NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE

No. 1315

FREE-FALLS AND PARACHUTE DESCENTS IN THE STANDARD ATMOSPHERE

By A. P. Webster

Bureau of Medicine and Surgery, Navy Department

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ERRATA NO. 1

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In figure 5 an error has been found in the label of the parameter shown at the top right. This parameter should be $\frac{1}{k} = \frac{1}{\sqrt{2W/C_DS}}$. The author of this paper suggests that, for maximum accuracy in computations, the relation $t_e = \frac{t_s}{k}$ be used with the values of t_s given in table I as a substitute for figure 5.

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By A. P. Webster*

SUMMARY

A detailed table of the standard equilibrium velocity and standard equilibrium time is presented for bodies falling in the standard atmosphere. This table gives the velocity at various altitudes and the time of fall from sea level to -4000 feet, and from 80,000 feet to sea level. In addition to this standard table, there are given short tables and charts of an open-parachute descent and free-falls; the terminal velocity at sea level, and the variation of the weight-to-drag ratio $(2W/C_DS)^{1/2}$ for various weight jumpers from 90 to 300 pounds free-falling and with parachute canopies from 20 to 30 feet in open-parachute descent; and estimations of drag coefficients of silk and nylon parachutes.

The table of standard equilibrium velocities and standard equilibrium times may be used directly for open-parachute descents, given the weight of the jumper, the diameter of the parachute, and the drag coefficient. For free-falls starting from horizontal flight, approximately 14 seconds must be added to the equilibrium time given in the table to obtain the total time to sea level.

INTRODUCTION

With the advent of high-altitude flying, hazards not previously encountered in the event of bail-out become of extreme importance. Without oxygen, consciousness is lost very quickly. The extreme cold necessitates the wearing of heavy flying suits which not only encumber the jumper but increase his weight. The duration of the descent subjects the jumper to anoxia and cold. A few questions which naturally arise are:

1. Can a man safely descend from high altitudes, say 40,000 feet, without oxygen equipment?

2. How long will it take to free-fall to an altitude at which the air is dense enough for survival without the use of oxygen equipment?

*Commander, HS, USNR, Research Division, Bureau of Medicine and Surgery, Navy Department.

3. Are the times of free-fall from high altitudes to low altitudes short enough to prevent ill effects from anoxia and cold when no special gear is worn?

4. What is the duration of open-parachute descents from high altitudes?

5. What are the rates of free-falls and parachute descents?

6. After free-falling 15,000 or 20,000 feet, is the velocity of fall so great as to cause tearing of the parachute or injury to the jumper when the parachute is opened?

7. How does the weight of the jumper, diameter of the parachute, added weight of high-altitude suits and equipment, affect the rate of fall at various altitudes, the time between altitudes, and the terminal velocity at sea level?

In order to have a background for answering some of the foregoing questions, altitude, velocity, and time relationships for free-falls and open-parachute descents have been obtained, and values tabulated for the situation in which the weight of the jumper equals the drag in the standard atmosphere.

SYMBOLS

D drag, pounds

W weight of jumper, pounds

S plan area of parachute or jumper, square feet

ρ mass density of air, standard atmosphere, slugs per cubic foot

C_D drag coefficient

V observed vertical velocity, feet per second

V_e equilibrium velocity, feet per second $(D = W)$

V_S standard equilibrium velocity, feet per second $(D = W,\ k = 1)$

$k = (2W/C_D S)^{1/2}$

h altitude, standard atmosphere, feet

t observed time of fall between altitudes, seconds

t_e equilibrium time between altitudes, seconds (D = W)

t_S standard equilibrium time, seconds (D = W, k = 1)

ρ_o standard density at sea level, 0.002378 slugs per cubic foot

V_T terminal equilibrium velocity at sea level, feet per second (D = W)

p pressure, millimeters of mercury

d diameter of parachute canopy, feet

Some useful expressions:

1. $V_e = V_T \left(\frac{\rho_o}{\rho}\right)^{1/2}$

2. $V_S = V_{So} \left(\frac{\rho_o}{\rho}\right)^{1/2}$ where V_{So} = standard equilibrium velocity at sea level, 20.51 feet per second

3. $\frac{V_e}{V_S} = \frac{V_T}{V_{So}}$

4. $C_D = \frac{2W}{\rho_o S V_T^2}$

5. $C_D = \frac{2W}{S}\left(\frac{t_e}{t_S}\right)^2$

6. $\frac{C_D'}{C_D} = \left(\frac{t_e}{t_e'}\right)^2$ when $S = S'$ and $W = W'$

7. $d = \left(\frac{8W}{\pi C_D \rho_o V_T^2}\right)^{1/2}$

8. $d = \left(\frac{8W}{\pi C_D}\right)^{1/2}$ for $k = 1$

9. $t_e = t_S \frac{V_{So}}{V_T}$

10. $\frac{t_e}{t_e'} = \frac{V_e'}{V_e}$

The following expressions are approximate, but quite accurate for ordinary purposes:

11. $m = 0.00003254$ per foot, altitude rate of decline of mass density

12. $\rho = \rho_o e^{-1/2mh}$

13. $V_e = V_T \, e^{1/2mh}$, $V_T = kV_{So}$

14. $V_e = kV_{So} \, e^{1/2mh}$

15. $V_e = \dfrac{kV_{So}}{1/2mkV_{So}t_e + e^{-1/2mh_1}}$, h_1 = altitude at jump

16. $V_S = V_{So} \, e^{1/2mh}$

17. $h = \dfrac{1}{m} \ln \dfrac{\rho_o}{\rho}$

18. $h = \dfrac{1}{m} \ln \left(\dfrac{V_S}{V_{So}} \right)^2$

19. $h = -\dfrac{2}{m} \ln \left(1/2mV_T t_e + e^{-1/2mh_1} \right)$ for open-parachute descent

20. $h = -\dfrac{2}{m} \ln \left[1/2mV_T(t_e - 14) + e^{-1/2mh_1} \right]$, for free-fall

21. $t_e = \dfrac{2}{mkV_{So}} \left(e^{-1/2mh} - e^{-1/2mh_1} \right)$, plus 14 for free-fall

22. $\dfrac{2}{m} = 61463$

23. $S = 0.1253 \, W^{2/3}$ for free-fall

24. $d = 1.664 \, W^{1/2}$ for $C_D = 0.92$, $k = 1$

25. $C_D = 1.04$ to 1.26 for flat plate

26. $\bar{\rho} = \dfrac{\rho - \rho_1}{\ln \dfrac{\rho}{\rho_1}}$, mean density

27. $\bar{V}_e = V_T \left(\dfrac{\rho_o}{\rho} \right)^{1/2}$, mean velocity

28. $t_e = \frac{h_1 - h}{\overline{V}_e}$

29. $\overline{V}_e = V_T \; e^{1/4m(h+h_1)}$

30. $t_e = \frac{h}{kV_{So}} \; e^{-1/4mh}$ for open-parachute descent; plus 14 for free-fall

EQUILIBRIUM VELOCITY AT ANY ALTITUDE

It is logical to assume that modern aerodynamic theory should apply to bodies falling through air propelled by the force of gravity. The elementary law, obtainable by dimensional analysis, for the drag, or resistive force, on a body moving in a fluid

$$D = \frac{1}{2} C_D S \rho V^2 \tag{1}$$

is taken, therefore, as fundamental to objects falling in air,

Defining the equilibrium velocity as that vertical velocity at which the drag in pounds is just equal to the weight of the body in pounds results in

$$W = \frac{1}{2} C_D S \rho V_e^2 \tag{2}$$

The equilibrium velocity is then given by

$$V_e = (2W/C_D S \rho)^{1/2} \tag{3}$$

Equation (3) may be used to calculate the equilibrium velocity of falling bodies at any altitude, provided the drag coefficient C_D and the area S can be estimated.

Replacing $(2W/C_D S)^{1/2}$ by k gives for equation (3)

$$V_e = \frac{k}{\rho^{1/2}} \tag{4}$$

By defining the standard equilibrium velocity V_S at any altitude as that velocity at which the drag is just equal to the weight, and

$$k = (2W/C_D S)^{1/2} = 1$$

the values of the standard equilibrium velocity were computed from the mass density (reference 1) of the standard atmosphere at various altitudes. These values are compiled in table I.

EQUILIBRIUM TIME BETWEEN ALTITUDES

Let t_e represent the time to fall between any two altitudes h_1 and h_2 for the situation

$$W = D$$

Then from equation (3)

$$dh/dt_e = (2W/C_D S\rho)^{1/2}$$

Inverting and integrating gives

$$t_e = (C_D S/2W)^{1/2} \int_{h_1}^{h_2} \rho^{1/2}\, dh \tag{5}$$

If $(C_D S/2W)^{1/2}$ is replaced by $1/k$, dh by Δh, and the integral sign by the summation sign, then on summing from sea level (corresponding to a mass density of ρ_o) to the altitude in question (corresponding to a mass density of ρ), the equilibrium time from any altitude to sea level is given by

$$t_e = 1/k \sum_{\rho_o}^{\rho} \rho^{1/2}\, \Delta h \tag{6}$$

With the standard equilibrium time t_S defined as that time from any given altitude to sea level during which the drag on the body was just equal to the weight of the body, and

$$k = (2W/C_D S)^{1/2} = 1$$

the values of this standard equilibrium time were computed by equation (6), using the mass density of the standard atmosphere at various altitudes. These values are compiled in table I. The summation was carried out by the trapezoidal rule for values of $\Delta h = 100$ feet up to 32,000 feet; $\Delta h = 200$ feet from 32,000 to 65,000 feet; $\Delta h = 1000$ feet from 65,000 to 80,000 feet; and $\Delta h = 200$ feet from sea level to −4000 feet. The mass density from 66,000 to 80,000 feet was computed by the equation

$$\rho = 4.1315 \times 10^{-6}\ p \tag{7}$$

for values of the pressure p in millimeters of mercury up to 80,000 feet. (See reference 2.)

