts for system analysis easier because only one directional profile needs to be given.

TABLE 3. CHATEAUROUX, SURFACE TO 2-km WIND PROFILE DATA
(1956-1964)

Month	Profile Parameters				Weibull			C_1		N
	\bar{C}_1	c_0	c_2	σ_{C_1}	γ	β	θ	Max	Min	
1	1.54	2.64	-0.10	1.40	-0.64	1.60	2.43	8.1	-1.7	360
2	1.57	2.84	-0.10	1.25	-1.20	2.34	3.12	5.5	-1.8	383
3	1.25	2.07	-0.002	1.16	-1.22	2.26	2.78	5.7	-1.8	420
4	1.21	1.92	-0.06	1.08	-1.28	2.46	2.81	4.3	-1.8	401
5	1.06	1.50	0.10	1.15	-1.39	2.26	2.76	4.9	-2.1	418
6	0.97	1.92	0.02	1.04	-0.85	1.82	2.05	5.0	-2.4	335
7	1.05	1.79	0.004	1.14	-1.90	2.80	3.32	4.3	-1.7	368
8	1.08	1.56	0.03	1.01	-1.13	2.32	2.49	5.1	-1.6	423
9	1.07	1.71	0.07	1.18	-1.13	1.94	2.48	5.2	-1.9	410
10	1.29	2.48	-0.07	1.14	-0.58	1.68	2.09	5.5	-1.5	419
11	1.62	3.22	-0.19	1.34	-0.66	1.76	2.57	7.2	-2.0	345
12	1.66	2.69	-0.14	1.51	-1.00	1.83	2.99	8.5	-1.8	419
Units: C_1 , σ_{C_1} , γ , Max, Min, and V_h in m/sec										
	D_1	d_0	d_2	σ_{D_1}	γ	β	θ	D_1		$r_{C_1 D_1}$
								Max	Min	
1	9.45	2.19	-0.11	16.5	-49.9	4.05	65.5	56.2	-43.6	0.11
2	10.57	1.12	-0.12	14.3	-40.2	3.98	56.0	56.5	-41.0	0.03
3	6.55	-2.87	-0.04	14.6	-46.5	4.10	58.6	57.3	-43.5	0.03
4	4.99	-1.18	-0.04	15.0	-64.5	5.32	75.5	59.5	-49.7	0.05
5	6.96	0.16	0.01	18.5	-44.3	3.62	57.3	63.9	-47.9	0.02
6	6.17	-1.60	0.01	20.7	-36.9	2.20	48.7	67.5	-47.6	-0.01
7	4.27	-1.34	0.01	18.8	-61.9	3.95	73.1	62.6	-54.9	-0.03
8	5.21	-1.64	-0.02	16.4	-56.6	4.24	67.9	56.3	-46.2	-0.04
9	5.38	0.27	-0.05	19.2	-63.3	4.01	75.7	63.5	-50.0	0.02
10	5.97	1.40	-0.07	15.9	-95.4	7.54	108.0	60.7	-47.8	-0.01
11	9.63	1.64	-0.16	13.1	-36.1	3.92	50.6	61.4	-45.0	-0.06
12	8.76	2.12	-0.09	14.3	-81.8	7.48	96.4	48.5	-44.4	-0.03
Units: D_1 , σ_{D_1} , γ , Max, and Min in deg										

c. The 10-km Profiles

Similar to the parameterization of the lower layer profiles, the entire range from surface to 10 km up has been parameterized. It may be noted that by the limitation to the first 10 km the wind profile is truncated before reaching its maximum level (jetstream) for most climatic regions. Consequently a polynomial representation is still applicable

$$V(h) = E_0 + E_1\phi_{1h} + E_2\phi_{2h} + E_3\phi_{3h} \quad (11a)$$

and

$$\theta(h) = F_0 + F_1\phi_{1h} + F_2\phi_{2h} + F_3\phi_{3h} \quad (11b)$$

The ϕ_{ij} denotes now an 11-point polynomial at 1-km intervals (Appendix). The parameterized form can be written

$$V_h = (E_1 - \bar{E}_1) (e_0 + \phi_{1h} + e_2\phi_{2h} + e_3\phi_{3h}) + \bar{V}_h \quad (12a)$$

and

$$\theta_h = (F_1 - \bar{F}_1) (f_0 + \phi_{1h} + f_2\phi_{2h} + f_3\phi_{3h}) + \bar{\theta}_h \quad (12b)$$

