# BRL

CONTRACT 169

REPORT NO. 7

UPPER ATMOSPHERE WINDS FROM
GUN LAUNCHED VERTICAL PROBES
(Yuma, 26-27 October 1966)



SPACE INSTRUMENTS RESEARCH, INC.

BRL CONTRACT 169 REPORT 7

# UPPER ATMOSPHERE WINDS FROM GUN LAUNCHED VERTICAL PROBES

(Yuma, 26-27 October 1966)

Prepared for

U. S. Army
Ballistic Research Laboratories
Aberdeen Proving Ground, Maryland

Contract No. DA-01-009-AMC-169(X)


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SPACE INSTRUMENTS RESEARCH, INC.
Atlanta, Georgia

August 1967

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NOTE: The wind vector as given in this report is considered to point in the direction toward which the wind is blowing, (that is, a west wind is toward the west). Most meteorologists are accustomed to a 180° difference (that is, a west wind is from the west.)

## INTRODUCTION

For several years upper atmospheric winds over the lower West Indies have been studied by firing high altitude ballistic probes from a sixteen-inch gun. The installation of a similar 16" gun at Yuma Proving Ground, Arizona, early in 1966 has made possible a similar study of winds in this region. These firings are being carried out by the U. S. Army Ballistic Research Laboratories, Aberdeen Proving Ground, Maryland, under the direction of Dr. Charles H. Murphy, and by the Space Research Institute of McGill University, Canada, under the direction of Dr. G. V. Bull.

Atmospheric winds are studied by releasing chemical trails from the gun-fired probes during the upper portion of their trajectories. To date, the primary chemical which has been released is trimethyl aluminum (TMA). TMA produces a chemiluminescent glow in regions of the atmosphere above 85 kilometers, thus allowing the trails to be photographed while being distorted by upper atmosphere winds. The photographs are then reduced to provide wind information by Space Instruments Research, Inc. (SIR), using computer techniques.

The purpose of this report is to summarize results of these studies for the period from October 26 through October 27, 1966. A "Table of Trail Information" is given on page 13 and lists the trail number, shot number, date, time and altitude interval. Previous results for winds over Barbados, West Indies, are covered in Technical Reports No. 1, 2, 3, and 5. Technical Reports No. 4 and 6 cover previous results for winds over Yuma, Arizona.

## DATA ACQUISITION

The chemical trails are formed almost vertically over the gunsite (longitude 114.3°W., latitude 32.9°N) and extend from an altitude of approximately 85 kilometers through apogee. In some firings, TMA is also released on the down leg of the trajectory. To the unaided eye, the chemical release first appears as a straight white trail resembling a jet contrail. Within a minute or so, the trail is distorted into strange shapes by the upper atmospheric winds (see Figure 1) and fades from view within approximately fifteen minutes after initial release.

Space Instruments Research has established three photographic triangulation stations at Yuma and Gila Bend, Arizona, and Blythe, Calif. These sites are located at distances of up to 150 kilometers from the gunsite (see Figure 2).

Equipment at each site, built by SIR, consists of a camera unit containing two seven-inch focal length cameras mounted on a concrete pedestal, and an electronic control unit. Cameras are automatically pulsed to take exposures of 3, 6, and 12 seconds duration every 30 seconds.

Since commercial power is either unreliable or unavailable at many site locations, SIR has developed a battery operated 115-volt power supply for the control equipment. The power supply is tuning-fork controlled and provides 60 cycle power with an accuracy of 0.005% for the camera programer so that pictures can be taken simultaneously at each site. A data block containing 24 tiny lights, mounted in each camera unit, records time, firing number, and site information in the corner of each frame of film.

During a typical night's operation, the gun is fired at one to two-hour intervals, from sunset to sunrise. Photographs are taken by all sites during the time that the trail is visible. The film is then returned to Atlanta for processing and data reduction.

## DATA REDUCTION

Several computer programs have been developed which make it possible to calculate upper atmosphere winds from measurements made directly on the photographs of the luminous trails.

Since the method used is basically three-dimensional triangulation using spherical trigonometry, it is necessary to know precisely the direction each camera was pointed during a given firing. The direction is determined by first taking accurate measurements of the locations of several star images on the film, and then computing the azimuth and elevation of the optical axis of the camera by means of a computer program. This computer program makes use of the celestial coordinates of some 6,000 stars which have been stored on magnetic tape.

Wind speeds and directions are then determined from the location of the trail in space at a succession of known times. The location is found, using either a point location program or a trail location program, or both, and depends on the physical shape of the chemical release cloud.

Point location method. If the chemical release exhibits discrete points (resulting either from turbulence or from the nature of the release mechanism) and these points can be identified on films from two or more sites, the point location program can be used to calculate the position of each point in longitude, latitude, and altitude above sea level.

These calculations are made from data taken at successive times. A wind program is then used to calculate both vertical and horizontal winds from the motion of these points as a function of time.

Trail location method. Most of the chemical releases produce a smooth trail having few, if any, identifiable points. In such cases, film coordinates of a large number of incremental points along the film image of the trail are fed into the computer from data from two or more sites. The trail location program attempts to triangulate each point from one site with many points from another site, finally choosing points from both sites whose optical paths from camera into space form the closest spatial intersection. After doing many hundreds of such calculations, the computer is able to construct coordinates for a mathematical curve in the shape of the trail in space. Then, as with the point location program, winds can be determined from the motion of the curve with time. Here, however, it must be assumed that vertical winds are essentially zero. This assumption is borne out by previous studies which have shown vertical winds in this altitude region to be of the order of a few meters per second compared to horizontal winds ranging up to 150 meters per second.

Corrections for variables such as atmospheric refraction, rotation of camera about optical axis, and camera focal length, are incorporated into the programs to maintain high accuracy. Focal length and camera rotation are, in fact, calculated from measurements of the positions of star images on the films.

## INTERPRETATION OF DATA

Following the "Table of Trail Information," horizontal wind velocities are presented in tabular form and in plots of wind speed, direction, and components.

Winds were calculated at altitude intervals of one kilometer. Points on the various plots show the actual computed result, as listed in the table preceding the plot. A curve has been fitted to each set of points to aid in detecting wind patterns and to indicate reliability of the plotted results. Each curve has been drawn with a knowledge of intermediate results leading to the wind calculations and of the consistency of the winds as calculated between each of the five or more time intervals used. In cases where point-to-point curve fitting was not thought to reflect actual variations in wind speed, direction, or components, a more appropriate smooth curve has been drawn. Otherwise, the curves are fitted directly to the data points. Results of certain potions of the trails are at times less accurate than others due to the spatial orientation of those trail segments relative to the available photographic stations. Less accurate data also can result from photographs obscured by haze and clouds and from trails of short duration.

Wind speed plot. This plot shows the speed of the wind in meters per second as a function of height in kilometers above sea level.

Wind direction plot. The wind vector is considered to point in the direction toward which the wind is moving. The direction plot shows the direction of this vector in degrees clockwise from north as seen from above. Thus, a wind direction toward the east would be 90 degrees.

Wind components plot. While plots of wind direction and speed do completely describe the wind vector, it has been found helpful in studying wind patterns to present the north-south (N-S) and east-west (E-W) velocity components of the vector. In the north-south plot, north is positive; south is negative. In the east-west plot, east is positive, west negative. Components are plotted in meters per second versus height in kilometers.

The wind direction and components desribed above are referenced to true north. In addition, components have been calculated relative to magnetic north for comparison with other ionospheric phenomena. These components are not plotted but are listed in the tabulations preceding each set of plots.

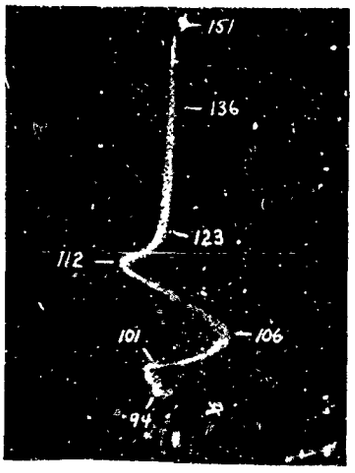
Throughout this report, where shorter notation was desirable, "Up" or "U" and "Down" or "D" have replaced uptrail and downtrail, respectively.