In the appendix are given short tables and charts of an open-parachute descent and free-falls; a discussion of the computation of the values given in tables II and III for the terminal velocity at sea level and the variation of $(2W/C_DS)^{1/2}$ for various weight jumpers both free-falling and, with various diameters of parachute canopy, in open-parachute descent; and estimations of drag coefficients of silk and nylon parachutes.

Biodynamics Branch,
Research Division,
Bureau of Medicine and Surgery,
Navy Department
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APPENDIX

FIT OF EQUATION (6) TO OBSERVED DATA OF ALTITUDE AND TIME AFTER JUMP

Open-Parachute Descent from 40,200 to 1000 Feet

In the following table are given the observed altitudes at various times after the jump for the open-parachute descent of Lieutenant Colonel W. R. Lovelace from a density altitude of 40,200 feet (reference 3), using a 28-foot canopy parachute. The ground was 1000 feet above sea level:

h (ft)	t (sec)
40,200	0
37,500	60
34,600	120
32,700	240
30,700	300
28,000	360
26,500	420
24,500	480
23,000	540
21,400	600
20,000	660
18,500	720
16,500	780
15,300	840
14,300	900
13,500	960
12,000	1020
9,700	1080
8,500	1140
7,200	1200
6,100	1260
4,800	1320
3,000	1380
1,000	1428

Figure 1 is a plot of the standard equilibrium time between the various altitudes and 40,200 feet as ordinates against the observed times as abscissas. Note the excellence of the visually fitted straight line. The slope of this line is

$$k = (2W/C_D S)^{1/2} = 0.920$$

Since the total weight of the jumper was 240 pounds, and $S = \pi\left(\frac{28^2}{4}\right) = 616$ square feet,

$$C_D = 0.921$$

This value was used to compute values of k for various weight jumpers and parachute diameters given in table II. Figure 2 is a plot of the raw data from the preceding table of altitude against time for the open-parachute descent, with the smooth curve representing the equilibrium times obtained from table I, using a value of $k = 0.920$. Note the agreement of the two sets of data.

Free-Fall from 31,400 to 2100 Feet

The observed altitudes and times after the jump are given in the following table for the free-fall of Arthur H. Starnes from 31,400 to 2100 feet where the parachute was opened (reference 4).

h (ft)	t (sec)
31,400	0
30,780	9.9
30,200	14.5
28,850	19.1
27,700	23.7
26,150	28.3
24,600	32.9
23,200	37.5
21,750	42.1
20,550	46.7
19,400	51.3
18,100	55.9
16,600	60.5
15,150	65.1
14,070	69.7
12,800	74.3
11,650	78.9
10,400	83.5
9,400	88.1
8,140	92.7
7,080	97.3
5,700	101.9
4,450	106.5
3,170	111.1
2,100	116.0

Figure 3 is a plot of the standard equilibrium time between the various altitudes and 31,400 feet as ordinates against the observed times after the jump as abscissas. Note that the dynamic equilibrium velocity, when drag equals weight, was not reached for about 25 seconds after the jump, and that to obtain the time to fall from the altitude at the jump to any other altitude, time must be counted from some value t' after the jump. From the graph, this value of t' is about 14 seconds. After equilibrium is reached, the fit of observed values to standard values is good. The slope of the straight line of figure 3 is

$$k = \left(\frac{2W}{C_D S}\right)^{1/2} = 10.69$$

Since the total weight of the jumper was 286 pounds,

$$C_D S = 5.005$$

Figure 4 is a plot of the raw data from the preceding table of altitude against time for the free-fall descent, with the smooth curve representing the equilibrium times obtained from table I and with a value of $k = 10.69$.

It is felt that Starnes' free-fall from 31,400 to 2100 feet should give a pretty fair average value for the drag coefficient (if it was calculable) because of the many attitudes his body took during the fall. He rolled, somersaulted, fell head first, and so forth. At the present time there are no specific estimations of the drag coefficient of fully clothed jumpers or of profile areas of fully clothed jumpers. In order to estimate variations of k for various weight jumpers, it is assumed that C_D does not vary with varying weights, and that the profile area S varies as the two-thirds power of the weight

$$S = \frac{1}{b} W^{2/3} \tag{8}$$

It follows that

$$k = W^{1/6} (2b/C_D)^{1/2} \tag{9}$$

and considering Starnes' free-fall as giving a fair average value for the drag coefficient

$$k = 4.1647 W^{1/6} \tag{10}$$

This equation was used to determine values of k for various weight jumpers free-falling as given in table II.

Free-Fall from 42,000 to 1100 Feet

At Wilmington Air Base, Lieutenant Colonel M. W. Boynton left an airplane flying horizontally at 42,000 feet and free-fell to 1100 feet (reference 5). His weight with full equipment was 240 pounds. The total time of the fall was observed by stop watch to be 151 to 153 seconds. His maximum velocity was observed to be 400 to 425 feet per second which was reached at 25 seconds after leaving the airplane.

Entering the standard equilibrium table at 42,000 feet and 1100 feet shows a difference of 1484.05 - 53.21 = 1431.84. For a weight of 240 pounds, k is estimated as 10.382 from table II. Then

$$t_e = \frac{1431.84}{10.382} + 14$$

$$t_e = 151.9 \text{ seconds}$$

VARIATION OF $(2W/C_DS)^{1/2}$ AND TERMINAL VELOCITY AT SEA LEVEL

Open-Parachute Descents

Assuming a value for the drag coefficient of 0.921, and further assuming that it does not vary appreciably with the diameter d of the parachute, the various values of $k = (2W/C_DS)^{1/2}$ shown in table II were computed by

$$k = 1.6628 \frac{W^{1/2}}{d} \tag{11}$$

For the terminal velocity at sea level, equation (3) becomes

$$V_T = (2W/C_DS\rho_o)^{1/2} \tag{12}$$

Since $\frac{1}{\rho_o^{1/2}} = 20.51$, the terminal velocity at sea level

$$V_T = \frac{k}{\rho_o^{1/2}}$$

given in table III was computed for various weight jumpers and diameters of parachutes by

$$V_T = 34.104 \frac{W^{1/2}}{d} \tag{13}$$

Free-Falls

As previously shown, the values of $k = (2W/C_DS)^{1/2}$ for free-falls given in table II were computed by

$$k = 4.1647^{1/6}$$

Then the terminal velocity at sea level

$$V_T = \frac{k}{\rho_o^{1/2}}$$

may be estimated by

$$V_T = 85.418W^{1/6} \tag{14}$$

DRAG COEFFICIENTS OF SILK AND NYLON PARACHUTES

The observed altitudes and descent times to 2800 feet of 200-pound dummies with 28-foot silk, 28-foot nylon, and 24-foot nylon parachutes (reference 6) are given in the following table:

Altitude (ft)	Descent times, t (sec)					
	28-foot silk		28-foot nylon		24-foot nylon	
	Mean ± σ	No. of descents	Mean ± σ	No. of descents	Mean ± σ	No. of descents
7,000	228 ± 14	9	208 ± 11	10	—— ——	——
15,000	584 ± 26	18	564 ± 21	17	464 ± 17	13
26,000	992 ± 68	15	958 ± 34	15	833 ± 68	8
33,000	—— ——	——	1230 ± 38	3	965 ± 71	3
40,000	1417 ± 91	10	1360 ± 74	14	1154 ± 7	3

The drag coefficient for bodies falling in the standard atmosphere is given by

$$C_D = \left(\frac{2W}{S}\right)\left(\frac{t}{t_S}\right)^2 \tag{15}$$

From the range of observed-descent times given by the standard deviation, σ in this table, and the standard equilibrium times from the given altitude to 2800 feet, the range of drag coefficients shown in the following table were computed by equation (15):

Altitude (ft)	Drag Coefficients		
	28-foot silk	28-foot nylon	24-foot nylon
7,000	0.820 – 1.031	0.695 – 0.859	—— ——
15,000	.657 – .892	.707 – .820	0.653 – 0.756
26,000	.671 – .883	.671 – .773	.627 – .869
33,000	—— ——	.736 – .833	.564 – .757
40,000	.672 – .751	.632 – .786	.686 – .702
Mean	0.705 – 0.889	0.688 – 0.814	0.633 – 0.771

The mean-observed-descent times give the following average drag coefficients:

28-foot silk, 0.828
28-foot nylon, 0.750
24-foot nylon, 0.699
28- and 24-foot nylon combined, 0.727

Note that it is assumed that the dummy descents, on which these drag coefficients are based, were made in the standard atmosphere. It is thought that the temperature and other corrections would be small compared with the magnitude of the variation between different descents.

