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HIGH ALTITUDE METEOROLOGICAL ROCKET WIND MEASURING SYSTEMS AND RESULTS TAKEN AT CAPE KENNEDY, FLORIDA

By R. E. Turner, D. L. Johnson, and L. P. Gilchrist
Aero-Astrodynamics Laboratory

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16. ABSTRACT

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SUMMARY

Mesospheric wind data between 65-85 kilometer altitudes at Cape Kennedy, Florida, as determined from the Cajun Dart, Super Loki Dart, and Hopi Dart rocket systems from February 1964 through April 1970 are presented. The three vehicle systems are individually described in detail. These rocket systems deliver wind-sensitive aluminized mylar chaff, which is ejected above 90 kilometers. Wind flow data are obtained by radar tracking of the chaff, which is free to drift with the wind as it falls. Wind data measurements made once daily from March 19 to April 21, 1970, were analyzed and an error analysis of the measuring system made. The data reduction methods are also described.

I. INTRODUCTION

The launching of large space vehicles and studies of new aerospace vehicle systems has increased the need for more accurate and detailed wind information in the upper atmosphere especially above 60 km altitude. Wind measurements are needed for (1) vehicle design, and re-evaluation of current design criteria, (2) mission planning, and (3) mission evaluation studies. The need to establish the degree of accuracy for the wind measuring system, and to provide a basis for the confidence a user may place on the data is obvious. Also, studies of wind flow characteristics from a meteorological viewpoint are dependent upon additional data in this region, where data are sparse.

Before 1964, there had been few high altitude wind soundings taken over Cape Kennedy, Florida. J. W. Smith* presented an early listing, with analysis, on a relatively few high altitude soundings obtained over the Cape Kennedy area during the late 1950's and early 1960's. Since 1964, high altitude winds have been measured at Cape Kennedy, Florida, by means of the Hopi-Dart, Cajun-Dart, Super Loki-Dart and other rocket systems. This report provides information on three of these vehicle measuring systems, the data reduction methods used, and an analysis of errors in the system based on tracking response and data reduction techniques. The MSFC Hopi-Dart, and Cajun-Dart systems have been phased out. Only the Super Loki-Dart wind system is currently active in MSFC programs

*MSFC Report MTP-AERO-62-3, "Cape Canaveral Wind Summary - Surface to 84 Kilometers, January 17, 1962."

at KSC. The three rocket systems could also be used to measure atmospheric parameters other than winds with a change in payload instrumentation. Also presented are all NASA-MSFC high altitude chaff-wind measurements between 65-85 km taken during the period February 1964 through April 1970 at Cape Kennedy, Florida, thereby extending the scope of our previous report [1]. A brief analysis of measurements made once daily from March 19 to April 21, 1970 is described. Many of the high altitude soundings presented here were obtained in support of NASA space vehicle launches.

Reference 2 gives a good discussion of the chaff-wind measuring system. The bibliography of reference 3 lists many chaff-wind reports that have been published.

Acknowledgement is given to Mr. Archie L. Jackson of the MSFC Computational Laboratory for his programming assistance.

II. VEHICLE DESCRIPTION

A. Cajun-Dart System

The Cajun-Dart chaff rocket [4] is a two-stage sounding vehicle with a solid propellant motor as the first stage and a nonpropulsive Dart as the second stage. The first stage of the vehicle consists of the Cajun Mod III rocket motor, an igniter, a booster fin set, an interstage, and a forward launch lug (Figure 1). The Cajun motor is 259.1 centimeters long, and has a principal diameter of 16.5 centimeters. The motor, without the flight hardware, weighs 77.566 kg with 53.752 kg of propellant. The normal burning time of 2.8 seconds, with a total impulse of 11,450 kg-sec, yields a vehicle burnout velocity of slightly over 1,525 m/sec at an altitude of 2,140 meters.

The booster fins, which are screwed onto the rocket motor at the launch site, are used to stabilize the vehicle during propulsive flight. The first fin set contains the aft launch lug as an integral structure. The forward launch lug is integral with its mounting ring, which is mated to the forward end of the rocket motor. This mounting ring is retained by the interstage assembly which is screwed onto the forward end of the motor. In addition to providing structural coupling between the booster and Dart, the interstage provides electrical leads and a connector to energize the Dart delay at launch.

The motor igniter (Figure 2) consists of a combustible plastic tube containing two Flare Northern Model 209 squibs, 7.5 grams of ignition powder and 90 grams of USF-2A ignition granules. The two squibs, which have a 1 ampere/1 watt rating, are wired in parallel to each other. The leads into the igniter, which are twisted and shielded, terminate in a self-shorting connector.

The characteristics of the booster squib are as follows:

Resistance (Squib)	0.95 to 1.25 ohm
Maximum No Fire	1.8 ampere
Minimum All Fire	2.4 ampere
Firing Circuit	4.5 ampere
Igniter Resistance	0.45 to 1.00 ohm

The second-stage Dart is 4.45 centimeters in diameter, is 131.0 centimeters long, and weighs 7.82 kilograms. It is a nonthrusting stage which functions only as a low drag payload housing for obtaining high coasting efficiency. The nose of the Dart has been designed to minimize wave drag, and the aft end of the Dart has been boattailed to minimize base drag. The forward end of the Dart consists of a steel ogive with a lead ballast insert to insure aerodynamic stability and provide a high ballistic coefficient. The Dart body houses the payload, which is contained within two split steel staves. A small piston is located aft of the payload staves and forward of the hot gas separation charge. When this charge is ignited, the piston forces the steel payload staves against the ogive, causing the shear screws which connect the ogive to the Dart body to yield, and the continued generation of gas pressure by the separation charge forces the piston to eject the payload staves from the forward end of the Dart body. The separation charge is ignited by an electrically initiated 145-second pyrotechnic time delay, which is incorporated in the Dart tail section just aft of the separation charge. The pyrotechnic time delay is connected in parallel with the rocket motor igniter and is initiated at launch. Leads for the time delay terminate in a male connector at the aft end of the Dart. This connector mates with the matching female connector in the booster's interstage during assembly of the Dart to the booster at the launch site.

The characteristics of the Dart Squib are as follows:

Resistance	1.0 ± 0.3 ohm
Maximum No Fire	0.5 ampere
Minimum All Fire	1.0 ampere
Firing Circuit	2.0 ampere
Delay (bridgewire initiation to flash)	145 ± 15 seconds

The payload of the Cajun-Dart is aluminized Mylar "SS" band chaff packed into the split staves. The chaff has a thickness of 0.0127 mm. The volume available for the chaff payload is 490 cubic centimeters. Upon ejection of the staves from the Dart body at apogee, the staves separate and the chaff bundles are free to disperse and follow the wind flow. A radar (FPS-16) skin tracks the Dart and the chaff after ejection, obtaining data between 85 and 65 km altitude.

The Cajun-Dart is launched from a simple rail in an underslung launch configuration (Figure 3). This launch rail can be attached to any suitable launcher framework structure which is capable of supporting the weight of the launch rail and vehicle and which provides for the setting and locking of launch elevation and azimuth angles. References 4 and 5 contain additional information on the Cajun-Dart system.

B. Super Loki-Dart System

The Super-Loki-Dart chaff rocket [5] is a two-stage sounding vehicle consisting of a solid-propellant Super Loki rocket motor as the first stage and a nonpropulsive Dart containing the payload as the second stage (Figure 4). The first stage of the Super Loki-Dart is essentially a scaled-up version of the standard Loki-Dart vehicle motor consisting of an aluminum cast with an internal burning case-in-the-case solid propellant. The Super Loki motor has a length of 198.12 cm and a principal diameter of 10.16 cm. The motor, without the flight hardware, weighs 5.26 kg and carries 16.87 kg of propellant. The nominal burning time of 2.1 seconds produces a total impulse of 19,580 kg-sec, and yields a burnout velocity of slightly over 1797 m/sec at an altitude of 1577.6 m. When the booster burns out, the aerodynamic differential drag causes the booster to separate from the Dart. After separation, the Dart coasts to payload ejection.

The igniter consists of two parallel 1 ampere/1 watt no-fire squibs and an appropriate ignition charge. The igniter, which is separable from the motor, is installed at the launch site.

The second-stage Dart is 4.13 cm in diameter, is 122.33 cm long and weighs 6.12 kg. The Dart body, made of steel, has a steel ogive and an aluminum tailpiece. The cylindrical body contains the chaff payload which is packaged into split steel staves. The ogive is retained at the forward end of the body with shear-screws, which are sheared during payload expulsion from the forward end of the Dart. The tailpiece contains an electrically activated pyrotechnic time delay and a small payload ejection charge. Four steel fins are roll-pinned into the Dart tail for flight stability. The aft end of the Dart tail is boattailed for reduction of aerodynamic drag and for mating the Dart to the booster.

The Dart igniter contains an electrically activated 145-second pyrotechnic time delay which is initiated at launch. The characteristics of the squib in the delay initiator are the same as those of the Cajun-Dart.

The payload consists of ten bundles of "S" band aluminized mylar chaff with a thickness of 0.0127 mm. The payload volume is 491.6 cm^3.

The Super Loki-Dart launcher consists of four helical rails, which complete approximately one-third of a revolution throughout the launch rail length. The launch rail assembly (see Figure 5) consists of six cast aluminum sections bolted together to form a continuous rail assembly, 4.39 m long. The four internal rails, which are equally spaced, form four continuous helics throughout the assembly length. The edges of the rails are stepped to support the vehicle by the Dart fins and the rocket motor nozzle ring. The outside diameter of the launch rail assembly is 26.04 cm.

The purpose of the launch rail is to impart a 8.5 rps spin to the vehicle by constraining the Dart's fins to a helical path during their travel along the launch rails. The aft end of the motor travels for 4.39 meters before its release from the launcher. The Super Loki-Dart Launcher Rail Assembly can be mounted to any suitable launcher base by means of forward and aft mounting brackets. A pull-away umbilical harness is provided with the launch rail assembly to retract the Dart firing line during first motion of the vehicle. See references 3 and 5 for additional details on the Super Loki-Dart System.

C. Hopi-Dart System

The objective of this program was to develop a high altitude wind measuring system in support of launches at Cape Kennedy, Florida, and to acquire data for use in vehicle development at altitudes between 70 and 85 kilometers. The Hopi-Dart [6] is a two-stage flight vehicle (Figure 6) consisting of a booster as first stage, and an unpowered Dart as second stage. The first stage uses a Hopi III solid propellant rocket motor, 0.114 meters in diameter, and 2.014 meters long. The second stage is an inert Dart, 0.035 meters in diameter and 1.128 meters long. The Dart contains aluminized Mylar chaff and the payload ejection system. At first-stage burnout (2.4 sec), differential drag causes separation of the first stage from the Dart. The Dart then coasts to apogee. The payload is designed to eject from the Dart at approximately T + 135 sec. The Hopi-Dart is launched from a rail attached to an I-beam structure (Figure 7).

The Hopi-Dart vehicle igniter consists of two S-90 squibs for firing the motor. The two squibs are wired in parallel, and are the one-amp/one-watt type. The characteristics of the motor igniter are as follows:

Igniter Resistance	1.1 ± 0.4 ohm
Maximum Safe Test Current	0.02 ampere
Recommended Firing Current	4.0 ampere

The Dart igniter used to eject the payload is a small propellant charge initiated by a pyrotechnic time delay. It is connected in parallel with the motor igniter. The characteristics of the igniter are as follows:

Igniter Resistance	1.0 ± 0.3 ohm
Maximum Safe Test Current	0.02 ampere
Recommended Firing Current	4.0 ampere

A radar (FPS-16) skin tracks the Dart and then tracks the chaff payload. The radar tracks the chaff from apogee to an altitude of 65 km or loss of signal. Data are obtained by radar printing of time, elevation and azimuth angles, and slant range position. Another method is by reducing the radar plotting board which is a graphical location of the chaff by altitude, time, and position.

III. TEST RESULTS

From February 13, 1964, through April 21, 1970, a total of 92 Hopi-Dart, Cajun-Dart, and Super Loki-Dart vehicles were launched at Cape Kennedy, Florida. Of this total 75 launches produced wind data. The 17 data failures were due to either (1) ejection mechanism failures or (2) radar not acquiring track of the chaff. The 75 usable data soundings resulted from three Hopi-Dart, 67 Cajun-Dart, and five Super Loki-Dart wind profiles (see Table 1). The 75 soundings obtained have been reduced to tabular form at 30-sec intervals and are plotted as arrowgrams in figures 8 through 35 (see paragraph c of section IV on Data Reduction Procedure). Note that not all 75 soundings are plotted in this report. Five soundings gave results at altitudes below those listed on the figures, and were therefore not plotted. The wind flow data shown in figures 8 through 35 indicate a westerly wind flow trend at most high altitudes (above 65 km) from November through March; easterly winds prevail from May through September. October and April appear to be

Table I. Summary of MSFC High Altitude Chaff-Wind Measurement Flights at Cape Kennedy, Florida

No.	Vehicle	Date	Time	Results
1	Hopi-Dart	13 Feb. 1964	1828 Z	Data Obtained
2	"	13 Feb. 1964	2145 Z	"
3	"	14 Feb. 1964	2103 Z	"
4	Cajun-Dart	17 Feb. 1965	1904 Z	"
5	"	24 Feb. 1965	1508 Z	"
6	"	26 Feb. 1965	1730 Z	"
7	"	5 Marc 1965	*	No Data Acquisition
8	"	10 Mar. 1965	1942 Z	Data Obtained
9	"	17 Mar. 1965	1710 Z	"
10	"	24 Mar. 1965	1745 Z	"
11	"	31 Mar. 1965	1700 Z	"
12	"	7 Apr. 1965	1700 Z	"
13	"	14 Apr. 1965	1744 Z	"
14	"	21 Apr. 1965	1715 Z	"
15	"	28 Apr. 1965	*	No Data Acquisition
16	"	12 May 1965	1900 Z	Data Obtained
17	"	26 May 1965	1700 Z	"
18	"	2 Jun. 1965	1700 Z	"
19	"	11 Jun. 1965	1700 Z	"
20	"	16 Jun. 1965	1800 Z	"
21	"	23 Jun. 1965	1725 Z	"
22	"	30 Jun. 1965	1503 Z	"
23	"	7 Jul. 1965	1500 Z	"
24	"	14 Jul. 1965	1709 Z	"
25	"	21 Jul. 1965	1700 Z	"
26	"	23 Jul. 1965	1700 Z	"
27	"	28 Jul. 1965	1400 Z	"
28	"	13 Aug. 1965	1722 Z	"
29	"	18 Aug. 1965	1700 Z	"
30	"	25 Aug. 1965	1700 Z	"
31	"	1 Sept. 1965	1700 Z	"
32	"	17 Sept. 1965	1700 Z	"
33	"	22 Sept. 1965	1700 Z	"
34	"	29 Sept. 1965	1600 Z	"
35	"	6 Oct. 1965	1718 Z	"
36	"	13 Oct. 1965	*	No Data Acquisition
37	"	20 Oct. 1965	1700 Z	Data Obtained
38	"	27 Oct. 1965	*	No Data Acquisition
39	"	1 Nov. 1965	1700 Z	Data Obtained
40	"	8 Nov. 1965	*	No Data Acquisition
41	"	17 Nov. 1965	1700 Z	Data Obtained
42	"	24 Nov. 1965	1700 Z	"
43	"	29 Nov. 1965	1700 Z	"
44	"	8 Dec. 1965	1700 Z	"
45	"	17 Dec. 1965	1700 Z	"

Table I (Continued)

No.	Vehicle	Date	Time	Results
46	Cajun-Dart	22 Dec. 1965	1640 Z	Data Obtained
47	"	5 Jan. 1966	1600 Z	"
48	"	12 Jan. 1966	*	No Data Acquisition
49	"	19 Jan. 1966	*	"
50	"	27 Jan. 1966	1705 Z	Data Obtained
51	"	11 Feb. 1966	*	No Data Acquisition
52	"	22 Feb. 1966	1100 Z	Data Obtained
53	"	25 Feb. 1966	1830 Z	"
54	"	26 Feb. 1966	1812 Z	"
55	"	4 Jul. 1966	*	No Data Acquisition
56	"	5 Jul. 1966	1645 Z	Data Obtained
57	"	24 Aug. 1966	1630 Z	"
58	"	25 Aug. 1966	1908 Z	"
59	"	24 Jan. 1967	0806 Z	"
60	"	8 Nov. 1967	1300 Z	"
61	"	9 Nov. 1967	1430 Z	"
62	"	23 Jan. 1968	0200 Z	"
63	"	4 Apr. 1968	1851 Z	"
64	"	11 Oct. 1968	2001 Z	"
65	"	20 Nov. 1968	1941 Z	"
66	Super-Loki	20 Nov. 1968	2245 Z	"
67	Super-Loki	19 Dec. 1968	1800 Z	Data Obtained
68	"	19 Dec. 1968	1910 Z	"
69	Cajun-Dart	19 Mar. 1970	1707 Z	"
70	"	20 Mar. 1970	1700 Z	"
71	"	23 Mar. 1970	1600 Z	"
72	"	25 Mar. 1970	1600 Z	"
73	"	26 Mar. 1970	*	No Data Acquisition
74	"	27 Mar. 1970	1700 Z	Data Obtained
75	"	30 Mar. 1970	*	No Data Acquisition
76	"	31 Mar. 1970	1700 Z	Data Obtained
77	"	1 Apr. 1970	*	No Data Acquisition
78	"	2 Apr. 1970	*	"
79	"	3 Apr. 1970	*	"
80	"	6 Apr. 1970	1700 Z	Data Obtained
81	"	7 Apr. 1970	1525 Z	"
82	"	8 Apr. 1970	1700 Z	"
83	"	9 Apr. 1970	1700 Z	"
84	Super-Loki	10 Apr. 1970	2020 Z	"
85	"	11 Apr. 1970	2143 Z	"
86	Cajun-Dart	13 Apr. 1970	*	No Data Acquisition
87	"	14 Apr. 1970	*	"
88	"	15 Apr. 1970	1700 Z	Data Obtained
89	"	16 Apr. 1970	1700 Z	"
90	"	17 Apr. 1970	1700 Z	"
91	"	20 Apr. 1970	1700 Z	"
92	"	21 Apr. 1970	*	No Data Acquisition

the transitional wind shift months. See references 7, and 8, which deal with seasonal shifting of the winds at high altitudes. The soundings also indicate wind speeds to be generally higher in winter than in summer. Table II summarizes the highest wind speeds by month as taken from all soundings between 66-80 km altitude.

Table II. Cape Kennedy, Florida Measured Peak Wind Speeds by Month

Month	Speed (m/s)	Altitude (km)	No. of Profiles
January	129	74	4
February	105	71	9
March	74	69	10
April	88	80	14
May	75	78	2
June	82	66	5
July	96	71	5
August	49	77	5
September	54	74	4
October	66	72	3
November	105	72	8
December	117	71	5

A. Special Month Long Series

The last series of meteorological rocket launches at Cape Kennedy, Florida, consisted of 24 vehicles fired at the rate of one per day. These firings occurred at or near local noon during a one-month period from March 19, 1970, through April 21, 1970. Of the 24 vehicles used, 22 were Cajun-Darts and 2 were Super-Loki Darts. There were 16 successful shots which gave wind data, along with 8 failures (6 ejection mechanism failures and 2 with radar not acquiring chaff cloud). For more details, see Table 1. Each chaff release was simultaneously tracked by two radars: the FPS-16 and the MOD II.

The 24 vehicles were launched in late March and throughout most of April 1970 in an attempt to sound the upper atmosphere (65 to 85 km altitude region), on a daily basis, during the wind regime change from the winter to the summer season. Webb [7] and Mitchell [8] have discussed these wind regime changes that occur in the spring and fall in some detail; therefore, no major analysis of the detailed wind structure or circulation is presented in this report. Only a quick look at the general wind change patterns at these high altitudes is given. Lovill and Reiter [10] conducted a similar project, using chaff (gun launched) as the wind sensor, to study the autumn wind reversal between 60-70 km altitude, over the Colorado Rockies, during September 1969.

The 16 wind-direction and wind-speed profiles obtained from this test are plotted from approximately 60 to 80 km altitude in vertical-time analyses shown in figures 36 and 37, respectively. Also shown in these figures are Loki-Dart meteorological rocket wind soundings which extend the primary data to lower altitude levels.

The Loki-Darts were launched within two hours of the Cajun-Darts. The two wind figures presented here were plotted from the tabular wind data which have been interpolated to the whole kilometer altitude levels.

Data are interpolated in figures 36 and 37 where there is no measured data. The wind directions shown in figure 36 were classified as follows: East winds are defined as all winds from 34° east of north through 146°; south winds from 147° through 213°; west winds from 214° through 326°, and north winds from 327° through true north to 34°.

B. Preliminary Analysis

Webb [7] indicates that the stratospheric circulation index (SCI) at Cape Kennedy, Florida, shifts from a westerly winter component to an easterly summer wind component around the end of April at the 50 km altitude level. Figure 36 indicates a breakdown of the dominant winter westerly flow starting around April 15, 1970. In the 45 to 50 km region, for that day, the wind shows a southerly direction with future days exhibiting an easterly flow pattern. The summer easterly regime begins to dominate by the end of May 1970. The entire 25 through 80 km wind directions given in figure 36 show a general clockwise shifting of the wind with altitude while in the late winter regime. Easterly flow prevails below 35 km and shifts through the south to the west throughout the 50 to 70 km region. From here it shifts through north to another easterly regime above 70 km. Unfortunately, no high altitude wind data were taken after April 20, 1970, thereby leaving a void in the high altitude wind pattern during this transition period. Wind speeds during the winter regime, shown in figure 37, indicate a band of strong winds from 65 to 70 km altitude enveloped by weaker winds below and above, although strong winds did exist between 70 and 80 km altitude just before and after April 15, 1970. The high wind speeds observed below 70 km altitude in figure 37 are questionable, since wind data measured in this region by radar tracking of the chaff cloud are usually unreliable because of chaff dispersion. Such a case occurred on April 10, 1970, with wind speeds of 102 m/sec observed at 60 km altitude. However, the entire chaff wind profiles were presented in figures 36 and 37 in order to provide a record of the data as recorded from the radar tracks.

IV. DATA ACCURACY

Although the evaluation of errors in rocket wind measuring systems at high altitudes has been the subject of considerable study, it cannot yet be considered as complete. Some conclusions appear reasonable and result in estimates of the system accuracy which are difficult to establish in every case from an objective and quantitative viewpoint.

Three types of errors exist in the data obtained by the Cajun-Dart System: errors in radar tracking, errors in measurement of response of the target to the winds, and errors introduced by the data reduction process. It is helpful to discuss these errors separately, examining the variation in one error while holding the others fixed. The errors interact on each other relative to the total system error. However, the maximum RMS error should not be greater than the total of all the errors obtained in the three types (9.8 mps). Likewise, the minimum RMS error should not be smaller than the smallest error (1.8 mps). The following sections present these error estimates.

A. Radar Tracking Errors

Radar information is obtained in the form of time, slant range, and elevation and azimuth angles from tracking the chaff from ejection near 90 km altitude. The only smoothing of the raw tracking data is the filtering due to the radar system tracking procedures.

The accuracy of the measured wind flow data is dependent upon the accuracy of the radar angular measurements. The RMS errors in the angular measurements are quoted for the AN/FPS-16 radar as follows: slant range 4.5 meters; elevation and azimuth angles 0.005 degrees.

The RMS errors in the computed X, Y, Z, position coordinates are presented graphically in Figures 1 through 3. It was assumed that $\Phi = 90°$ (azimuth), $\sigma_r = 4.5$ meters (slant range RMS), σ_θ and $\sigma_\Phi = 0.005$ degrees (elevation and azimuth RMS, respectively). Elevation (θ) measurement values between 30 and 75 degrees were used.

The above assumptions are realistic because the wind at high altitude blows from west to east during the winter when the wind speeds are highest. Figures 38 through 40 show the errors in Z and Y increase as the elevation angle decreases, while the error in X increases as the elevation angle increases. These curves are plotted from equations used by Scoggins [10]. Accuracy of the measured wind flow is determined by the accuracy of the position coordinates, the averaging interval Δt, and the layer Δh also. The RMS accuracy in wind speeds, σ_{wx}, is given by

$$\sigma_{wx} = \frac{[(\sigma_{x_2})^2 + (\sigma_{x_1})^2]^{1/2}}{\Delta t}, \tag{1}$$

where Δt is the time interval between the two measurements with RMS errors of one position to the next, σ_{x_1} and σ_{x_2}.