FIGURE 1

PHOTOGRAPHS OF TRAIL NO. Y7

Photographs taken 142 seconds after firing:



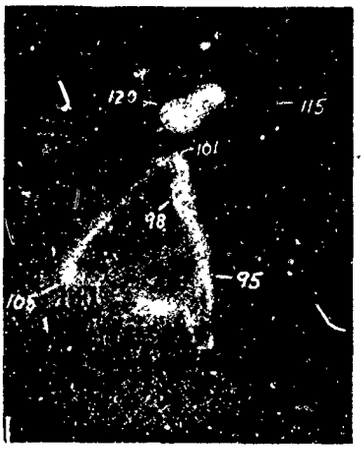


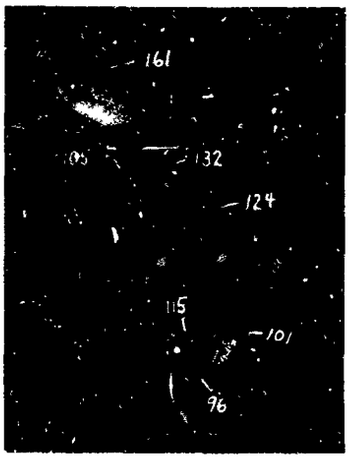

YUMA BLYTHE GILA BEND

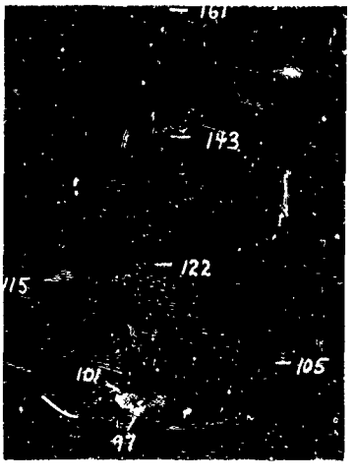
The pictures on this page show the effect of high altitude winds on a typical trail over a period of one minute. The stars visible in the background are used to determine the direction each camera was pointed.

Numbers indicate height in kilometers.

Photographs taken 202 seconds after firing:




YUMA BLYTHE GILA BEND

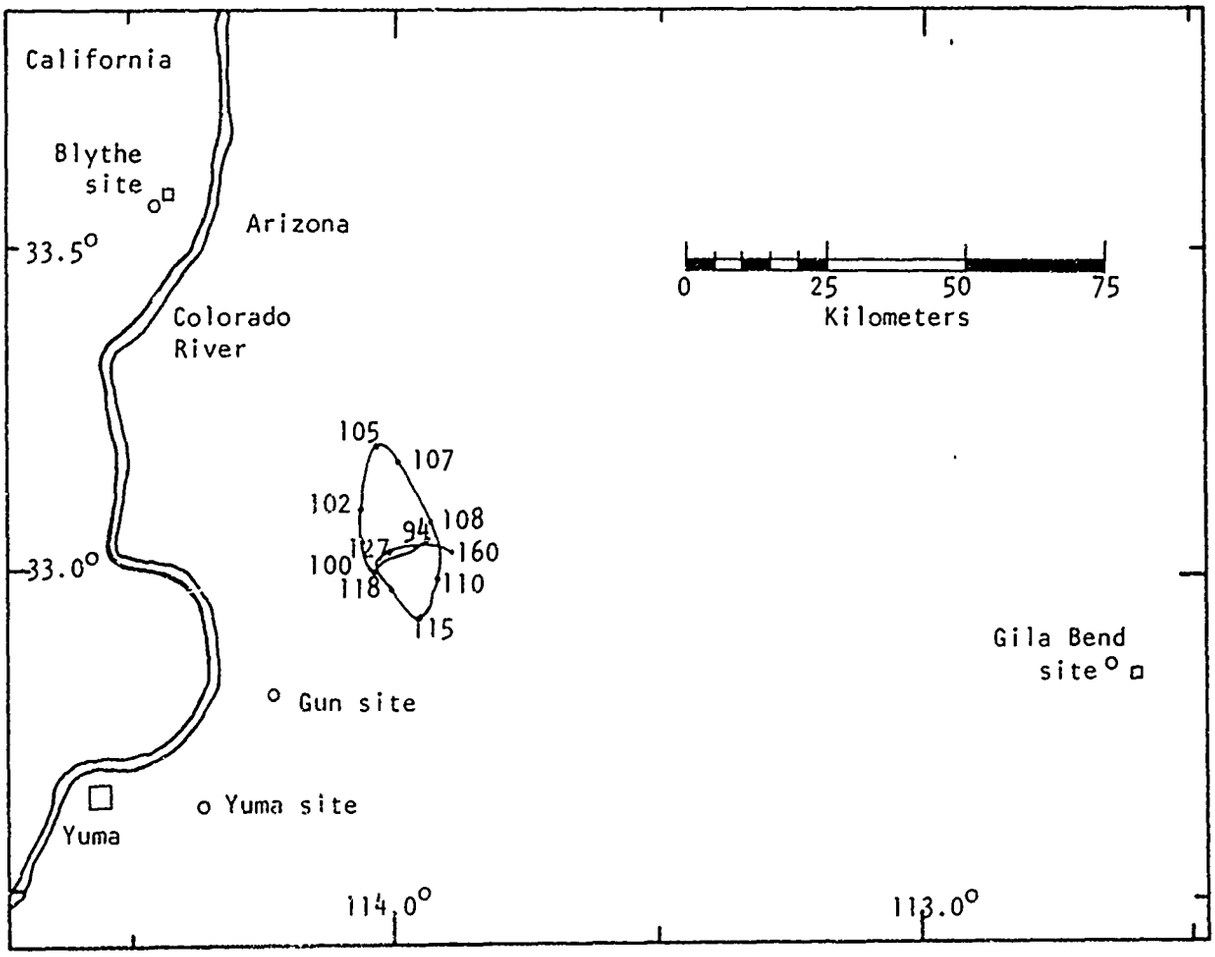
A ground projection, relative to photographic sites, is plotted on the next page.

Figure 2

Ground Projection of Trail No. Y7

at 202 Seconds After Firing

HARP - Yuma




The above plot shows the location of each SIR photographic site and the projection of the trail on the ground.

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TABLE OF TRAIL INFORMATION

| Trail No. | Shot No. | Date | Time (MST) | Altitudes (km) |
|---|---|---|---|---|
| Y6 | 0011 | 26 October 1966 | 20:55:01 | 87-124 |
| Y7 | 0012 | 26 October 1966 | 23:56:00 | 90-160 |
| Y8 | 0014 | 27 October 1966 | 19:52:01 | 94-124 |
| Y9 | 0015 | 27 October 1966 | 21:46:01 | 90-135 |

TABULATIONS AND PLOTS

FOUR TMA TRAILS - 26-27 OCTOBER 1966

NOTE: The wind vector as given in this report is considered to point in the direction toward which the wind is blowing, (that is, a west wind is toward the west.) Most meteorologists are accustomed to a 180° difference, (that is, a west wind is from the west.)