In order to facilitate use of the material given in the present paper, some of the data have been plotted in chart form. (See figs. 5 to 8.)

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TABLE I.- STANDARD EQUILIBRIUM VELOCITY AND STANDARD EQUILIBRIUM TIME

h	Vs (ft/sec)	ts (sec)	h	Vs (ft/sec)	ts (sec)
-4000	19.36	200.83	2000	21.12	96.11
-3800	19.41	190.51	2100	21.15	100.84
-3600	19.47	180.22	2200	21.18	105.56
-3400	19.52	169.96	2300	21.21	110.28
-3200	19.58	159.73	2400	21.25	114.99
-3000	19.63	149.53	2500	21.28	119.69
-2800	19.69	139.36	2600	21.31	124.39
-2600	19.75	129.22	2700	21.34	129.08
-2400	19.80	119.10	2800	21.37	133.76
-2200	19.86	109.02	2900	21.40	138.44
-2000	19.92	98.96	3000	21.44	143.11
-1800	19.98	88.94	3100	21.47	147.77
-1600	20.04	78.94	3200	21.50	152.42
-1400	20.09	68.97	3300	21.53	157.07
-1200	20.15	59.03	3400	21.57	161.71
-1000	20.21	49.12	3500	21.60	166.34
-800	20.27	39.24	3600	21.63	170.97
-600	20.33	29.39	3700	21.66	175.59
-400	20.39	19.56	3800	21.69	180.20
-200	20.45	9.77	3900	21.73	184.81
0	20.51	0.0	4000	21.76	189.41
100	20.54	4.87	4100	21.80	194.00
200	20.57	9.74	4200	21.83	198.58
300	20.60	14.60	4300	21.86	203.16
400	20.63	19.45	4400	21.90	207.73
500	20.66	24.29	4500	21.93	212.30
600	20.69	29.13	4600	21.96	216.85
700	20.72	33.96	4700	21.99	221.41
800	20.75	38.78	4800	22.03	225.95
900	20.78	43.60	4900	22.06	230.49
1000	20.81	48.41	5000	22.09	235.02
1100	20.84	53.21	5100	22.12	239.54
1200	20.87	58.00	5200	22.16	244.06
1300	20.90	62.79	5300	22.19	248.57
1400	20.93	67.57	5400	22.23	253.07
1500	20.96	72.34	5500	22.26	257.56
1600	21.00	77.11	5600	22.29	262.05
1700	21.03	81.87	5700	22.33	266.53
1800	21.06	86.62	5800	22.36	271.01
1900	21.09	91.37	5900	22.40	275.48

TABLE I.- Cont'd.

h	Vs (ft/sec)	ts (sec)	h	Vs (ft/sec)	ts (sec)
6000	22.43	279.94	10000	23.87	452.89
6100	22.46	284.40	10100	23.90	457.08
6200	22.50	288.84	10200	23.94	461.26
6300	22.54	293.28	10300	23.98	465.43
6400	22.57	297.72	10400	24.02	469.60
6500	22.60	302.15	10500	24.06	473.76
6600	22.64	306.57	10600	24.09	477.91
6700	22.68	310.98	10700	24.13	482.06
6800	22.71	315.39	10800	24.16	486.20
6900	22.74	319.79	10900	24.20	490.34
7000	22.77	324.18	11000	24.24	494.47
7100	22.81	328.57	11100	24.28	498.59
7200	22.85	332.95	11200	24.32	502.70
7300	22.88	337.32	11300	24.35	506.81
7400	22.92	341.69	11400	24.40	510.92
7500	22.95	346.05	11500	24.43	515.01
7600	22.99	350.40	11600	24.47	519.10
7700	23.03	354.75	11700	24.52	523.18
7800	23.06	359.09	11800	24.55	527.26
7900	23.09	363.42	11900	24.59	531.33
8000	23.13	367.75	12000	24.63	535.39
8100	23.17	372.07	12100	24.68	539.45
8200	23.20	376.38	12200	24.72	543.50
8300	23.24	380.69	12300	24.75	547.54
8400	23.27	384.99	12400	24.79	551.58
8500	23.31	389.28	12500	24.83	555.61
8600	23.34	393.57	12600	24.88	559.63
8700	23.38	397.85	12700	24.91	563.65
8800	23.42	402.12	12800	24.96	567.66
8900	23.45	406.39	12900	24.99	571.66
9000	23.49	410.65	13000	25.03	575.66
9100	23.53	414.90	13100	25.07	579.65
9200	23.56	419.15	13200	25.11	583.64
9300	23.60	423.39	13300	25.16	587.62
9400	23.64	427.63	13400	25.20	591.59
9500	23.67	431.85	13500	25.24	595.56
9600	23.71	436.07	13600	25.28	599.52
9700	23.75	440.29	13700	25.32	603.47
9800	23.79	444.49	13800	25.36	607.41
9900	23.82	448.70	13900	25.40	611.35

TABLE I.- Cont'd.

h	Vs (ft/sec)	ts (sec)	h	Vs (ft/sec)	ts (sec)
14000	25.44	615.29	18000	27.17	767.50
14100	25.48	619.22	18100	27.20	771.18
14200	25.52	623.14	18200	27.26	774.85
14300	25.56	627.05	18300	27.30	778.52
14400	25.61	630.96	18400	27.34	782.18
14500	25.65	634.86	18500	27.39	785.83
14600	25.69	638.76	18600	27.43	789.48
14700	25.73	642.65	18700	27.48	793.12
14800	25.77	646.53	18800	27.53	796.76
14900	25.81	650.41	18900	27.58	800.39
15000	25.85	654.28	19000	27.62	804.01
15100	25.90	658.14	19100	27.67	807.63
15200	25.94	662.00	19200	27.72	811.24
15300	25.99	665.85	19300	27.75	814.85
15400	26.03	669.70	19400	27.81	818.45
15500	26.06	673.54	19500	27.86	822.04
15600	26.11	677.37	19600	27.89	825.63
15700	26.15	681.20	19700	27.94	829.21
15800	26.20	685.02	19800	28.00	832.78
15900	26.23	688.83	19900	28.03	836.35
16000	26.28	692.64	20000	28.10	839.92
16100	26.32	696.44	20100	28.14	843.47
16200	26.37	700.24	20200	28.18	847.02
16300	26.41	704.03	20300	28.22	850.57
16400	26.46	707.81	20400	28.28	854.11
16500	26.50	711.59	20500	28.33	857.64
16600	26.55	715.36	20600	28.38	861.17
16700	26.58	719.12	20700	28.42	864.69
16800	26.63	722.88	20800	28.47	868.21
16900	26.67	726.64	20900	28.52	871.72
17000	26.72	730.38	21000	28.57	875.22
17100	26.77	734.12	21100	28.63	878.72
17200	26.80	737.85	21200	28.68	882.21
17300	26.85	741.58	21300	28.73	885.69
17400	26.89	745.30	21400	28.77	889.17
17500	26.94	749.02	21500	28.82	892.64
17600	26.99	752.73	21600	28.88	896.11
17700	27.03	756.43	21700	28.93	899.57
17800	27.08	760.13	21800	28.98	903.02
17900	27.11	763.82	21900	29.03	906.47

TABLE I.- Cont'd.

h	V_s (ft/sec)	t_s (sec)	h	V_s (ft/sec)	t_s (sec)
22000	29.08	909.91	26000	31.19	1042.80
22100	29.12	913.35	26100	31.25	1046.00
22200	29.17	916.78	26200	31.31	1049.20
22300	29.22	920.20	26300	31.36	1052.39
22400	29.27	923.62	26400	31.42	1055.57
22500	29.33	927.04	26500	31.47	1058.75
22600	29.38	930.44	26600	31.53	1061.93
22700	29.42	933.84	26700	31.60	1065.10
22800	29.47	937.24	26800	31.64	1068.26
22900	29.52	940.63	26900	31.71	1071.42
23000	29.58	944.01	27000	31.75	1074.57
23100	29.63	947.39	27100	31.82	1077.72
23200	29.68	950.76	27200	31.87	1080.86
23300	29.74	954.13	27300	31.93	1083.99
23400	29.79	957.49	27400	31.98	1087.12
23500	29.84	960.84	27500	32.04	1090.24
23600	29.90	964.19	27600	32.09	1093.36
23700	29.95	967.53	27700	32.15	1096.48
23800	30.00	970.87	27800	32.21	1099.58
23900	30.06	974.20	27900	32.28	1102.69
24000	30.11	977.52	28000	32.32	1105.78
24100	30.17	980.84	28100	32.39	1108.87
24200	30.20	984.16	28200	32.45	1111.96
24300	30.26	987.46	28300	32.51	1115.04
24400	30.32	990.77	28400	32.56	1118.11
24500	30.36	994.06	28500	32.62	1121.18
24600	30.41	997.35	28600	32.69	1124.24
24700	30.47	1000.64	28700	32.73	1127.30
24800	30.53	1003.92	28800	32.79	1130.35
24900	30.58	1007.19	28900	32.86	1133.40
25000	30.65	1010.46	29000	32.94	1136.44
25100	30.70	1013.72	29100	32.98	1139.47
25200	30.76	1016.97	29200	33.06	1142.50
25300	30.82	1020.22	29300	33.11	1145.52
25400	30.87	1023.46	29400	33.17	1148.54
25500	30.92	1026.70	29500	33.22	1151.55
25600	30.98	1029.93	29600	33.30	1154.56
25700	31.03	1033.15	29700	33.36	1157.56
25800	31.08	1036.37	29800	33.41	1160.55
25900	31.14	1039.59	29900	33.48	1163.54