The mean profiles \bar{V}_h and $\bar{\theta}_h$ are treated the same as previously. The constants again can be obtained by linear regression

$$e_0 = r_{E_0E_1} \cdot \frac{\sigma_{E_0}}{\sigma_{E_1}} \quad (13a)$$

$$e_2 = r_{E_2E_1} \cdot \frac{\sigma_{E_2}}{\sigma_{E_1}} \quad (13b)$$

$$e_3 = r_{E_3E_1} \cdot \frac{\sigma_{E_3}}{\sigma_{E_1}} \quad (13c)$$

$$f_0 = r_{F_0 F_1} \cdot \frac{\sigma_{F_0}}{\sigma_{F_1}} \quad (13d)$$

$$f_2 = r_{F_2 F_1} \cdot \frac{\sigma_{F_2}}{\sigma_{F_1}} \quad (13e)$$

$$f_3 = r_{F_3 F_1} \cdot \frac{\sigma_{F_3}}{\sigma_{F_1}} \quad (13f)$$

Table 4 lists the parameters for the same pilot station by month. Inspection of Table 4 reveals that the contribution of the e_2 and e_3 coefficients is less than 2 percent. Thus they could be neglected. The major factor for the windspeed profile is the linear slope (i.e., E_1).

Although the contribution of the higher order terms is larger for the wind direction, only the second-order term displays a share of 15 percent and should be kept. The dominant term is the slope (F_1).

In contrast to the previous profile sets, the mean \bar{E}_1 and the major coefficient e_0 for the wind profile appear with little seasonal variations. This trait is also valid for the wind direction profile. Although this fact may be a surprise at the first moment, one must remember that the wind profile in the midlatitude for the selected pilot station keeps very constant throughout the year [2]. This stability is reflected in the absence of a seasonal trend in the coefficients of the windspeed profile, and is even discerned in the distribution and the maximum or minimum values. Only the wind direction profile deviates with displaying of seasonal variation in the distribution and the maximum or minimum.

Table 2 lists the mean coefficients.

d. Profile Interrelation Between 1-, 2- and 10-km Sets

The question may arise whether the individual profile sets are redundant and the essential information could have been reduced. The intercorrelations between the characteristic coefficients have been expressed by the linear correlation coefficient and are displayed in Table 5. A further topic of interest was the linear correlation with the surface windspeed. These results are exhibited in Table 5.

TABLE 4. CHATEAUROUX, SURFACE TO 10-km WIND PROFILE DATA (1956-1964)

Month	Profile Parameters					Weibull			E_1		N
	\bar{E}_0	e_0	e_2	e_3	σ_{E_1}	γ	β	θ	Max	Min	
1	1.80	4.41	-0.01	-0.03	1.40	-0.60	1.77	2.77	6.3	-0.8	232
2	1.84	3.74	0.02	-0.03	1.36	-0.21	1.53	2.27	6.8	-0.9	298
3	1.92	3.90	0.03	-0.02	1.45	-0.72	1.89	2.96	7.4	-1.3	319
4	1.75	3.96	0.05	-0.02	1.36	-0.13	1.40	2.06	8.6	-0.7	332
5	2.03	3.99	0.03	-0.02	1.37	-0.56	1.98	2.92	6.5	-0.8	365
6	1.57	3.92	0.05	-0.01	1.21	-0.44	1.71	2.26	5.3	-1.5	296
7	2.00	4.20	0.04	-0.01	1.31	-0.74	2.21	3.09	6.8	-0.6	313
8	2.13	3.94	0.05	-0.01	1.17	-0.50	2.40	2.98	5.4	-0.9	368
9	1.72	4.32	0.03	-0.02	1.33	-0.31	1.70	2.27	6.3	-0.5	338
10	1.64	3.95	0.05	-0.02	1.34	-0.32	1.49	2.17	8.4	-1.0	335
11	2.01	3.84	0.04	-0.02	1.44	-0.98	2.25	3.45	6.6	-1.1	234
12	1.76	3.91	0.04	-0.02	1.38	-0.44	1.63	2.46	8.4	-0.6	265
Units: C_1 , σ_{C_1} , γ , Max, Min, and V_h in m/sec											
	F_1	f_0	f_2	f_3	σ_{D_1}	γ	β	θ	F_1		$r_{E_1 F_1}$
									Max	Min	
1	0.64	-2.94	-0.13	-0.01	9.71	-39.4	4.69	43.7	24.3	-29.6	0.19
2	3.10	-2.41	-0.11	0.05	9.19	-14.9	2.06	20.4	39.6	-23.9	0.07
3	0.81	-2.83	-0.10	0.03	9.48	-23.4	2.76	27.2	36.6	-29.7	0.03
4	1.46	-1.74	-0.12	-0.01	8.18	-15.9	2.25	19.6	46.4	-23.6	-0.02
5	1.18	-2.50	-0.15	0.04	10.74	-20.9	2.19	25.0	59.9	-25.9	-0.04
6	1.26	-1.02	-0.13	0.00	9.93	-24.7	2.83	29.1	44.5	-29.9	-0.11
7	2.22	-1.97	-0.14	0.04	9.39	-14.2	1.81	18.5	43.5	-20.5	-0.04
8	0.75	-1.05	-0.17	0.01	7.17	-23.8	3.83	27.2	34.1	-21.1	0.07
9	1.75	-3.03	-0.01	-0.02	9.13	-30.9	4.02	36.0	28.4	-30.4	-0.07
10	1.05	-2.30	-0.04	-0.02	10.24	-41.2	4.70	46.2	29.3	-30.0	0.05
11	2.94	-1.58	-0.09	0.02	7.74	-55.9	9.10	62.1	26.1	-34.3	0.02
12	2.12	-2.08	-0.10	0.02	9.77	-41.5	5.13	47.5	34.5	-29.3	0.16
Units: D_1 , σ_D , γ , Max, and Min in deg											

