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HOPI-DART AND CAJUN-DART ROCKET WIND MEASURING SYSTEMS

By Robert E. Turner and Luke P. Gilchrist
Aero-Astrodynamics Laboratory

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Luke P. Gilchrist*

George C. Marshall Space Flight Center

Huntsville, Alabama

ABSTRACT

11197

Three Hopi-Dart rockets were fired in February 1964, and during February 1965 through June 1965 seventeen Cajun-Dart rockets were fired to obtain wind flow data. These wind flow data are obtained by radar tracking of Mylar chaff expelled from these rocket systems. An altitude profile of the measured winds and a description of the two-stage rocket-delivery systems are given.

In February 1964 the observed winds were westerly. In 1965 the observed winds were westerly during February and March, changing to easterly in late March and continuing through May, and reversing to northwesterly in June. These data are presented graphically.

*Luke P. Gilchrist is associated with the Lockheed Corporation working under Contract No. NAS 8-20082.

NASA - GEORGE C. MARSHALL SPACE FLIGHT CENTER

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RESEARCH AND DEVELOPMENT OPERATIONS

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SUMMARY

Wind data between 70 - 85 kilometers altitude at Cape Kennedy, Florida, as determined from the Hopi-Dart and Cajun-Dart rocket systems, are presented from February 1964 through June 1965. These rocket systems deliver wind sensitive aluminized Mylar chaff which is ejected above 90 kilometers. Wind flow data are obtained by tracking the chaff, which is free to drift with the wind as it falls, by radar.

It is evident from this small amount of data that only a brief summation can be made. Therefore, conclusions from these data should be handled cautiously by the user. Data obtained in 1964 were from the Hopi-Dart system, and data obtained in 1965 were from the Cajun-Dart system.

I. INTRODUCTION

The firing of large space vehicles at Cape Kennedy, Florida, has increased the demand for more accurate and detailed wind information to ever higher altitudes. As a space vehicle rises through the atmosphere, it is subjected to the variations of the wind conditions. These variations of the wind conditions may excite the rigid and elastic body dynamic characteristics of the vehicle during flight. Wind data are needed from ground level through stage separation altitude in the upper atmosphere for the optimum in space vehicle design and operation. Very few observations have been made above 70 kilometers altitude, and the accuracy of the limited data available is open to question [1]. Thus, efforts to obtain a larger and reliable data sample for analysis are required to provide adequate design information. The importance of small rockets lies in their ability to probe a region of our atmosphere that cannot be explored any other way. The primary zone of interest that these rockets probe lies between the highest balloon altitude and the lowest satellite altitude [2].

Because the altitude with which we are concerned is accessible by small rockets, it is relatively easy to accumulate data which may be studied empirically. At Cape Kennedy, Florida, winds have been measured between 70 - 85 km altitude by means of the Hopi-Dart and Cajun-Dart rocket systems. These rockets may be used to measure other atmospheric parameters.

II. HOPI-DART SYSTEM

The objective of this program was to develop a high altitude wind measuring system in support of firings at Cape Kennedy, Florida, and to acquire data for use in vehicle development at altitudes between 70 and 85 kilometers. The Hopi-Dart is a two-stage flight vehicle (Fig. 1) consisting of a booster as first stage, and an unpowered dart as second stage [3]. The first stage is 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, that contains aluminized Mylar chaff and the payload ejection system. At first stage burnout (2.4 seconds), differential drag causes separation of the first stage from the dart. The dart then coasts to apogee. The payload ejection from the dart is designed to occur at approximately T + 135 seconds. The Hopi-Dart is launched from a rail attached to an I-Beam structure (Fig. 2).

The Hopi-Dart vehicle igniter (Fig. 3) 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 $\pm$ 0.4 ohm
Maximum Safe Test Current	0.02 amp
Recommended Firing Current	4.0 amp

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

Igniter Resistance	1.0 $\pm$ 0.3 ohm
Maximum Safe Test Current	0.02 amp
Recommended Firing Current	4.0 amp

A radar (FPS-16) skin tracks the Dart and then the chaff payload. The radar tracks the chaff from apogee to an altitude of 70 km or loss of signal. Data were obtained by radar printout of time, elevation and azimuth angles, and slant range position, and also by reducing the radar plotting board which is a graphical location of the chaff by altitude, time, and position. Only three of this type system were fired at Cape Kennedy (see Fig. 4).

III. CAJUN-DART SYSTEM

The objective of the Cajun-Dart system (Fig. 5) was the same as for the Hopi-Dart, but at a reduction of cost. The Cajun-Dart chaff rocket is a two-stage dart type sounding rocket [4]. The first stage of the Cajun-Dart is the Cajun, Mod. III, rocket motor. The Cajun motor is 2.591 meters long, and has a principal diameter of 0.165 meters. The motor, less flight hardware, weighs 77.566 kilograms with 53.752 kilograms of propellant. The nominal burning time of 2.8 seconds, with a total impulse of 11453.4 kilograms-seconds, yields a burnout velocity of slightly over 1.524 kilograms per second at an altitude of 2.134 kilometers. When the booster burns out, the aerodynamic differential drag causes the booster to separate from the Dart. After separation the Dart continues to coast to payload ejection.

The Dart is 0.044 meters in diameter, weighs 7.711 kilograms, is 1.313 meters long, and is a non-thrusting stage functioning only as a low drag payload housing. The nose of the Dart is designed to have a hypersonic optimum shape, keeping the aerodynamic drag to a minimum, and the aft end is boat-tailed forming the interstaging surfaces, as well as reducing the base drag. The payload housed inside the Dart is 655.6 cubic cm of 5-mil, aluminized Mylar, foil chaff cut to S-Band length. When the Dart has reached its apogee, the payload is ejected by the use of a 145-second pyrotechnic time delay housed in the Dart's tail and initiated at launch. At 145 seconds the time delay ignites the expulsion system which ejects the Dart nose cone and the chaff payload by forcing a piston the full length of the Dart. The chaff is then free to drift with the wind as it falls. The Cajun-Dart system is launched from a rail type launcher (Fig. 6).

The Cajun-Dart igniter (Fig. 7) consists of a tube containing two U. S. Flare 209 Squibs, 7.5 grams of ignition powder, and 90 grams of USF 2A granules. The two squibs are wired in parallel and are of the one amp, one watt type. The igniter leads are twisted and shielded by an insulated metal jacket. They terminate in a self-shortening connector. The characteristics of the motor igniter are as follows:

Resistance (Squib)	0.95 to 1.25 ohms
Maximum No Fire	1.8 amp
Minimum All Fire	2.4 amp
Firing Current	4.5 amp
Igniter Resistance	.45 to 1.00 ohm

The Dart igniter is a small propellant charge initiated by a pyrotechnic time delay. The pyrotechnic time delay is initiated at launch, and is connected in parallel with the motor igniter which is initiated simultaneously. The delay column burns slowly for 145 seconds; this ignites the 6 1/2 grams of a USF-2C granular squib.

When the propellant is ignited, the gases generated drive a piston which forces the Dart ogive and a set of staves containing the chaff from the Dart. The characteristics of the Dart Squib are as follows:

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

A radar (FPS-16) skin tracks the Dart and the chaff after ejection. Data between 70 and 85 km are obtained in the same manner that data from the Hopi-Dart system are obtained.

Seventeen of these rockets were fired at Cape Kennedy from February 1965 through June 1965,* and the results are presented in Figs. 8 through 12.