TABLE I.- Cont'd.

h	V_s (ft/sec)	t_s (sec)	h	V_s (ft/sec)	t_s (sec)
30000	33.53	1166.53	36000	37.69	1335.73
30100	33.59	1169.51	36200	37.85	1341.02
30200	33.65	1172.48	36400	38.04	1346.29
30300	33.73	1175.45	36600	38.21	1351.54
30400	33.78	1178.41	36800	38.40	1356.76
30500	33.84	1181.37	37000	38.61	1361.95
30600	33.90	1184.32	37200	38.80	1367.12
30700	33.97	1187.27	37400	38.99	1372.26
30800	34.04	1190.21	37600	39.17	1377.38
30900	34.09	1193.15	37800	39.34	1382.48
31000	34.16	1196.08	38000	39.53	1387.55
31100	34.22	1199.00	38200	39.71	1392.60
31200	34.28	1201.92	38400	39.90	1397.62
31300	34.34	1204.83	38600	40.10	1402.62
31400	34.40	1207.74	38800	40.29	1407.60
31500	34.46	1210.65	39000	40.49	1412.55
31600	34.54	1213.55	39200	40.68	1417.48
31700	34.60	1216.44	39400	40.90	1422.38
31800	34.66	1219.33	39600	41.07	1427.26
31900	34.73	1222.21	39800	41.27	1432.12
32000	34.79	1225.09	40000	41.46	1436.95
32200	34.92	1230.82	40200	41.67	1441.76
32400	35.05	1236.54	40400	41.84	1446.55
32600	35.20	1242.23	40600	42.07	1451.32
32800	35.34	1247.91	40800	42.27	1456.06
33000	35.46	1253.56	41000	42.48	1460.78
33200	35.60	1259.18	41200	42.68	1465.48
33400	35.74	1264.79	41400	42.88	1470.16
33600	35.89	1270.38	41600	43.07	1474.81
33800	36.04	1275.94	41800	43.27	1479.44
34000	36.15	1281.48	42000	43.48	1484.05
34200	36.30	1287.00	42200	43.73	1488.64
34400	36.44	1292.50	42400	43.94	1493.20
34600	36.56	1297.98	42600	44.15	1497.74
34800	36.71	1303.44	42800	44.33	1502.27
35000	36.86	1308.87	43000	44.54	1506.77
35200	36.98	1314.29	43200	44.72	1511.25
35400	37.13	1319.69	43400	44.94	1515.71
35600	37.31	1325.06	43600	45.13	1520.15
35800	37.50	1330.41	43800	45.35	1524.57

TABLE I.- Cont'd.

h	Vs (ft/sec)	ts (sec)	h	Vs (ft/sec)	ts (sec)
44000	45.60	1528.97	52000	55.22	1688.66
44200	45.79	1533.35	52200	55.56	1692.28
44400	46.02	1537.70	52400	55.80	1695.87
44600	46.23	1542.04	52600	56.09	1699.44
44800	46.47	1546.35	52800	56.34	1703.00
45000	46.69	1550.65	53000	56.63	1706.54
45200	46.88	1554.92	53200	56.79	1710.07
45400	47.15	1559.18	53400	57.08	1713.58
45600	47.35	1563.41	53600	57.34	1717.08
45800	47.62	1567.62	53800	57.64	1720.56
46000	47.85	1571.81	54000	57.94	1724.02
46200	48.05	1575.98	54200	58.14	1727.46
46400	48.29	1580.13	54400	58.41	1730.90
46600	48.50	1584.27	54600	58.72	1734.31
46800	48.73	1588.38	54800	59.03	1737.71
47000	48.97	1592.48	55000	59.35	1741.09
47200	49.21	1596.55	55200	59.56	1744.45
47400	49.46	1600.60	55400	59.88	1747.80
47600	49.70	1604.64	55600	60.20	1751.13
47800	49.95	1608.65	55800	60.42	1754.45
48000	50.20	1612.65	56000	60.75	1757.75
48200	50.45	1616.62	56200	61.09	1761.03
48400	50.63	1620.58	56400	61.31	1764.30
48600	50.89	1624.52	56600	61.65	1767.55
48800	51.18	1628.44	56800	61.88	1770.79
49000	51.36	1632.34	57000	62.27	1774.01
49200	51.65	1636.22	57200	62.50	1777.22
49400	51.84	1640.08	57400	62.85	1780.41
49600	52.14	1643.93	57600	63.13	1783.58
49800	52.41	1647.76	57800	63.49	1786.74
50000	52.63	1651.57	58000	63.78	1789.89
50200	52.85	1655.36	58200	64.14	1793.01
50400	53.16	1659.13	58400	64.43	1796.12
50600	53.39	1662.88	58600	64.68	1799.22
50800	53.68	1666.62	58800	64.98	1802.31
51000	53.91	1670.34	59000	65.36	1805.38
51200	54.14	1674.04	59200	65.53	1808.43
51400	54.47	1677.72	59400	65.79	1811.48
51600	54.70	1681.39	59600	66.09	1814.51
51800	54.98	1685.03	59800	66.53	1817.53

TABLE I.- Concl'd.

h	V_s (ft/sec)	t_s (sec)	h	V_s (ft/sec)	t_s (sec)
60000	66.80	1820.53	64000	73.53	1877.59
60200	67.11	1823.51	64200	73.91	1880.31
60400	67.43	1826.49	64400	74.35	1883.00
60600	67.75	1829.45	64600	74.74	1885.69
60800	68.03	1832.39	64800	75.19	1888.36
61000	68.35	1835.32	65000	75.36	1891.01
61200	68.82	1838.24	66000	77.16	1904.13
61400	69.16	1841.14	67000	79.05	1916.93
61600	69.49	1844.02	68000	80.84	1929.44
61800	69.83	1846.90	69000	82.78	1941.67
62000	70.18	1849.75	70000	84.82	1953.60
62200	70.52	1852.60	71000	87.03	1965.24
62400	70.87	1855.42	72000	89.13	1976.60
62600	71.07	1858.24	73000	91.32	1987.68
62800	71.43	1861.05	74000	93.28	1998.52
63000	71.79	1863.84	75000	95.79	2009.10
63200	72.15	1866.62	76000	98.04	2019.42
63400	72.57	1869.39	77000	100.50	2029.49
63600	72.94	1872.13	78000	102.67	2039.34
63800	73.31	1874.87	79000	105.37	2048.95
			80000	107.87	2058.33
			∞		2446

TABLE II.- COMPUTED VALUES OF k.

Weight (lb)	Diameter of parachute (ft) 20	22	24	26	28	30	Free-fall
	Values of k						
90	0.79	0.72	0.66	0.61	0.56	0.53	8.82
95	.81	.74	.68	.62	.58	.54	8.90
100	.83	.76	.69	.64	.59	.55	8.97
105	.85	.77	.71	.66	.61	.57	9.05
110	.87	.79	.72	.67	.62	.58	9.12
115	.89	.81	.74	.69	.64	.59	9.18
120	.91	.83	.76	.70	.65	.61	9.25
125	.93	.85	.78	.72	.66	.62	9.31
130	.95	.86	.79	.73	.68	.63	9.37
135	.97	.88	.81	.74	.69	.64	9.43
140	.98	.89	.82	.76	.70	.66	9.49
145	1.00	.91	.83	.77	.72	.67	9.55
150	1.02	.93	.85	.78	.73	.68	9.60
155	1.04	.94	.86	.80	.74	.69	9.65
160	1.05	.96	.88	.81	.75	.70	9.70
165	1.07	.97	.89	.82	.76	.71	9.75
170	1.08	.99	.90	.83	.77	.72	9.80
175	1.10	1.00	.92	.85	.79	.73	9.85
180	1.12	1.01	.93	.86	.80	.74	9.90
185	1.13	1.03	.94	.87	.81	.75	9.94
190	1.15	1.04	.96	.88	.82	.76	9.99
195	1.16	1.06	.97	.89	.83	.77	10.03
200	1.18	1.07	.98	.90	.84	.78	10.07
205	1.19	1.08	.99	.92	.85	.79	10.11
210	1.21	1.10	1.00	.93	.86	.80	10.15
215	1.22	1.11	1.02	.94	.87	.81	10.19
220	1.23	1.12	1.03	.95	.88	.82	10.23
225	1.25	1.13	1.04	.96	.89	.83	10.27
230	1.26	1.15	1.05	.97	.90	.84	10.31
235	1.28	1.16	1.06	.98	.91	.85	10.35
240	1.29	1.17	1.07	.99	.92	.86	10.38
245	1.30	1.18	1.08	1.00	.93	.87	10.42
250	1.32	1.20	1.10	1.01	.94	.88	10.45
255	1.33	1.21	1.11	1.02	.95	.89	10.49
260	1.34	1.22	1.12	1.03	.96	.89	10.52
265	1.35	1.23	1.13	1.04	.97	.90	10.56
270	1.37	1.24	1.14	1.05	.98	.91	10.59
275	1.38	1.25	1.15	1.06	.99	.92	10.62
280	1.39	1.27	1.16	1.07	.99	.93	10.65
285	1.40	1.28	1.17	1.08	1.00	.94	10.68
290	1.42	1.29	1.18	1.09	1.01	.94	10.72
295	1.43	1.30	1.19	1.10	1.02	.95	10.75
300	1.44	1.31	1.20	1.11	1.03	.96	10.78

TABLE III.-

TERMINAL VELOCITY AT SEA LEVEL FOR JUMPERS OF VARIOUS WEIGHTS IN FREE-FALL AND, WITH VARIOUS DIAMETERS OF PARACHUTE CANOPY, IN OPEN-PARACHUTE DESCENT.