TABLE 5. INTERCORRELATION BETWEEN CHARACTERISTIC COEFFICIENTS AND CORRELATION WITH SURFACE WINDSPEED

Month	A ₁ Versus				B ₁ Versus				C ₁ Versus			D ₁ Versus			E ₁	F ₁	
	V _{sfc}	C ₁	D ₁	E ₁	F ₁	V _{sfc}	C ₁	D ₁	E ₁	F ₁	V _{sfc}	E ₁	F ₁	V _{sfc}	E ₁	F ₁	
1	0.30	0.69	0.04	0.09	-0.00	-0.07	0.76	0.04	0.17	0.36	0.23	0.23	0.09	0.01	0.18	0.60	0.04
2	0.22	0.67	-0.03	-0.02	-0.07	-0.05	0.76	0.07	-0.07	0.27	0.09	0.09	-0.04	-0.03	0.03	0.29	-0.04
3	0.05	0.033	0.13	0.09	0.07	-0.02	0.69	-0.03	-0.00	0.19	0.10	0.18	0.02	0.005	0.07	0.41	-0.01
4	-0.04	0.62	0.11	0.12	-0.06	0.01	0.66	0.01	-0.03	0.25	-0.04	0.19	-0.02	0.07	-0.00	0.29	-0.09
5	-0.11	0.48	0.03	0.07	-0.02	-0.13	0.61	0.05	-0.12	0.26	-0.10	0.21	0.01	-0.08	-0.16	0.53	0.005
6	-0.02	0.50	0.02	0.04	-0.01	-0.15	0.71	0.04	-0.06	0.23	0.03	0.14	-0.05	-0.14	-0.14	0.46	-0.11
7	-0.01	0.61	0.05	0.21	-0.05	-0.07	0.65	0.05	0.11	0.19	-0.04	0.31	-0.07	0.03	-0.003	0.46	0.04
8	-0.13	0.49	0.002	0.02	0.00	-0.09	0.56	-0.02	0.04	0.04	-0.08	0.25	0.07	0.002	0.001	0.44	-0.02
9	0.02	0.51	0.08	0.10	-0.01	-0.06	0.52	-0.02	-0.07	0.14	-0.02	0.29	0.05	0.03	0.007	0.39	-0.002
10	0.14	0.67	-0.00	0.09	0.06	-0.06	0.71	-0.05	0.12	0.09	0.22	0.21	0.10	-0.000	0.12	0.26	0.007
11	0.27	0.75	-0.02	0.02	-0.09	-0.17	0.69	-0.07	0.01	0.22	0.41	0.14	-0.07	-0.03	-0.01	0.37	-0.01
12	0.27	0.75	0.04	0.05	-0.10	-0.07	0.74	-0.09	0.12	0.19	0.27	0.11	-0.07	0.04	0.14	0.38	-0.001

It should be pointed out immediately that some statistically significant correlation exists only from October through February between surface windspeed and the 1- and 2-km windspeed profiles. This correlation is very low, however, and for practical purposes negligible. In addition, it may be spurious [4].

The other correlations behave as expected. Strong association prevails between the 1- and 2-km sets, where A_1 with C_1 and B_1 with D_1 are highly correlated. These correlations are mostly spurious, however. Sufficient differences in the actual probability profiles (Paragraph 3) justify the existence of separate sets for the surface to 1- and surface to 2-km layer.

The only other stronger correlation is displayed between the directional profiles of the 2- and 10-km sets (D_1 versus F_1). This correlation merely reflects the consistency of the wind structure at midlatitude determined by the general circulation, while the windspeed profile in the lower 2-km layer is not a real indicator of the total speed profile structure up to 10 km.

3. Recomputation of the Profiles and Profiles of Selected Probability

The information compiled in the previous sections in conjunction with the pertinent equations was utilized to compute special windspeed profiles of interest (Table 6).

This analysis was performed for all months (only January and July are given here). Six levels of probability were selected corresponding to certain typical thresholds for the Gaussian distribution. As previously mentioned, the coefficients are not Gaussian distributed. The first obvious evidence is the disagreement of the 50 percent and mean profile, although for some altitude levels the differences are not very large.