YUMA

TRAIL NO. Y6
26 OCTOBER 1966

20-55-01 MST

UPTRAIL

| ALTITUDE (KM) | WIND DIRECTION (DEG) | WIND SPEED (M/S) | WIND COMPONENTS (M/S) GEOGRAPHIC N-S | GEOGRAPHIC E-W | MAGNETIC N-S | MAGNETIC E-W |
|---|---|---|---|---|---|---|
| 87.0 | 15.0 | 10.5 | 10.2 | 2.7 | 10.6 | 0.1 |
| 88.0 | 54.5 | 16.7 | 9.7 | 13.6 | 12.7 | 10.8 |
| 89.0 | 40.8 | 28.5 | 21.6 | 18.6 | 25.5 | 12.7 |
| 90.0 | 13.1 | 29.7 | 28.9 | 6.8 | 29.7 | -0.5 |
| 91.0 | 359.6 | 33.2 | 33.2 | -0.2 | 32.1 | -8.4 |
| 92.0 | 2.3 | 27.1 | 27.0 | 1.1 | 26.4 | -5.6 |
| 93.0 | 353.9 | 9.6 | 9.6 | -1.0 | 9.1 | -3.3 |
| 94.0 | 310.3 | 4.3 | 2.8 | -3.3 | 1.9 | -3.9 |
| 95.0 | 266.4 | 4.2 | -0.3 | -4.2 | -1.3 | -4.0 |
| 96.0 | 106.5 | 10.4 | -3.0 | 10.0 | -0.4 | 10.4 |
| 97.0 | 107.2 | 22.7 | -6.7 | 21.6 | -1.2 | 22.6 |
| 98.0 | 112.4 | 37.5 | -14.3 | 34.7 | -5.3 | 37.2 |
| 99.0 | 115.2 | 48.8 | -20.8 | 44.1 | -9.3 | 47.9 |
| 100.0 | 118.5 | 54.5 | -26.0 | 47.9 | -13.4 | 52.8 |
| 101.0 | 127.6 | 60.5 | -36.9 | 47.9 | -24.0 | 55.5 |
| 102.0 | 168.5 | 81.5 | -79.9 | 16.3 | -73.4 | 35.5 |
| 103.0 | 179.1 | 97.6 | -97.6 | 1.5 | -94.2 | 25.5 |
| 104.0 | 182.9 | 101.3 | -101.2 | -5.0 | -99.3 | 20.1 |
| 105.0 | 197.9 | 94.9 | -90.3 | -29.2 | -94.7 | -6.1 |
| 106.0 | 252.5 | 54.0 | -16.2 | -51.5 | -28.4 | -45.9 |
| 107.0 | 315.0 | 64.0 | 45.2 | -45.3 | 32.7 | -55.0 |
| 108.0 | 336.8 | 79.5 | 73.1 | -31.3 | 63.1 | -48.3 |
| 109.0 | 346.6 | 91.7 | 89.2 | -21.2 | 81.2 | -42.5 |
| 110.0 | 355.1 | 101.2 | 100.9 | -8.6 | 95.7 | -33.2 |
| 111.0 | 359.0 | 102.4 | 102.4 | -1.8 | 98.8 | -27.0 |
| 112.0 | 2.0 | 101.7 | 101.6 | 3.5 | 99.3 | -21.6 |
| 113.0 | 3.0 | 100.2 | 100.1 | 5.2 | 98.3 | -19.6 |
| 114.0 | 5.4 | 92.5 | 92.1 | 8.6 | 91.4 | -14.3 |
| 115.0 | 7.8 | 82.6 | 81.8 | 11.2 | 82.0 | -9.3 |
| 116.0 | 9.7 | 69.0 | 68.0 | 11.7 | 68.8 | -5.4 |
| 117.0 | 11.3 | 59.0 | 57.8 | 11.6 | 58.9 | -3.0 |
| 118.0 | 9.6 | 46.2 | 45.5 | 7.7 | 46.0 | -3.7 |
| 119.0 | 5.1 | 36.8 | 36.6 | 3.3 | 36.3 | -5.8 |
| 120.0 | 354.5 | 28.1 | 28.0 | -2.7 | 26.5 | -9.5 |
| 121.0 | 344.0 | 25.4 | 24.5 | -7.0 | 22.0 | -12.8 |
| 122.0 | 321.5 | 24.3 | 19.0 | -15.1 | 14.7 | -19.3 |
| 123.0 | 299.2 | 25.5 | 12.4 | -22.3 | 6.5 | -24.7 |
| 124.0 | 285.1 | 40.3 | 10.5 | -38.9 | 0.6 | -40.3 |