The accuracy of the measured wind speeds as a function of altitude is determined by the mean wind speed (this essentially controls the slant range and elevation angles), and the direction of the wind relative to the radar. Therefore, successively measured wind speeds at a given altitude may or may not have the same accuracy [10].

While holding all other errors fixed, the RMS error in the wind due to errors in the radar position coordinates was estimated to be 1.8 mps and 2 degrees.

B. Errors in Response of Chaff to the Wind

When chaff is used as a sensor of high altitude winds, the question arises as to how accurately the chaff responds to the wind.

Radar observations obtained from 0.0127-mm aluminized mylar chaff indicate that the chaff disperses over regions of about 0.1 sq. km within one minute after chaff deployment at an altitude of approximately 80 km (see Figure 41). In addition, the radar usually shows more than one particular area within the chaff cloud that reflects substantially more energy than any other area. Because of the changing wind flow, these high energy areas vary with time. Therefore, the chaff tracking error depends to a large extent upon the ambient wind conditions. To arrive at an RMS error from an examination of the quality of data, we may compute the sample variance:

$$S_{R_i}^2 = \frac{\sum_{i=1}^{N} R_i^2 - \frac{\left(\sum_{i=1}^{N} R_i\right)^2}{N}}{N - 1} , \qquad (2)$$

where S_{R_i} is the sample standard deviation of the "resultant" X and Y coordinate distances, R_i is the resultant distance, and N the sample size. To obtain the X and Y positions, the data on the radar plotting charts are reduced manually. This reduction shows the standard deviation (from the center of the chaff cloud) to be 118.6 meters. Therefore, the chaff cloud's highest energy areas can be within approximately 118 m of the cloud center.

While holding all the other errors fixed, the RMS error in the wind due to the response (shifting of primary energy of reflection areas) of the chaff was estimated to be 5 mps and 10 degrees.

C. Data Reduction Errors

Data reduction errors may be introduced into the computed winds by approximations in the equations or by the method selected for smoothing the target position data. The purpose of smoothing the data is to obtain a representative value of the variable over some Δt and/or Δh. The optimum smoothing technique is one that filters the noise from the data while retaining as much detailed information as possible. Unfortunately, the wind flow variable can behave in a random manner, and therefore some real wind flow information will always be filtered out along with the noise (or the noise will be left in with the real wind information). The appropriate amount of filtering to be done is a matter of judgement based on experience, assumed instrumented capabilities, and the requirement of the users.

1. Data Reduction Procedure

The Cajun-Dart data were computed by both the manual and the computer technique, and compared for likeness. The comparison of the results showed the two methods to be very nearly the same. The method currently being used (computer technique) decreases the possibility of human error in data handling. The radar output (Ele, Az, SR) data for each 15 seconds is arithmetically averaged to obtain the midpoint value. This midpoint value is tabulated at 30-second intervals with two 15-second data points on each side of the midpoint. This produces a variable

Δh (averaging) as a function of height due to the variation of chaff fall rate. See figure 42 regarding various fall rates.

The data reduction technique used is based on the assumption that the horizontal motion of the chaff is completely responsive to the wind flow for fall rates below 70 m/sec. Tracking data from the chaff with a fall rate of more than 70 m/sec were disregarded (see reference 11). The following equations were used for reduction of the Cajun-Dart chaff measurements. The altitude above the surface (Y_S') is

$$Y_S' = [R^2 + (R_E + Y_{SG})^2 + 2R(R_E + Y_{SG}) \sin \theta]^{1/2} - (R_E + Y_{SG}). \qquad (3)$$

The altitude above mean sea level (Y_S) is computed by the following equation:

$$Y_S = Y_S' + Y_{SG}, \qquad (4)$$

where

R = slant range in meters,

R_E = mean radius of the earth in meters,

Y_{SG} = station height in meters,

θ = elevation angle in degrees.

The rate of fall of the chaff (ROF) is computed over a 60-second interval by the following equation:

$$ROF_i = \frac{Y_{S_{(i-2)}} - Y_{S_{(i+2)}}}{t_{(i+2)} - t_{(i-2)}}, \qquad (5)$$

where Y_S is the altitude above mean sea level in meters and t is time in seconds. Rectangular position coordinates (X_c, Z_c, and Y_c) are determined by

$$X_c = R \cos \theta \sin \Phi$$

$$Z_c = R \cos \theta \cos \Phi \qquad (6)$$

$$Y_c = R \sin \theta,$$

where

θ = elevation angle,

Φ = azimuth angle,

R = slant range in meters.

Spherical position coordinates (Z_s and X_s) are determined by the following equations:

$$X_s = (R_E + Y_S) \sin^{-1} \frac{X_c}{R_E + Y_S}$$

$$Z_s = (R_E + Y_S) \sin^{-1} \frac{Z_c}{R_E + Y_S} \ . \tag{7}$$

Wind speed components (W_{WE} and W_{SN}) are then determined by the following equations:

$$W_{WE} = \frac{X_s(i+2) - X_s(i-2)}{t_{(i+2)} - t_{(i-2)}}$$

$$W_{SN} = \frac{Z_s(i+2) - Z_s(i-2)}{t_{(i+2)} - t_{(i-2)}} . \tag{8}$$

Component wind speeds are then resolved into wind speed (W) for time (t_i) by the equation

$$W_{t_i} = (W_{WE}^2 + W_{SN}^2)^{1/2} . \tag{9}$$

Wind direction (W_D) is determined by the following equation. Let

$$Q = \tan^{-1} \left| \frac{W_{WE}}{W_{SN}} \right| , \tag{10}$$

when neither the numerator nor the denominator is zero. Therefore, the following quadrant correction is applied to Q:

If W_{WE} + and W_{SN} + : $W_D = 180° + Q$

If W_{WE} + and W_{SN} - : $W_D = 360° - Q$

If W_{WE} - and W_{SN} - : $W_D = Q$

If W_{WE} - and W_{SN} + : $W_D = 180° - Q$

If W_{WE} + and $W_{SN} = 0$: $W_D = 270°$

If W_{WE} - and $W_{SN} = 0$: $W_D = 90°$

If $W_{WE} = 0$ and W_{SN} +: $W_D = 180°$

If $W_{WE} = 0$ and W_{SN} -: $W_D = 360°$

If $W_{WE} = 0$ and $W_{SN} = 0$: $W_D = 360°$.

2. Errors in Data Reduction

Using the above equations and the smoothing technique (computer handling of the sine, cosine, and arc tangent functions) the RMS error in the wind is estimated to be 3 mps and 5 degrees while holding all other errors fixed.

V. CONCLUSIONS

The following results were obtained in this study:

1. The chaff wind flow data obtained over Cape Kennedy, Florida, substantiates the fact of winter westerlies and summer easterlies up to altitudes of approximately 75 km. Wind directions at altitudes greater than 75 km appear somewhat erratic at times.

2. The maximum winds between 65-80 km altitude occur during the winter months over Cape Kennedy, Florida.

3. Mid-April 1970 appeared to be the starting of the winter westerly wind breakdown over Cape Kennedy, Florida, between 50 and 70 km altitude. Easterly winds prevailed thereafter into the summer months.

4. The winds shifted (clockwise) with increasing altitude from 25 to 80 km altitude just before the breakdown of the winter westerly flow in April 1970 over Cape Kennedy.

5. The RMS error in the wind due to errors in the radar position coordinates is estimated to be 1.8 mps and 2 degrees.

6. The RMS error in the wind due to the response of the chaff is estimated to be 5 mps and 10 degrees.

7. The RMS error in the wind due to data reduction techniques is estimated to be 3 mps and 5 degrees.

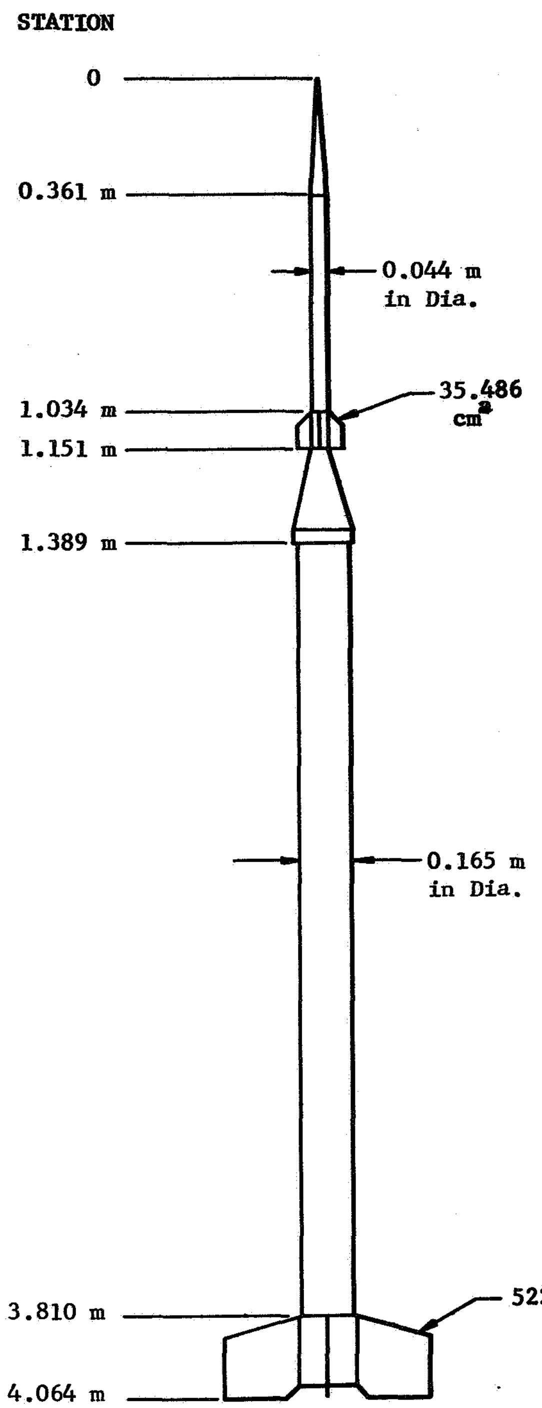
8. Although each of the errors interact to some extent with each other, the maximum RMS error should not be greater than the total of all the errors obtained in the three types (9.8 mps).

9. The minimum RMS error should not be smaller than the smallest error (1.8 mps).

10. The following equation can be used to compute a quick estimate for the accuracy of wind speeds in the 70-85 km altitude region based on chaff measurements:

$$W_c = W_R \pm W_R(0.59 - 0.007Z),$$

where W_R is the measured wind speed (mps), Z is the altitude (km), and W_c is the correct speed (mps).



WEIGHTS (KILOGRAMS)

DART	
Case	2.245
Ogive	3.175
Tail Ass'y	1.161
Chaff, Staves, etc.	1.257
TOTAL	7.838
CAJUN	
Interstage	1.814
Fins	3.320
Motor Hardware	21.909
Propellant	54.205
Total at Burnout	34.882
Total Vehicle at Launch	89.086

PERFORMANCE

(80^{o} Q.E. Sea Level Launch)

Sumit Altitude (km)	92.964
Max Velocity (m/sec)	1554.500
Burnout Time (sec)	3.100
Altitude at Burnout (km)	2.134
Ejection System	Pyrotechnic
Time Delay (T+sec)	Adjustable to Requirement

Developer: Space-Data, Inc.
Phoenix, Arizona

Figure 1. Cajun-Dart Vehicle

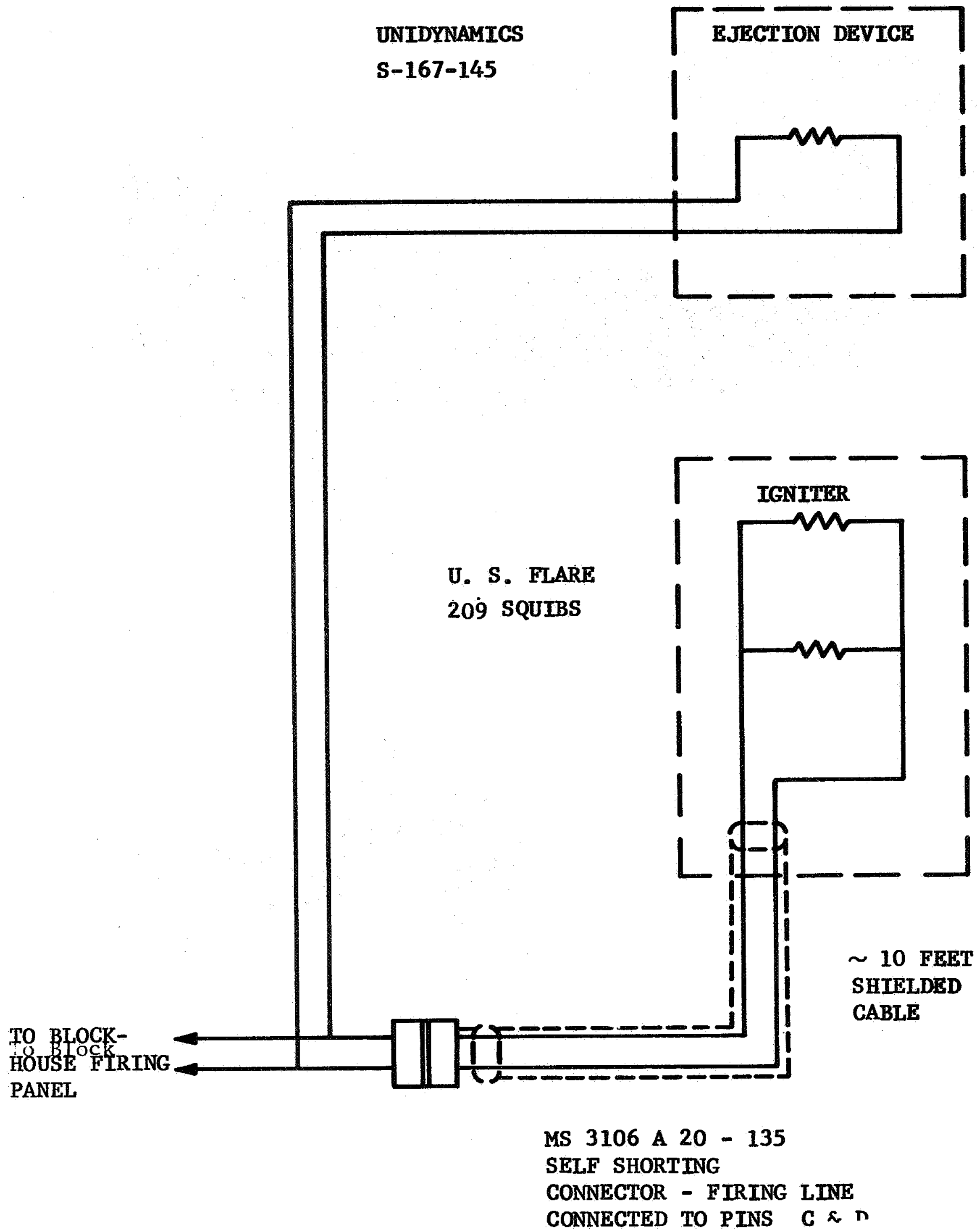


Figure 2. Cajun-Dart Igniter System

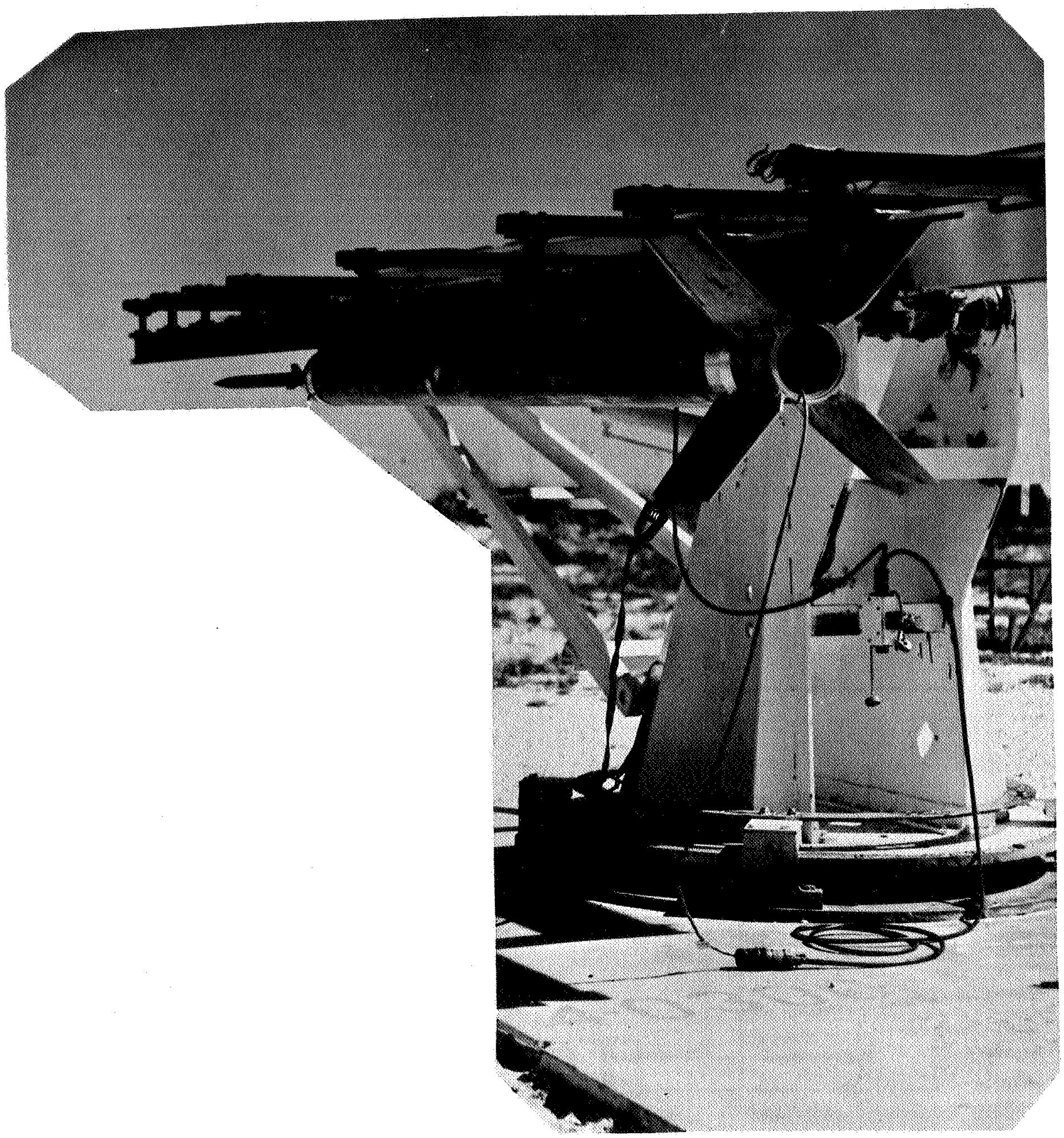
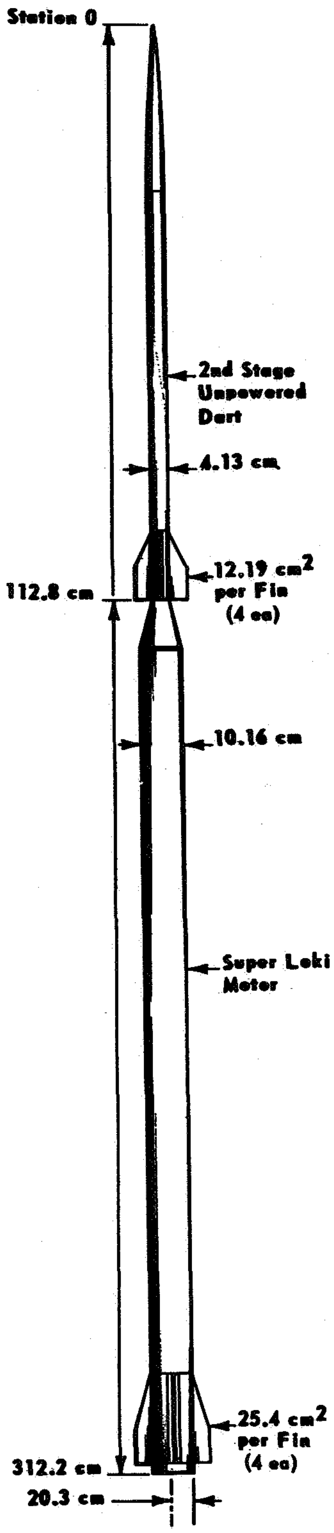


Figure 3. Cajun-Dart Vehicle and Launcher



WEIGHT (kilograms)

DART

Case Ogive Tail Assembly Chaff, Staves etc.	6.12

SUPER LOKI MOTOR

Interstage Fins Motor Hardware	5.32
Propellant	16.87
Total Vehicle at Launch	22.19

PERFORMANCE

(80° Q.E. Sea Level Launch)

Max. Altitude (km)	113.4
Max. Velocity (m/sec)	1797
Burnout Time (sec)	2.1
Altitude at Burnout (km)	1.577
Ejection System	Pyrotechnic
Time Delay (T sec)	Adjustable to Requirement

Developer: Space-Developer, Inc.
Phoenix, Arizona

Figure 4. Super Loki-Dart Vehicle

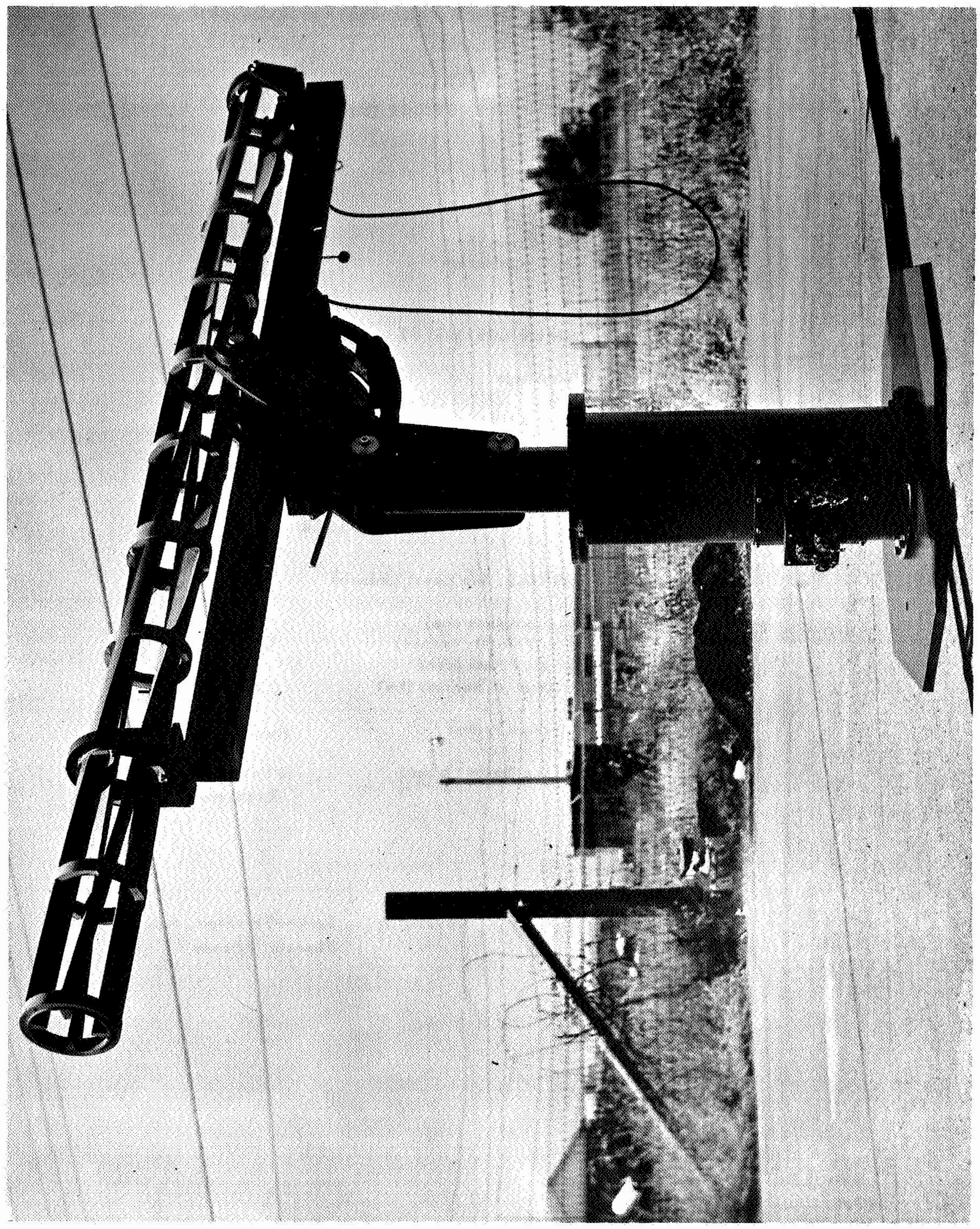
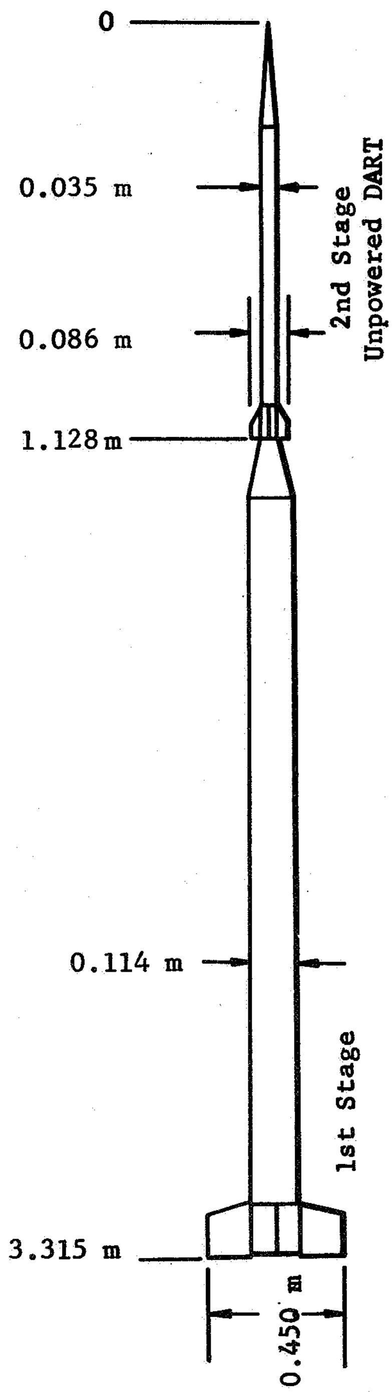