IV. DATA REDUCTION

The wind flow data obtained have been reduced to tabular form in 30-second intervals, and plotted as arrowgrams. The data were computed by two methods, and compared for likeness. Data were

*It is planned to complete 52 firings of this rocket system by February 1966 at Cape Kennedy.

obtained from the first method by reducing the radar plotting board, which is a graphical location of the chaff by altitude, time, and position. Data from the second method were obtained by using the radar tape output of time, slant range, and elevation and azimuth angles.* The equations used in the second method will be given later in this report. The comparison of the results proved the two methods to be very nearly the same. The second method is currently being used, because it utilizes computer reduction techniques and decreases the possibility of human error.

These data are based on the assumption that any horizontal motion of the chaff as it free falls from apogee is wind flow. Wind data from chaff with a fall rate of more than 70 meters per second were disregarded and are not presented in this report.

The following equations were used for reduction of the Hopi-Dart and Cajun-Dart chaff measurements. When the altitude above the surface (YS') is

$$Y_S' = \left[R^2 + (R_E + Y_{SG})^2 + 2R(R_E + Y_{SG})\sin\Theta\right]^{\frac{1}{2}} - (R_E + Y_{SG}), \tag{1}$$

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

$$Y_S = Y_S' + Y_{SG}, \tag{2}$$

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 by the following equation:

$$ROF_i = \frac{Y_{S(i-2)} - Y_{S(i+2)}}{t_{(i+2)} - t_{(i-2)}}, \tag{3}$$

*Radar output data averaged over one minute intervals, and tabulated at 30-second interval midpoints were used as input to the computer.

where

Y_S = Altitude above mean sea level in meters,

T = Time in seconds.

Rectangular position coordinates (X_c, Z_c, and Y_c) are determined by

$$\begin{aligned} X_c &= R \cos\Theta \sin\Psi \\ Z_c &= R \cos\Theta \cos\Psi \\ Y_c &= R \sin\Theta \end{aligned} \tag{4}$$

where

Θ = Elevation angle

Ψ = Azimuth angle

R = Slant range in meters.

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

$$\begin{aligned} X_s &= (R_E + Y_S) \sin^{-1} \frac{X_c}{R_E+Y_S} \\ Z_s &= (R_E+Y_S) \sin^{-1} \frac{Z_c}{R_E+Y_S}. \end{aligned} \tag{5}$$

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

$$\begin{aligned} W_{WE} &= \frac{X_{s(i+2)} - X_{s(i-2)}}{t_{(i+2)} - t_{(i-2)}} \\ W_{SN} &= \frac{Z_{s(i+2)} - Z_{s(i-2)}}{t_{(i+2)} - t_{(i-2)}}. \end{aligned} \tag{6}$$

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

$$W_i = (W_{WE}^2 + W_{SN}^2)^{\frac{1}{2}}. \tag{7}$$

Wind direction (W_D) is determined by the following equation:

$$\text{Let } Q = \tan^{-1}\left|\frac{W_{WE}}{W_{SN}}\right| \frac{\text{when neither numerator}}{\text{or denominator is zero}}. \tag{8}$$

The following quadrant correction is then applied to Q:

If W_{WE} + and W_{SN} + : $W_D = 180^\circ + Q$

If W_{WE} + and W_{SN} - : $W_D = 360^\circ - Q$

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

If W_{WE} - and W_{SN} + : $W_D = 180^\circ - Q$

If W_{WE} + and $W_{SN} = 0$: $W_D = 270^\circ$

If W_{WE} - and $W_{SN} = 0$: $W_D = 90^\circ$

If $W_{WE} = 0$ and W_{SN} + : $W_D = 180^\circ$

If $W_{WE} = 0$ and W_{SN} - : $W_D = 360^\circ$

If $W_{WE} = 0$ and $W_{SN} = 0$: $W_D = 360^\circ$

Fall rates of the Mylar chaff from the Hopi-Dart and Cajun-Dart rocket systems, curves C and D of Fig. 13, agree well with the chaff fall rates measured by L. B. Smith at Johnston Island and Tonopah Test Range.

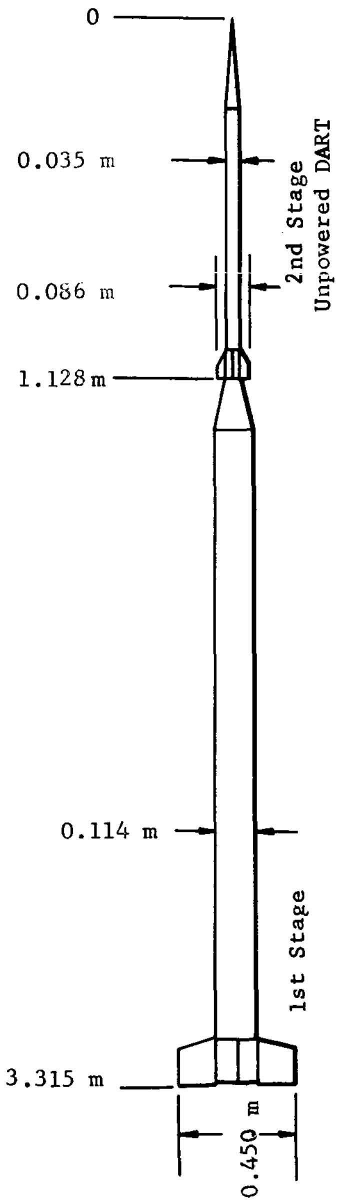
V. CONCLUSIONS

The primary purpose of these observations was to develop a system to measure wind flow data between 70 km and 85 km. The Hopi-Dart and the Cajun-Dart systems are capable of delivering a small payload, or sensor, to obtain certain atmospheric parameters in the range of 70 km to 85 km.

Chaff provides the only usable technique with a sufficiently high drag coefficient and area-to-mass ratio to measure wind flow, except for vapor or smoke trails, between 70 km and 85 km [5]. The accuracy of the wind data in this report is a function of the chaff's response to the horizontal wind flow as it falls through the atmosphere. Wind data from chaff with a fall rate of more than 70 meters per second were disregarded in this report (Fig. 13). The assumption is that an object falling in excess of 70 meters per second will not respond satisfactorily to the horizontal wind flow [6]. These data are based on the assumption that any horizontal motion of the chaff as it free-falls from apogee is wind flow. This assumption is open to debate.

The principal weakness of the chaff type radar target lies in its rapid dispersion as it falls through the atmosphere, and the accuracy of the data is dependent on the drag of the chaff, which results from the free fall, to the horizontal flow of the winds.

Data presented in this report are based on a limited number of data samples and should be interpreted, physically and statistically, with caution in any study.