Weight (lb)	Parachute diameter (ft)						Free-fall	
	20	22	24	26	28	30	(ft/sec)	(mph)
	Terminal velocity (ft/sec)							
90	16.2	14.7	13.5	12.4	11.5	10.8	181	123
95	16.6	15.1	13.8	12.8	11.9	11.1	182	124
100	17.0	15.5	14.2	13.1	12.2	11.4	184	125
105	17.5	15.9	14.6	13.4	12.5	11.6	186	126
110	17.9	16.3	14.8	13.8	12.8	11.9	187	127
115	18.3	16.6	15.2	14.1	13.1	12.2	188	128
120	18.7	17.0	15.6	14.4	13.3	12.4	190	129
125	19.1	17.3	15.9	14.7	13.6	12.7	191	130
130	19.4	17.7	16.2	14.9	13.9	13.0	192	131
135	19.8	18.0	16.5	15.2	14.1	13.2	193	132
140	20.2	18.3	16.8	15.5	14.4	13.5	195	133
145	20.5	18.7	17.1	15.8	14.7	13.7	196	133
150	20.9	19.0	17.4	16.1	14.9	13.9	197	134
155	21.2	19.3	17.7	16.3	15.2	14.1	198	135
160	21.6	19.6	18.0	16.6	15.4	14.4	199	136
165	21.9	19.9	18.3	16.8	15.6	14.6	200	136
170	22.2	20.2	18.5	17.1	15.9	14.8	201	137
175	22.6	20.5	18.8	17.3	16.1	15.0	202	138
180	22.9	20.8	19.1	17.6	16.3	15.3	203	138
185	23.2	21.1	19.3	17.8	16.6	15.5	204	139
190	23.5	21.4	19.6	18.1	16.8	15.7	205	140
195	23.8	21.6	19.8	18.3	17.0	15.9	206	140
200	24.1	21.9	20.1	18.5	17.2	16.1	207	141
205	24.4	22.2	20.3	18.8	17.4	16.3	207	141
210	24.7	22.5	20.6	19.0	17.7	16.5	208	142
215	25.0	22.7	20.8	19.2	17.9	16.7	209	143
220	25.3	23.0	21.1	19.5	18.1	16.9	210	143
225	25.6	23.3	21.3	19.7	18.3	17.0	211	144
230	25.9	23.5	21.6	19.9	18.5	17.2	211	144
235	26.1	23.8	21.8	20.1	18.7	17.4	212	145
240	26.4	24.0	22.0	20.3	18.9	17.6	213	145
245	26.7	24.3	22.2	20.5	19.1	17.8	214	146
250	27.0	24.5	22.5	20.7	19.3	18.0	214	146
255	27.2	24.8	22.7	20.9	19.4	18.1	215	147
260	27.5	25.0	22.9	21.1	19.6	18.3	216	147
265	27.7	25.2	23.1	21.3	19.8	18.5	216	148
270	28.0	25.5	23.3	21.6	20.0	18.7	217	148
275	28.3	25.7	23.6	21.8	20.2	18.8	218	149
280	28.5	25.9	23.8	21.9	20.4	19.0	218	149
285	28.8	26.2	24.0	22.1	20.5	19.2	219	149
290	29.0	26.4	24.2	22.3	20.7	19.4	220	150
295	29.3	26.6	24.4	22.5	20.9	19.5	220	150
300	29.5	26.8	24.6	22.7	21.1	19.7	221	151

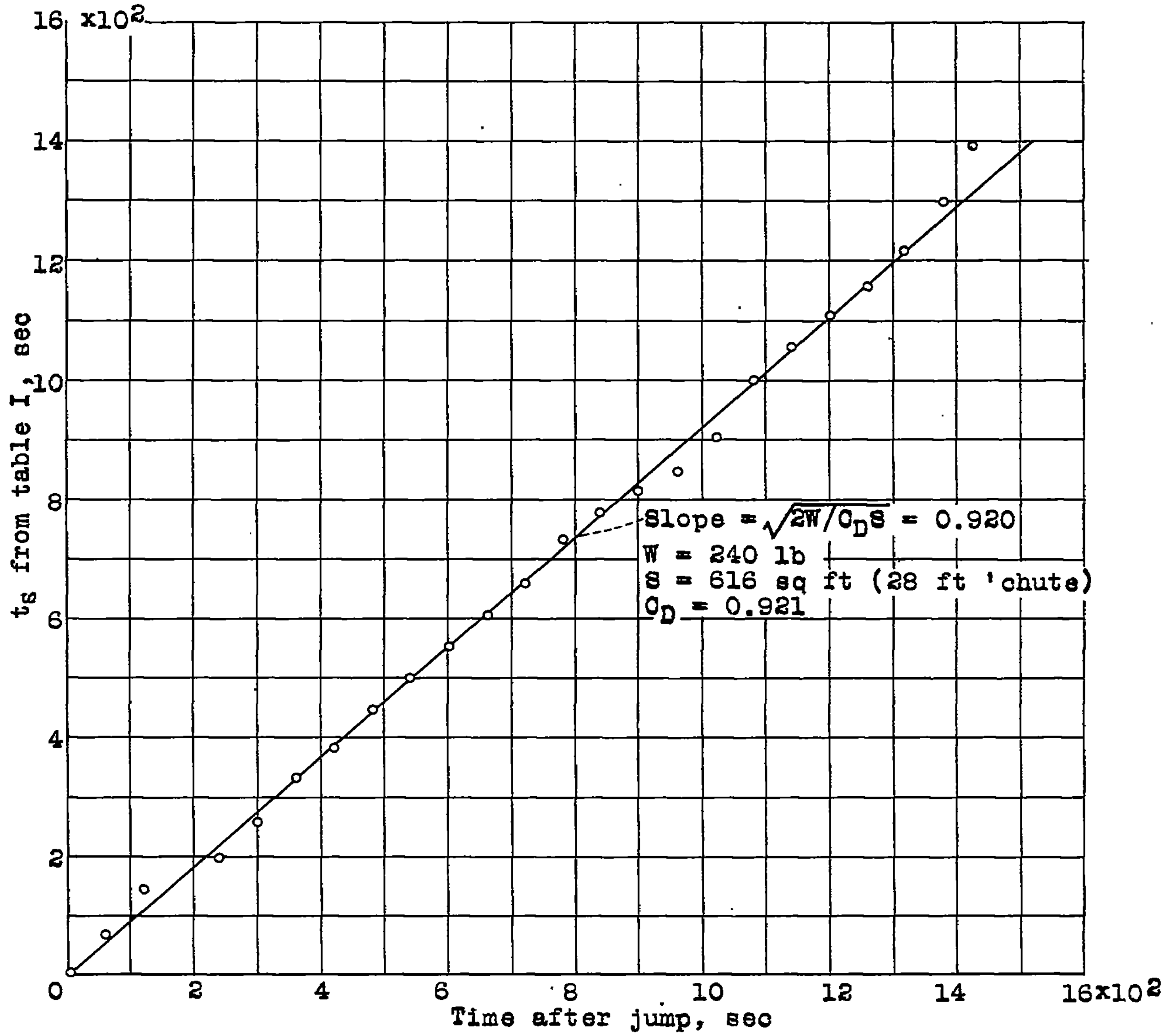

Figure 1.- Plot of the standard equilibrium time between various altitudes and 40,200 feet against the observed times after the jump, for the open-parachute descent of Lt. Col. W. R. Lovelace from a density altitude of 40,200 feet, using a 28-foot-canopy parachute. (See reference 3.)