Figure 5. Super Loki-Dart Launcher



WEIGHTS (KILOGRAMS)

1st Stage Booster w/fins & interstage	38.102
Propellant	26,898
2nd Stage Dart	4.990
Total Vehicle	43.092

PAYLOAD

Diameter (m)	0.028
Internal Volume (cu. cm.)	295

PERFORMANCE

(80^{o} Q.E. Sea Level Launch)

Summit Altitude (km)	115.824
Max Velocity (m/sec)	1859.300
Max Acceleration (g's)	150
Burnout Time (sec)	2,400
Altitude at Burnout (km)	1.981
Ejection System	Pyrotechnic
Time Delay (T+sec)	Adjustable to Requirement

Developer: Rocket Power, Inc., Mesa, Arizona

Figure 6. Hopi-Dart Vehicle

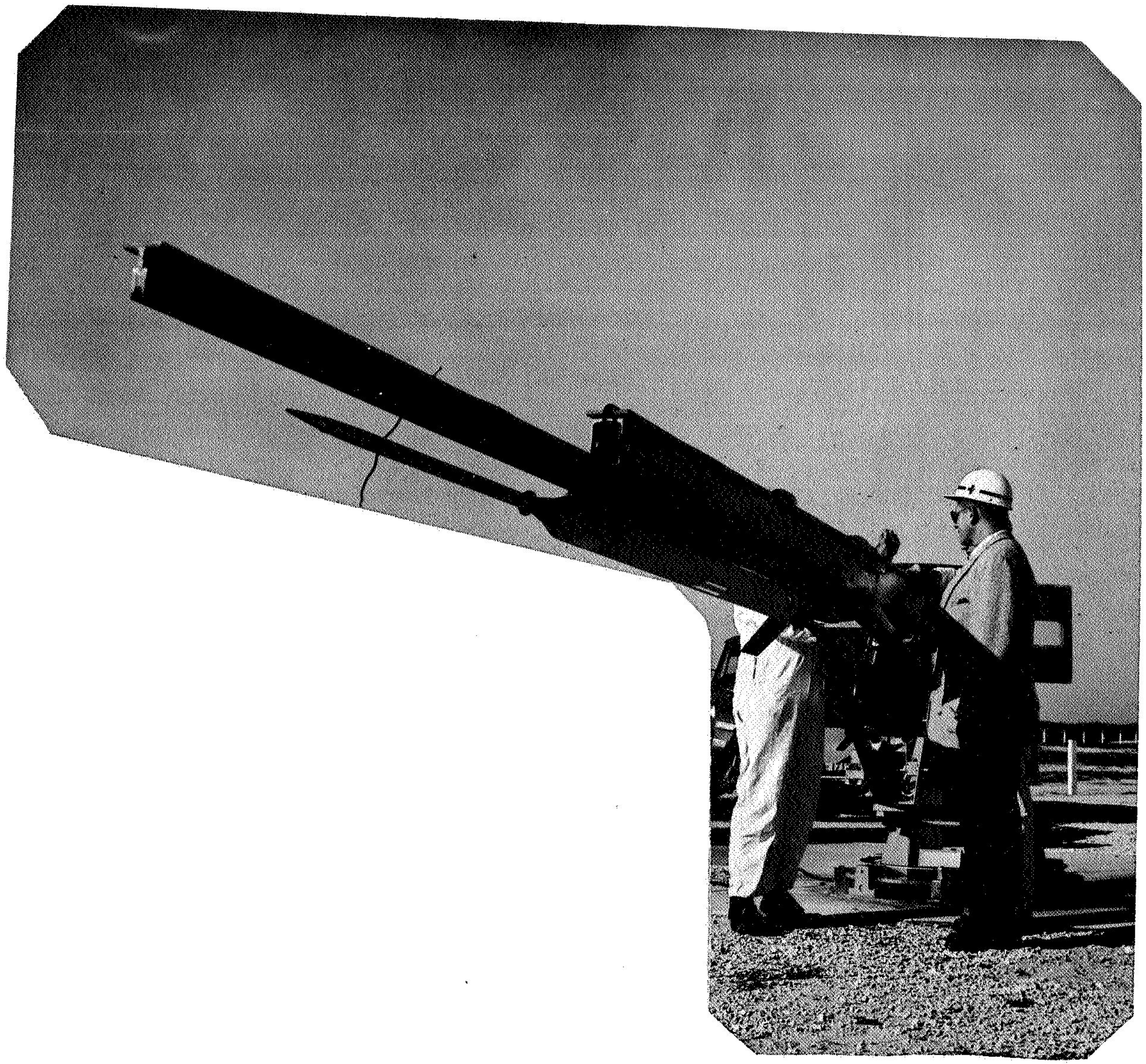


Figure 7. Hopi-Dart Vehicle and Launcher

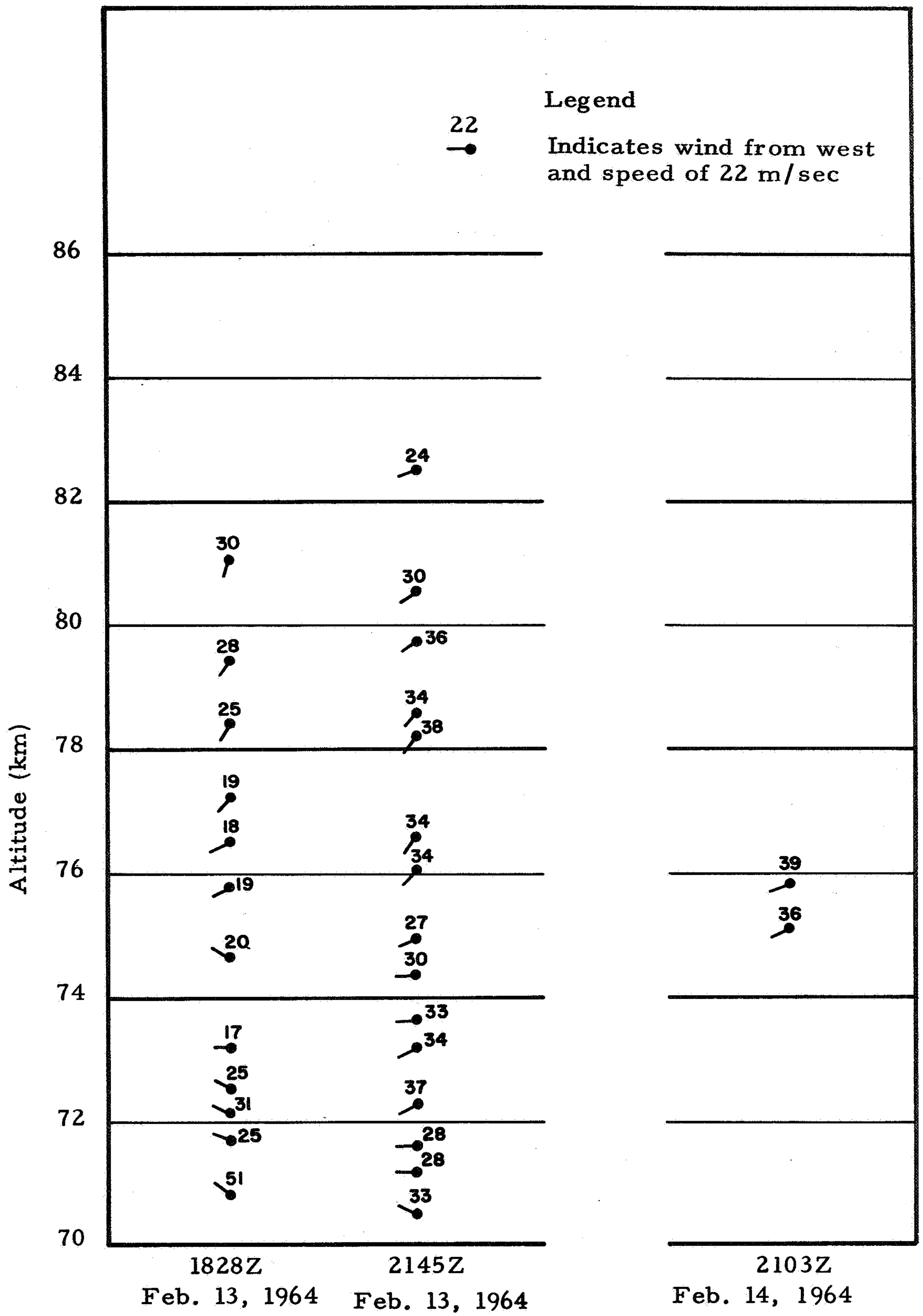


Figure 8. Hopi-Dart Measured Wind Profiles,
Cape Kennedy, Florida, February 1964

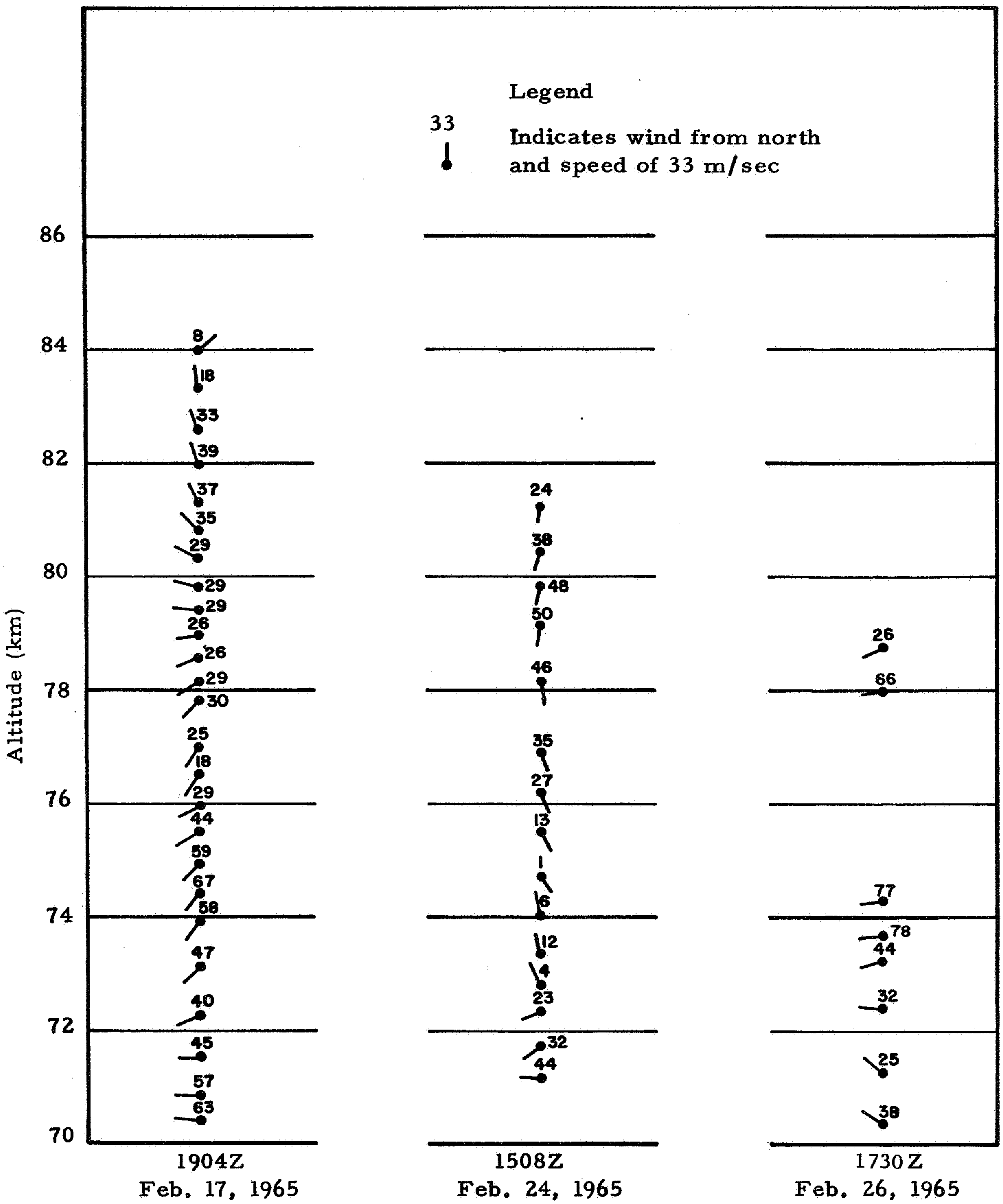


Figure 9. Cajun-Dart Measured Wind Profiles, Cape Kennedy, Florida, February 1965