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° 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 1. HOPI-DART VEHICLE

FIGURE 2. HOPI-DART VEHICLE AND LAUNCHER

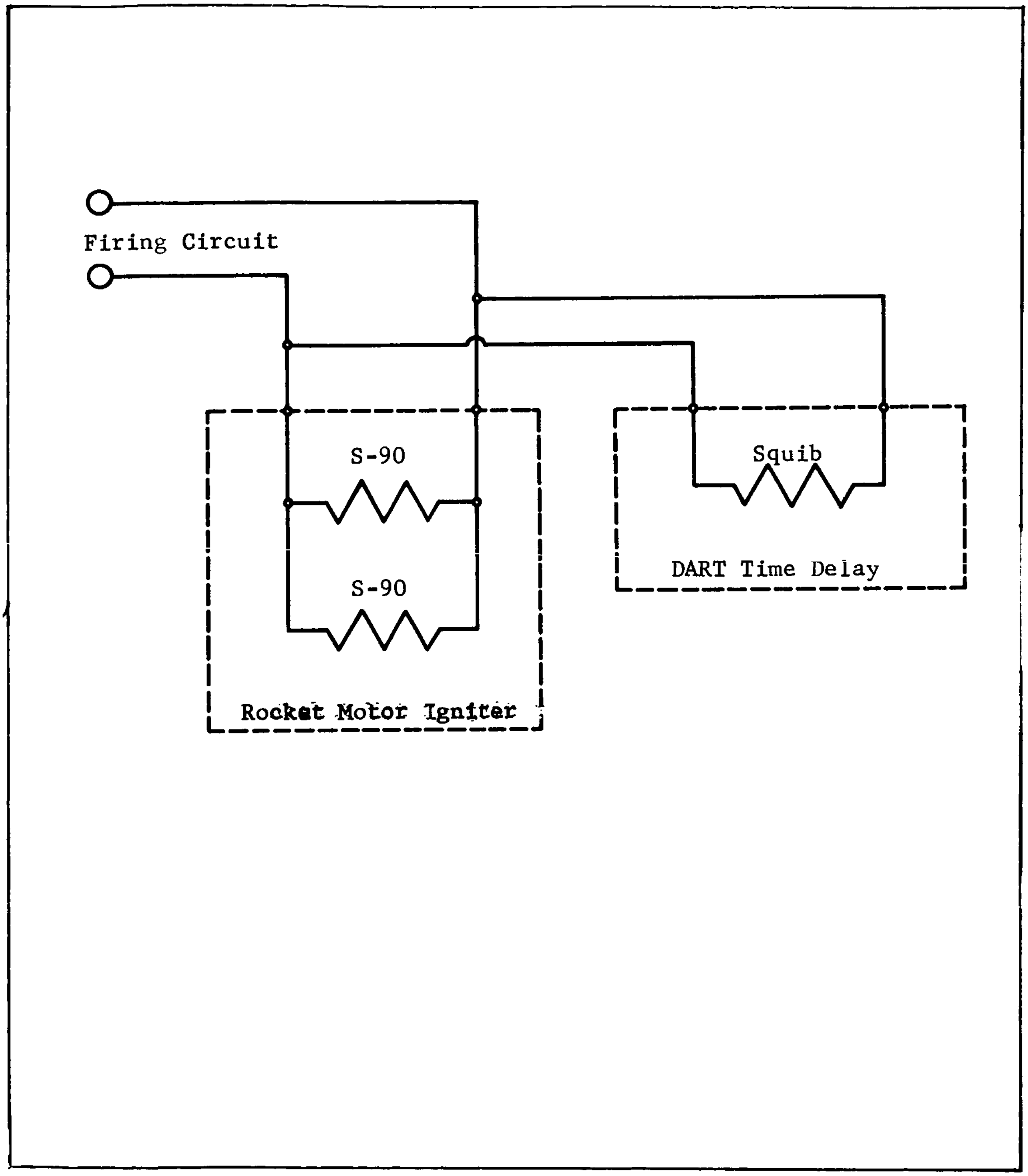


FIGURE 3. HOPI-DART IGNITER SYSTEM

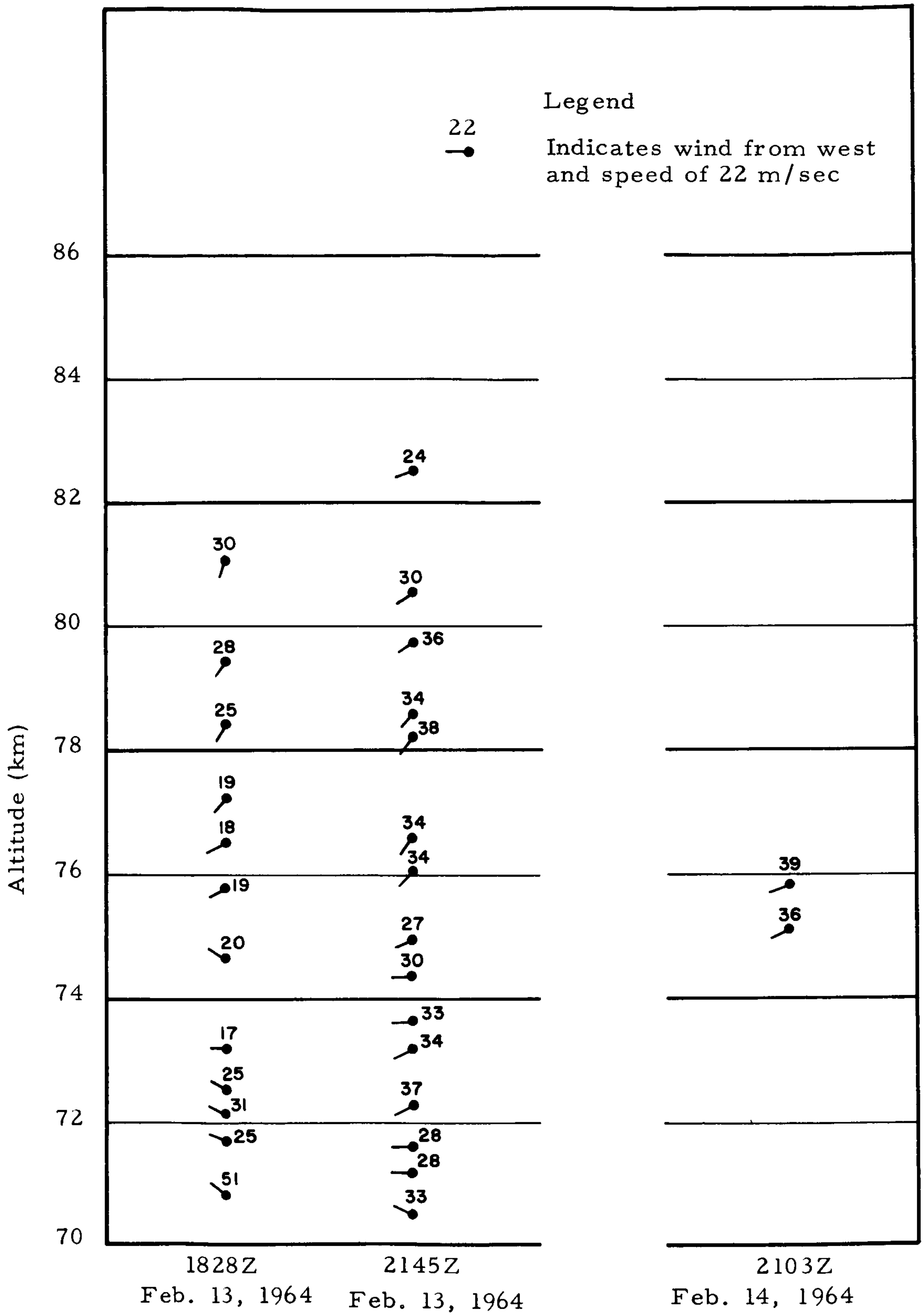
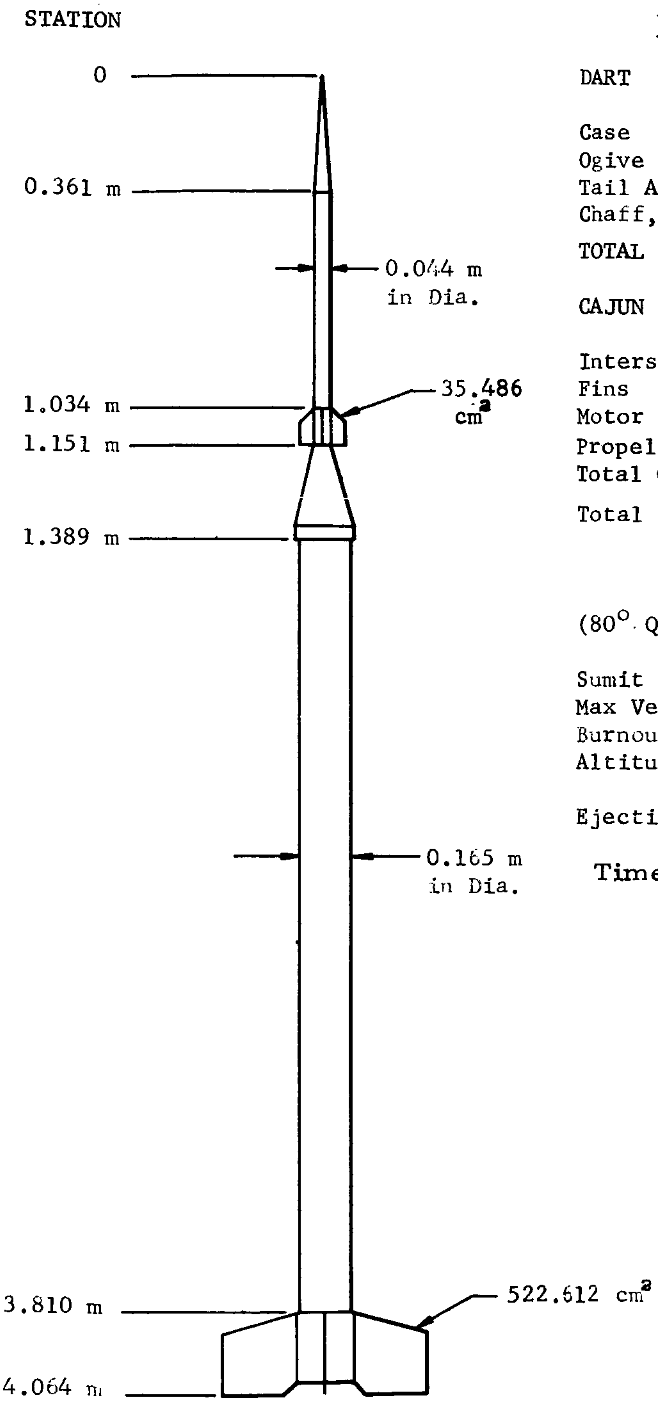