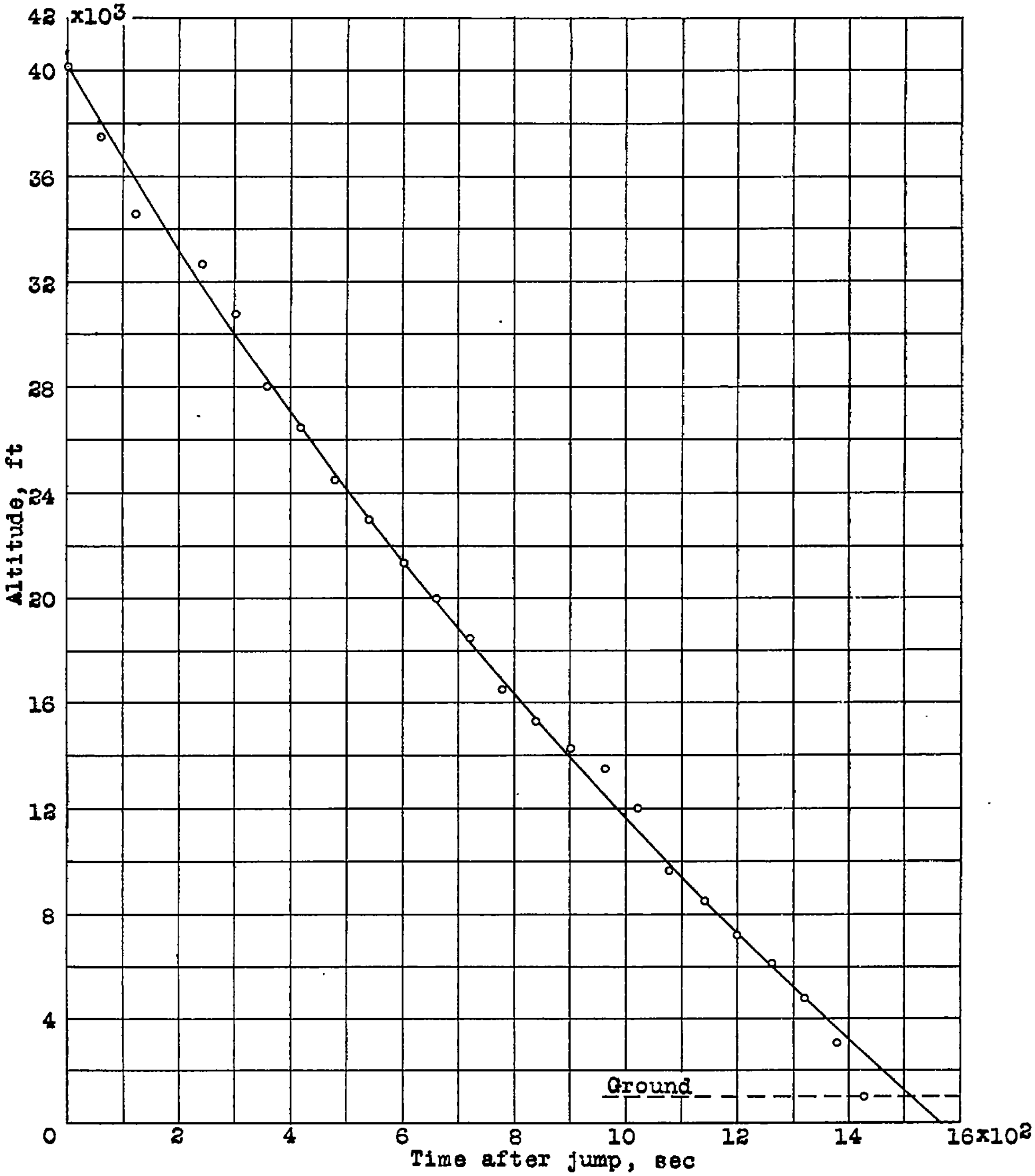

Figure 2.- Plot of the observed altitudes against the observed times after jump for the open-parachute descent of Lt. Col. W. R. Lovelace from a density altitude of 40,200 feet, using a 28-foot-canopy parachute. (See reference 3.) The smooth curve through the observed points represents the equilibrium times obtained from table I using a value of k = 0.920.

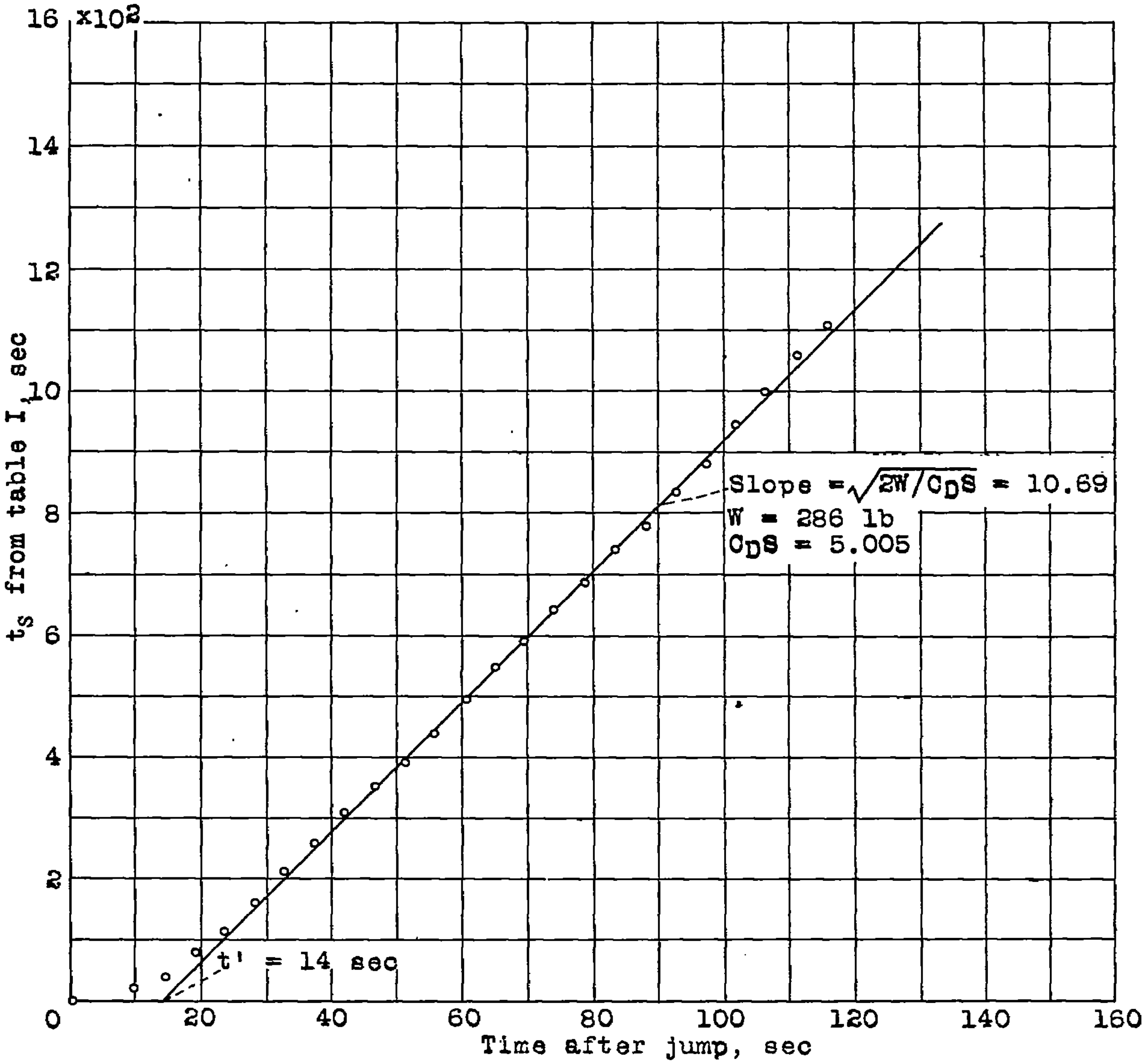

Figure 3.- Plot of the standard equilibrium time between the various altitudes and 31,400 feet against the observed times after the jump, for the free-fall of Arthur H. Starnes from 31,400 feet to 2,100 feet. (See reference 4.)