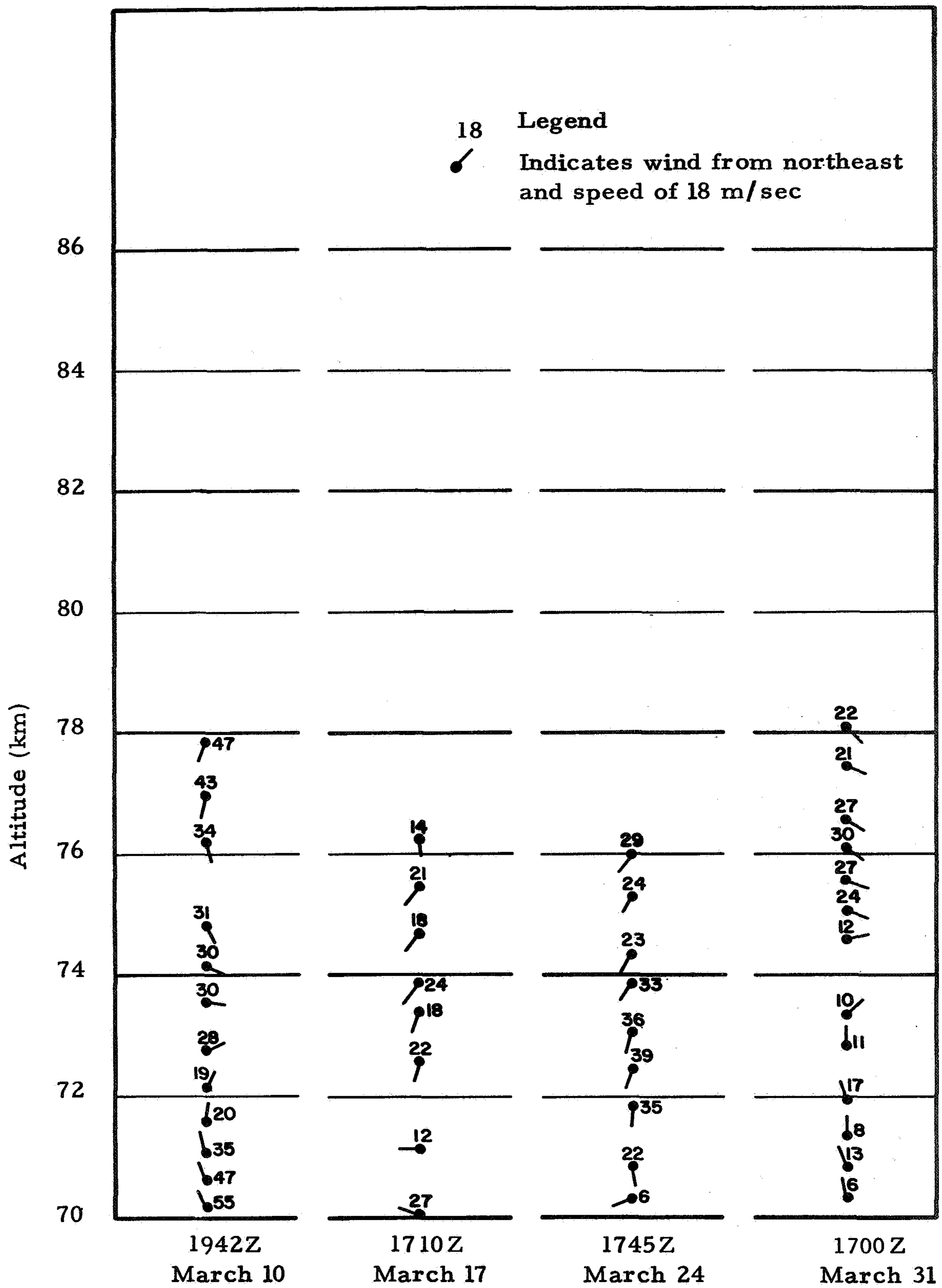


Figure 10. Cajun-Dart Measured Wind Profiles, Cape Kennedy, Florida, March 1965

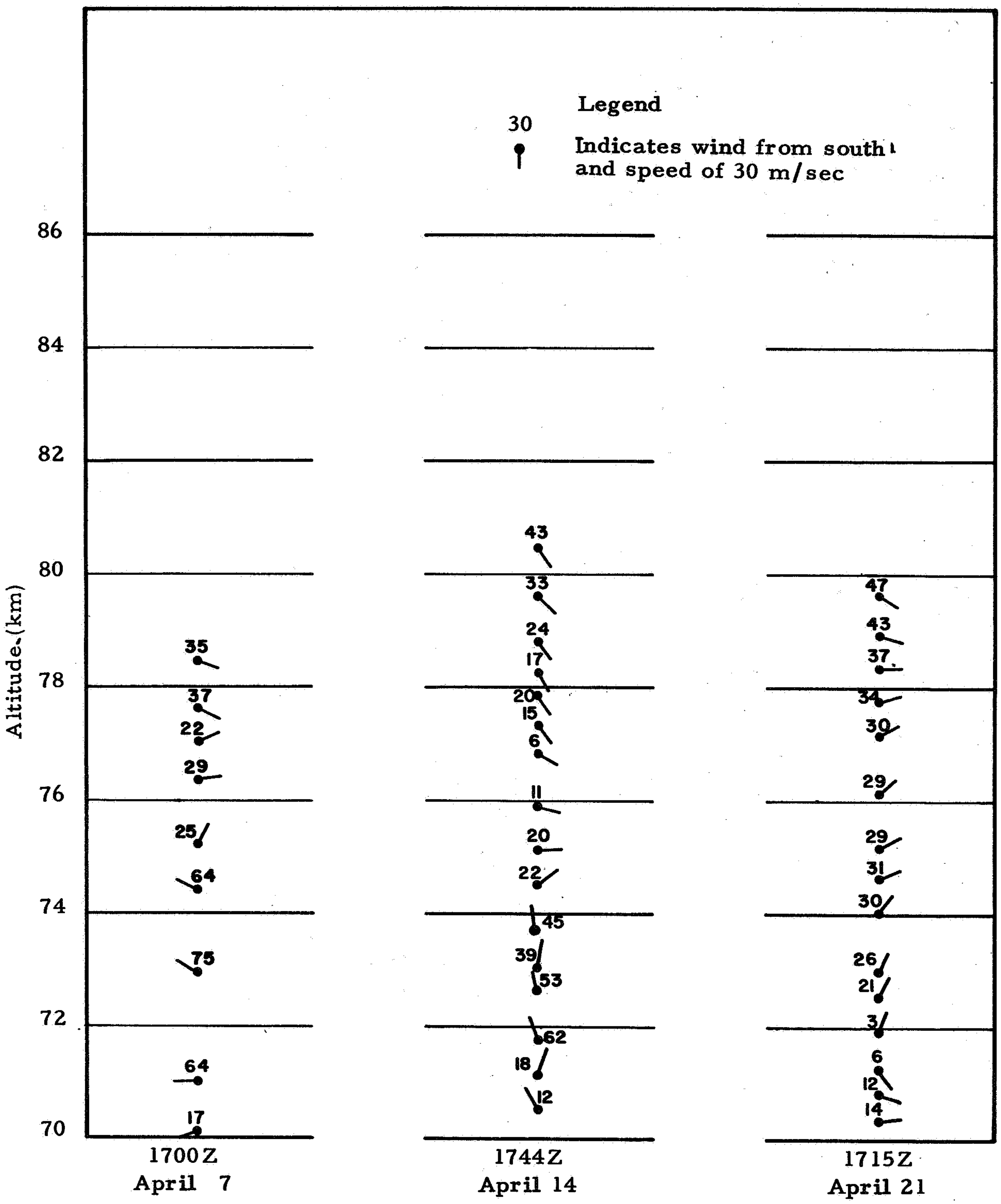


Figure 11. Cajun-Dart Measured Wind Profiles, Cape Kennedy, Florida, April 1965

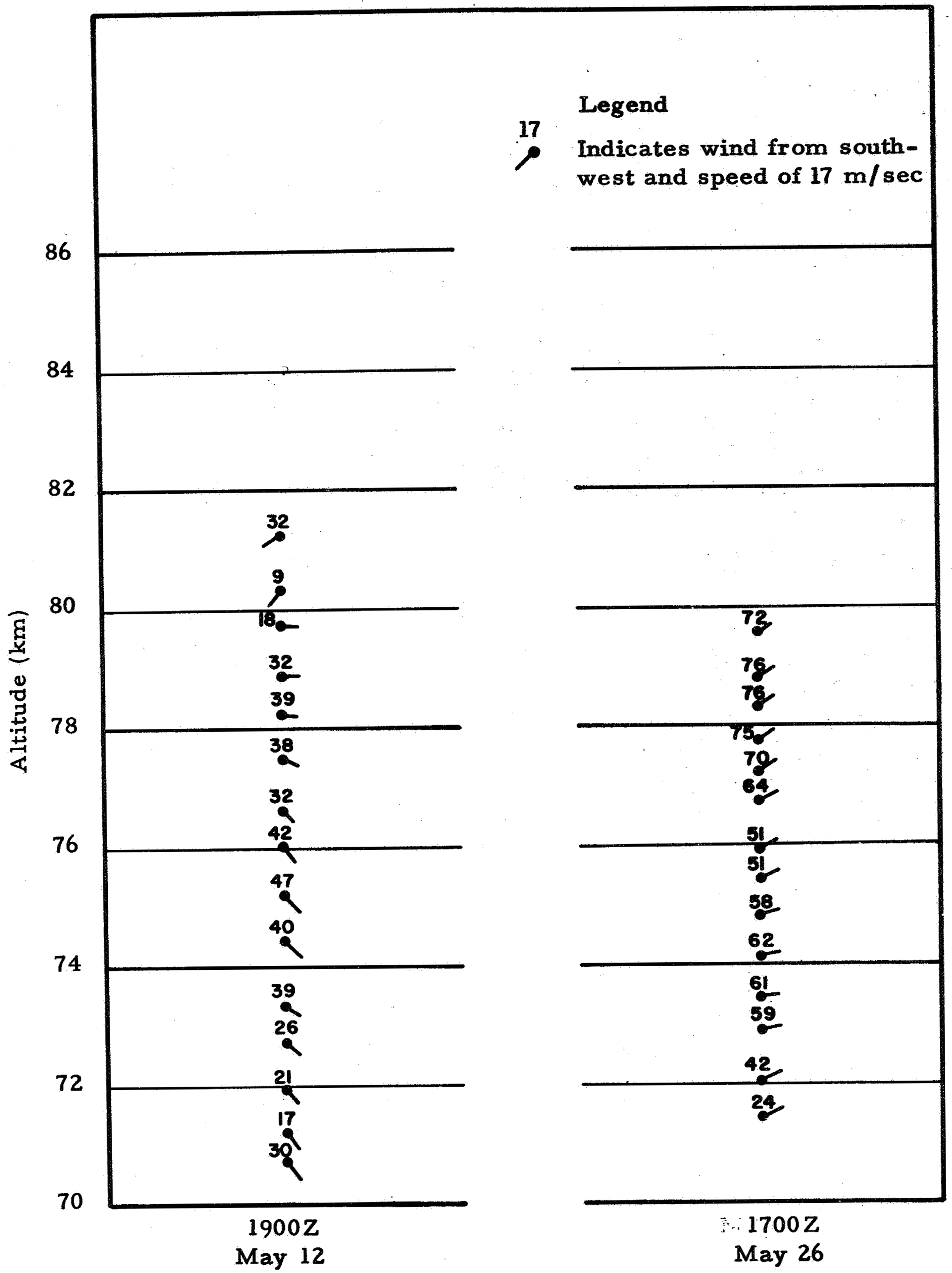


Figure 12. Cajun-Dart Measured Wind Profiles, Cape Kennedy, Florida, May 1965

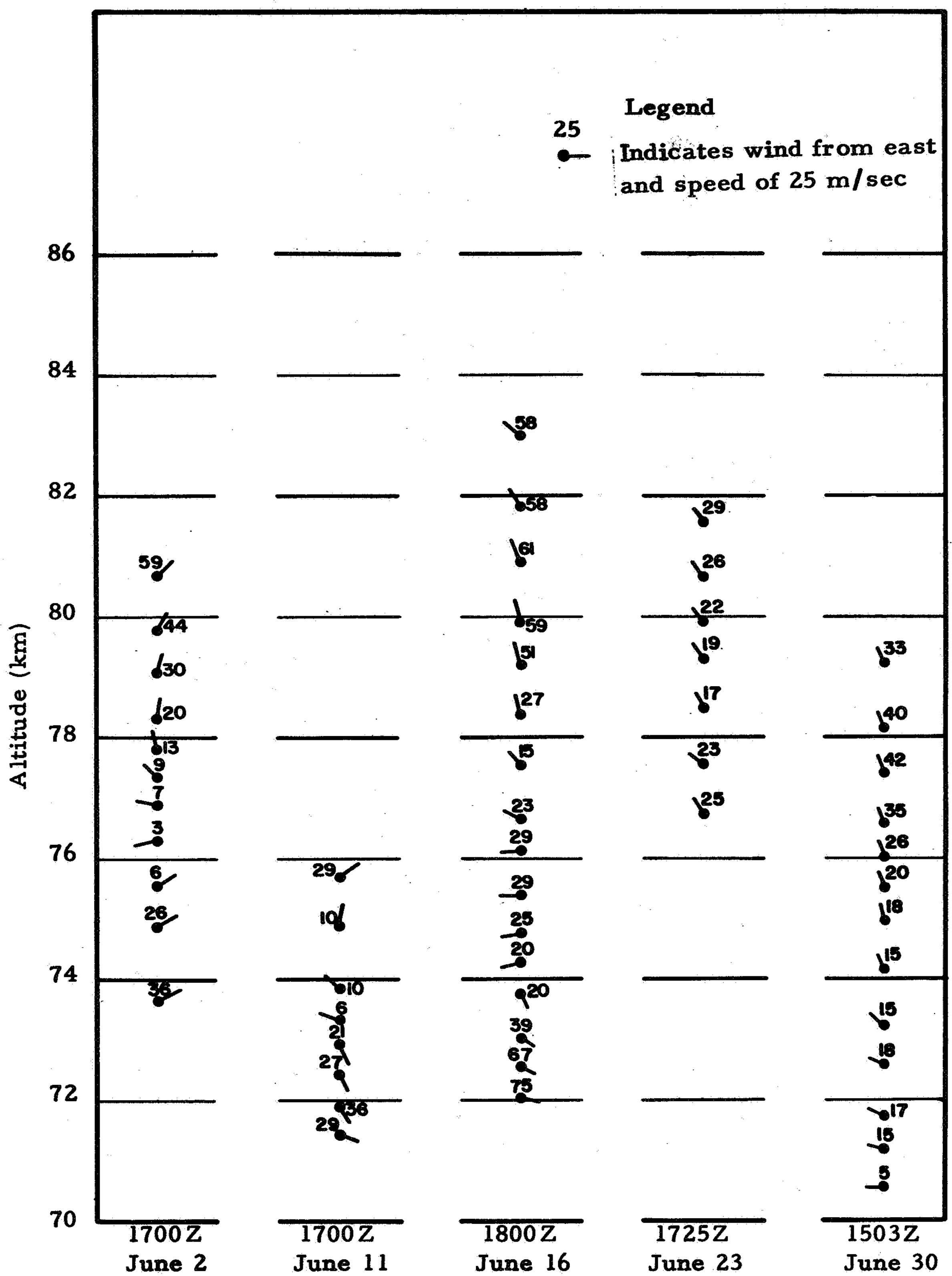


Figure 13. Cajun-Dart Measured Wind Profiles, Cape Kennedy, Florida, June 1965

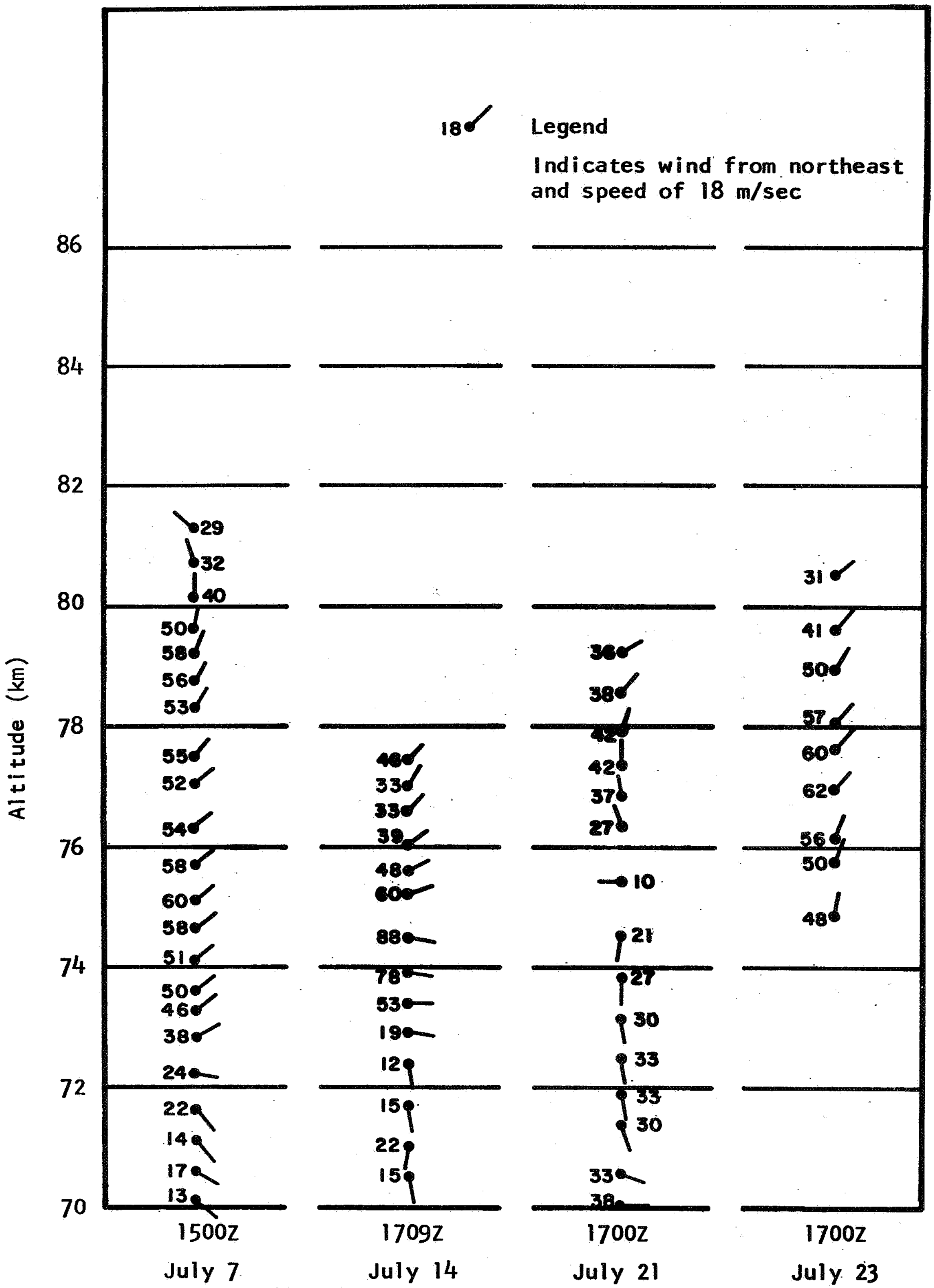


Figure 14. Cajun-Dart Measured Wind Profiles,
Cape Kennedy, Florida, July 1965

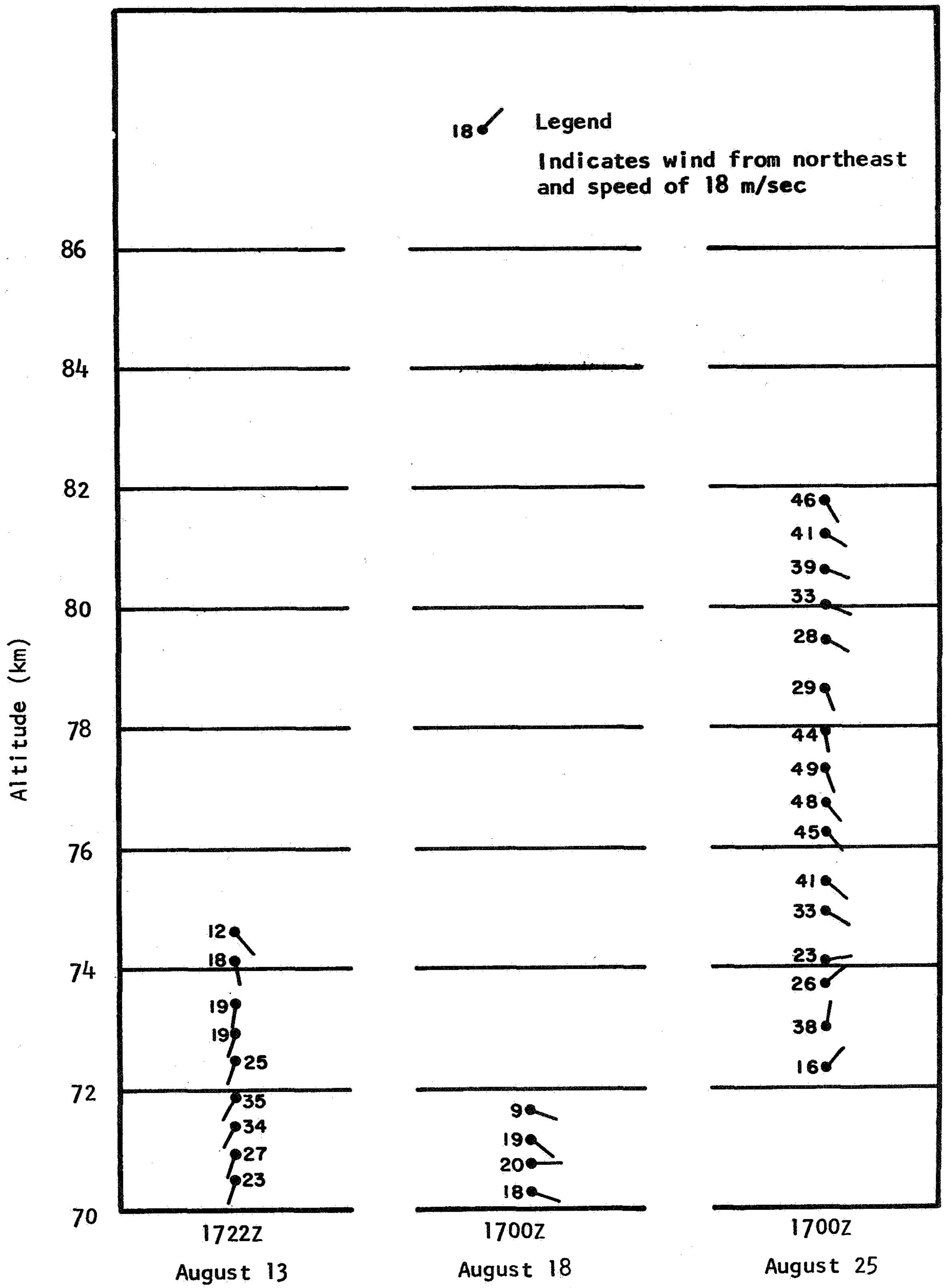


Figure 15. Cajun-Dart Measured Wind Profiles, Cape Kennedy, Florida, August 1965

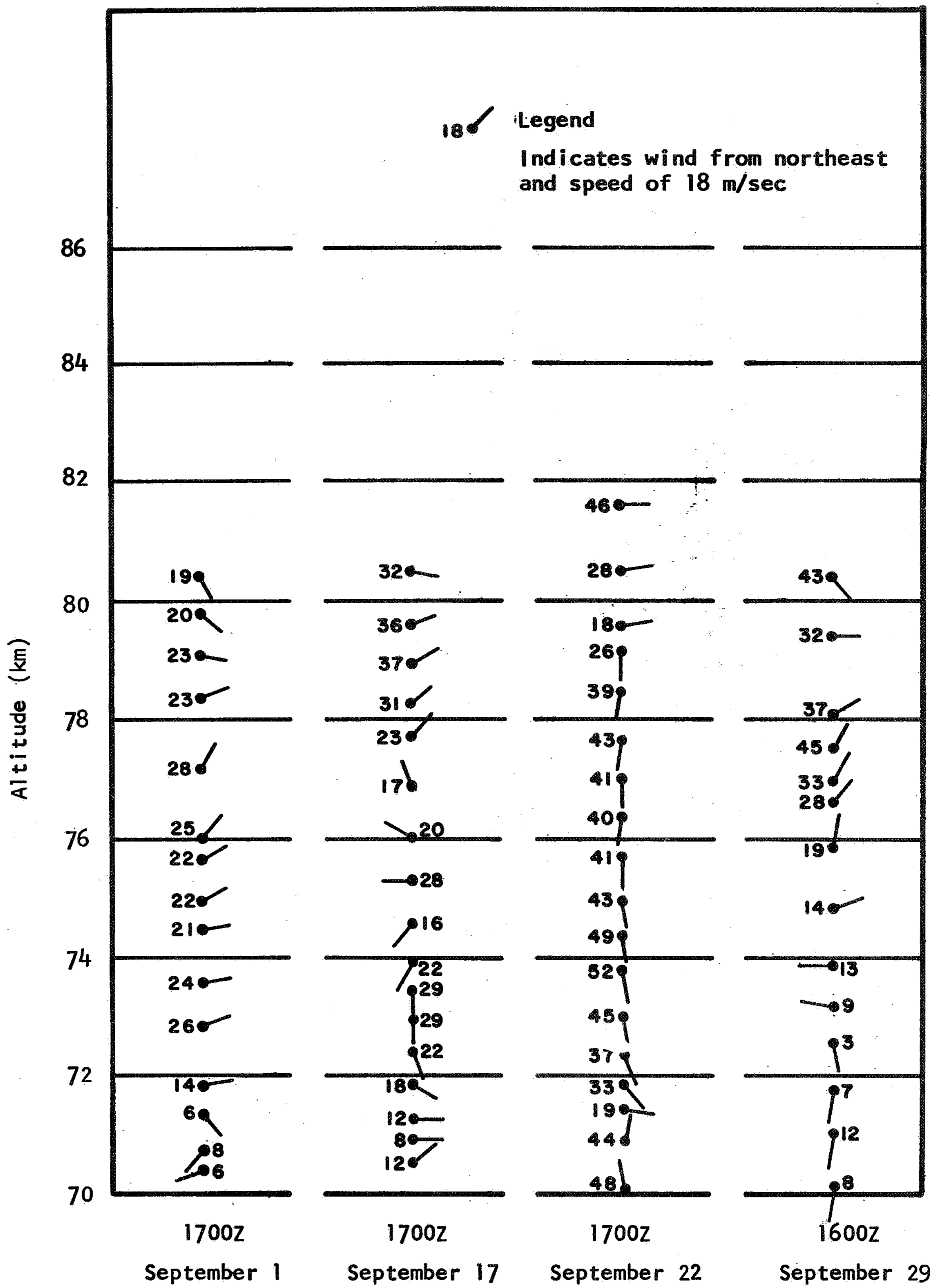


Figure 16. Cajun-Dart Measured Wind Profile, Cape Kennedy, Florida, September 1965

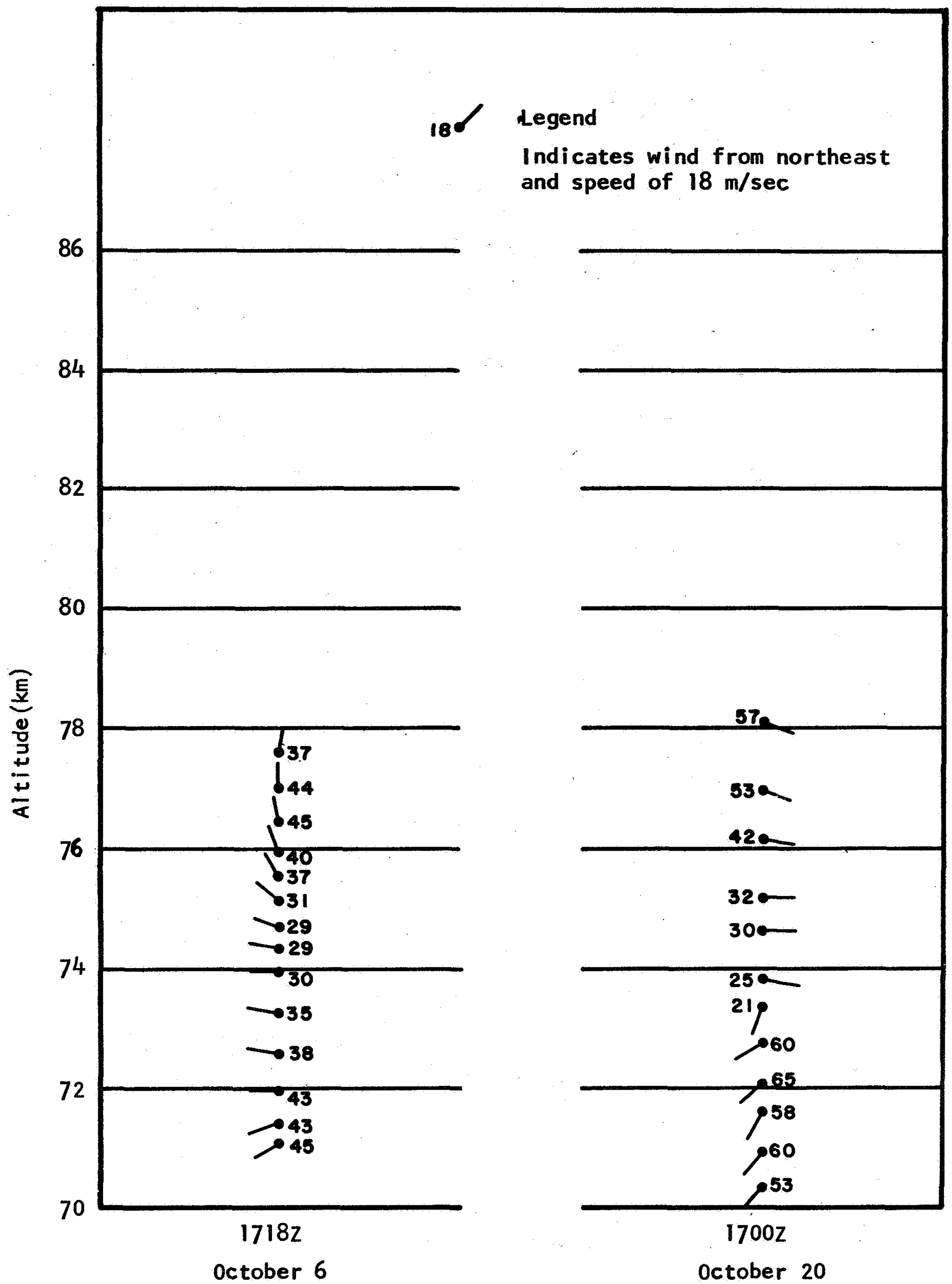


Figure 17. Cajun-Dart Measured Wind Profiles,
Cape Kennedy, Florida, October 1965

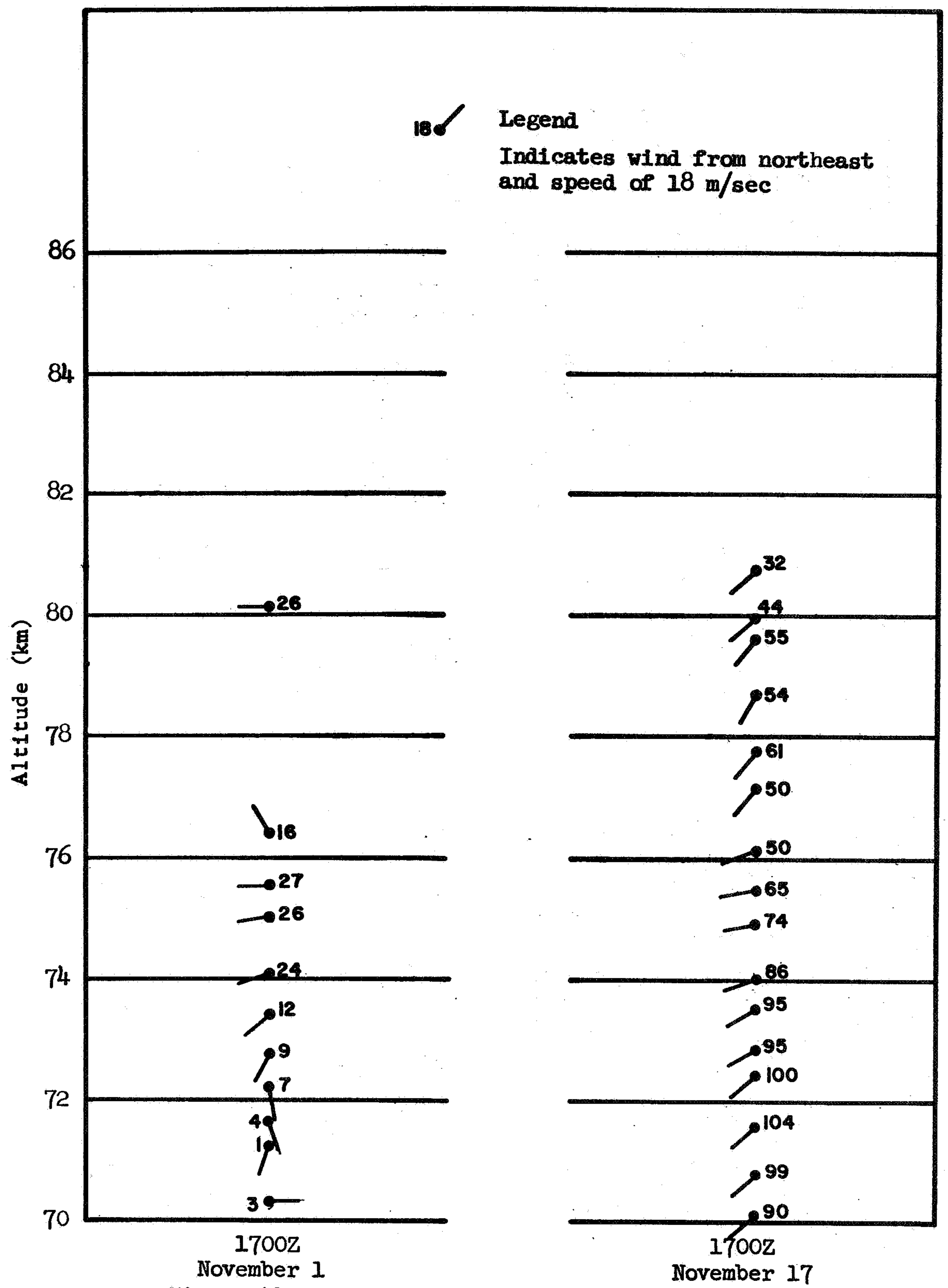


Figure 18. Cajun-Dart Measured Wind Profiles, Cape Kennedy, Florida, November 1965