FIGURE 4. HOPI-DART MEASURED WIND PROFILES, CAPE KENNEDY, FLORIDA, FEBRUARY 1964



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 @ Burnout	34.882
Total Vehicle @ Launch	89.086

PERFORMANCE

(80° 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 5. CAJUN-DART VEHICLE

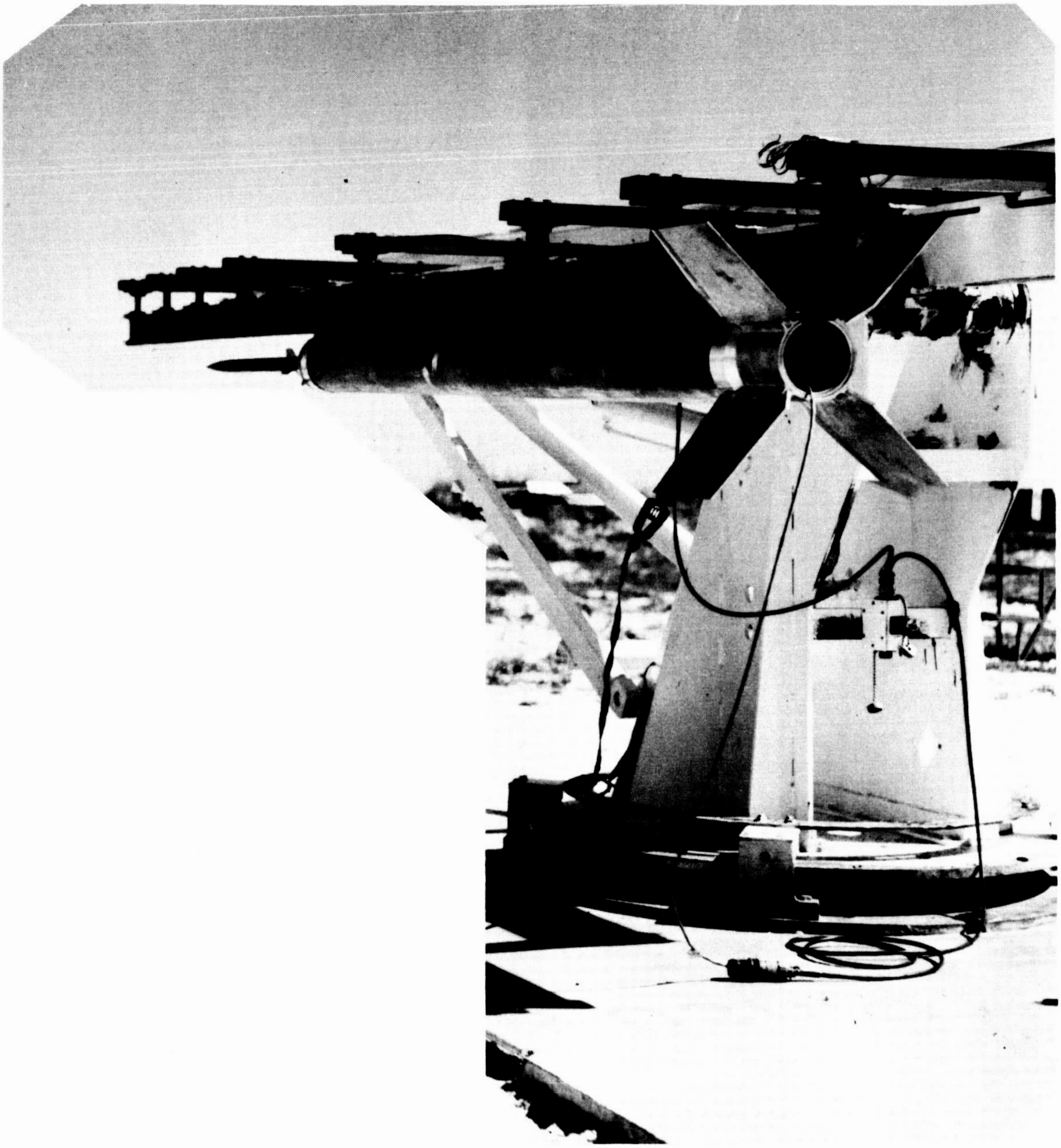


FIGURE 6. CAJUN-DART VEHICLE AND LAUNCHER

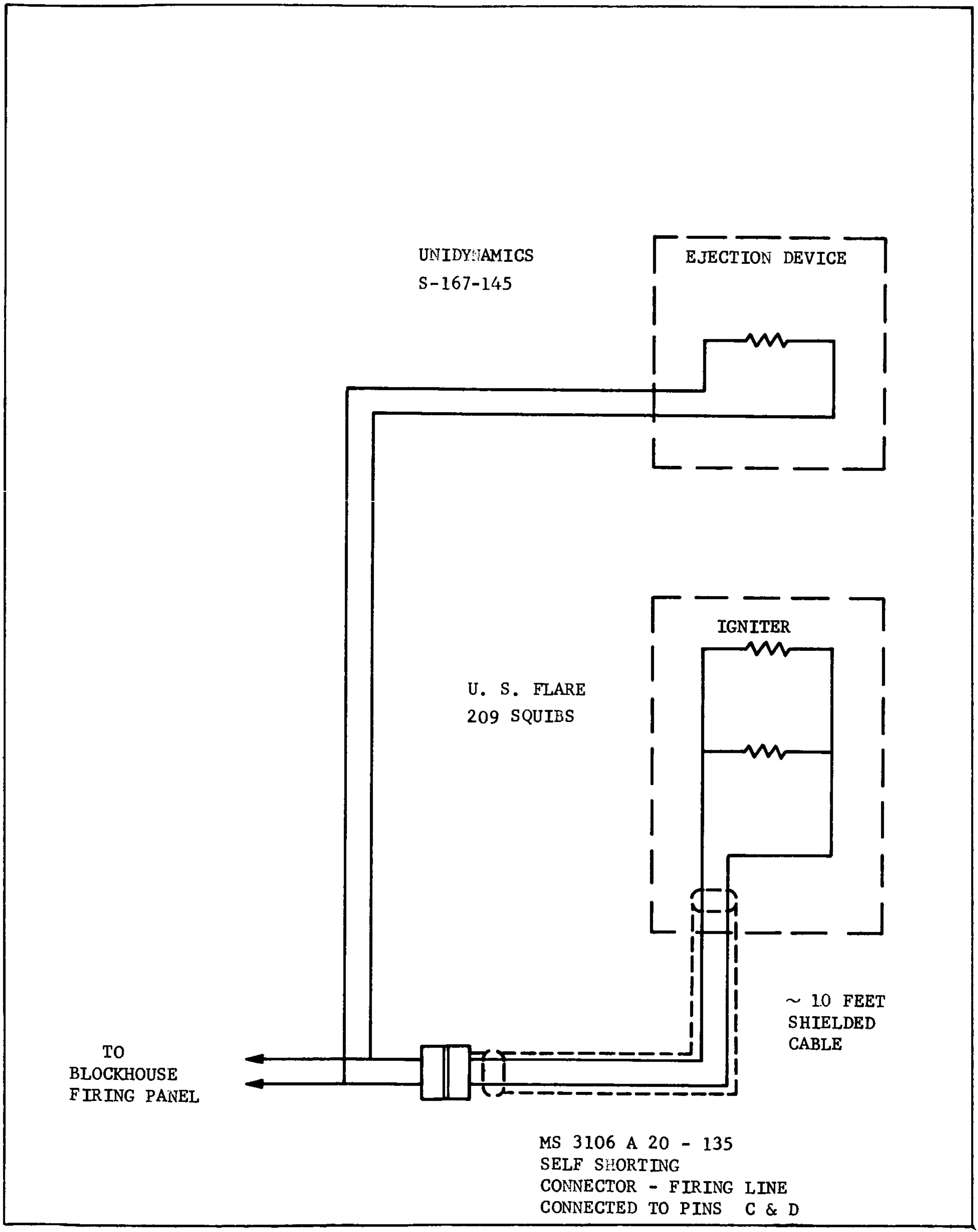


FIGURE 7. CAJUN-DART IGNITER SYSTEM

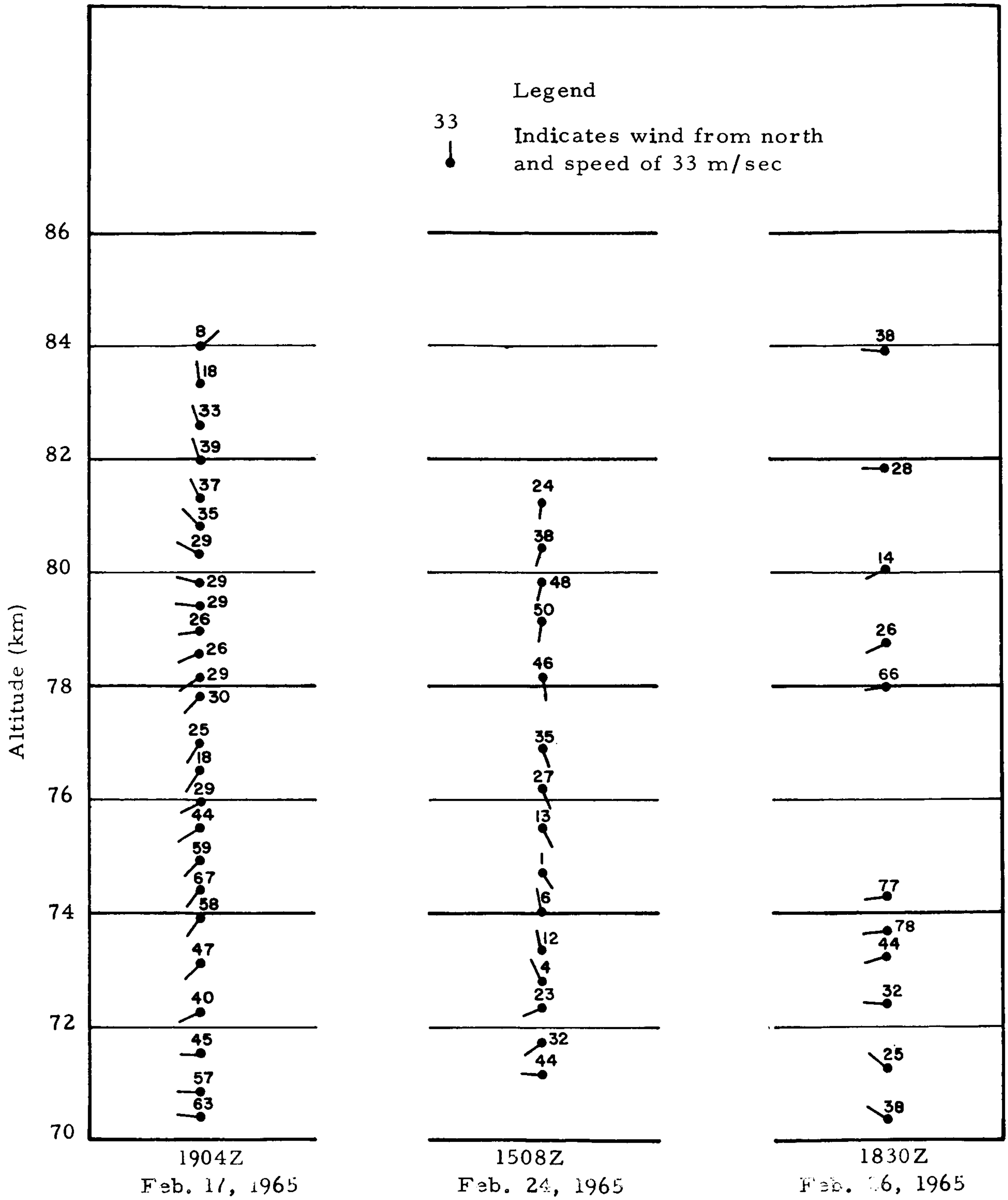


FIGURE 8. CAJUN-DART MEASURED WIND PROFILES, CAPE KENNEDY, FLORIDA, FEBRUARY 1965

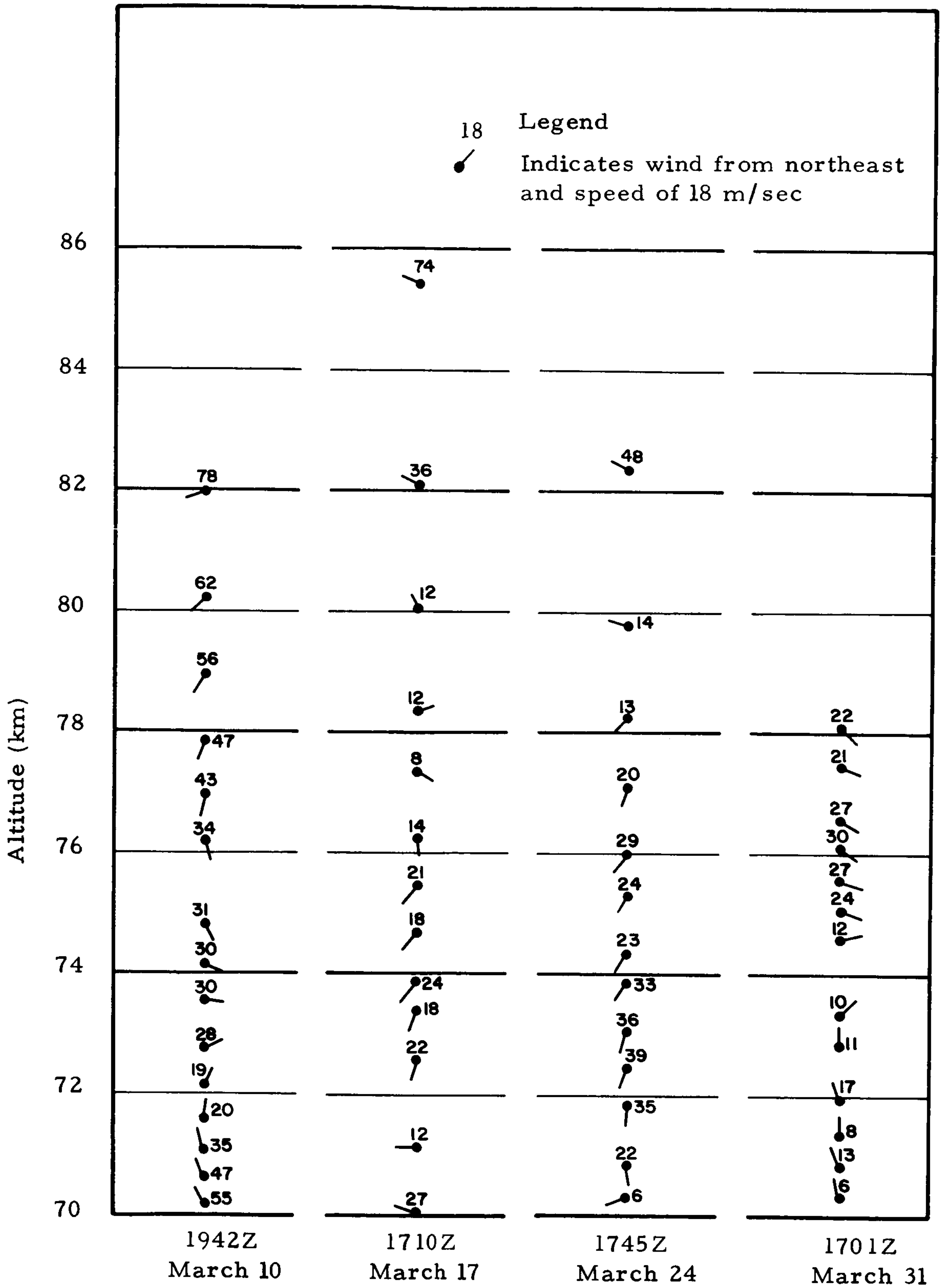