The 68.3-percent value was chosen because this is the amount one can find in a range of $\pm \sigma$ for a Gaussian distribution. Between $\pm 2\sigma$, one would expect 95.4 percent of the observations. Because the profiles have mathematically been derived, the empirical fluctuations have been removed by the Weibull model.

In addition to the previous levels of probabilities, the thresholds 84.1 and 97.7 percent have been selected as in the Gaussian model; these levels correspond to 1σ and 2σ . The 99-percent profile rounds up the sets. It represents profiles exceeded in only 1 percent of the cases and serves as an indicator of extreme conditions.

TABLE 6. SPECIAL WINDSPEED AND DIRECTION PROFILES

		Windspeed (m/sec)														Wind Direction deg	
		January							July								
		50%	Mean	68.3	84.1	95.4	97.7	99.0%	50%	Mean	68.8	84.1	95.4	97.7	99.0%		
1 km		4.31	4.40	4.73	5.32	5.93	6.25	6.60	3.21	3.20	3.19	3.16	3.12	3.10	3.07	161	293
sfc		6.43	6.66	7.51	8.79	10.57	11.40	12.29	4.67	4.89	5.19	5.88	6.95	7.49	8.09	153	295
250 m		8.12	8.48	9.84	11.89	14.74	16.07	17.49	5.65	6.08	6.68	8.03	10.13	11.18	12.37	164	298
500 m		9.38	9.88	11.73	14.53	18.44	20.26	22.21	6.16	6.78	7.65	9.61	12.66	14.19	15.90	174	302
1000 m		10.20	10.84	13.19	16.73	21.67	23.97	26.44	6.19	6.98	8.10	10.62	14.53	16.50	18.70	182	306
2 km																	
sfc		4.84	4.94	5.15	5.54	6.13	6.41	6.73	3.80	3.79	3.69	3.56	3.39	3.32	3.24	148	263
250		6.46	6.73	7.24	8.23	9.71	10.43	11.22	4.77	4.70	4.94	5.13	5.38	5.49	5.60	159	266
500		8.09	8.52	9.34	10.92	13.29	14.44	15.72	5.74	5.77	6.19	6.70	7.36	7.66	7.96	171	269
750		9.20	9.77	10.85	12.96	16.10	17.63	19.32	6.46	6.51	7.20	8.03	9.11	9.59	10.09	179	271
1000		10.04	10.74	12.07	14.66	18.52	20.41	22.49	7.07	7.13	8.09	9.24	10.73	11.40	12.09	185	273
1250		10.49	11.31	12.86	15.87	20.38	22.57	25.00	7.48	7.57	8.80	10.26	12.18	13.03	13.92	188	275
1500		10.67	11.60	13.35	16.76	21.84	24.32	27.06	7.78	7.88	9.38	11.17	13.51	14.55	15.63	190	277
1750		10.34	11.35	13.27	16.99	22.54	25.25	28.25	7.83	7.95	9.72	11.83	14.59	15.82	17.10	188	279
2000 m		10.00	11.10	13.18	17.21	23.24	26.18	29.43	7.87	8.02	10.06	12.50	15.68	17.10	18.58	186	280
10 km																	
sfc		5.61	5.64	5.72	5.84	6.03	6.12	6.21	3.63	3.64	3.67	3.73	3.80	3.84	3.88	131	256
1		7.77	7.88	8.14	8.61	9.28	9.60	9.95	5.75	5.80	6.07	6.46	6.98	7.22	7.48	319	263
2		9.78	9.94	10.33	11.00	11.98	12.45	12.96	7.96	8.07	8.59	9.33	10.34	10.81	11.30	328	269
3		11.70	12.09	12.99	14.58	16.88	17.98	19.17	9.77	9.98	10.94	12.31	14.18	15.04	15.96	331	273
4		13.51	14.17	15.73	18.48	22.46	24.36	26.44	11.46	11.78	13.28	15.42	18.34	19.68	21.11	331	276
5		15.19	16.16	18.44	22.46	28.28	31.07	34.11	13.10	13.55	15.66	18.66	22.76	24.65	26.66	330	277
6		16.73	18.01	21.00	26.28	33.92	37.57	41.55	14.77	15.36	18.12	22.04	27.41	29.88	32.51	327	278
7		18.13	19.68	23.30	29.67	38.91	43.32	48.14	16.55	17.28	20.71	25.57	32.24	35.30	38.57	325	279
8		19.39	21.13	25.21	32.40	42.81	47.79	53.22	18.52	19.39	23.47	29.26	37.20	40.84	44.73	324	280
9		20.49	22.32	26.63	34.21	45.20	50.45	56.18	20.76	21.77	26.46	33.12	42.24	46.43	50.90	324	281
10 km		21.42	23.22	27.43	34.86	45.61	50.75	56.36	23.36	24.48	29.71	37.14	47.32	51.99	56.98	327	282

Figures 1 through 4 illustrate the differences between the profile sets of 1, 2, and 10 km. Immediately the question arises, why the profiles for the same probability differ in the corresponding altitudes.