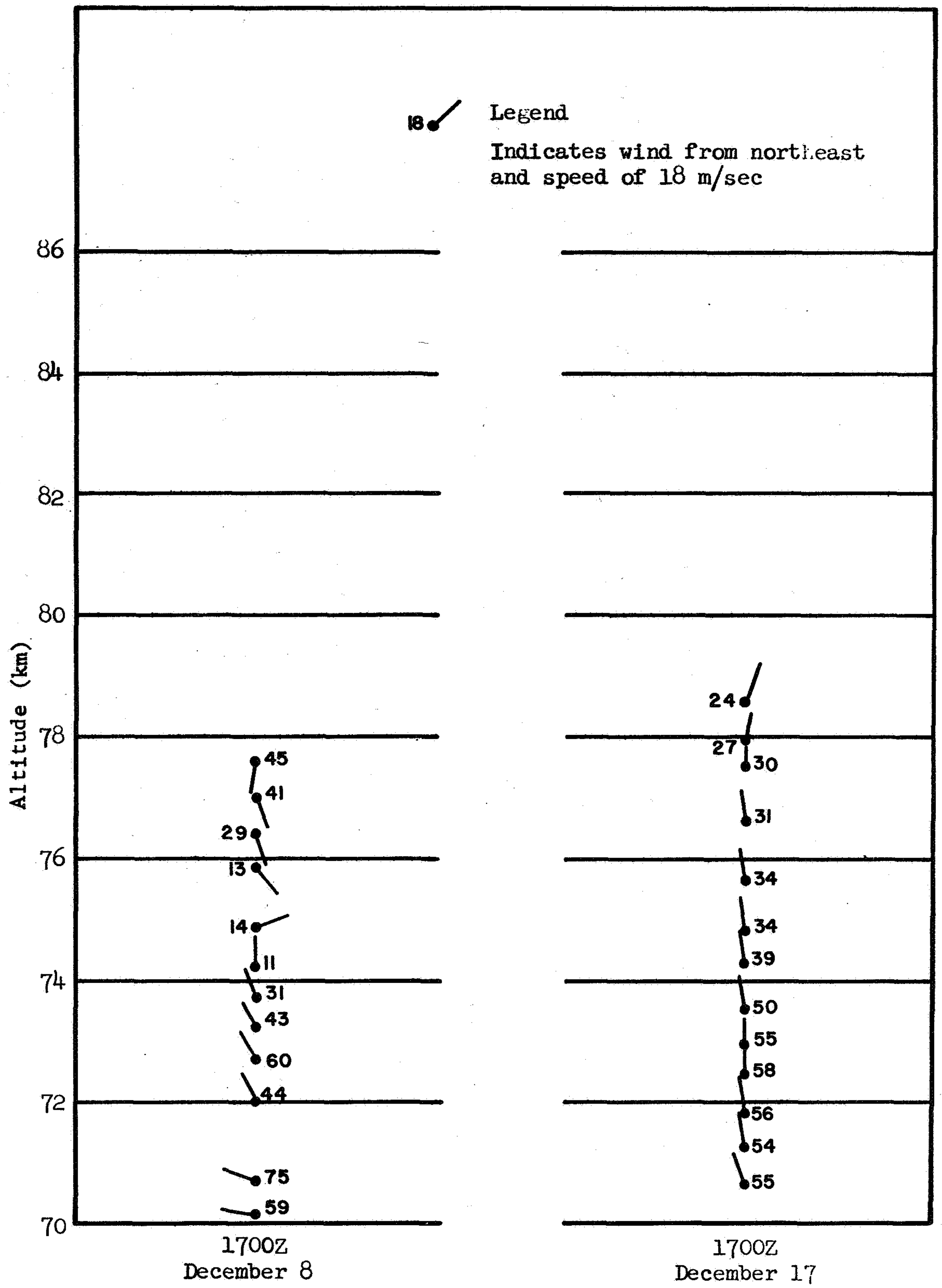


Figure 19. Cajun-Dart Measured Wind Profiles, Cape Kennedy, Florida, December 1965

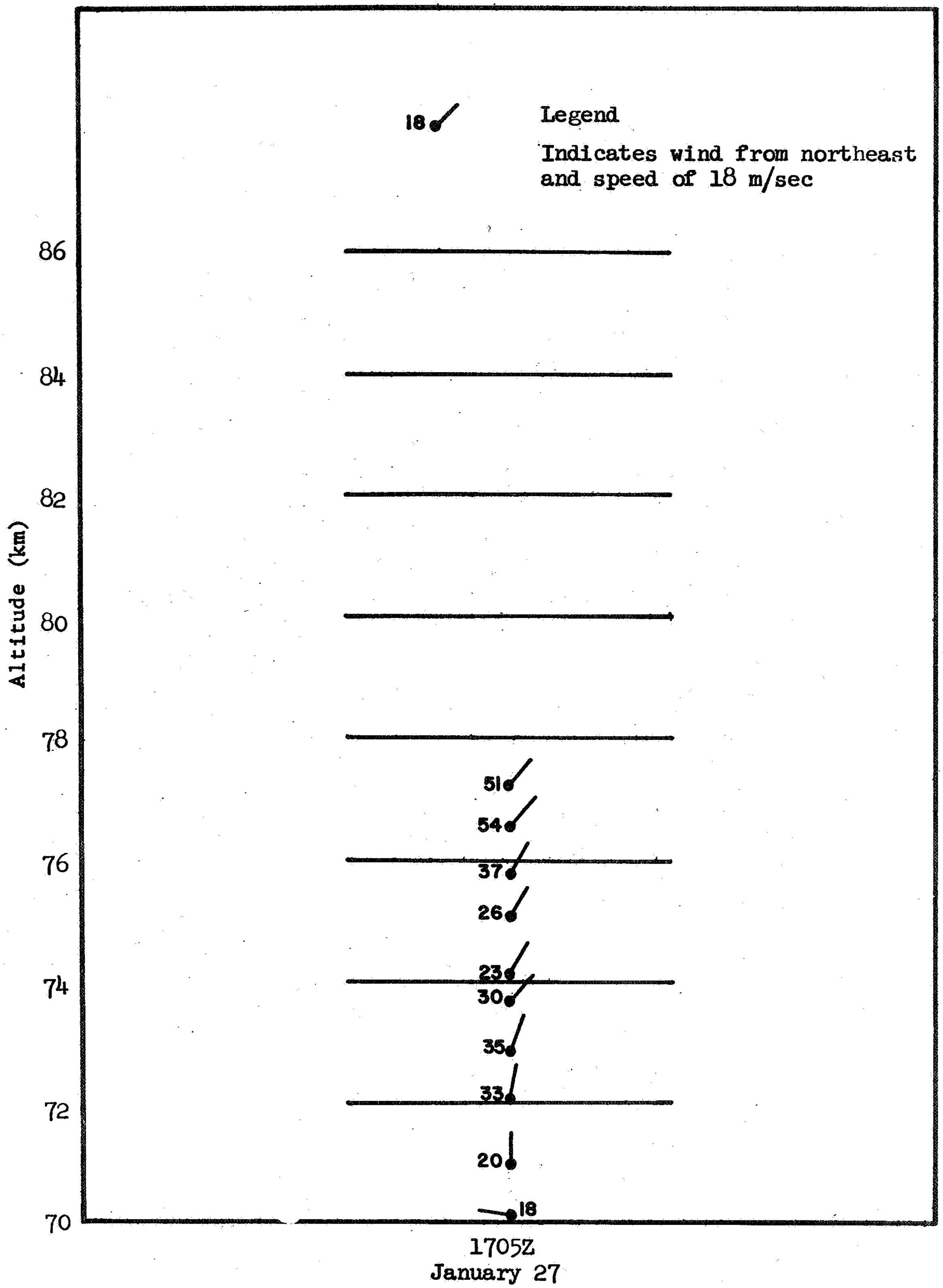


Figure 20. Cajun-Dart Measured Wind Profiles, Cape Kennedy, Florida, January 1966

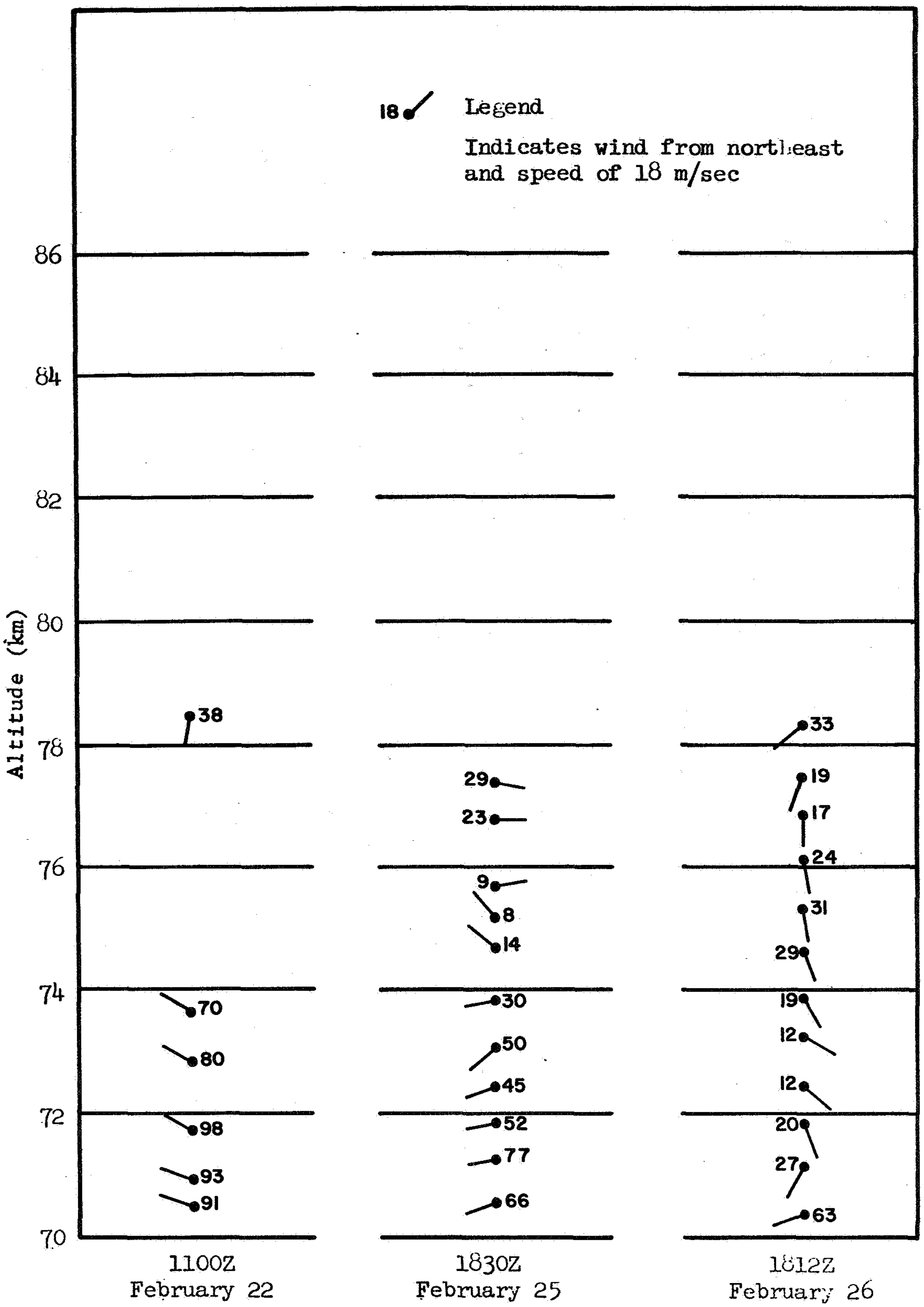


Figure 21. Cajun-Dart Measured Wind Profiles,
Cape Kennedy, Florida, February 1966

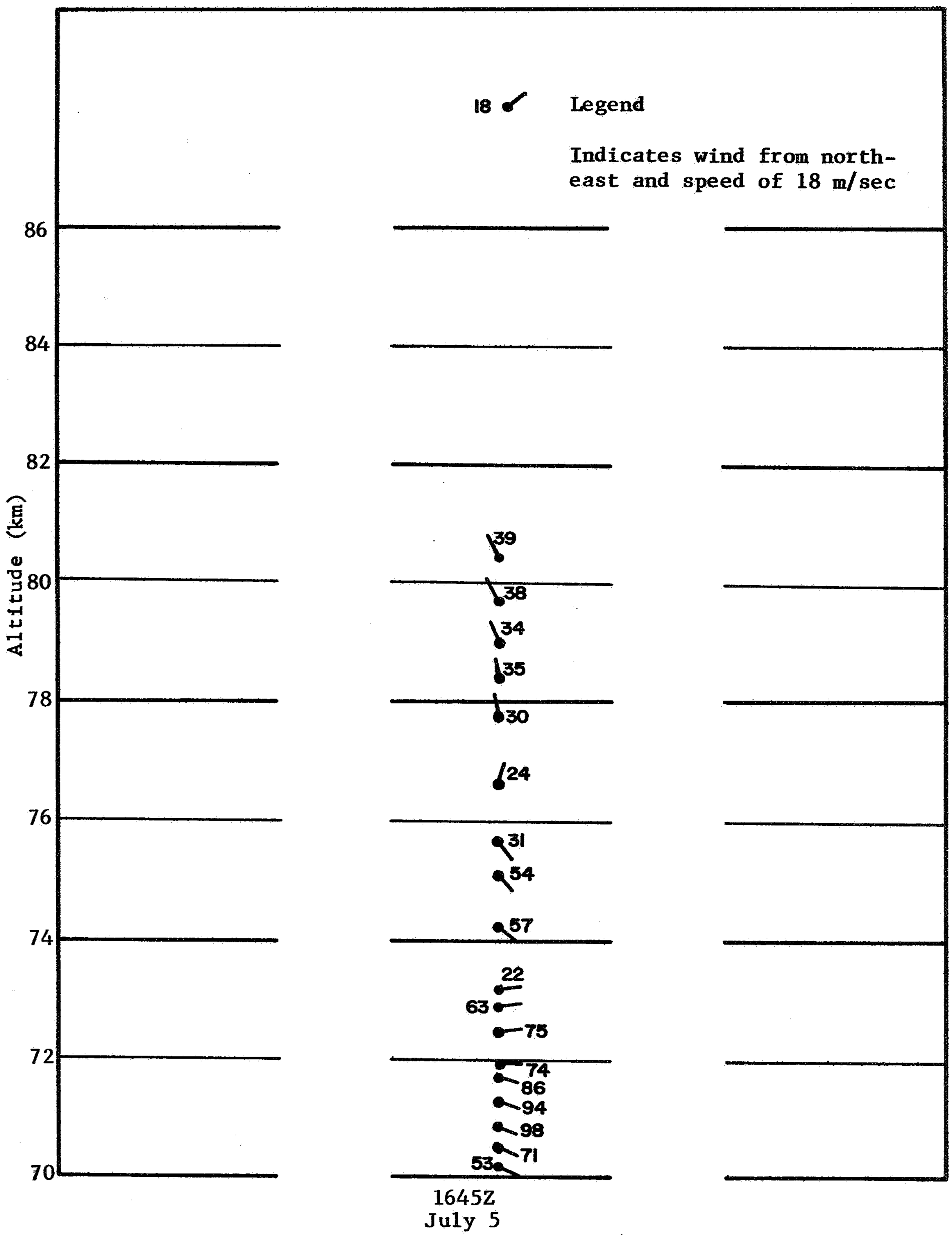


Figure 22. Cajun-Dart Measured Wind Profiles, Cape Kennedy, Florida, July 1966

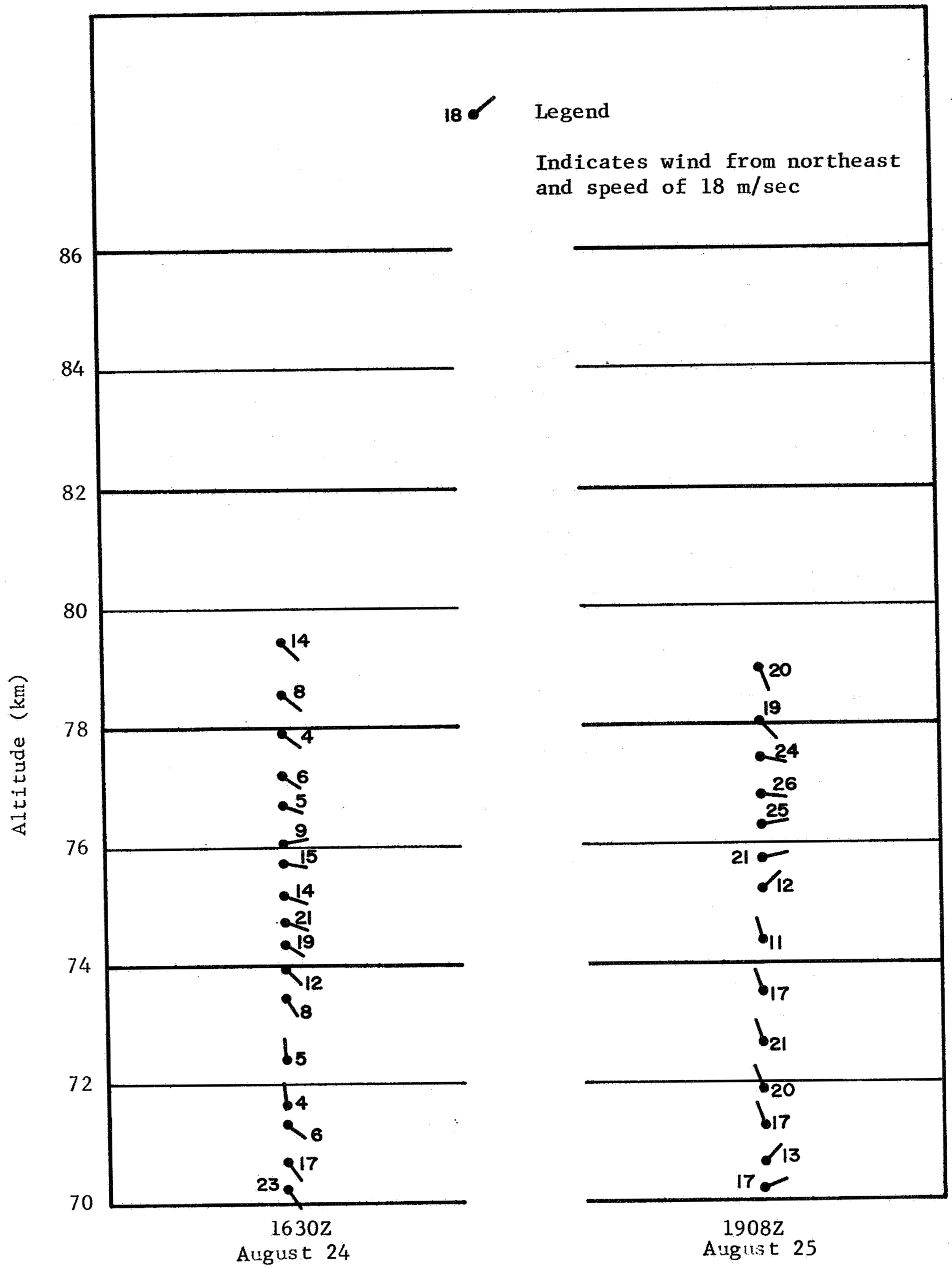


Figure 23. Cajun-Dart Measured Wind Profiles, Cape Kennedy, Florida, August 1966

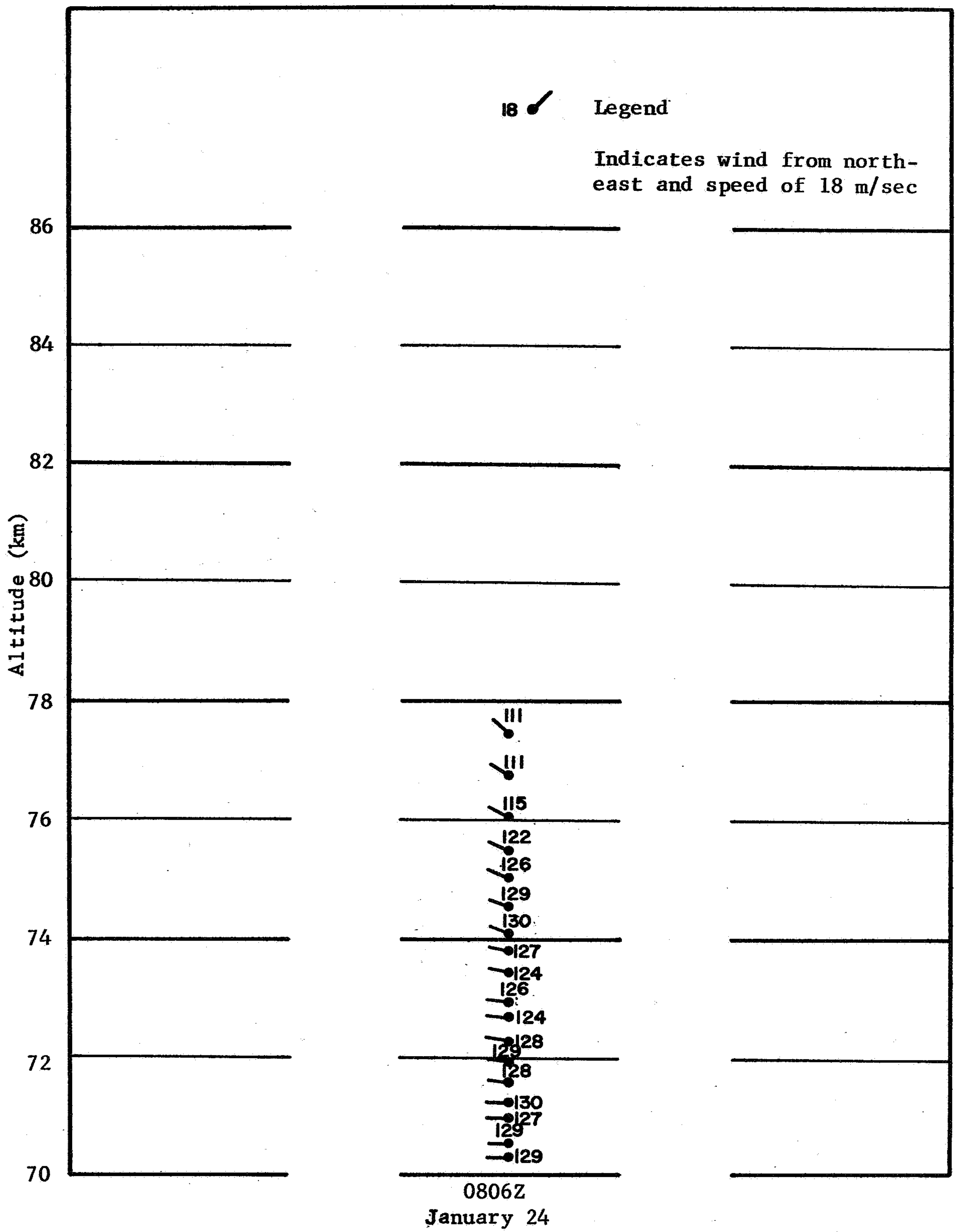


Figure 24. Cajun-Dart Measured Wind Profiles,
Cape Kennedy, Florida, January 1967