WIND COMPONENTS

UP

N–S ○

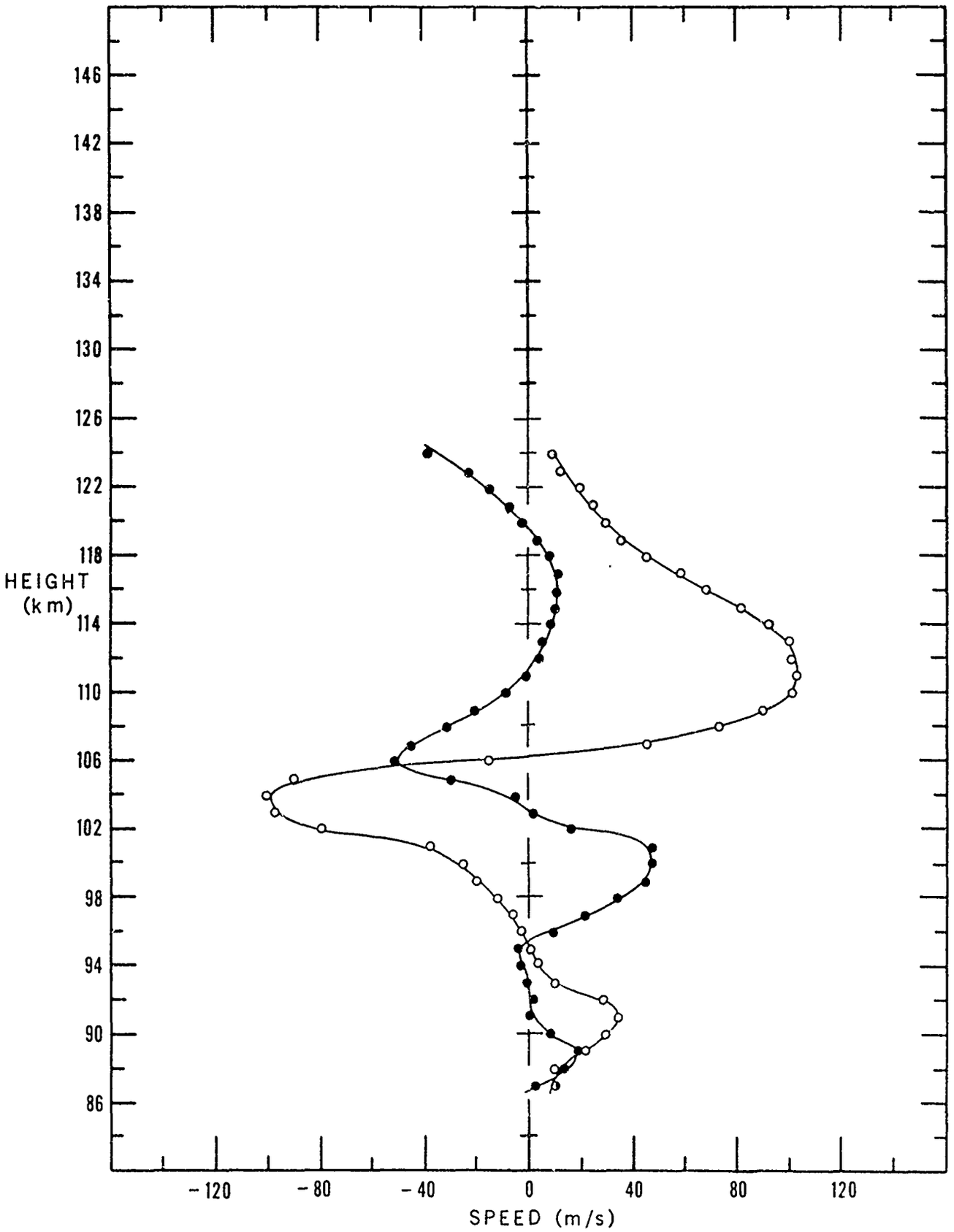
E–W ●

TRAIL NO. Y6

20:55:01 MST

26 OCTOBER 1966

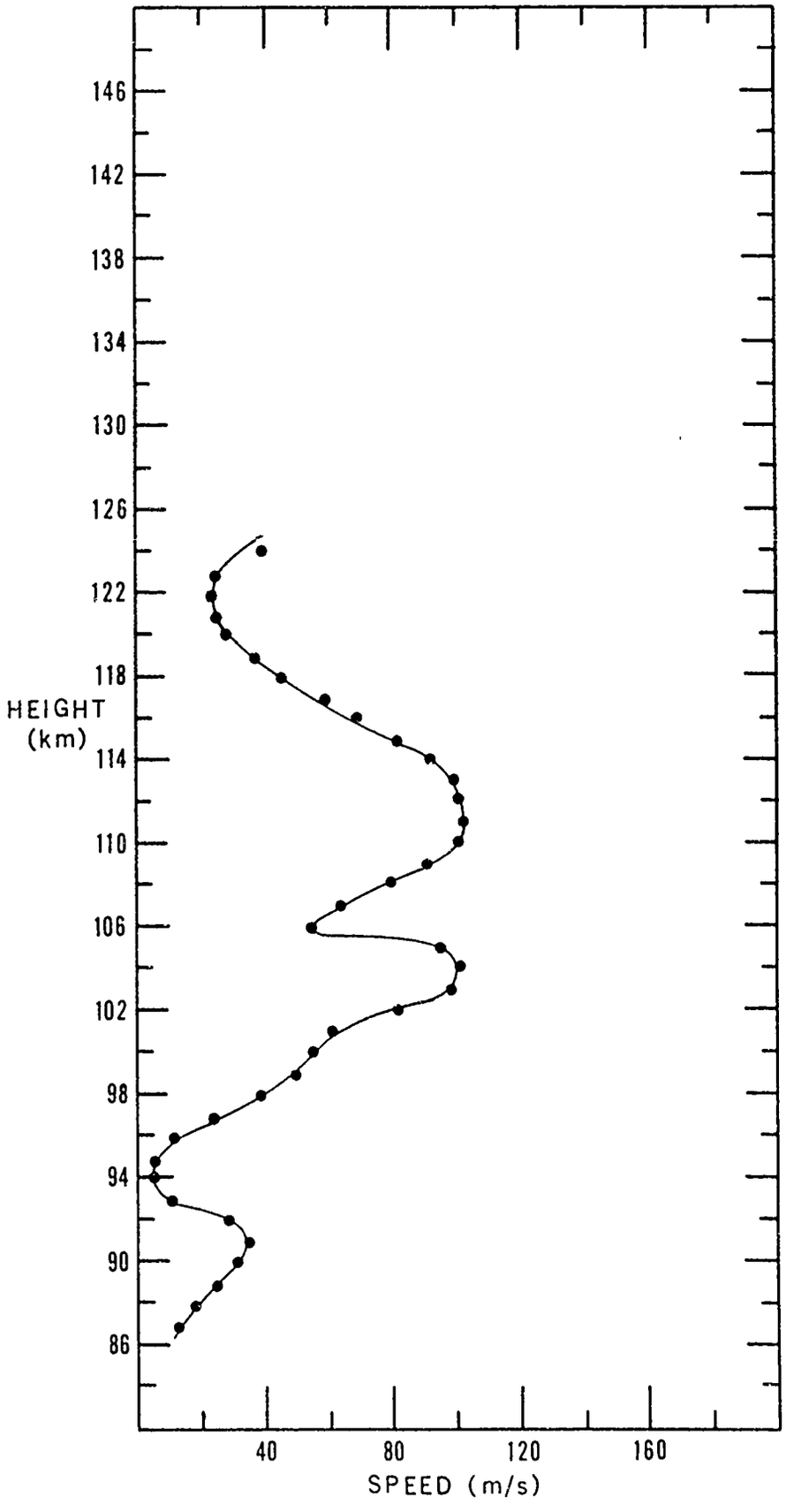
H.A.R.P. YUMA



WIND SPEED

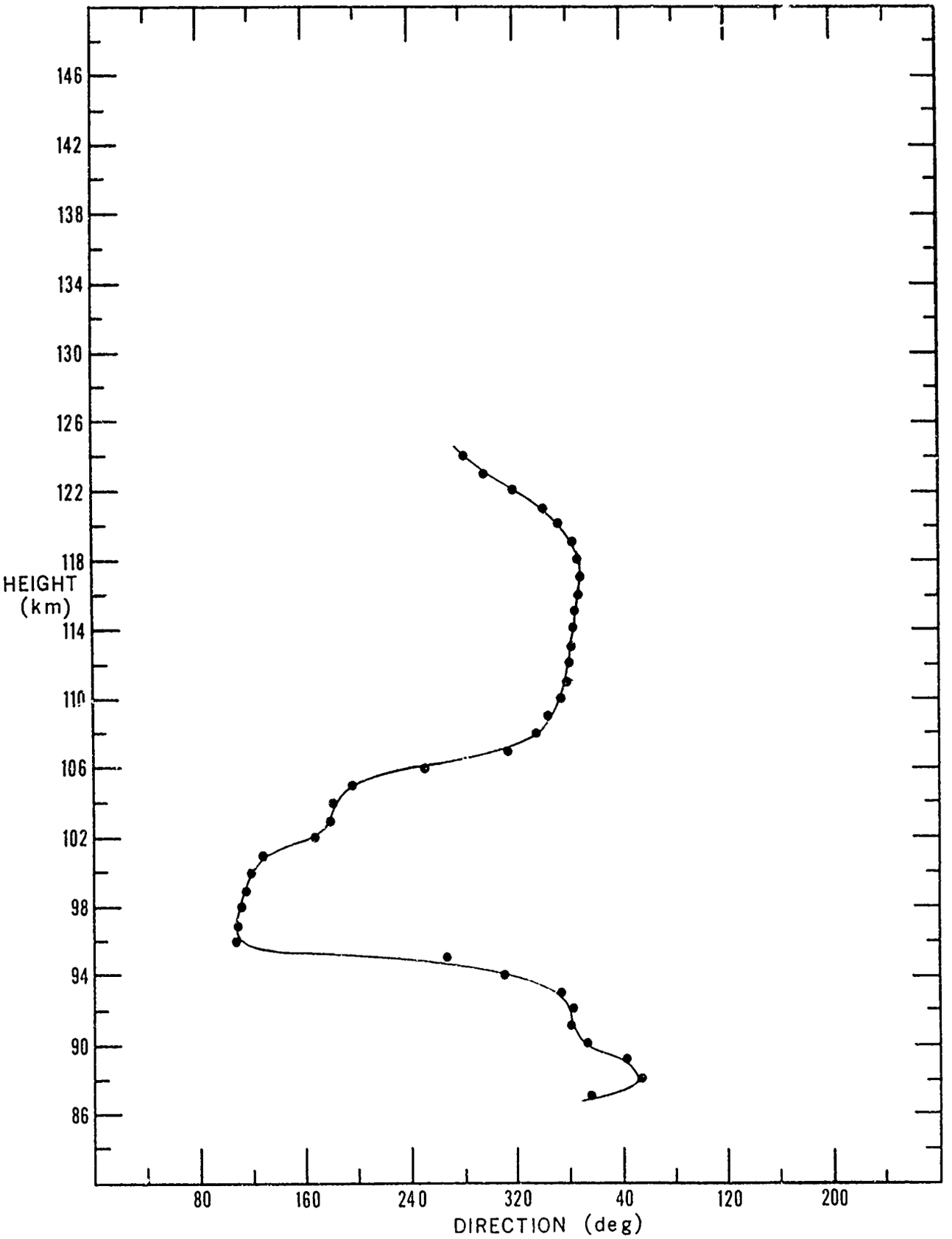
• UP

TRAIL NO. Y6
20:55:01 MST
26 OCTOBER 1966
H.A.R.P. YUMA



WIND DIRECTION
• UP

TRAIL NO. Y6
20:55:01 MST
26 OCTOBER 1966
H.A.R.P. YUMA



TRAIL NO. Y7

YUMA 26 OCTOBER 1966 23-56-00 MST

UPTRAIL

| ALTITUDE (KM) | WIND DIRECTION (DEG) | WIND SPEED (M/S) | WIND COMPONENTS (M/S) GEOGRAPHIC N-S | GEOGRAPHIC E-W | MAGNETIC N-S | MAGNETIC E-W |
|---|---|---|---|---|---|---|
| 90.0 | 44.4 | 71.3 | 51.0 | 49.9 | 61.7 | 35.8 |
| 91.0 | 44.0 | 80.0 | 57.5 | 55.6 | 69.4 | 39.7 |
| 92.0 | 47.3 | 89.9 | 61.0 | 66.1 | 75.4 | 49.1 |
| 93.0 | 53.3 | 86.0 | 51.4 | 69.0 | 66.8 | 54.2 |
| 94.0 | 59.0 | 60.2 | 31.0 | 51.6 | 42.7 | 42.4 |
| 95.0 | 61.4 | 38.8 | 18.6 | 34.1 | 26.4 | 28.5 |
| 96.0 | 59.0 | 26.3 | 13.6 | 22.5 | 18.7 | 18.5 |
| 97.0 | 39.5 | 14.1 | 10.9 | 9.0 | 12.8 | 6.0 |
| 98.0 | 16.5 | 7.7 | 7.4 | 2.2 | 7.7 | 0.3 |
| 99.0 | 299.1 | 3.7 | 1.8 | -3.2 | 1.0 | -3.5 |
| 100.0 | 246.0 | 8.5 | -3.5 | -7.8 | -5.3 | -6.7 |
| 101.0 | 258.6 | 14.7 | -2.9 | -14.4 | -6.4 | -13.2 |
| 102.0 | 341.0 | 73.4 | 69.4 | -23.9 | 61.4 | -40.2 |
| 103.0 | 345.0 | 95.9 | 92.7 | -24.8 | 83.7 | -46.9 |
| 104.0 | 350.5 | 129.5 | 127.7 | -21.4 | 118.5 | -52.2 |
| 105.0 | 354.5 | 148.1 | 147.4 | -14.2 | 139.4 | -50.0 |
| 106.0 | 2.9 | 141.3 | 141.1 | 7.0 | 138.5 | -27.9 |
| 107.0 | 12.6 | 118.3 | 115.4 | 25.7 | 118.2 | -3.5 |
| 108.0 | 26.5 | 86.7 | 77.6 | 38.8 | 84.8 | 18.5 |
| 109.0 | 84.5 | 66.3 | 6.4 | 66.0 | 22.4 | 62.4 |
| 110.0 | 100.2 | 65.1 | -11.6 | 64.1 | 4.5 | 65.0 |
| 111.0 | 114.9 | 68.2 | -28.7 | 61.8 | -12.6 | 67.0 |
| 112.0 | 125.9 | 73.3 | -43.0 | 59.4 | -27.1 | 68.2 |
| 113.0 | 132.9 | 77.0 | -52.4 | 56.4 | -36.9 | 67.6 |
| 114.0 | 143.4 | 79.1 | -63.6 | 47.1 | -50.0 | 61.3 |
| 115.0 | 149.7 | 75.2 | -65.0 | 37.9 | -53.7 | 52.7 |
| 116.0 | 155.7 | 77.8 | -70.9 | 32.0 | -60.8 | 48.5 |
| 117.0 | 167.5 | 52.2 | -51.0 | 11.3 | -46.6 | 23.5 |
| 118.0 | 191.5 | 32.6 | -31.9 | -6.5 | -32.5 | 1.6 |
| 119.0 | 226.3 | 25.3 | -17.5 | -18.3 | -21.5 | -13.4 |
| 120.0 | 250.2 | 27.1 | -9.2 | -25.5 | -15.2 | -22.5 |