FIGURE 9. CAJUN-DART MEASURED WIND PROFILES, CAPE KENNEDY, FLORIDA, MARCH 1965

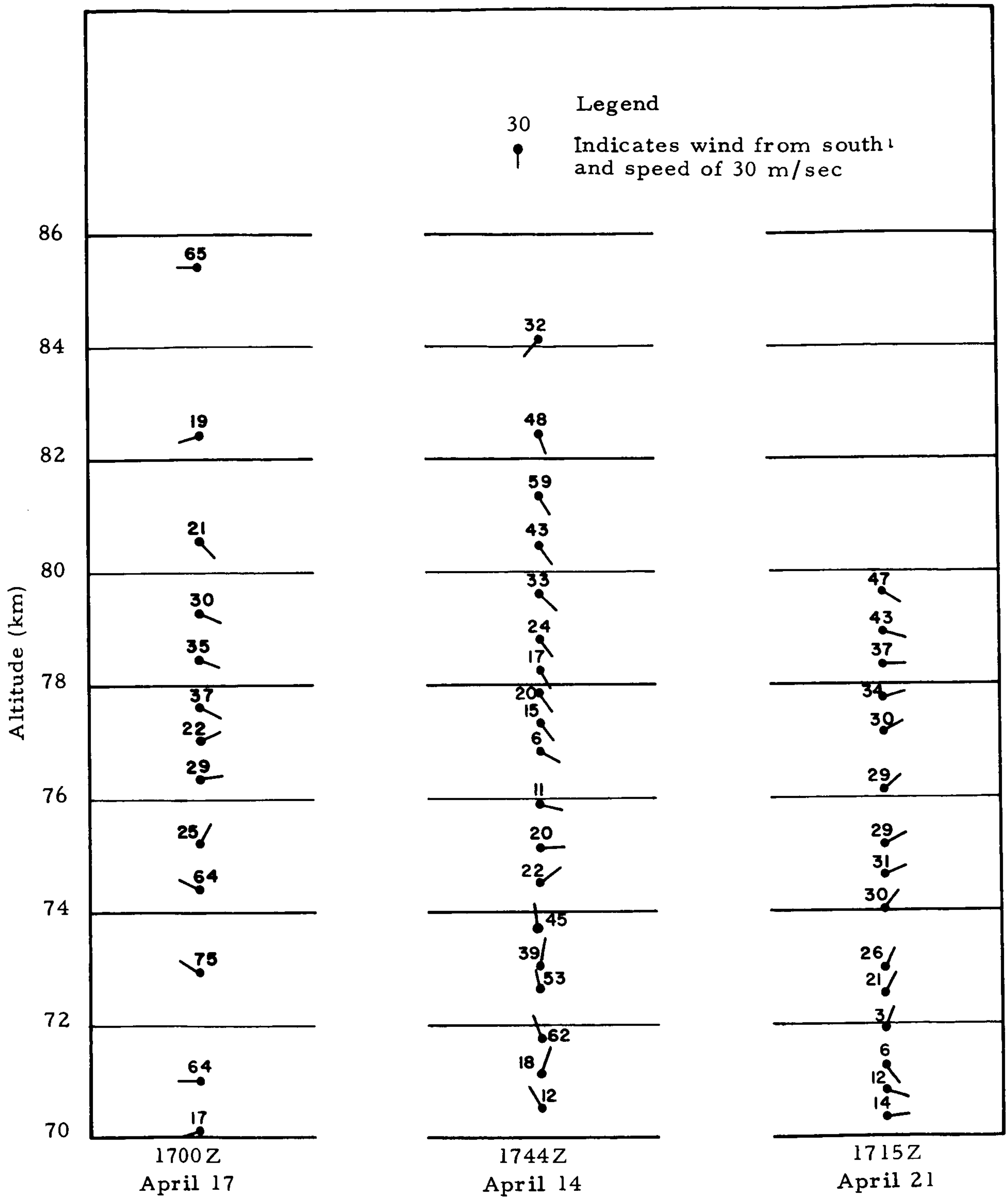


FIGURE 10. CAJUN-DART MEASURED WIND PROFILES, CAPE KENNEDY, FLORIDA, APRIL 1965

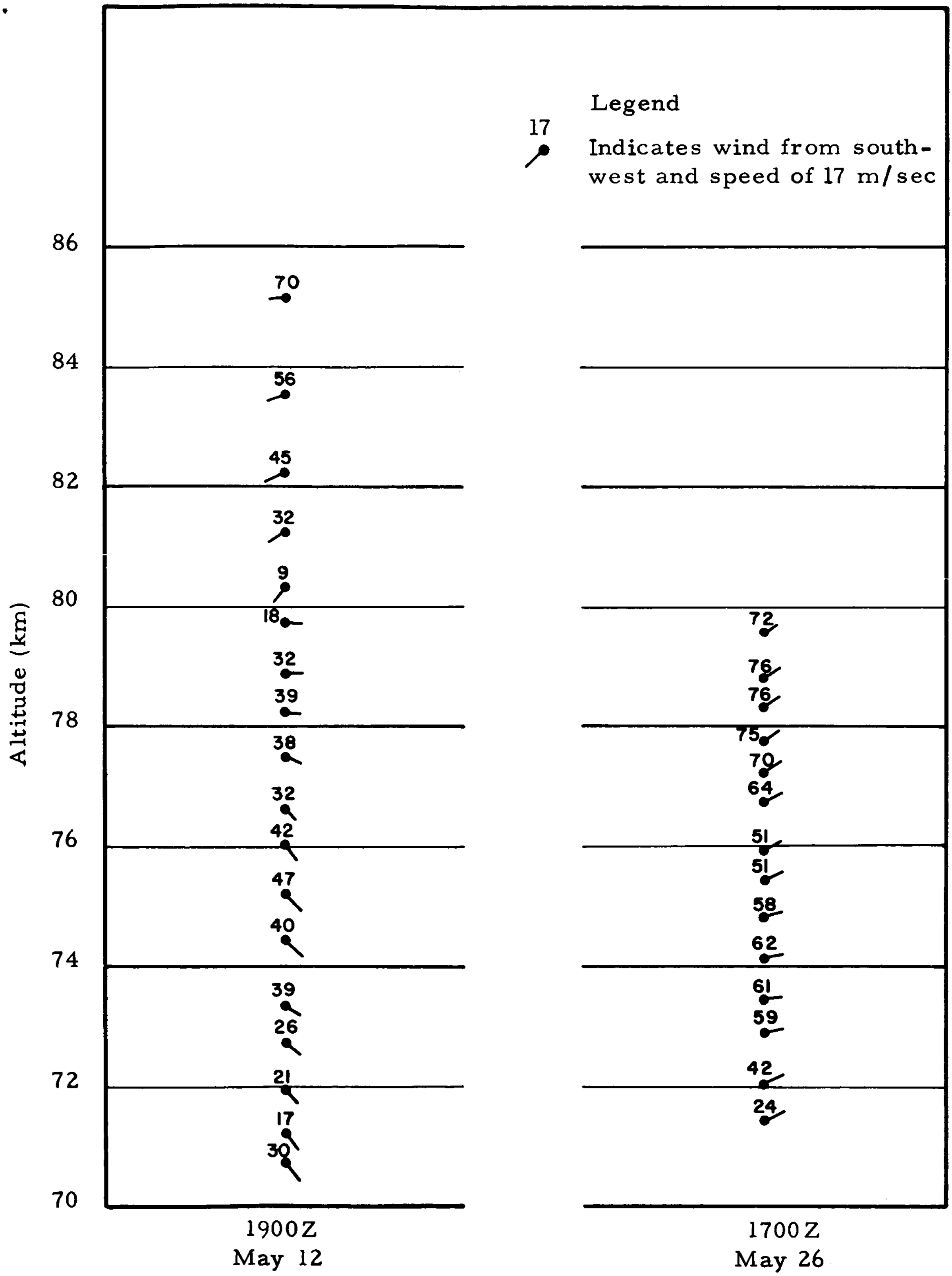


FIGURE 11. CAJUN-DART MEASURED WIND PROFILES, CAPE KENNEDY, FLORIDA, MAY 1965

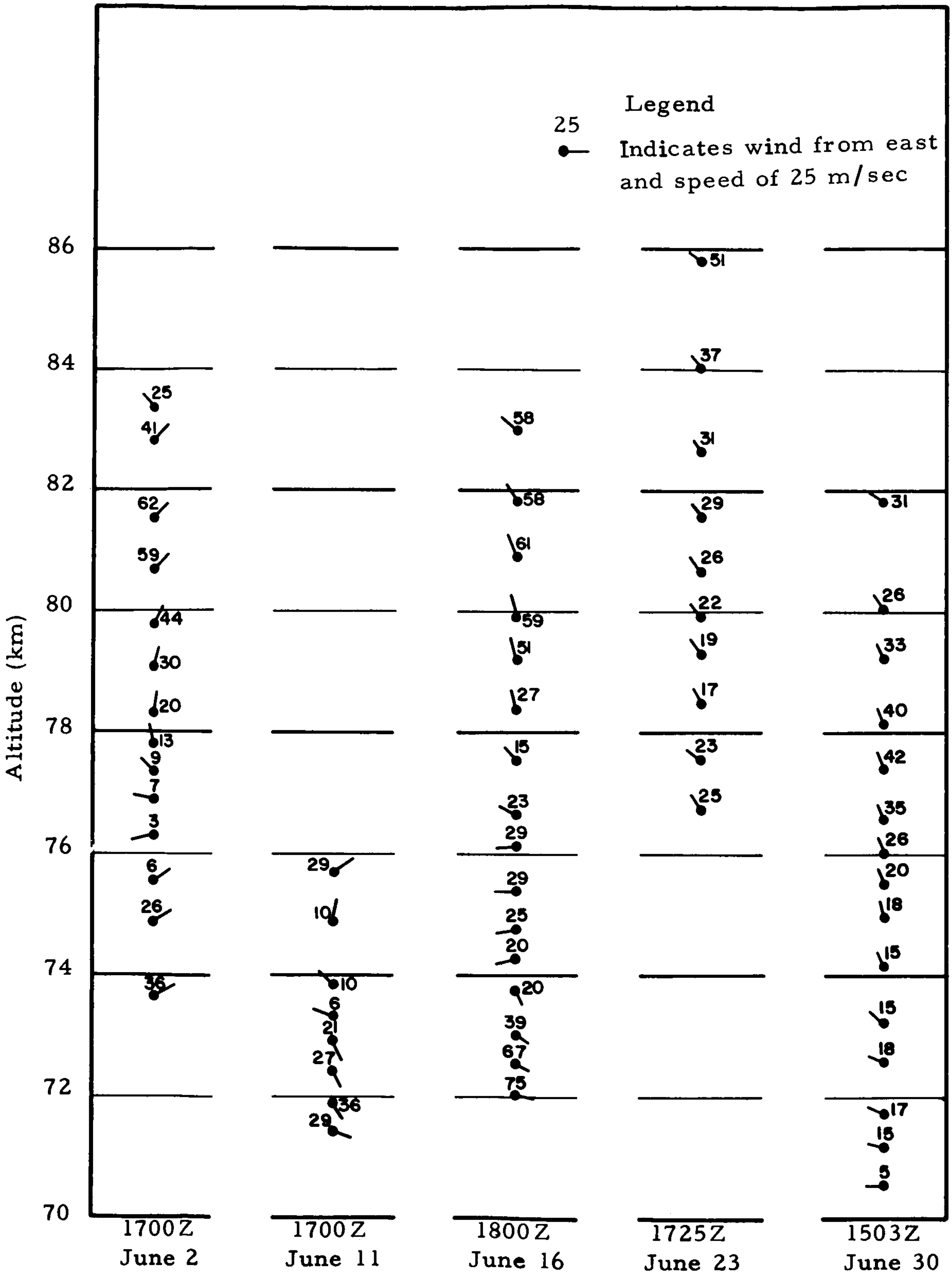


FIGURE 12. CAJUN-DART MEASURED WIND PROFILES, CAPE KENNEDY, FLORIDA, JUNE 1965

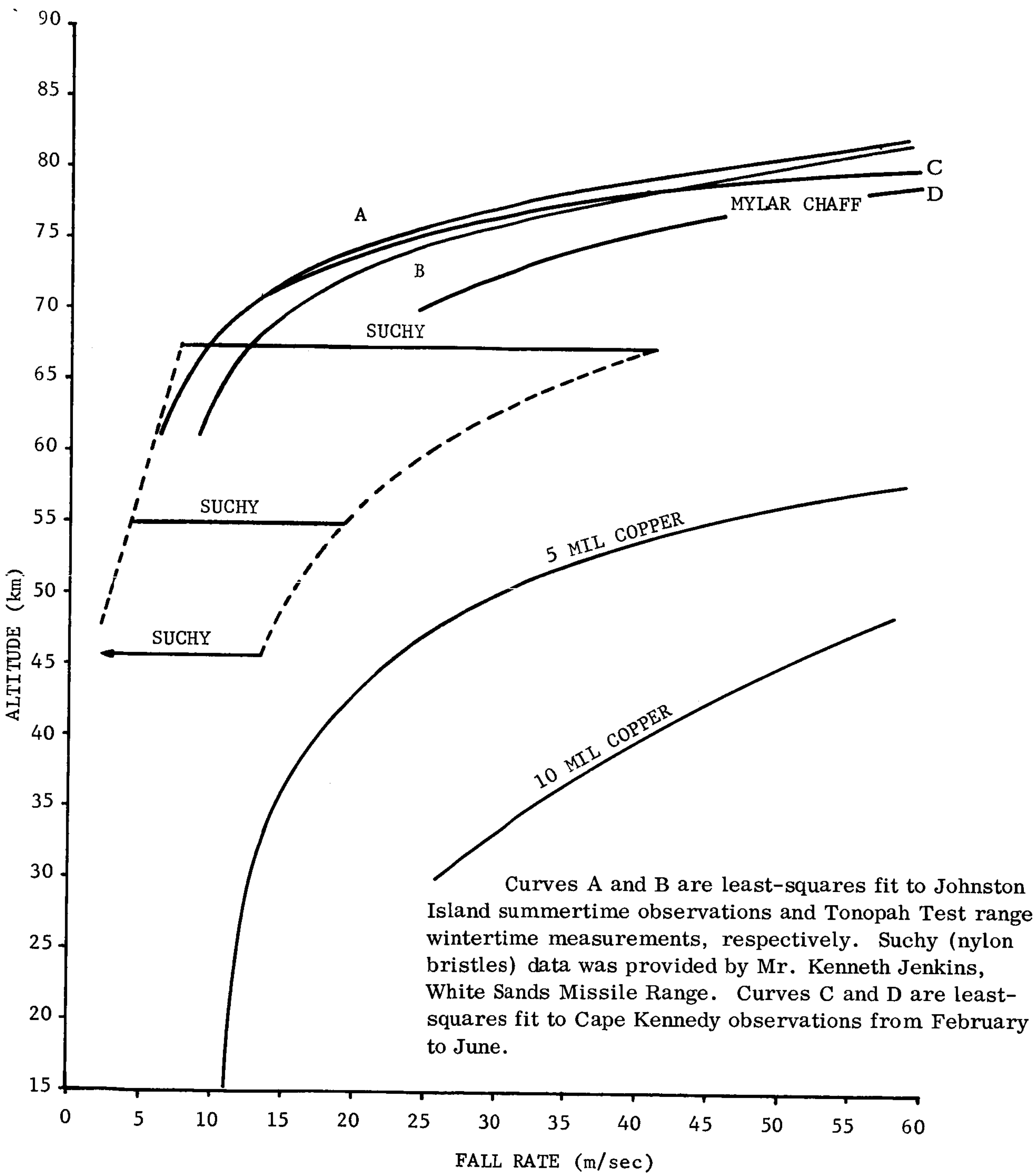


FIGURE 13. RATES OF FALL FOR VARIOUS METEOROLOGICAL SENSORS

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APPROVAL