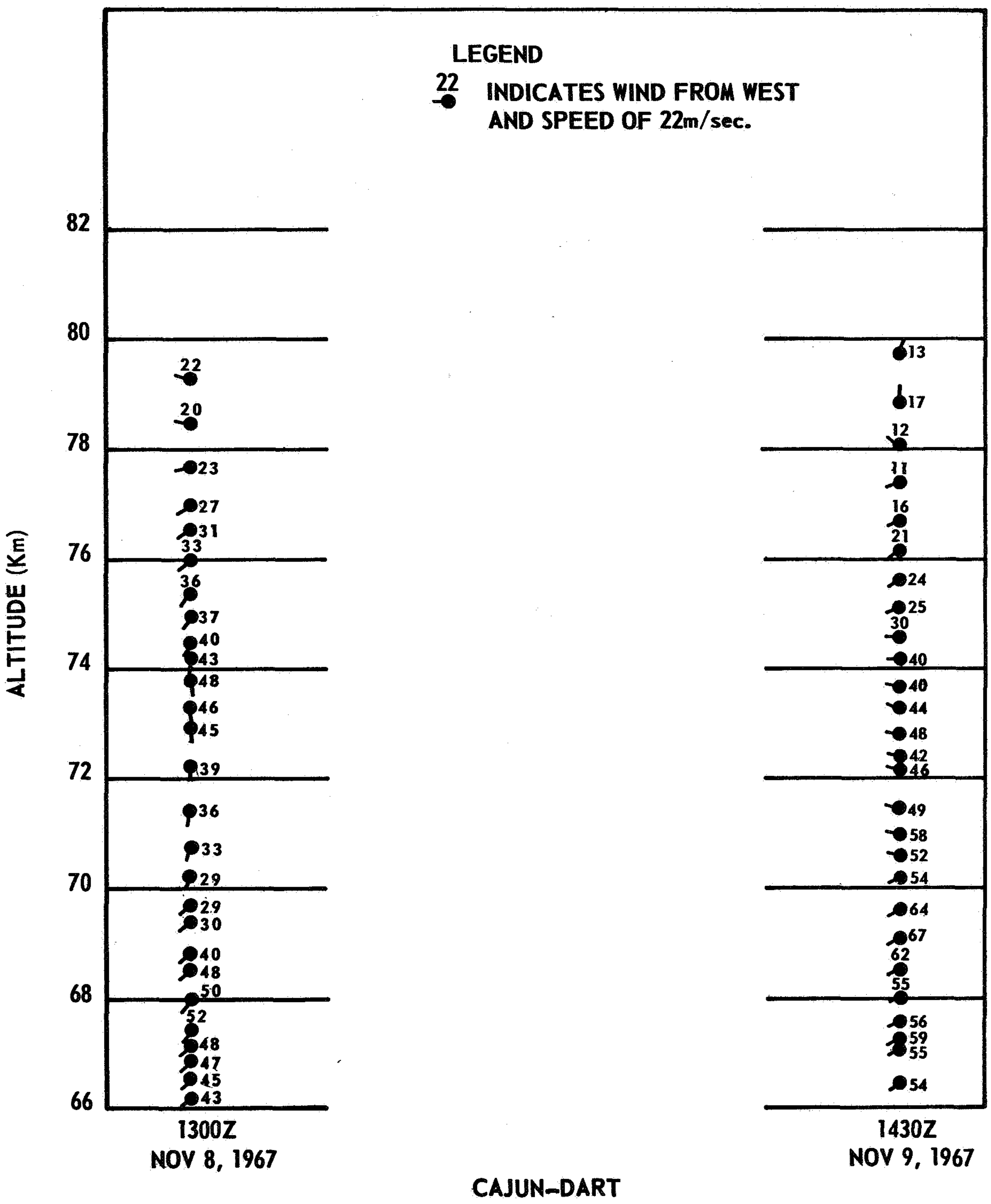


Figure 25. High Altitude Chaff Measured Wind Profiles, Cape Kennedy, Florida, November 1967

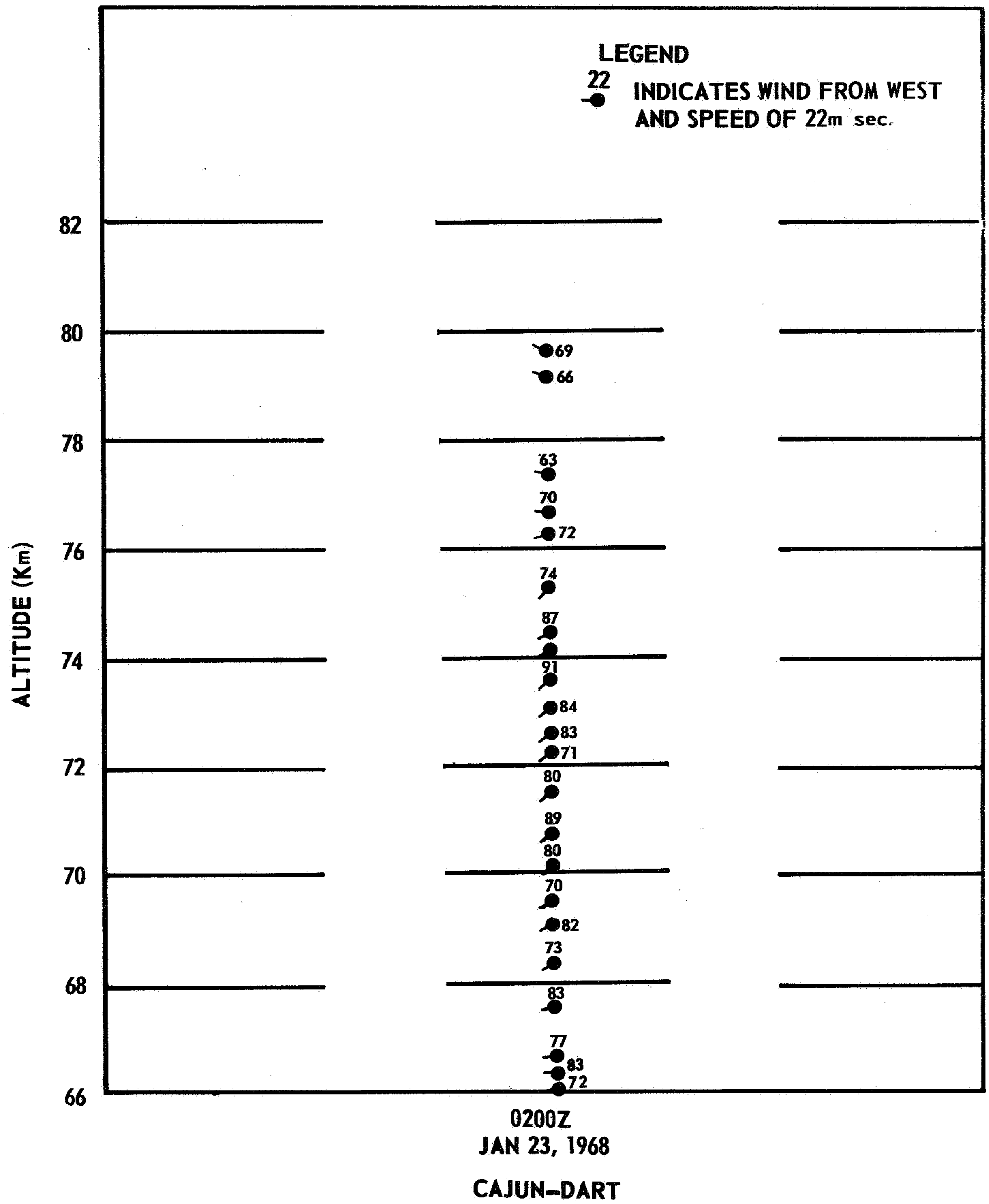


Figure 26. High Altitude Chaff Measured Wind Profiles, Cape Kennedy, Florida, January 1968

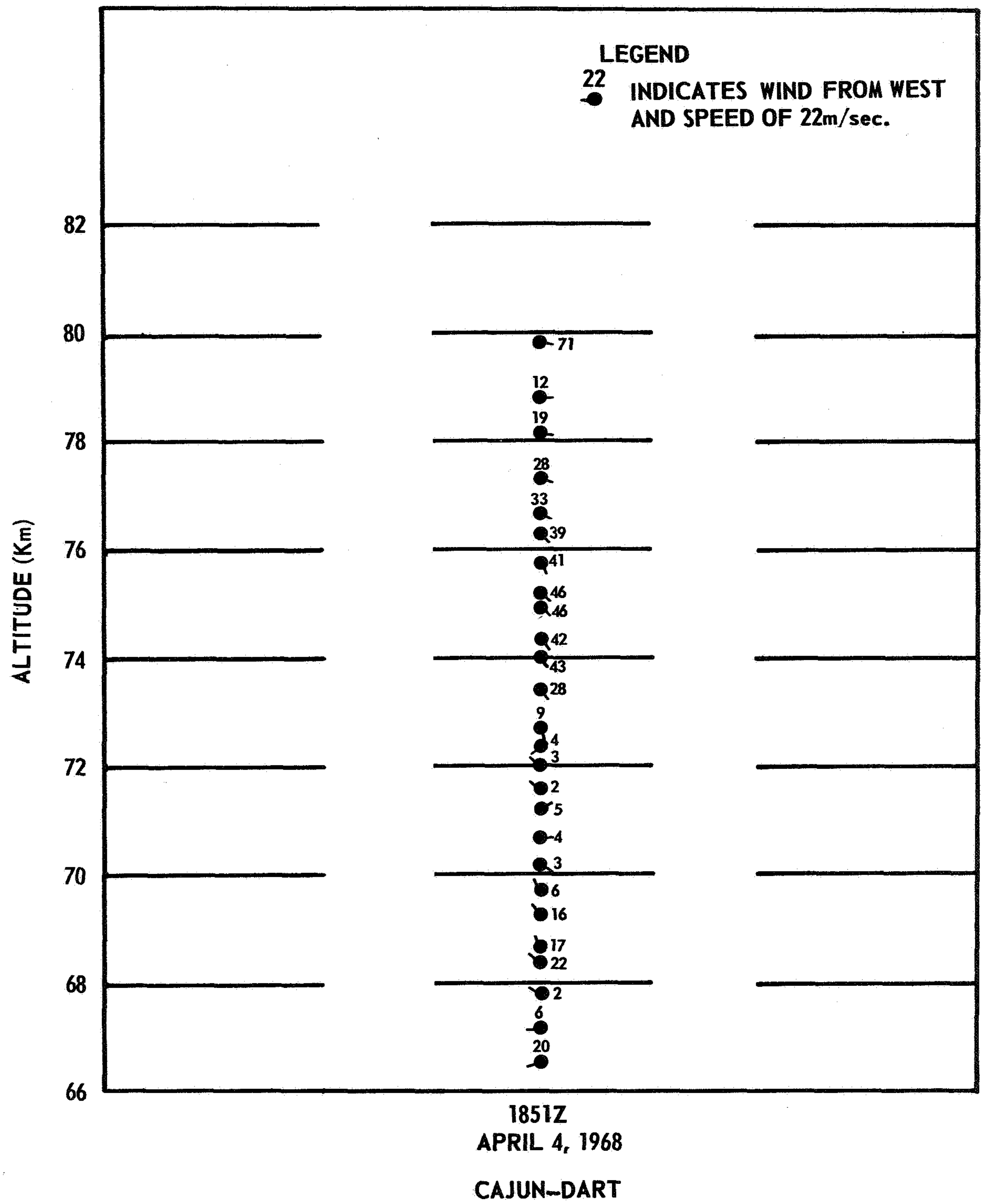


Figure 27. High Altitude Chaff Measured Wind Profiles, Cape Kennedy, Florida, April 1968

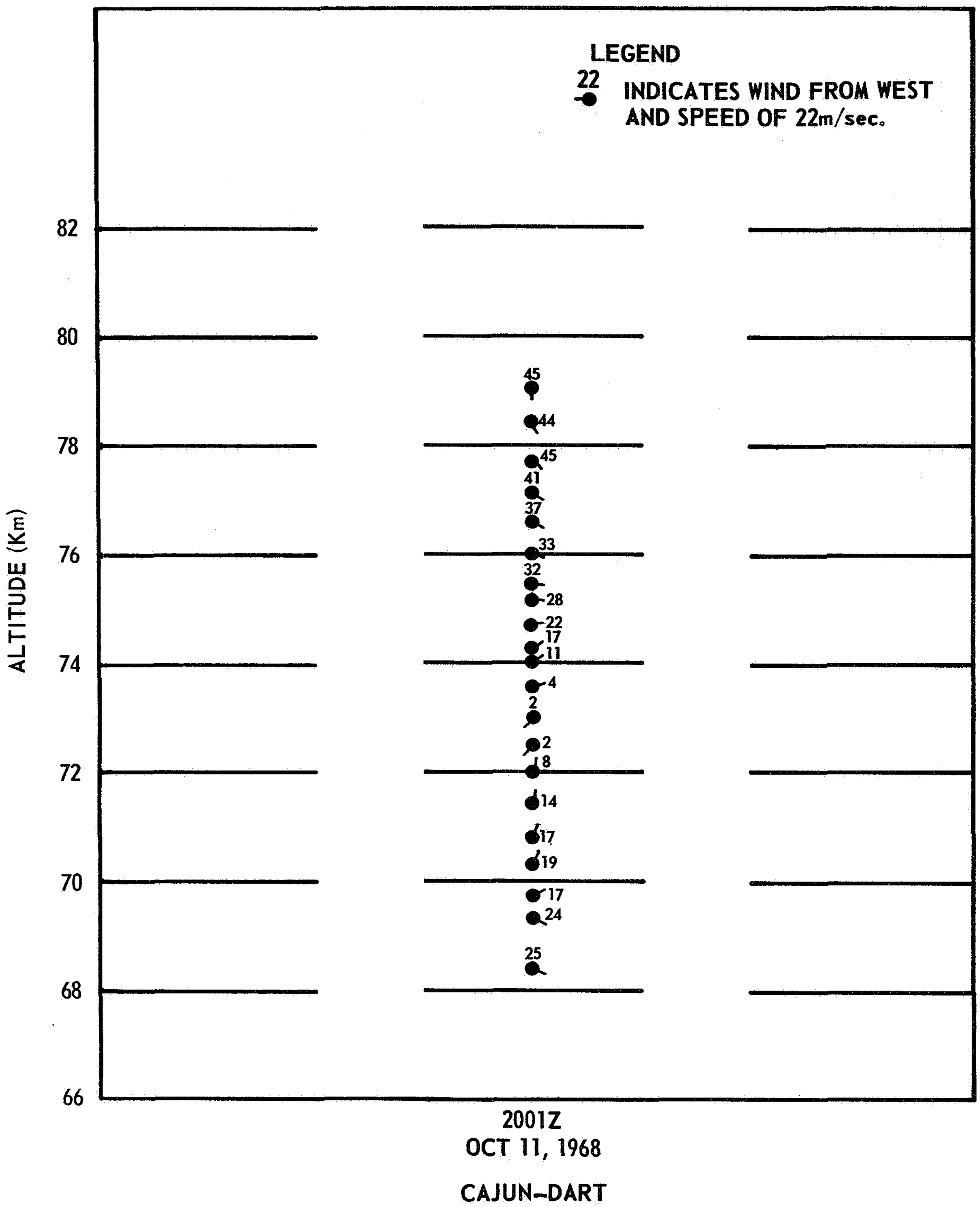


Figure 28. High Altitude Chaff Measured Wind Profiles, Cape Kennedy, Florida, October 1968

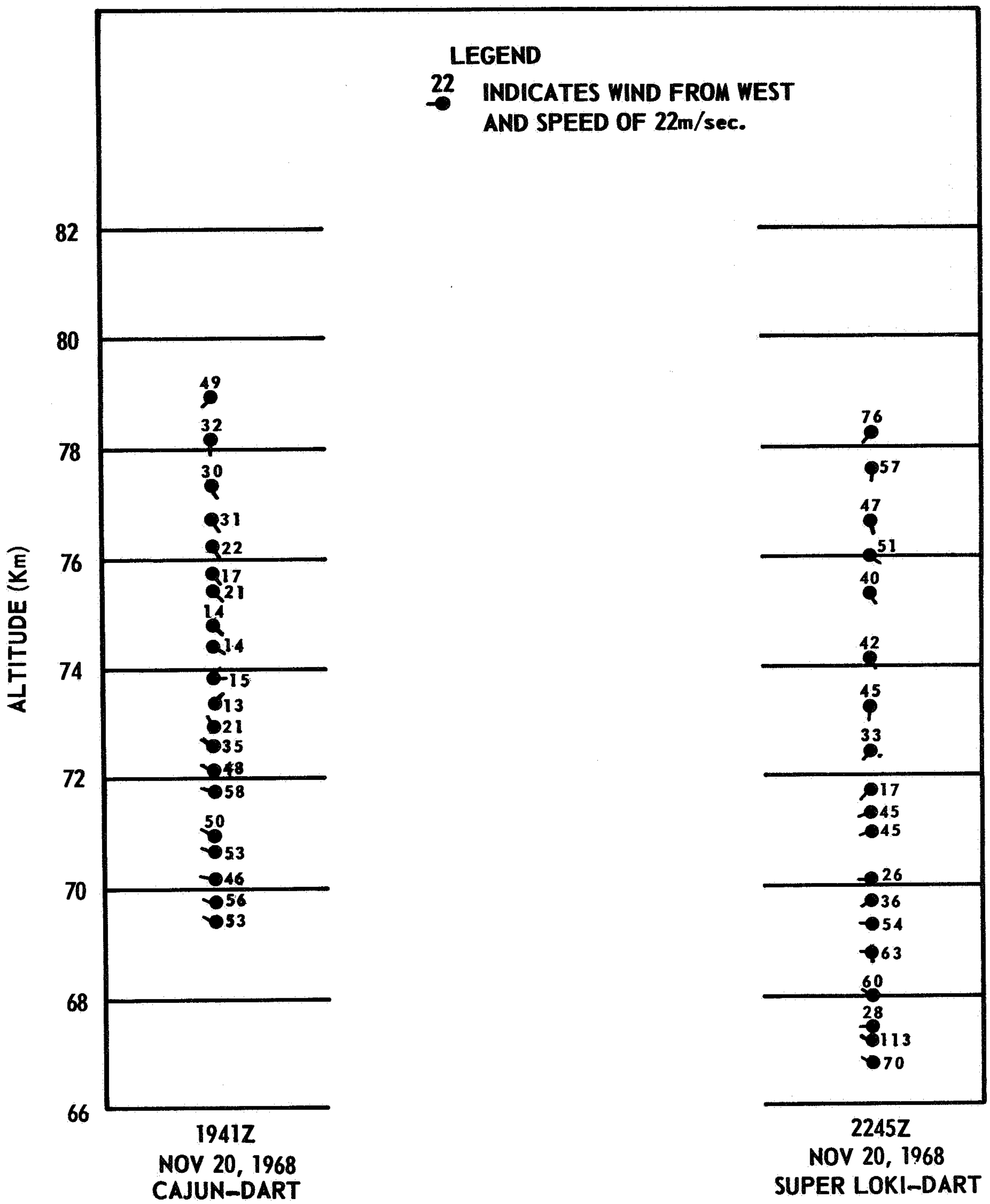


Figure 29. High Altitude Chaff Measured Wind Profiles, Cape Kennedy, Florida, November 1968

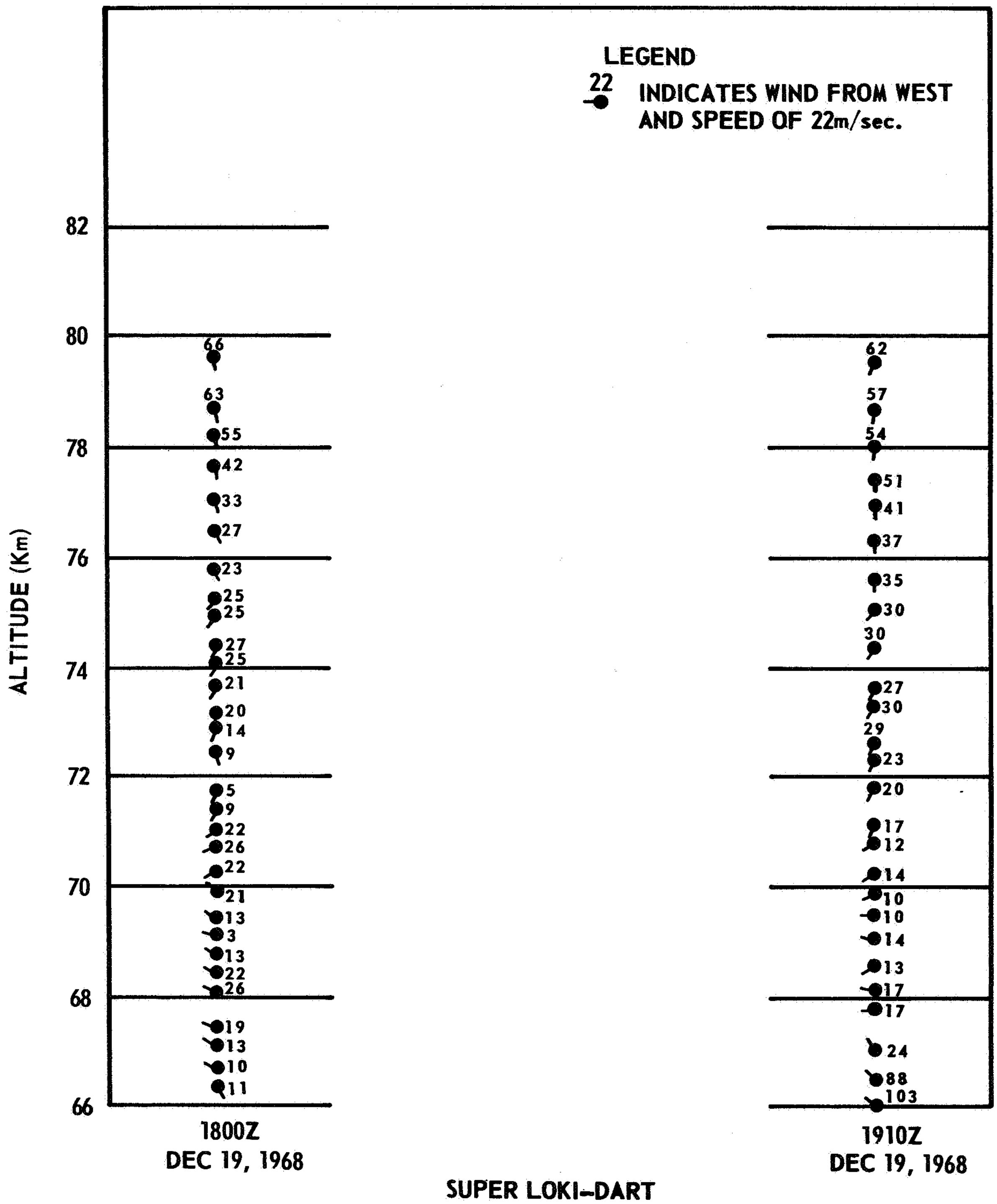


Figure 30. High Altitude Chaff Measured Wind Profiles, Cape Kennedy, Florida, December 1968