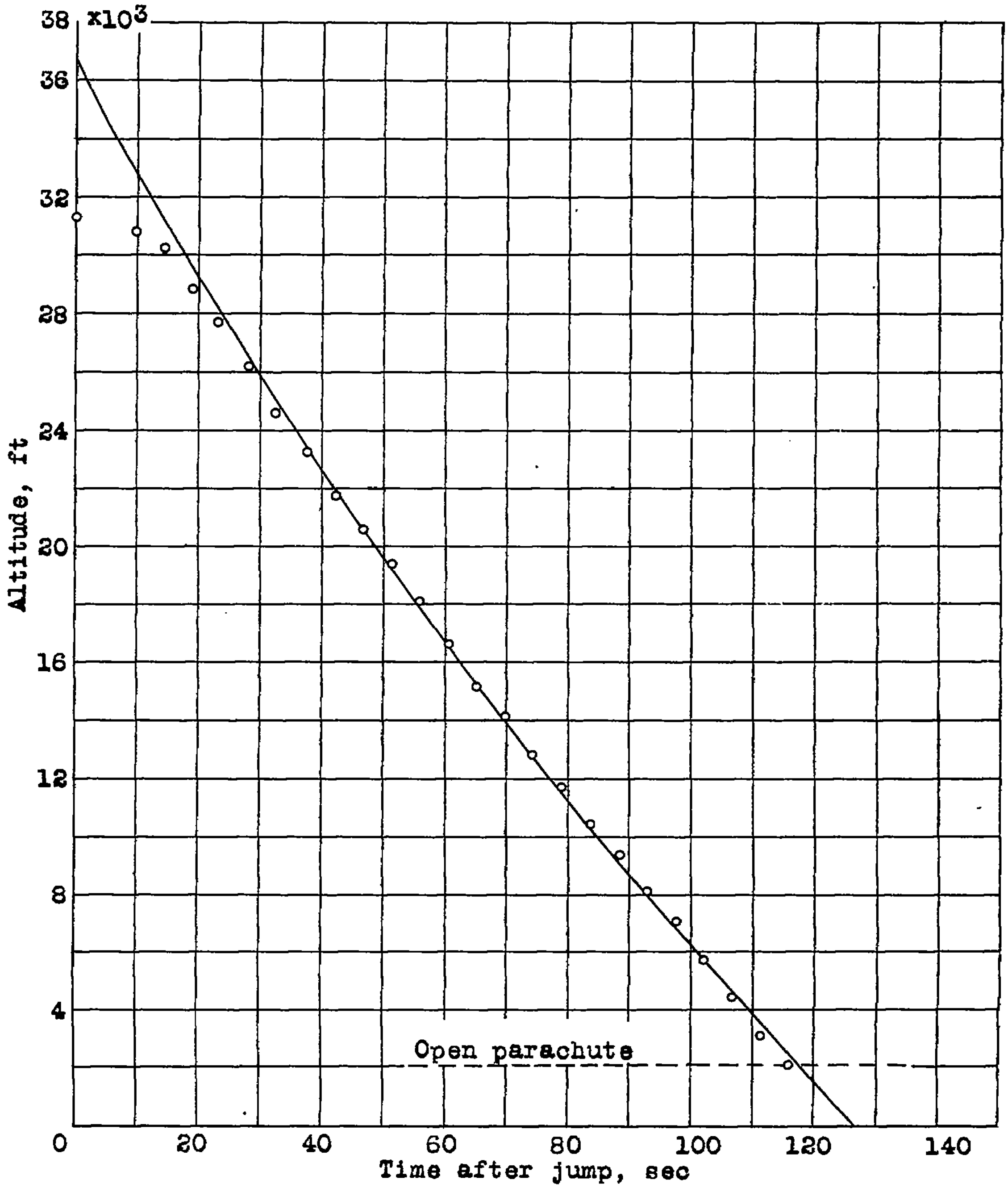

Figure 4.- Plot of the observed altitudes against the observed times after the jump for the free-fall of Arthur H. Starnes from 31,400 feet to 2,100 feet. (See reference 4.) The smooth curve passing through the points represents the equilibrium times obtained from table I, using a value of k = 10.69.

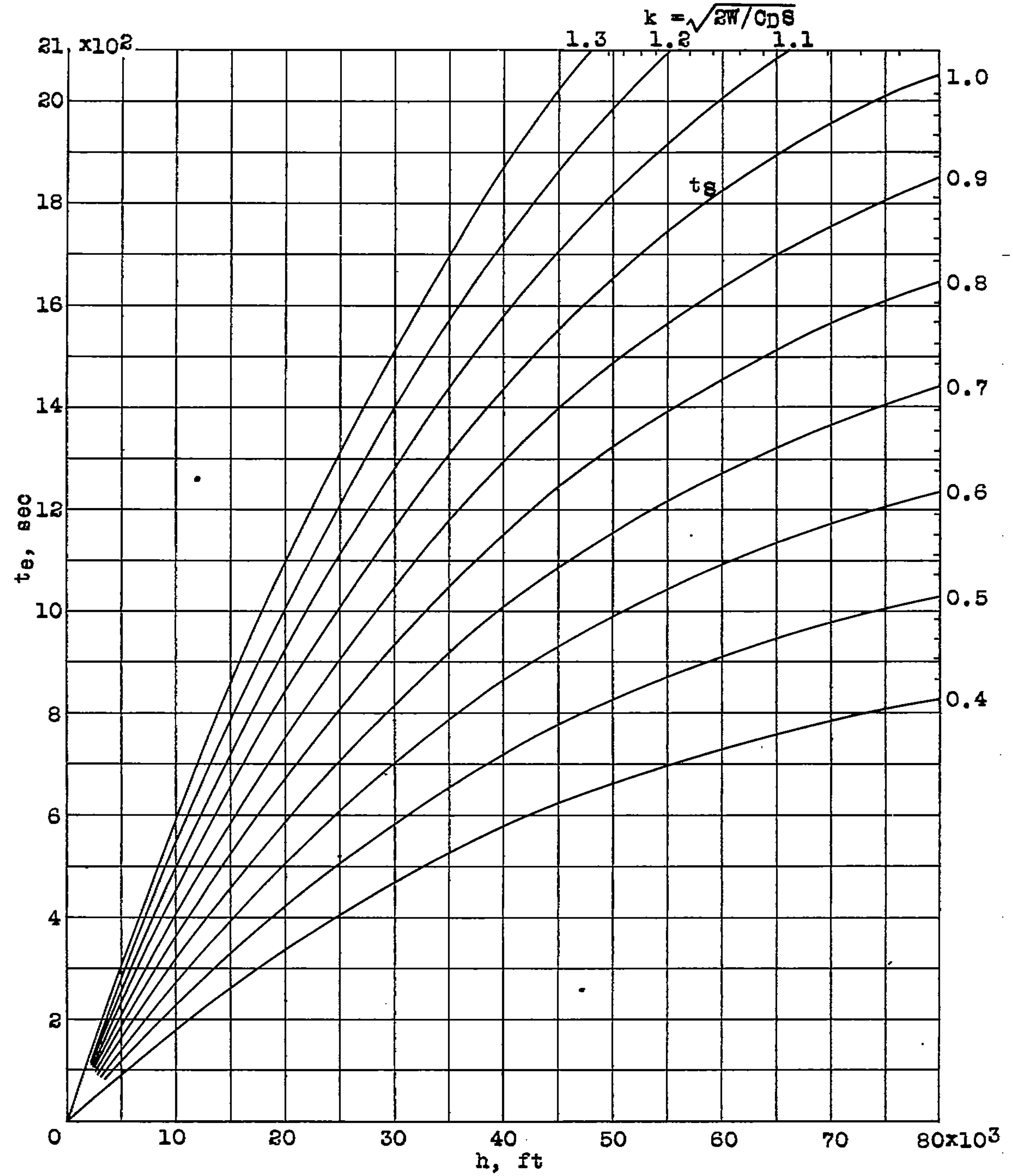

Figure 5.- Graph of the equilibrium time t_e against the altitude h for various values of $k = (2W/C_DS)^{1/2}$. A shift of decimal point in k causes a shift of the decimal point in t_e in the opposite direction.

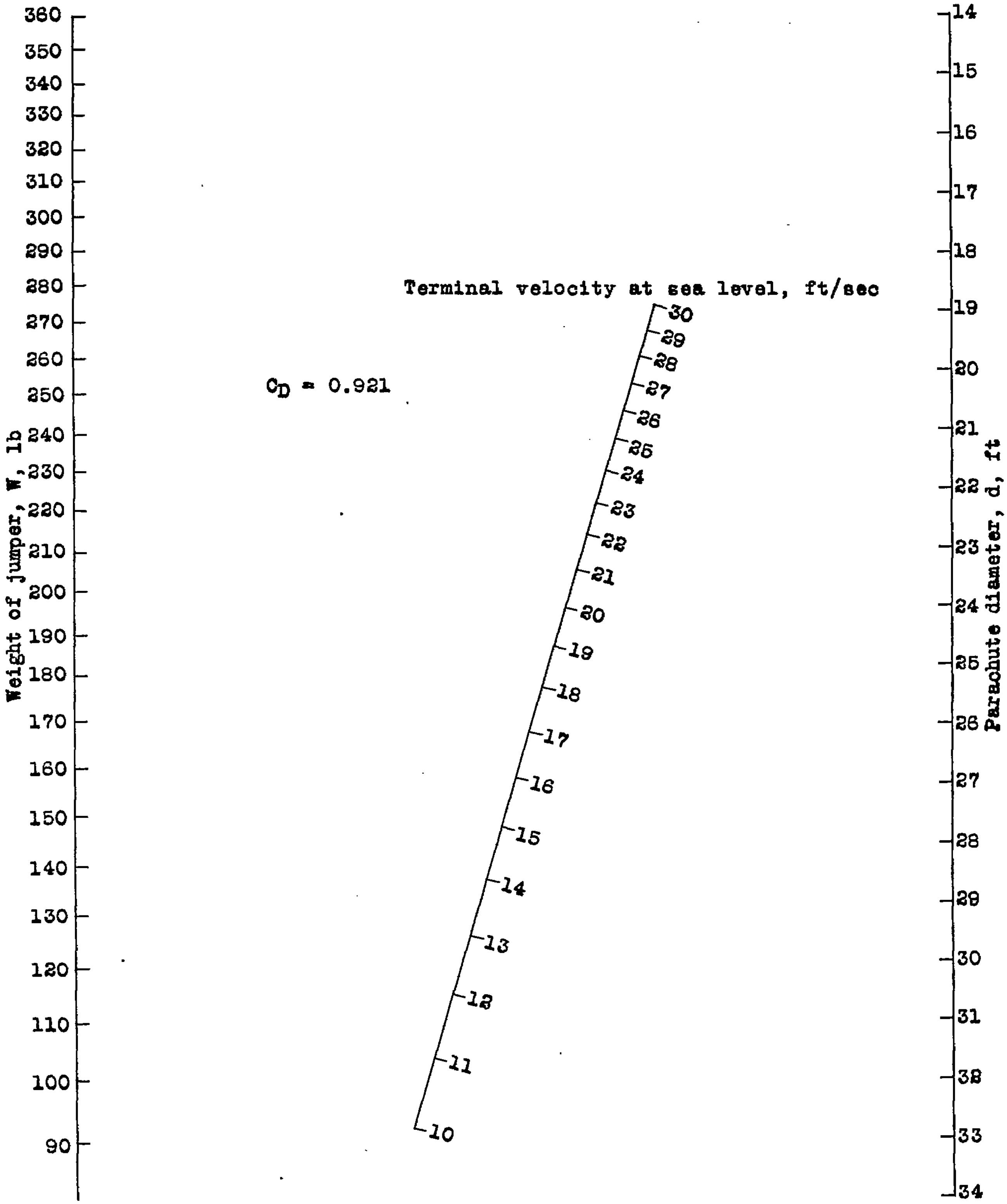

Figure 6.- Nomogram giving the terminal velocity at sea level V_T for various values of the weight W and the diameter of the parachute d.