To elucidate this problem one must go back to the mathematical formulation of the windspeed profiles. The profile characteristic has been derived as an integral effect of the total layer and, e.g., the 99-percent value must be considered as an average condition, combining the typical features of profiles towards the extreme side with the vertical structure and correlation of all levels. The profiles do not constitute the "envelope" of the 1-percent exceedance threshold at all levels and should not be interpreted as such. The profile is valid, however, if a 1 percent exceedance for surface to top altitude is sought. It is, therefore, necessary to pinpoint the exact altitude range for which profiles are derived for optimal effects. The tolerance of deviations is approximately 15 to 20 percent of the altitude range. This means that the 10-km profiles could be employed when 8-km profiles are needed. For optimal effect, however, a 7-km set would have to be derived when the ranges of interest were surface to 7 km.

A typical example of the "vertical integration" effect is illustrated for July at the surface. Table 5 exhibits that the surface windspeed diminishes as the probability threshold rises. This is completely contradictory to the cumulative distribution of the windspeed at the surface, but it is consistent with the vertical profile relationship and correlation where evidently higher windspeeds aloft are not running parallel with higher windspeed at the surface.

4. Summary and Conclusions

The parameterization of three sets of wind profiles for different ranges of the altitude layer have been discussed in detail. Tables have been compiled with the results for one pilot station of the midlatitudes, Chateauroux (France). From the established mathematical models, Equations (6), (9), and (12), windspeed and direction profiles for six levels of probability have been derived. With the given procedure and published set of coefficients, other probability levels of interest to the engineer can be readily computed.

This study was limited to a pilot station in the midlatitude because it may provide some approximation of global average conditions. To obtain a true average the results should be expanded to other stations from different climatic regimes and a combination attempted. It should also be stressed that a combination beyond seasons leads to multimodal mixtures of the frequency distribution of coefficients.