| 121.0 | 268.6 | 27.7 | -0.7 | -27.7 | -7.5 | -23.7 |
| 122.0 | 274.3 | 29.2 | 2.2 | -29.1 | -5.0 | -28.7 |
| 123.0 | 280.1 | 29.0 | 5.1 | -28.5 | -2.1 | -28.9 |
| 124.0 | 286.8 | 27.7 | 8.0 | -26.5 | 1.2 | -27.7 |
| 125.0 | 294.0 | 25.6 | 10.4 | -23.4 | 4.3 | -25.2 |

CONTINUED

| ALTITUDE (KM) | WIND DIRECTION (DEG) | WIND SPEED (M/S) | WIND COMPONENTS (M/S) GEOGRAPHIC N-S | GEOGRAPHIC E-W | MAGNETIC N-S | MAGNETIC E-W |
|---|---|---|---|---|---|---|
| 126.0 | 300.3 | 24.4 | 12.3 | -21.1 | 6.7 | -23.5 |
| 127.0 | 309.1 | 22.1 | 13.9 | -17.1 | 9.3 | -20.0 |
| 128.0 | 313.6 | 20.6 | 14.2 | -14.9 | 10.1 | -17.9 |
| 129.0 | 321.4 | 18.8 | 14.7 | -11.8 | 11.3 | -15.1 |
| 130.0 | 332.7 | 17.8 | 15.8 | -8.2 | 13.3 | -11.8 |
| 131.0 | 346.7 | 17.5 | 17.1 | -4.0 | 15.6 | -8.1 |
| 132.0 | 354.1 | 17.8 | 17.7 | -1.8 | 16.7 | -6.1 |
| 133.0 | 2.0 | 18.1 | 18.1 | 0.6 | 17.7 | -3.9 |
| 134.0 | 7.2 | 18.9 | 18.7 | 2.4 | 18.7 | -2.3 |
| 135.0 | 11.6 | 19.7 | 19.3 | 4.0 | 19.7 | -0.9 |
| 136.0 | 8.2 | 21.3 | 21.1 | 3.1 | 21.2 | -2.2 |
| 137.0 | 14.6 | 22.7 | 22.0 | 5.7 | 22.7 | 0.1 |
| 138.0 | 13.6 | 24.5 | 23.8 | 5.8 | 24.5 | -0.2 |
| 139.0 | 14.9 | 25.4 | 24.5 | 6.5 | 25.3 | 0.3 |
| 140.0 | 16.0 | 26.1 | 25.1 | 7.2 | 26.1 | 0.8 |
| 141.0 | 17.0 | 26.5 | 25.3 | 7.7 | 26.4 | 1.2 |
| 142.0 | 17.8 | 26.5 | 25.3 | 8.1 | 26.5 | 1.6 |
| 143.0 | 18.9 | 26.2 | 24.8 | 8.5 | 26.1 | 2.1 |
| 144.0 | 19.9 | 25.8 | 24.3 | 8.8 | 25.7 | 2.5 |
| 145.0 | 20.3 | 24.0 | 22.5 | 8.3 | 23.9 | 2.5 |
| 146.0 | 21.5 | 23.2 | 21.5 | 8.5 | 22.9 | 2.9 |
| 147.0 | 25.2 | 22.4 | 20.2 | 9.5 | 21.9 | 4.2 |
| 148.0 | 21.9 | 20.5 | 19.0 | 7.7 | 20.3 | 2.8 |
| 149.0 | 23.9 | 19.6 | 17.9 | 7.9 | 19.3 | 3.3 |
| 150.0 | 26.7 | 18.5 | 16.5 | 8.3 | 18.0 | 4.0 |
| 151.0 | 35.8 | 17.6 | 14.3 | 10.3 | 16.4 | 6.5 |
| 152.0 | 39.6 | 16.7 | 12.9 | 10.7 | 15.1 | 7.2 |
| 153.0 | 55.1 | 16.2 | 9.3 | 13.3 | 12.3 | 10.6 |
| 154.0 | 40.1 | 16.7 | 12.8 | 10.8 | 15.1 | 7.3 |
| 155.0 | 48.8 | 16.1 | 10.6 | 12.1 | 13.3 | 9.1 |
| 156.0 | 67.9 | 16.4 | 6.2 | 15.2 | 9.8 | 13.2 |
| 157.0 | 73.0 | 15.7 | 4.6 | 15.0 | 8.2 | 13.4 |
| 158.0 | 77.9 | 12.3 | 2.6 | 12.1 | 5.5 | 11.1 |
| 159.0 | 90.0 | 11.4 | 0.0 | 11.4 | 2.8 | 11.0 |
| 160.0 | 128.9 | 10.6 | -6.7 | 8.3 | -4.5 | 9.7 |