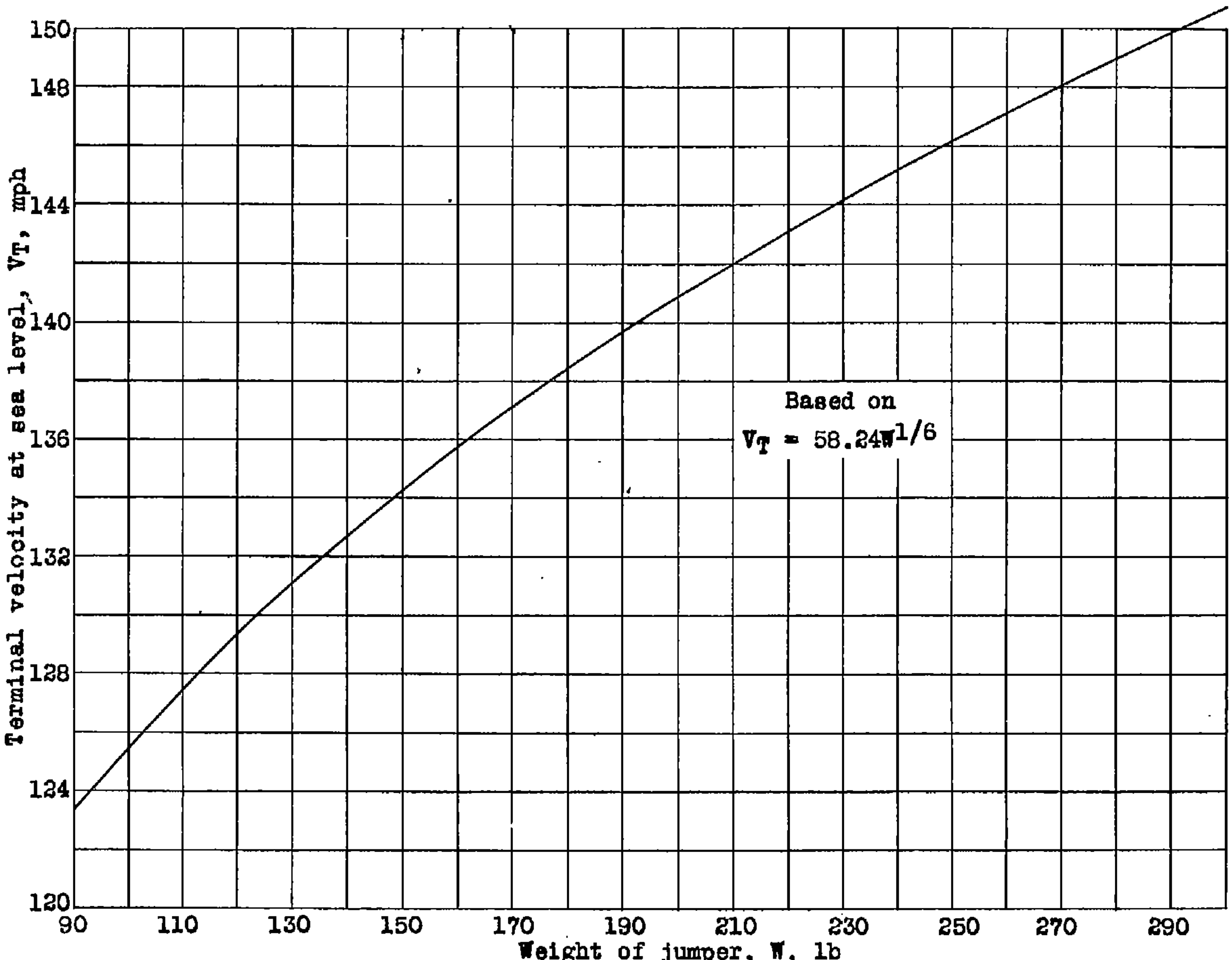

Figure 7.- Graph of the terminal velocity at sea level V_T for various weight jumpers free-falling. $V_T = 58.24W^{1/6}$.

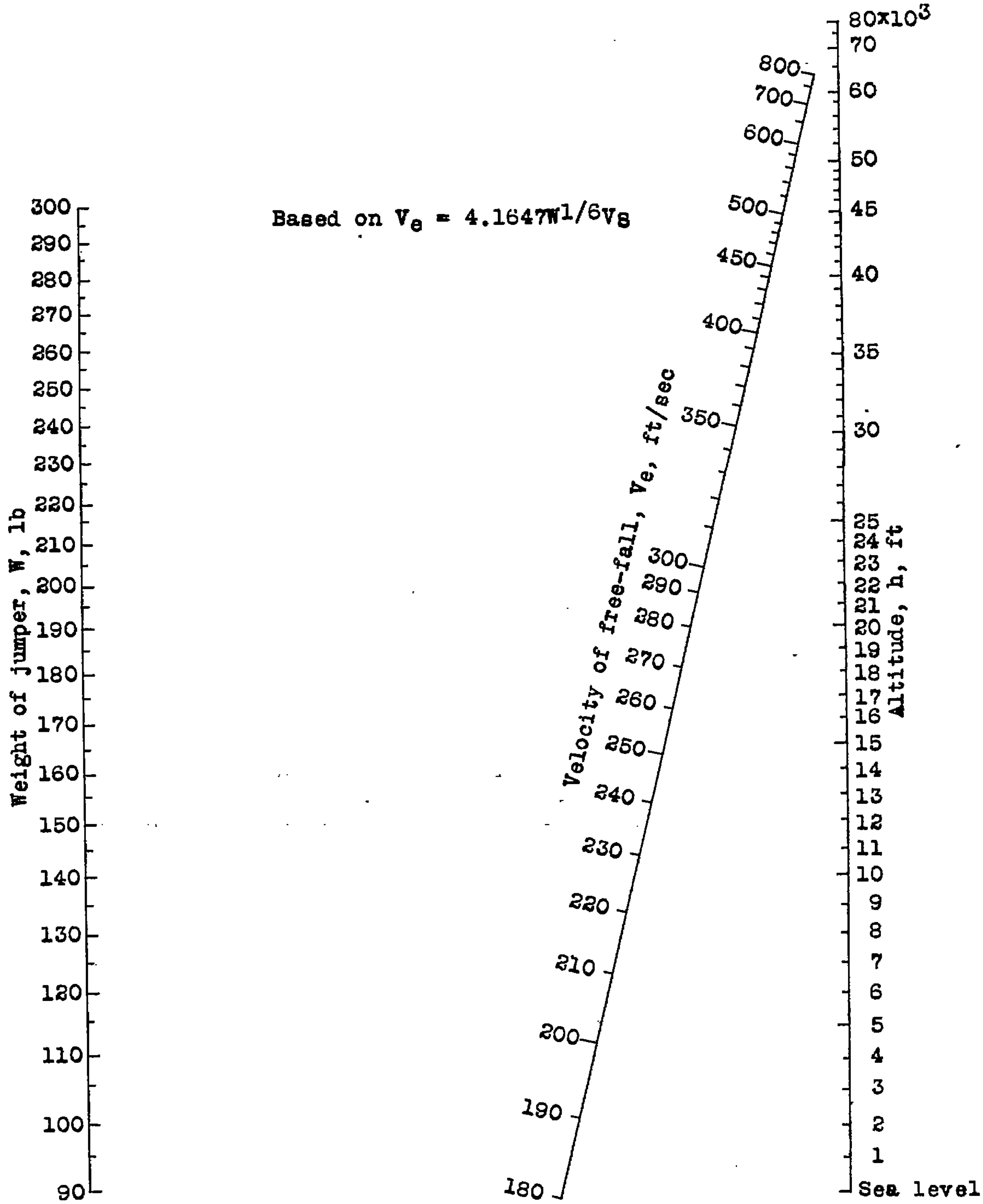

Figure 8.- Nomogram giving the equilibrium velocity at various altitudes for various weight jumpers free-falling. $V_e = 4.1647W^{1/6}V_s$.