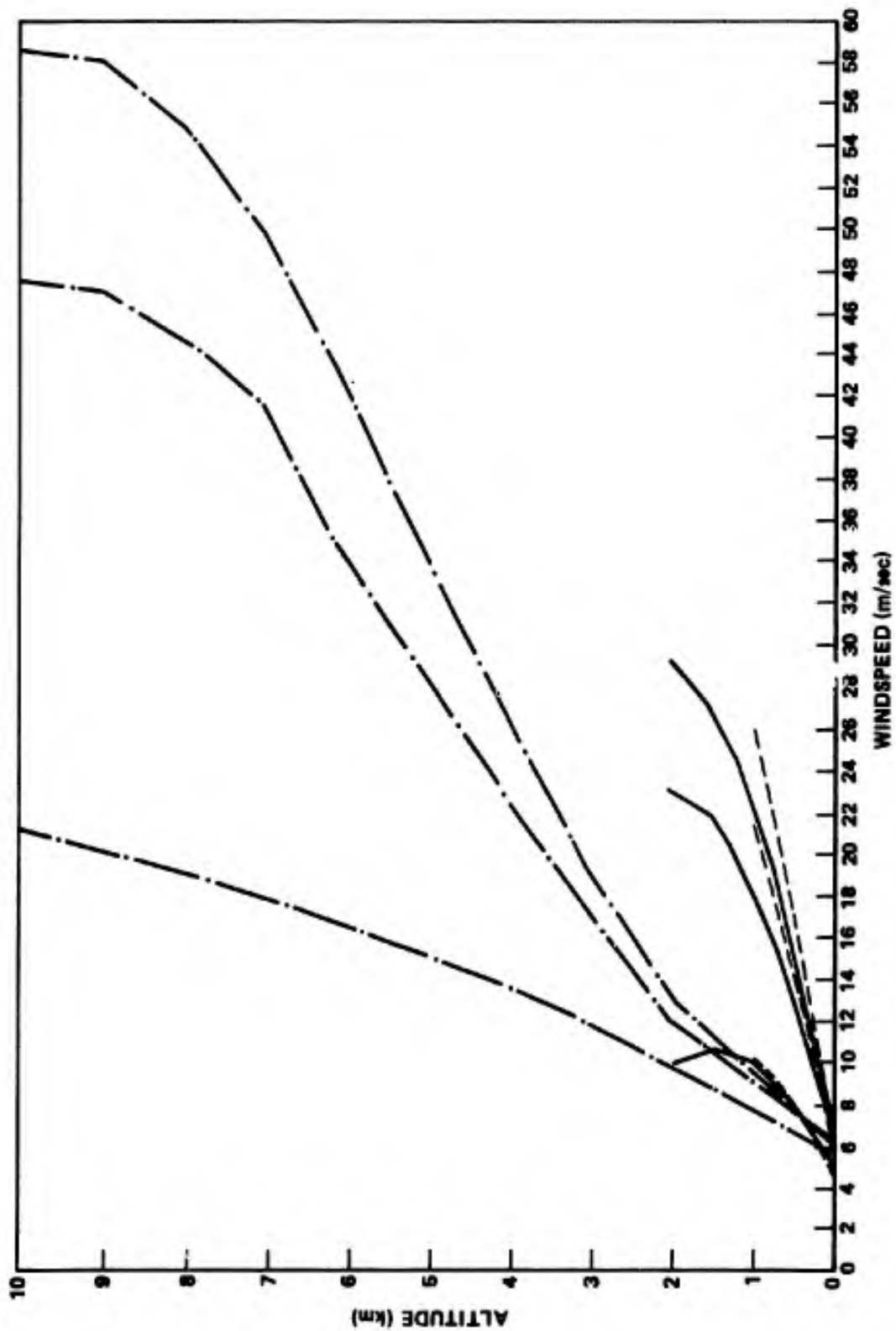


Figure 1. January, Chateauroux
 Mean, 95- and 99-percent wind speed profiles for surface to 1, 2, and 10 km.

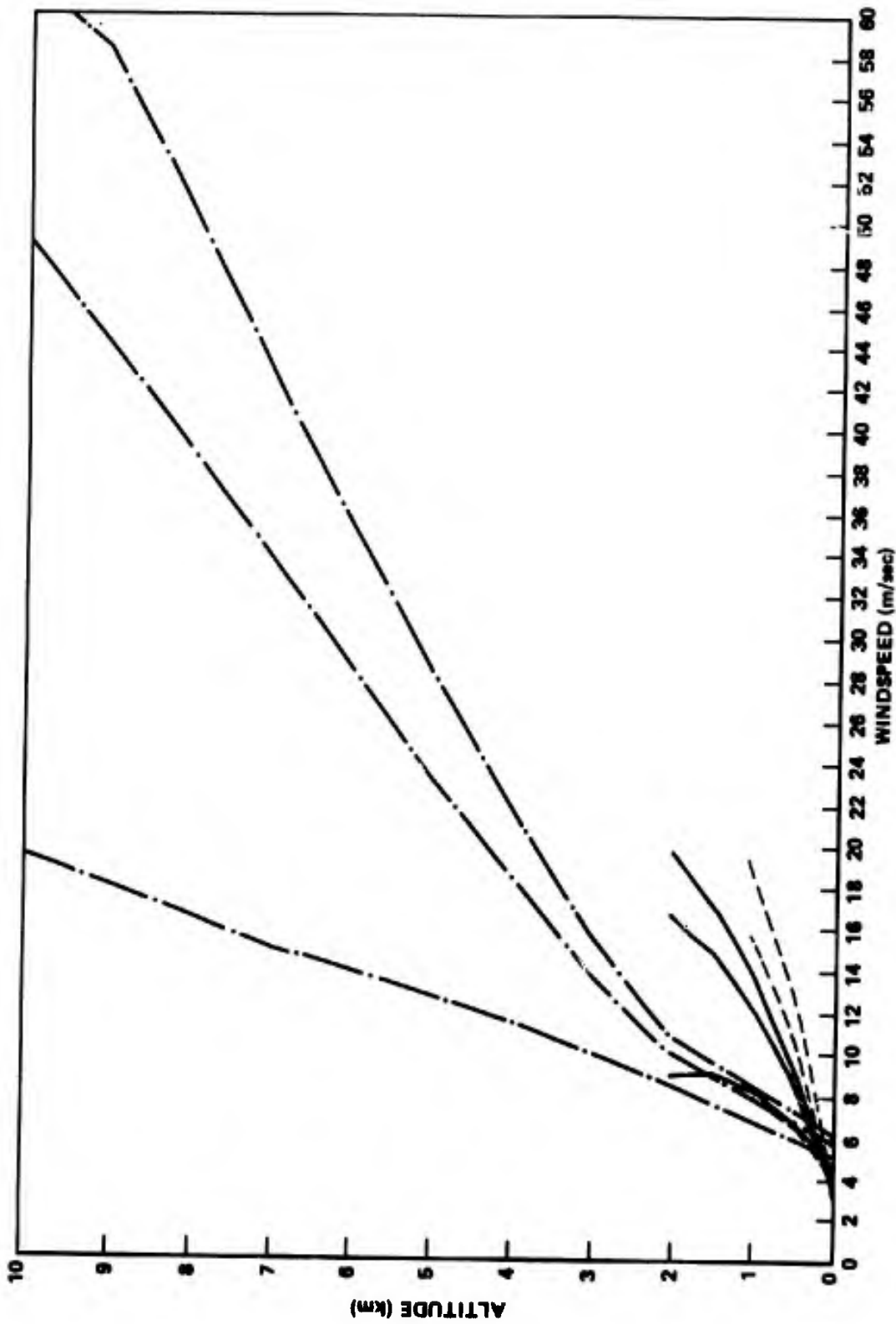


Figure 2. April, Chateauroux.
 Mean, 95- and 99-percent wind speed profiles for surface to 1, 2, and 10 km.