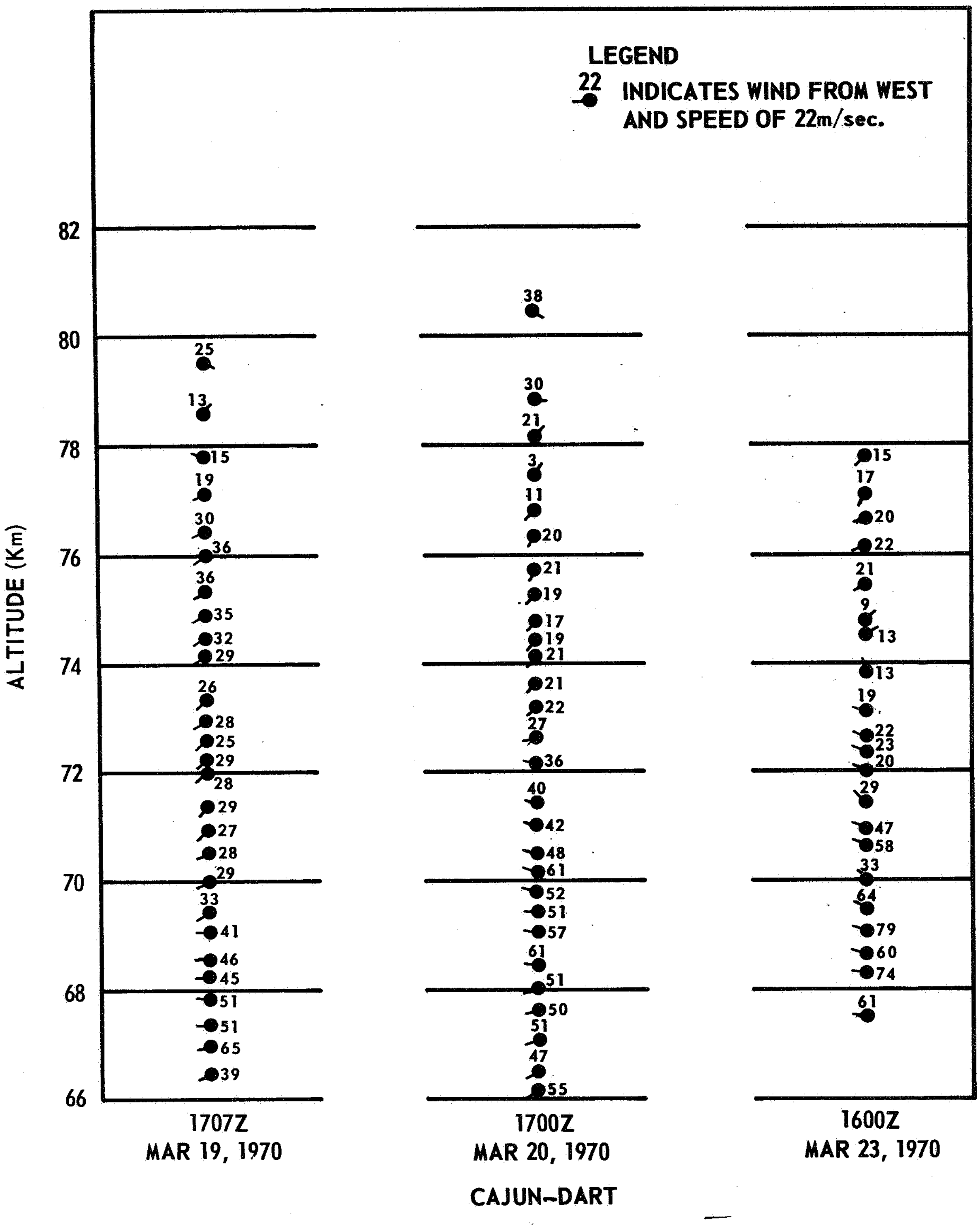


Figure 31. High Altitude Chaff Measured Wind Profiles, Cape Kennedy, Florida, March 1970

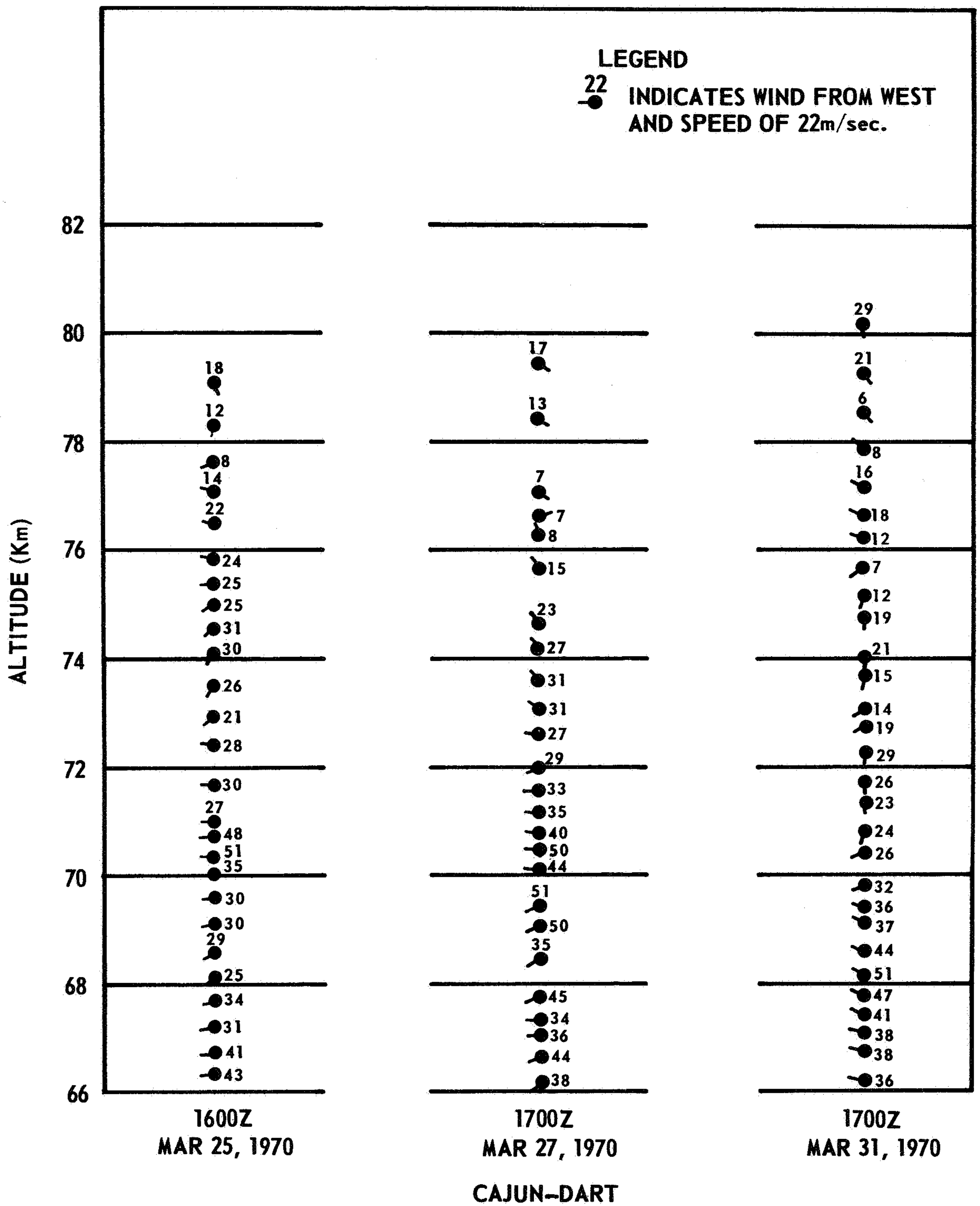


Figure 32. High Altitude Chaff Measured Wind Profiles, Cape Kennedy, Florida, March 1970

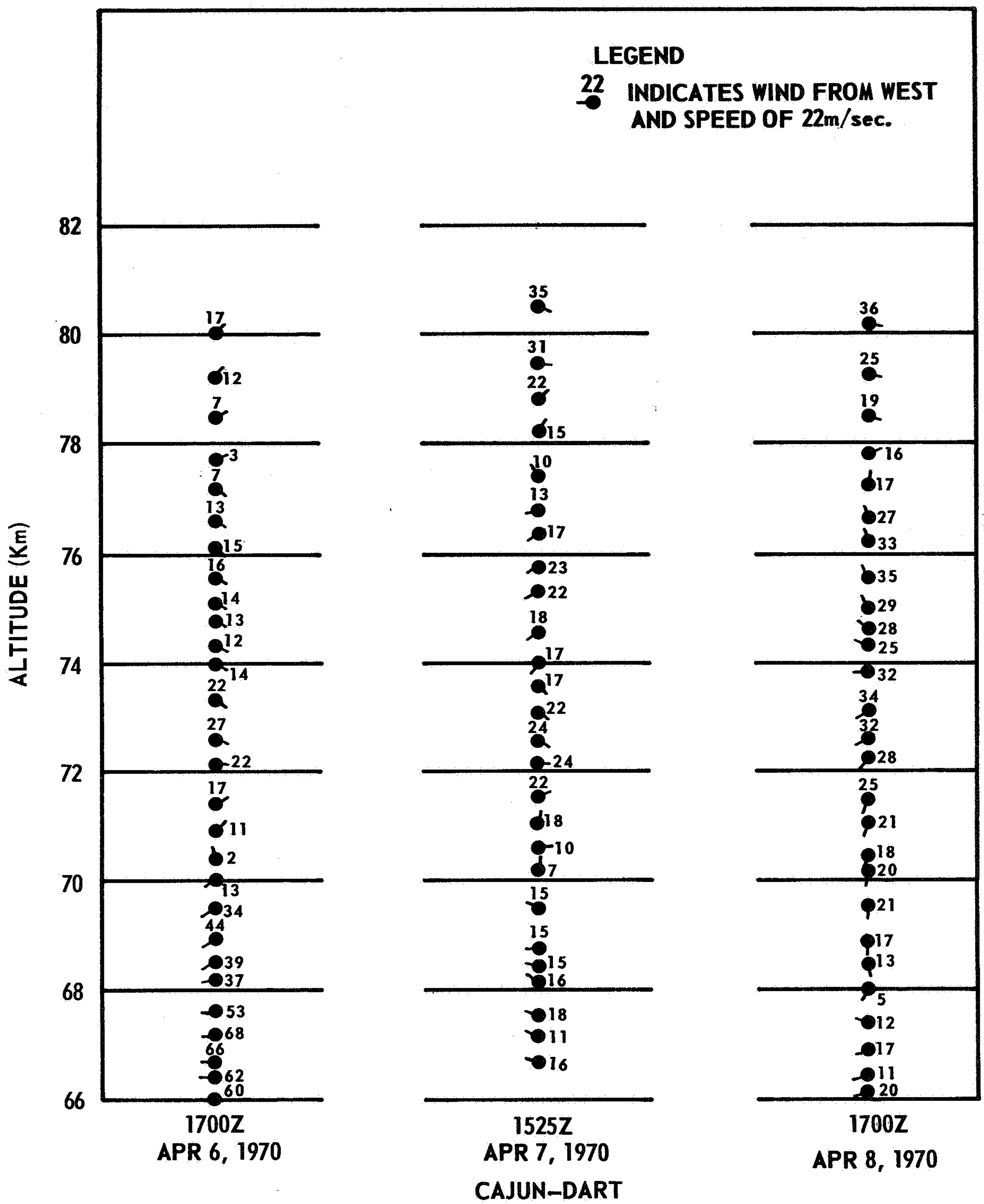


Figure 33. High Altitude Chaff Measured Wind Profiles, Cape Kennedy, Florida, April 1970

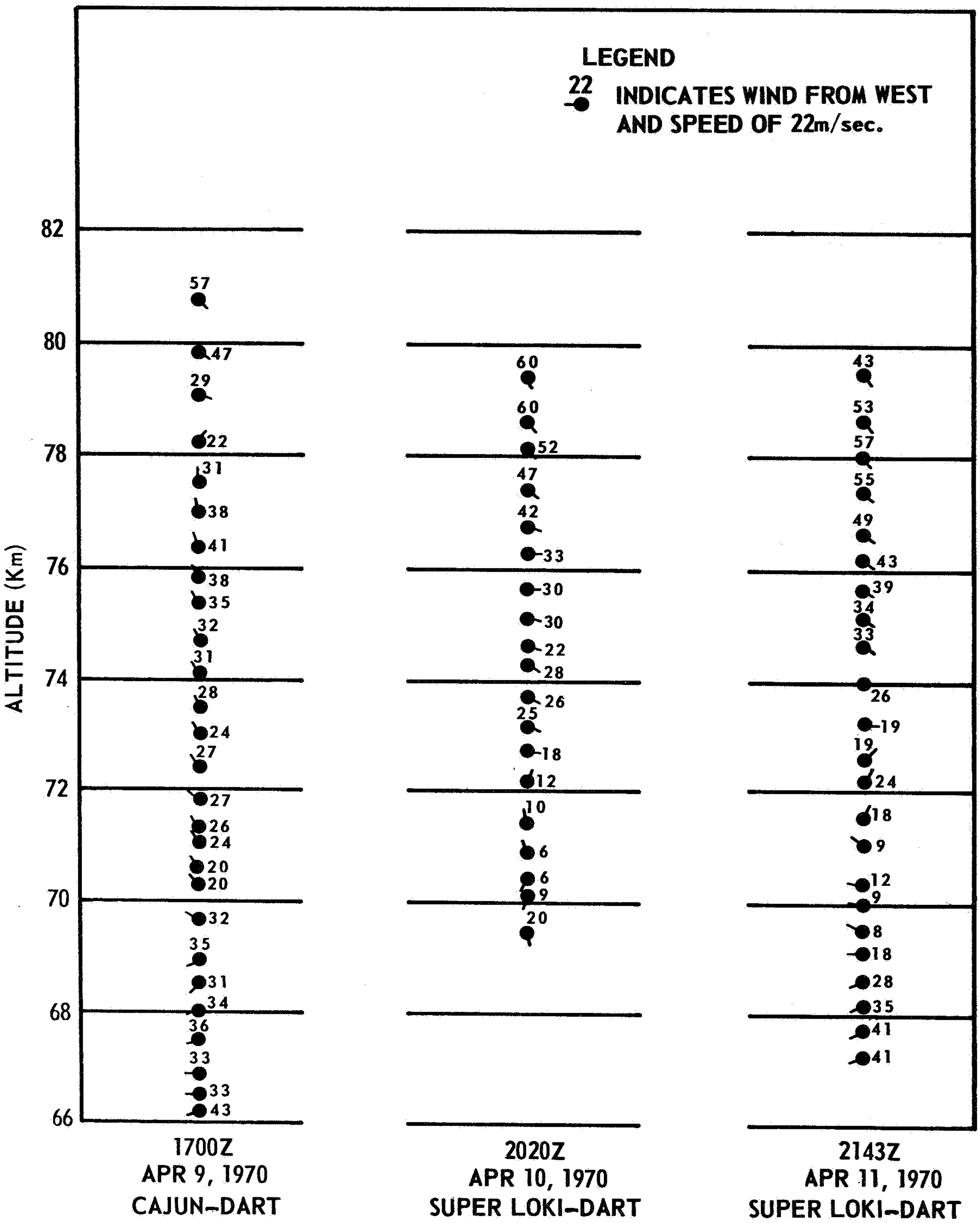


Figure 34. High Altitude Chaff Measured Wind Profiles, Cape Kennedy, Florida, April 1970

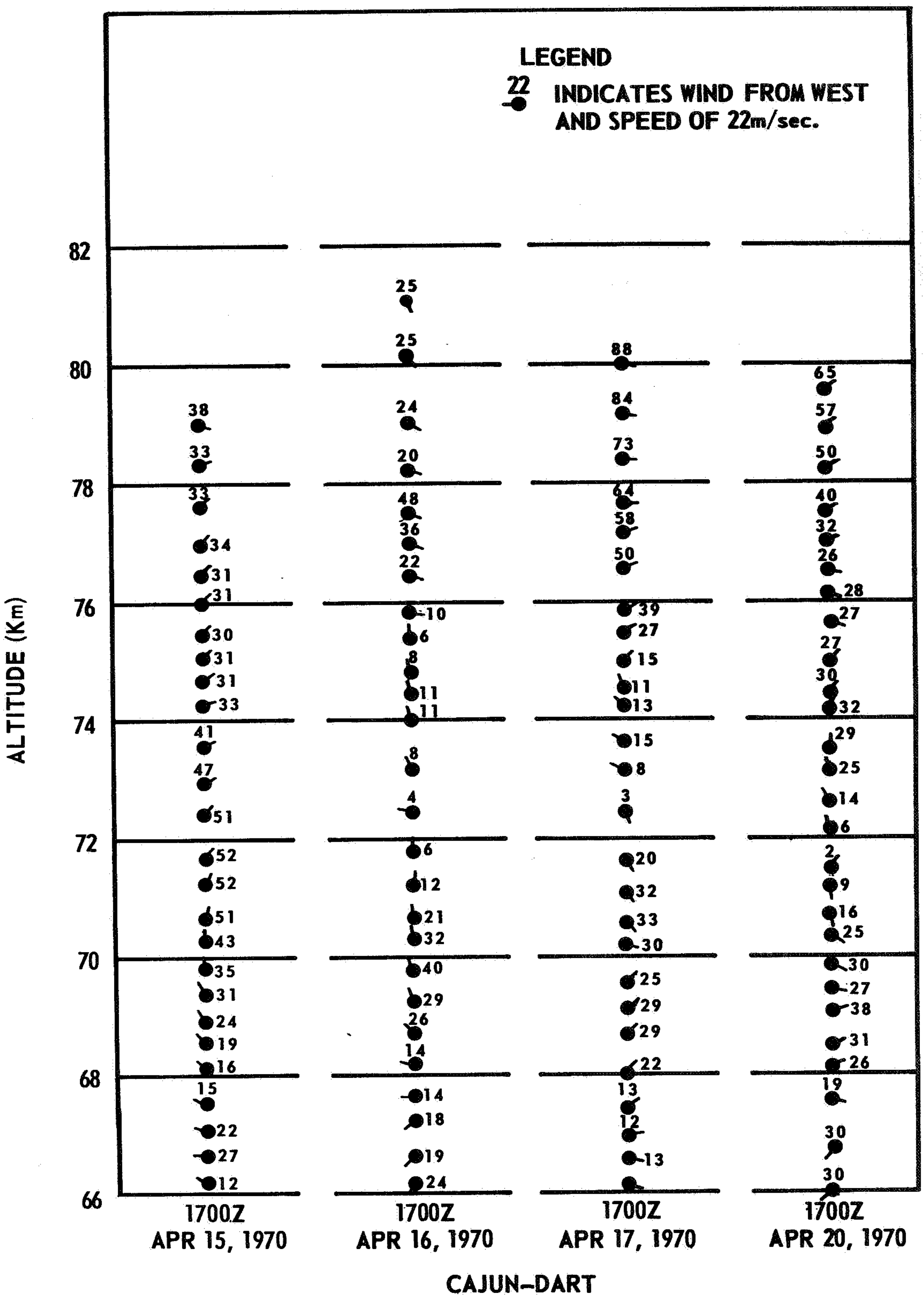


Figure 35. High Altitude Chaff Measured Wind Profiles, Cape Kennedy, Florida, April 1970