WIND COMPONENT

UP

N—S ○

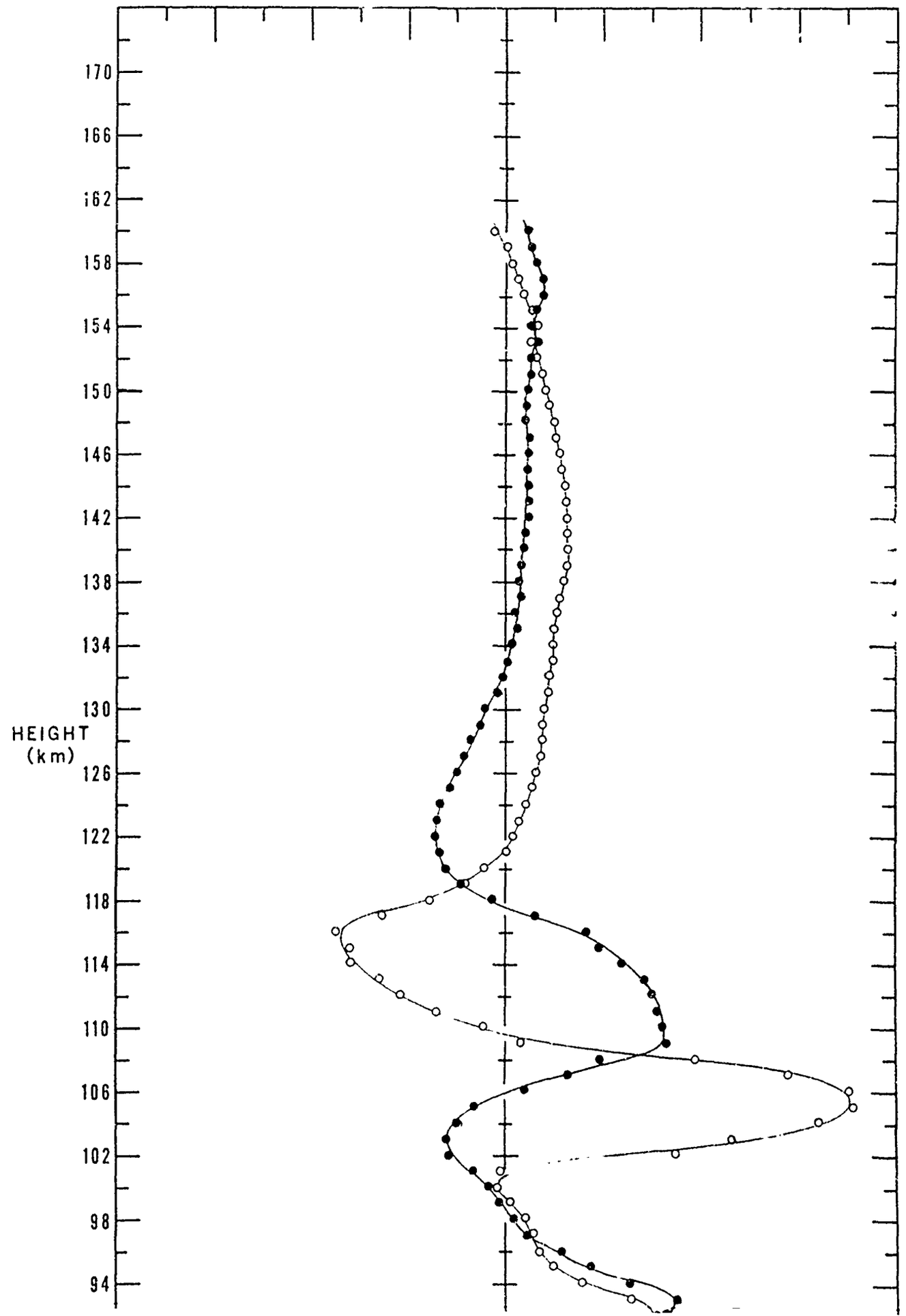
E—W ●

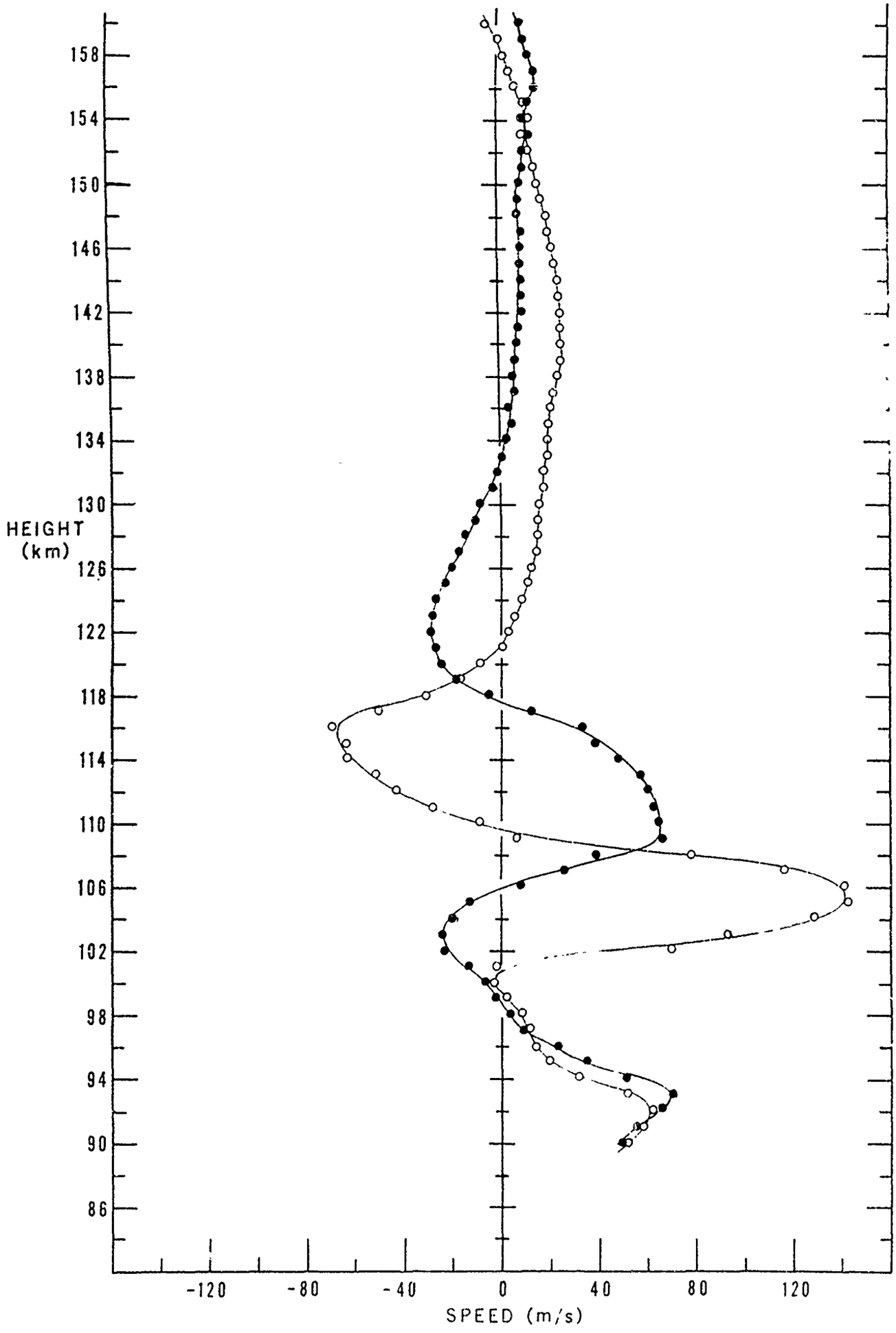
TRAIL NO. Y7

23:56:00 MST

26 OCTOBER 1966

H.A.R P YUMA

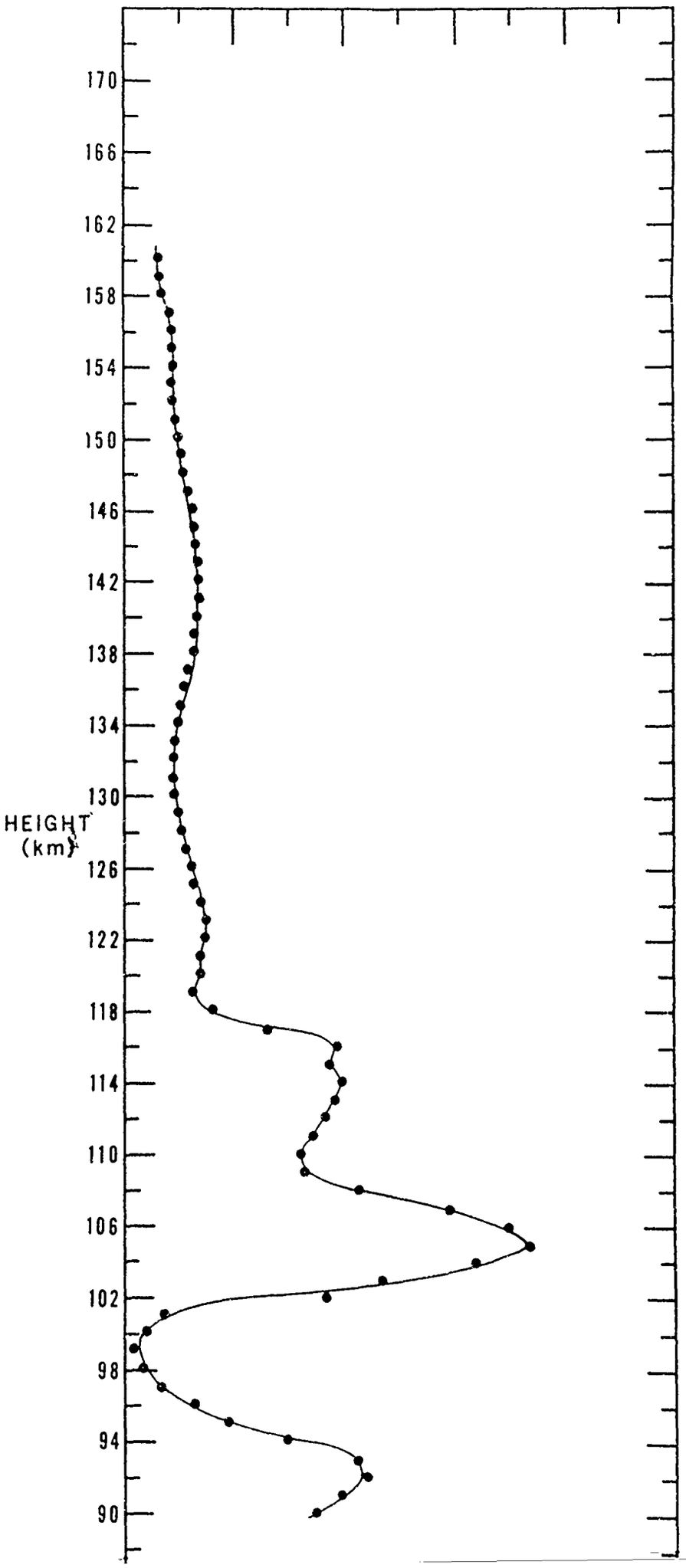


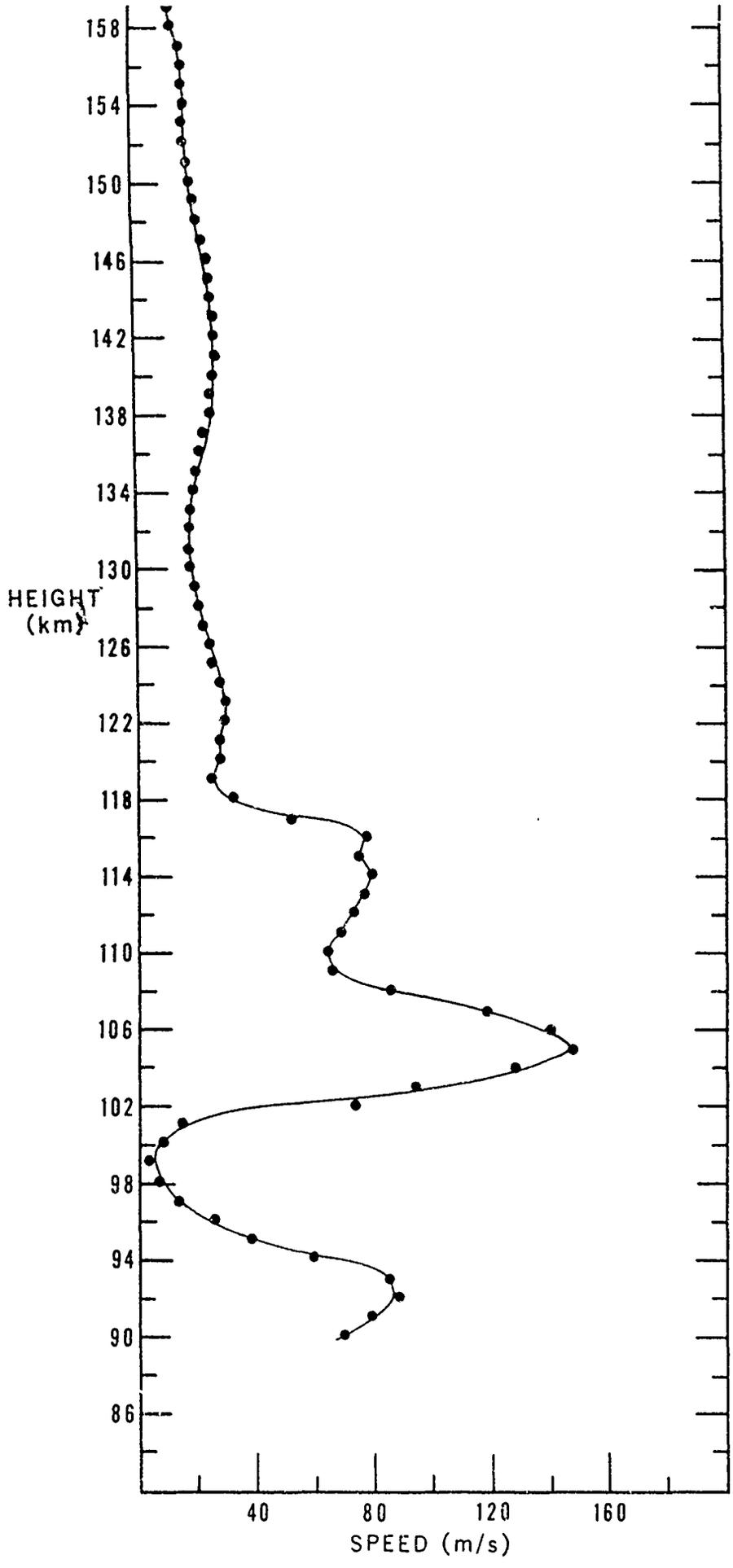

158
154
150
146
142
138
134
130
HEIGHT
(km)
126
122
118
114
110
106
102
98
94
90
86
-120
-80
-40
0
40
80
120
SPEED (m/s)

WIND SPEED

• UP

TRAIL NO Y7
23:56:00 MST
26 OCTOBER 1966
H.A.R.P. YUMA




158
154
150
146
142
138
134
130
126
122
118
114
110
106
102
98
94
90
86
HEIGHT (km)
40
80
120
160
SPEED (m/s)