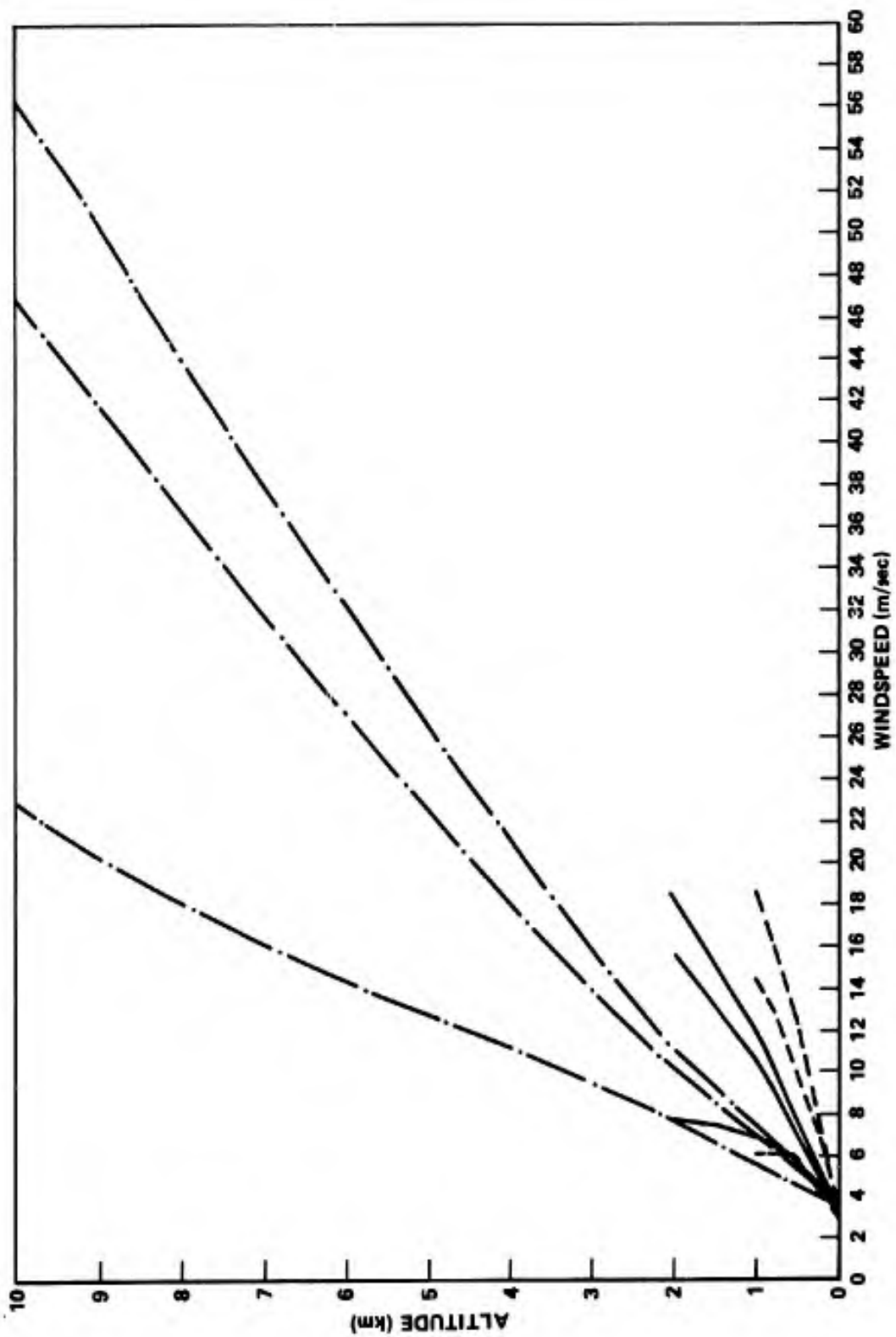


Figure 3. July, Chateauroux.
 Mean, 95- and 99-percent wind speed profiles for surface to 1, 2, and 10 km.