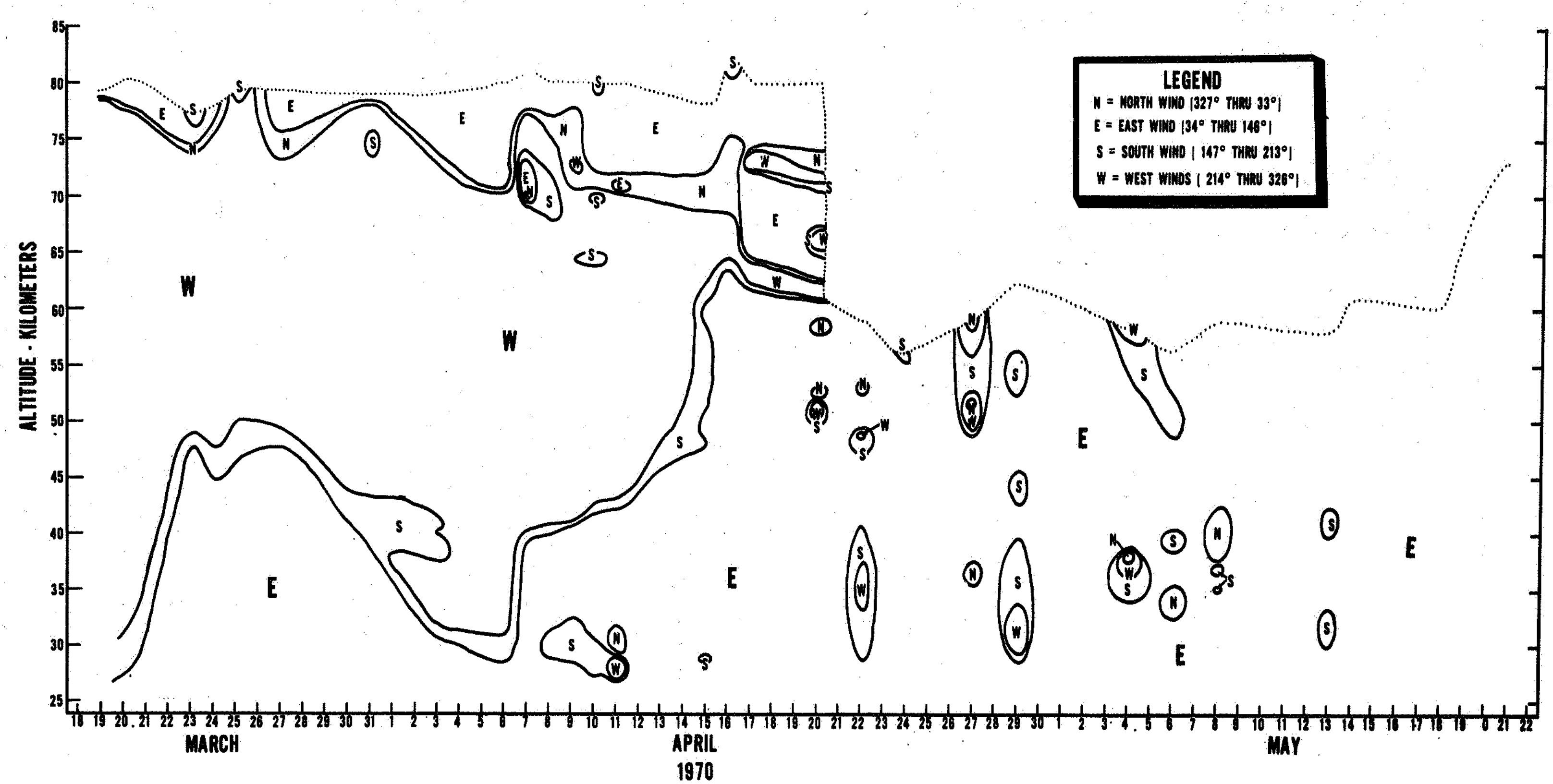


Figure 36. Vertical Time Analyses - Wind Direction over Cape Kennedy, Florida

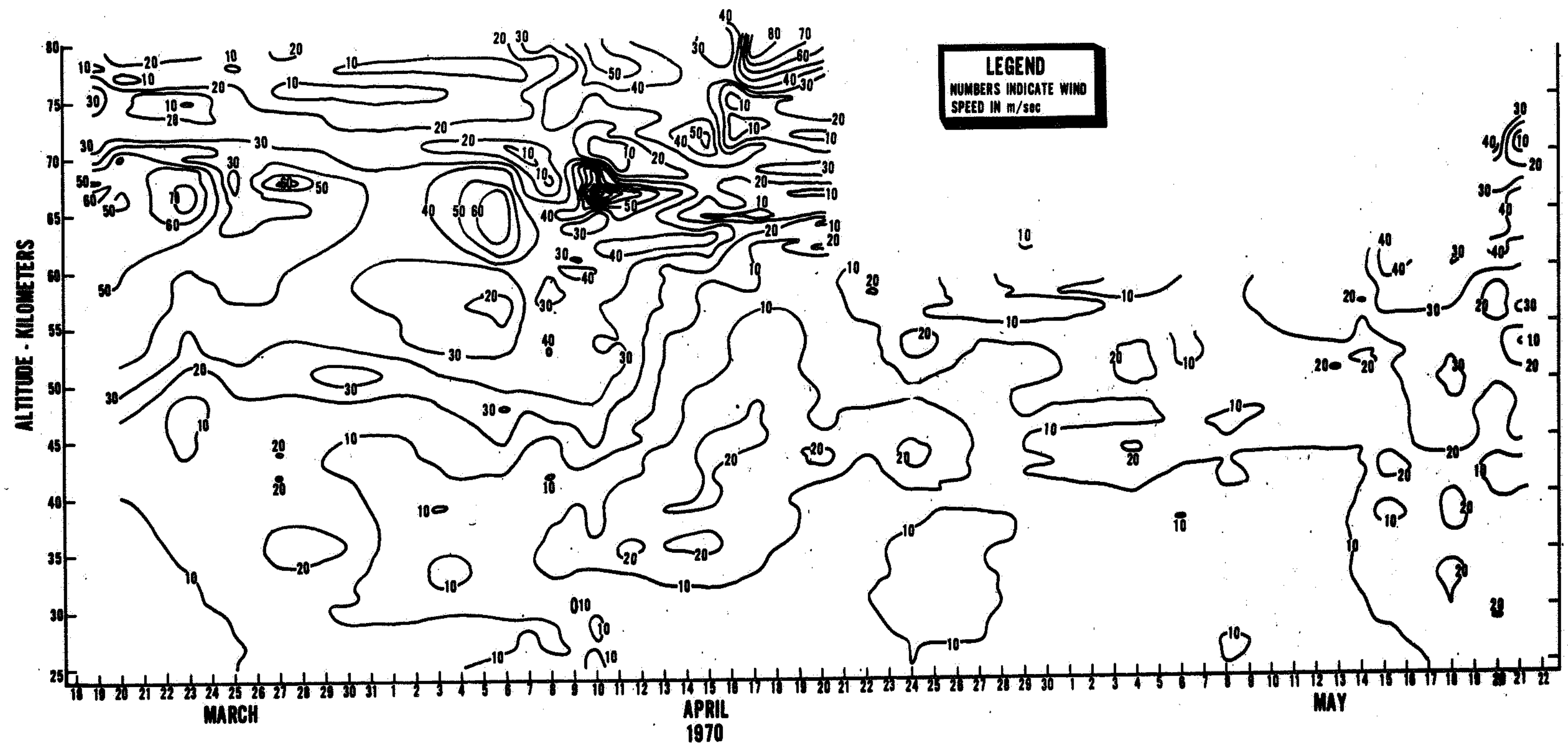


Figure 37. Vertical Time Analyses - Wind Speed over Cape Kennedy, Florida

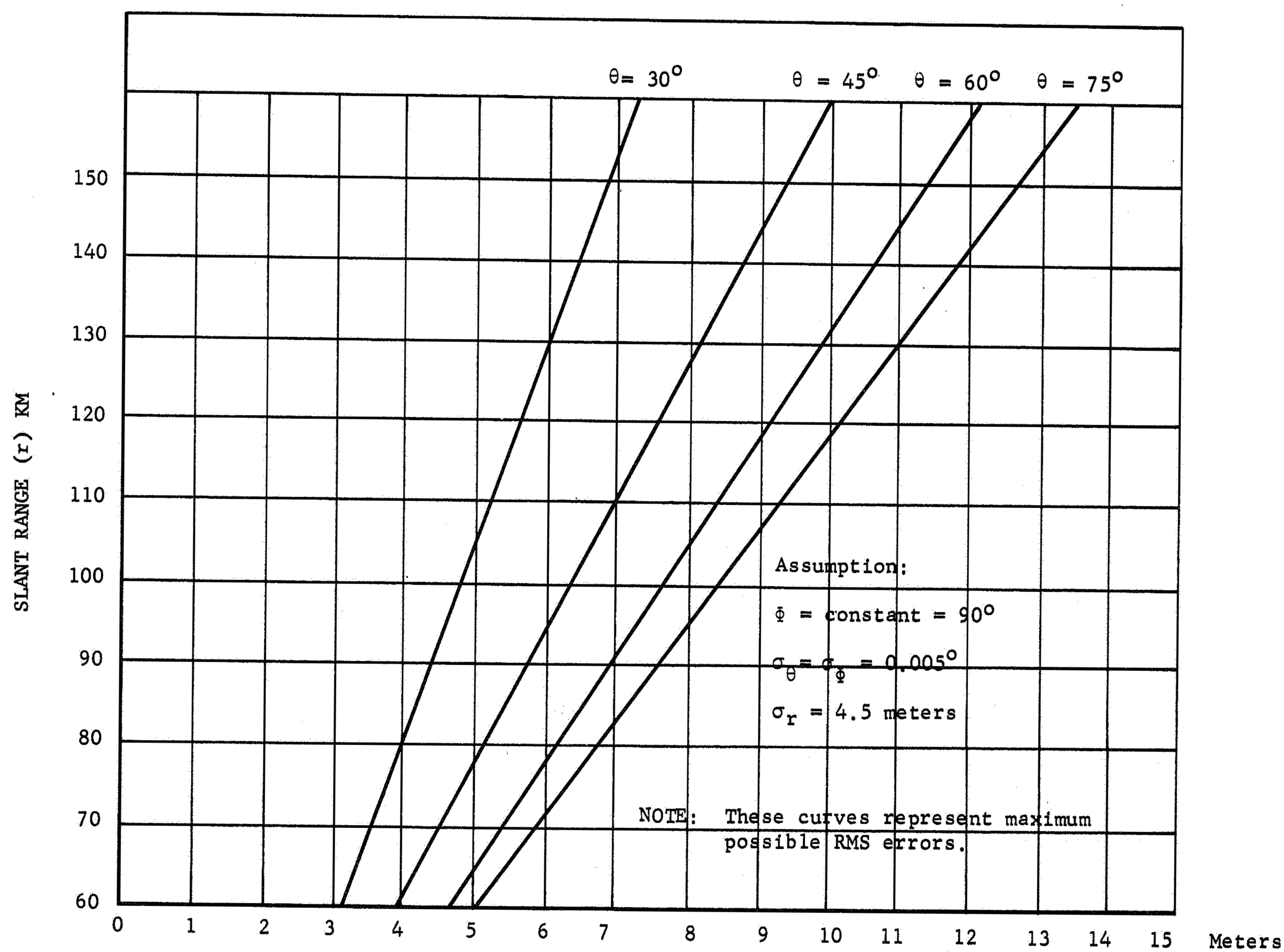


Figure 38. RMS Error in X-Coordinate

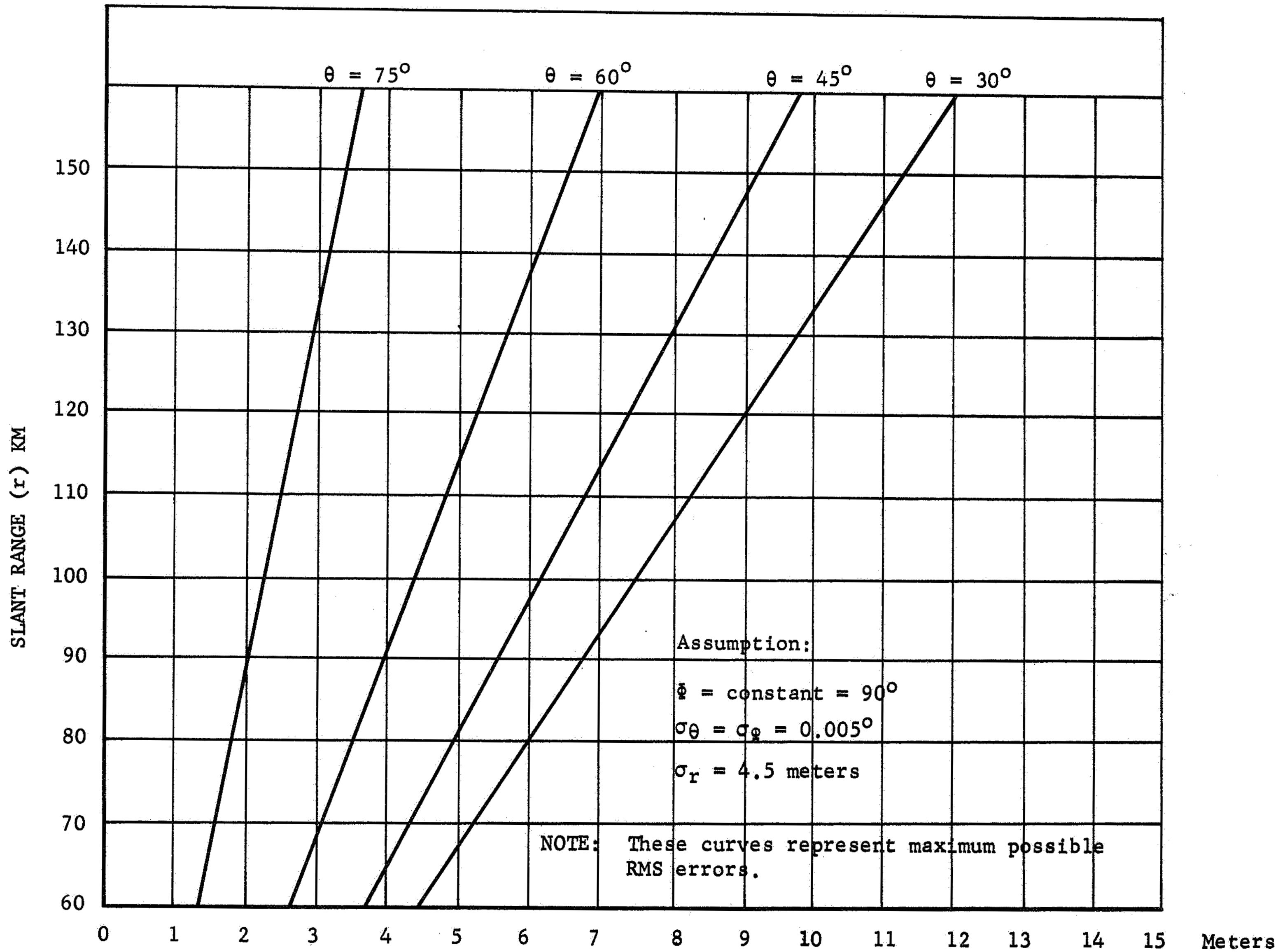


Figure 39. RMS Error in Y-Coordinate

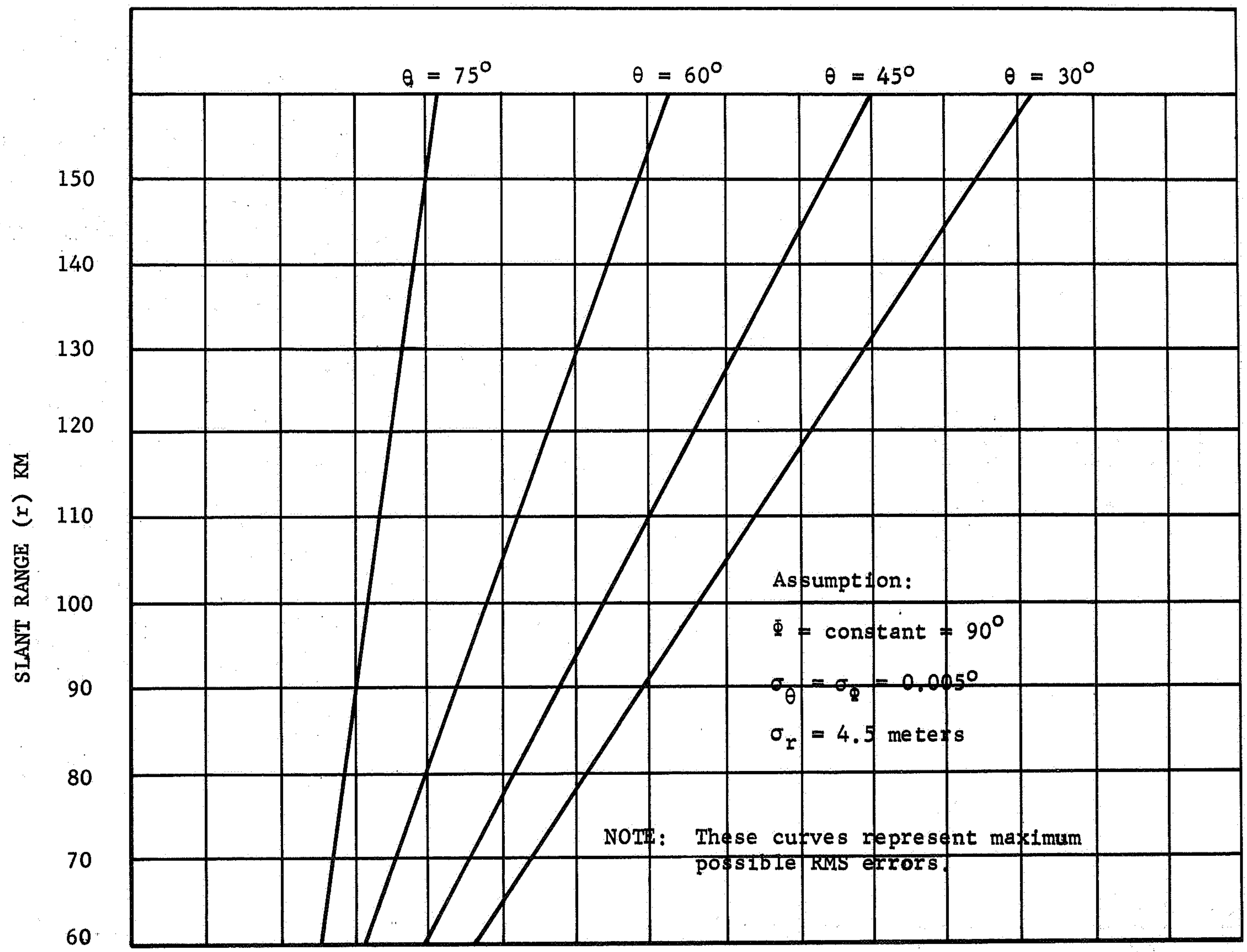


Figure 40. RMS Error in Z-Coordinate

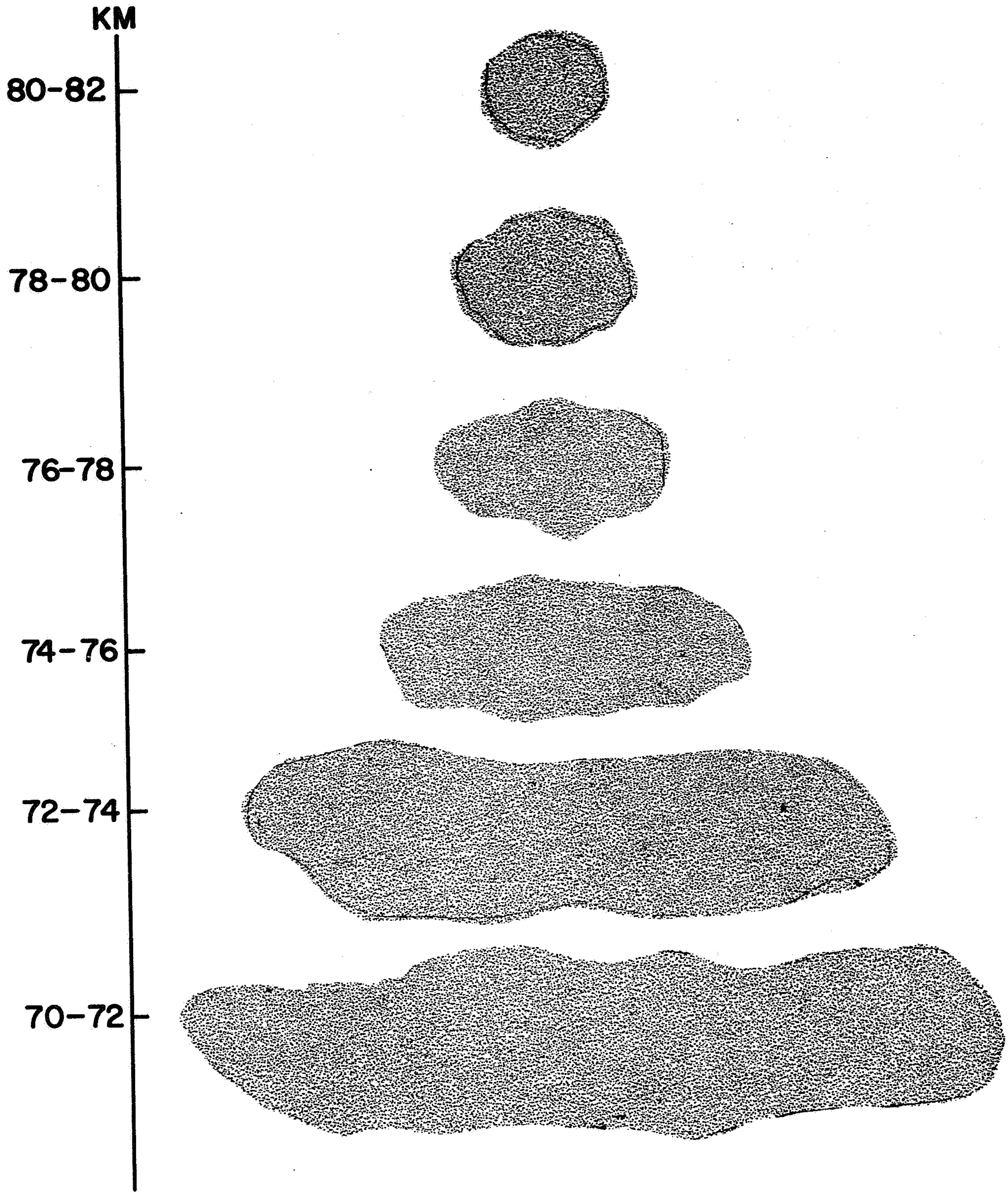


Figure 41. Typical Chaff Dispersion

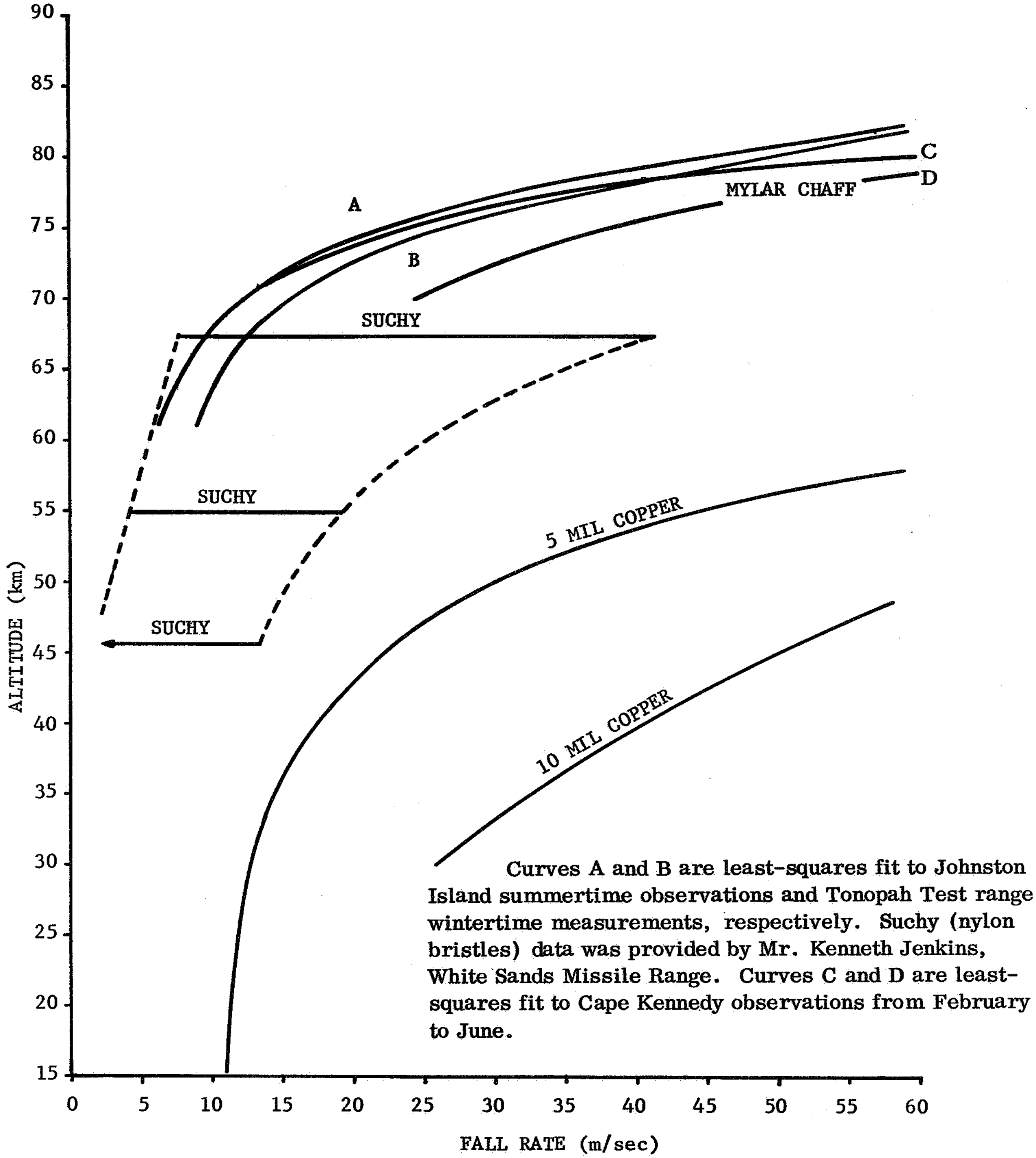


Figure 42. Rates of Fall for Various Meteorological Sensors

REFERENCES

1. Turner, R. E. and L. P. Gilchrist, "Hopi-Dart and Cajun-Dart Rocket Wind Measuring Systems," NASA TM X-53303, MSFC, July 26, 1965.

2. Bollermann, Bruce, "A Study of 30 km to 90 km Meteorological Rocket Sounding Systems,"Volume 1, Literature and Data Review, Part 1," NASA CR-1529, May 1970.

3. Bollermann, Bruce, "A Study of 30 km to 90 km Meteorological Rocket Sounding Systems, Volume 1, Literature and Data Review, Part 2," NASA CR-1529.

4. Bollermann, Bruce and Robert L. Walker, "Cajun-Dart 95 Kilometer Sounding Rocket," NASA CR-61175, August 29, 1967.

5. Bollermann, Bruce and Robert L. Walker, "Super Loki-Dart Meteorological Rocket System," NASA CR-61238, June 30, 1968.

6. Spear, Robert C., "Hopi-Dart High Altitude Wind Measuring System," Final Report No. 7999, Contract NAS8-5175, Rocket Power, Inc., Mesa, Arizona, December 1964.

7. Webb, W. L., "Stratospheric Solar Response," Journal of the Atmospheric Sciences, Vol. 21, No. 6, pp. 582-591, 1964.

8. Mitchell, L. V., "Variability of the Monthly Mean Zonal Wind, 30-60 km," AWS TR-195, April 1970.

9. Lovill, James E., "Dynamics of the Structure of the Atmosphere over Mountainous Terrain from 4-70 km as Inferred from High-Altitude Chaff, Ozone Sensors and Super-Pressure Balloons," Atmospheric Science Paper No. 160, COO-1340-20, January 1970.

10. Scoggins, J. R., "An Evaluation of Detail Wind Data as Measured by the FPS-16 Radar/Spherical Balloon Technique," NASA TN D-1572, May 1963.

11. Leviton, Robert and Vincent E. Lally, "Accuracy of Wind Determination from the Track of a Falling Object," AFCRC-TN-58-213, Air Force Cambridge Research Center, March 1958.

APPROVAL

HIGH ALTITUDE METEOROLOGICAL ROCKET WIND MEASURING SYSTEMS AND RESULTS TAKEN AT CAPE KENNEDY, FLORIDA

by R. E. Turner, D. L. Johnson and L. P. Gilchrist

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 Officer. This report, in its entirety, has been determined to be unclassified.

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

W. W. Vaughan
Chief, Aerospace Environment Division

for E. D. Geissler
Director, Aero-Astrodynamics Laboratory