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By Robert E. Turner and Luke 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.

William W. Vaughan

William W. Vaughan
Chief, Aerospace Environment Office

E. D. Geissler
Director, Aero-Astrodynamics Laboratory

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Air Force Cambridge Research Laboratories
L. G. Hanscom Field
Bedford, Mass.

Mr. Robert Leviton, CRER
1065 Main Street
Waltham, Massachusetts 02154

Mr. Henry Demboski
Code 421
Office of Naval Research
Washington 25, D. C.

Mr. Kenneth C. Steelman
AMSEL-RD-SM
US Army Electronics Labs.
Fort Monmouth, New Jersey

Commander
Sixth Weather Wing
Andrews Air Force Base
Washington, D. C.

Meteorological & Geoastrophysical
Abstracts
P. O. Box 1736
Washington 13, D. C.

Mr. K. R. Jenkins, SELWS-MR
U. S. Army Electronics Research
& Development Activity
White Sands Missile Range, N. M. 88002

Mr. Vaughn Williams (2)
Rocket Power, Inc.
P. O. Box 231
Mesa, Arizona 85202

Mr. Robert Walker (2)
Space Data Corporation
2875 Sky Harbor Boulevard
Suite 204
Phoenix, Arizona

Mr. W. L. Webb, SELWS-M
U. S. Army Electronics Research
& Development Activity
White Sands Missile Range, N. M. 88002

Mr. T. R. Carr, Code 3251, Box 22
Geophysics Division
Western Test Range
Point Mugu, California 93041

Mr. John E. Masterson
Code 3150, Box 7
Environmental Sciences Division
Range Development Department
Western Test Range
Point Mugu, California 93041

Mr. Royal C. Gould
Code 3069
Naval Ordnance Test Station
China Lake, California 93557

Mr. Arlin J. Krueger
Code 50
Naval Ordnance Test Station
China Lake, California 93557

Maj. J. O. de Bellefeuille, FTZBW
Air Force Flight Test Center
Edwards Air Force Base, California 93523

Maj. Ralph R. Ruyle, PGGW
U. S. Air Force
Air Proving Ground Center
Eglin Air Force Base, Florida 32542

Lt/Col. W. L. Dotson, WTW
Air Force Western Test Range
Vandenberg AFB, California

Mr. Lawrence B. Smith
Sandia Corporation
Sandia Base
Albuquerque, N. M. 87115