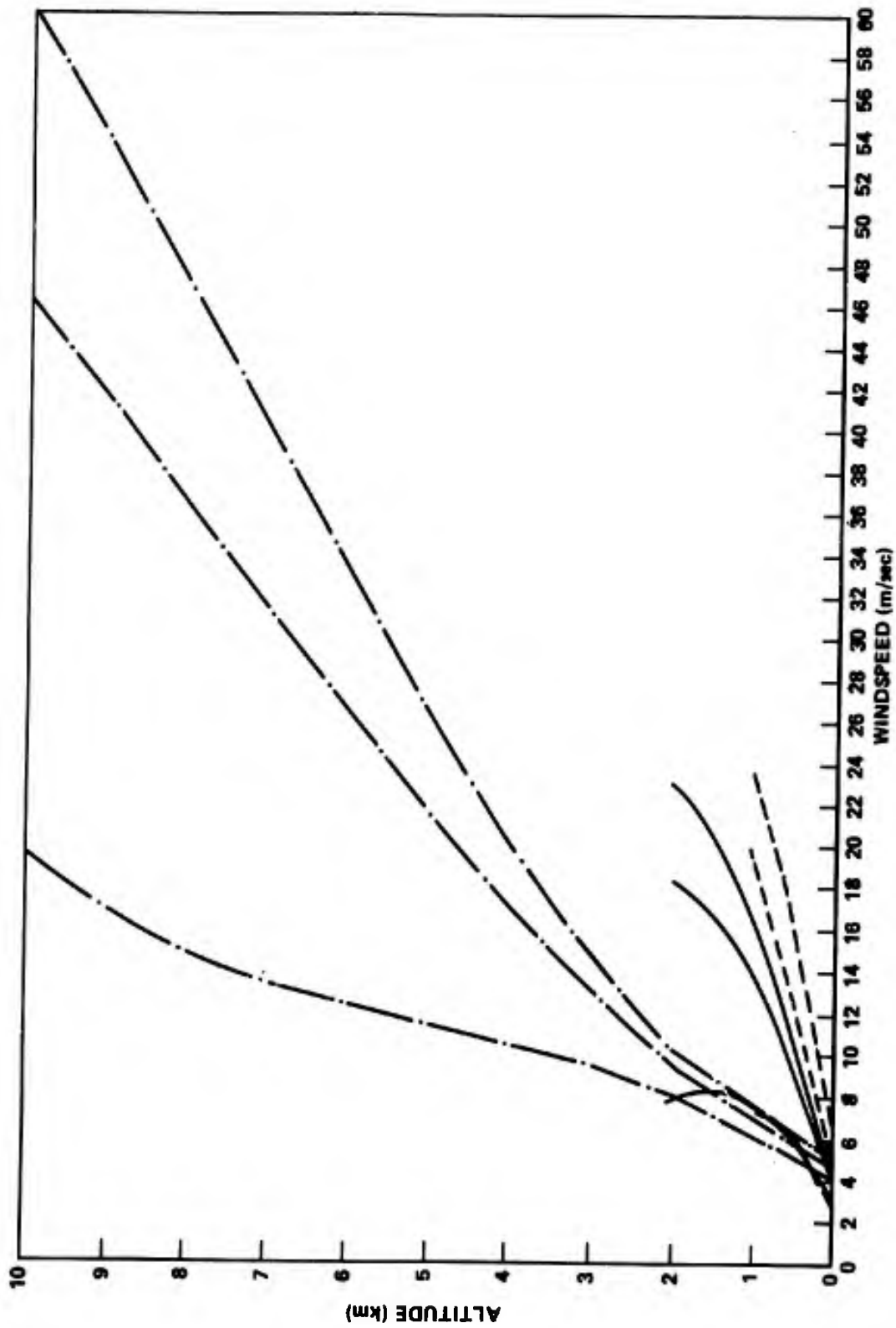


Figure 4. October, Chateauroux.
 Mean, 95- and 99-percent wind speed profiles for surface to 1, 2, and 10 km.

It should also be noted that the results provide typical smooth profiles as they would be attained by elimination of all small scale turbulence and gustiness. If the windshear is a critical factor, then smooth profiles would also not reflect the true probability level of small increment windshears [9]. In a forthcoming report attempts will be discussed to generate some data where the turbulence and gust factors with time and space variations are superimposed upon the smooth profile.

It is evident that this short report leaves some questions unanswered. It would be especially desirable to include some other stations and a special surface to 16-km wind profile set. Again, the choice is between making this report available with some limitations or to wait until this additional information is available. The author selected the first alternative.

Appendix. TCHEBYCHEFF POLYNOMIALS

Tchebycheff polynomials utilized:

5-point polynomials (surface to 1 km at 250 m intervals and surface to 2 km at 800 m intervals)

first order -2, -1, 0, 1, 2, $\sum\phi^2 = 10$

second order 2, -1, -2, -1, 2, $\sum\phi^2 = 14$
(the first value is associated with the surface wind)

11-point polynomials (surface to 10 km at 1 km intervals)

first order -5, -4, -3, -2, -1, 0, 1, 2, 3, 4, 5, $\sum\phi^2 = 110$

second order 15, 6, -1, -6, -9, -10, -9, -6, -1, 6, 15,
 $\sum\phi^2 = 858$

third order -30, 6, 22, 23, 14, 0, -14, -23, -22, -6, 30,
 $\sum\phi^2 = 4290$.

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