WIND DIRECTION

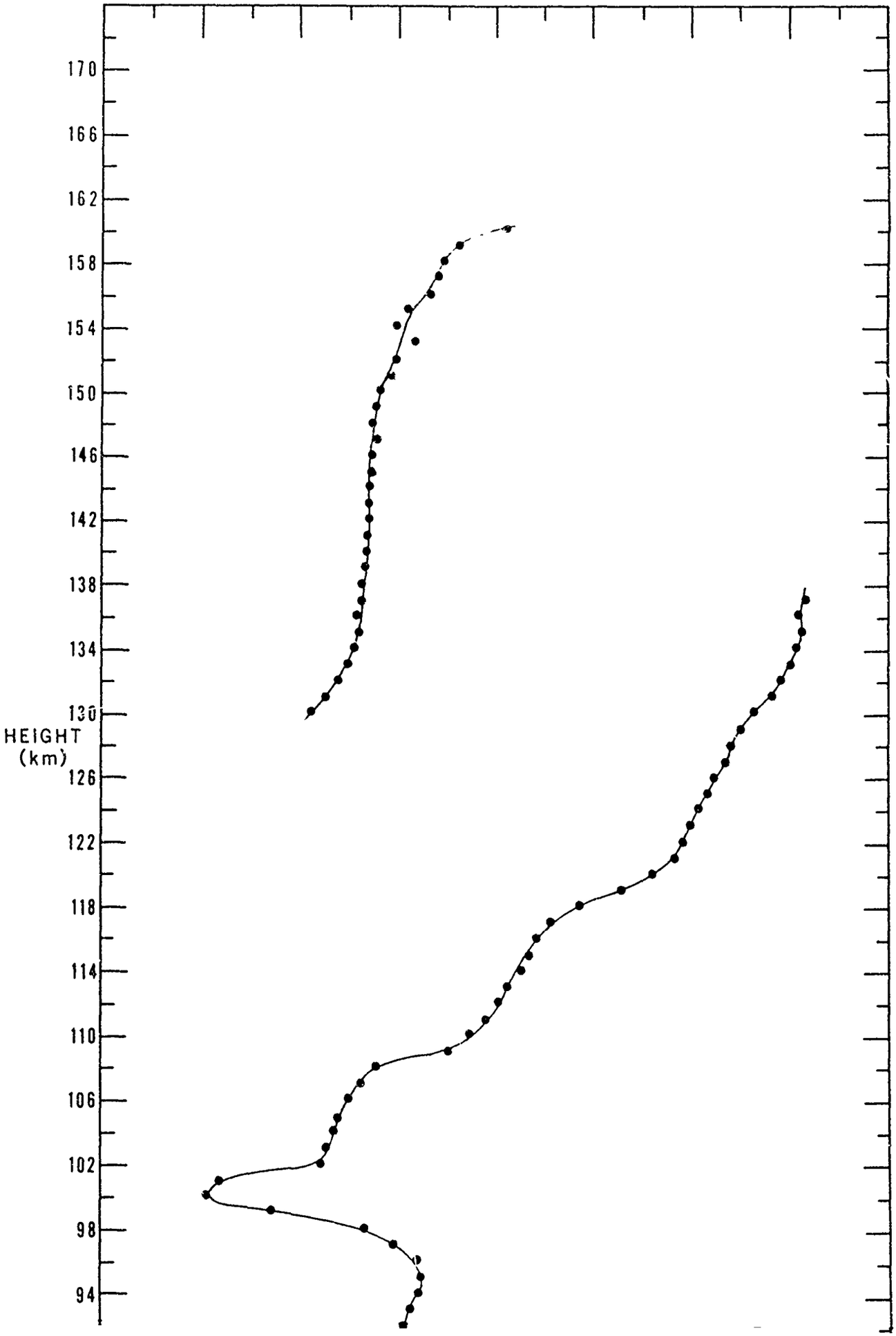
• UP

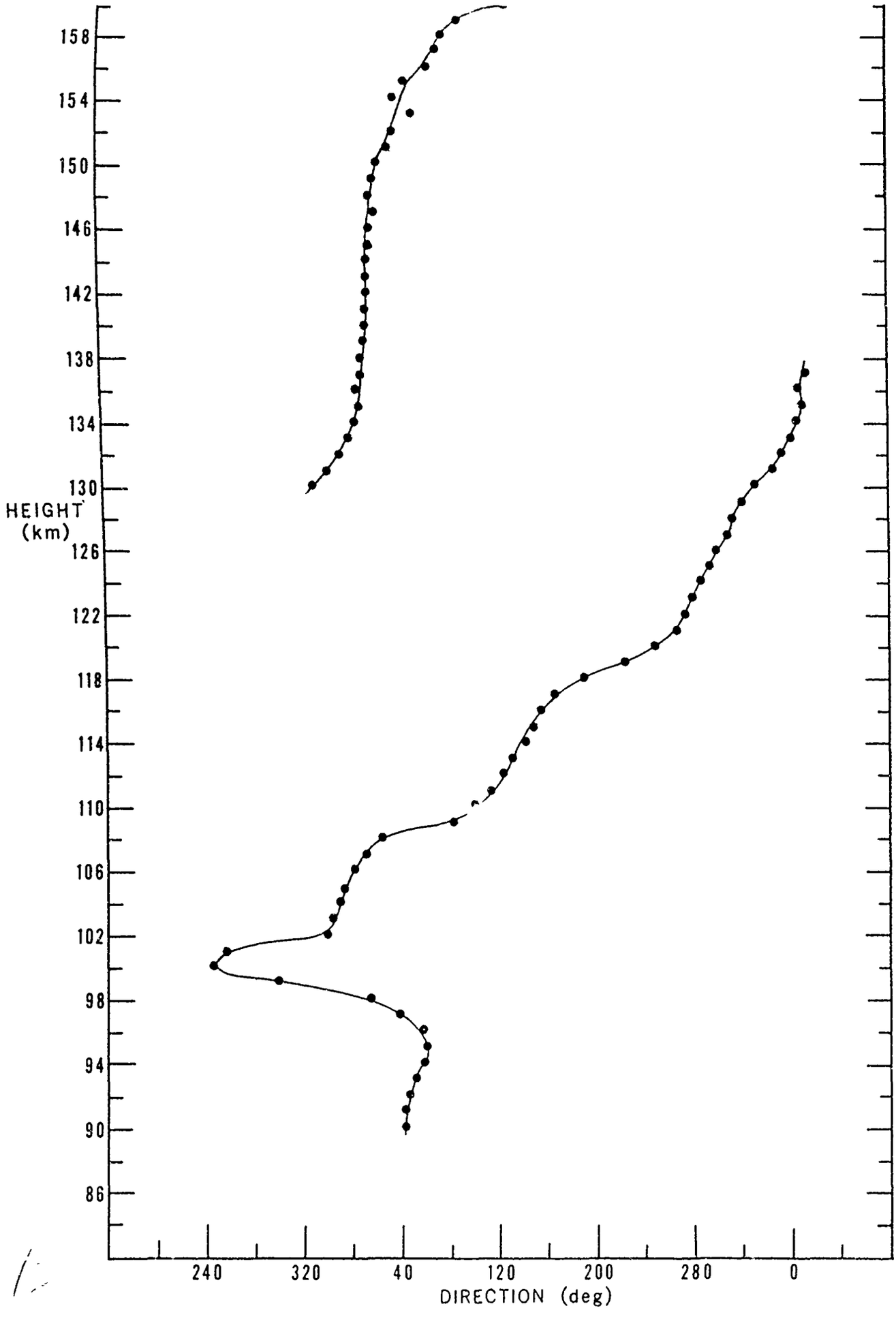
TRAIL NO Y7

23:56.00 MST

26 OCTOBER 1966

H.A.R.P. YUMA




158
154
150
146
142
138
134
130
126
122
118
114
110
106
102
98
94
90
86
HEIGHT (km)
240
320
40
120
200
280
0
DIRECTION (deg)

YUMA

TRAIL NO. Y8
27 OCTOBER 1966

19-52-01 MST

UPTRAIL

| ALTITUDE (KM) | WIND DIRECTION (DEG) | WIND SPEED (M/S) | WIND COMPONENTS (M/S) GEOGRAPHIC N-S | GEOGRAPHIC E-W | MAGNETIC N-S | MAGNETIC E-W |
|---|---|---|---|---|---|---|
| 94.0 | 49.4 | 60.1 | 39.1 | 45.6 | 49.1 | 34.6 |
| 95.0 | 53.1 | 64.4 | 38.6 | 51.6 | 50.1 | 40.5 |
| 96.0 | 64.1 | 66.9 | 29.2 | 60.2 | 43.1 | 51.2 |
| 97.0 | 92.4 | 59.3 | -2.5 | 59.2 | 12.1 | 58.0 |
| 98.0 | 151.5 | 84.9 | -74.6 | 40.5 | -62.3 | 57.6 |
| 99.0 | 164.0 | 111.3 | -107.0 | 30.7 | -96.2 | 56.1 |
| 100.0 | 171.3 | 116.3 | -115.0 | 17.5 | -107.2 | 45.3 |
| 101.0 | 176.7 | 119.2 | -119.0 | 6.9 | -113.6 | 36.0 |
| 102.0 | 182.3 | 110.9 | -110.9 | -4.5 | -108.6 | 22.9 |
| 103.0 | 182.8 | 103.8 | -103.7 | -5.1 | -101.8 | 20.6 |
| 104.0 | 186.3 | 94.4 | -93.9 | -10.3 | -93.5 | 13.1 |
| 105.0 | 193.6 | 96.0 | -93.3 | -22.5 | -96.0 | 1.2 |
| 106.0 | 198.5 | 105.6 | -100.2 | -33.5 | -105.4 | -7.8 |
| 107.0 | 204.7 | 100.6 | -91.4 | -42.1 | -99.0 | -18.3 |
| 108.0 | 224.9 | [illegible].3 | -66.1 | -65.9 | -80.3 | -47.6 |
| 109.0 | 258.1 | 103.5 | -21.3 | -101.3 | -45.6 | -92.9 |
| 110.0 | 265.4 | 108.6 | -8.7 | -108.3 | -35.1 | -102.8 |
| 111.0 | 272.5 | 111.7 | 4.9 | -111.6 | -22.7 | -109.4 |
| 112.0 | 284.0 | 114.2 | 27.5 | -110.8 | -0.6 | -114.2 |
| 113.0 | 292.0 | 113.2 | 42.4 | -104.9 | 15.3 | -112.1 |
| 114.0 | 299.3 | 110.9 | 54.2 | -96.7 | 28.7 | -107.1 |
| 115.0 | 305.1 | 107.4 | 61.8 | -87.9 | 38.3 | -100.4 |
| 116.0 | 314.0 | 87.1 | 60.6 | -62.7 | 43.3 | -75.7 |
| 117.0 | 318.6 | 90.1 | 67.6 | -59.6 | 50.8 | -74.4 |
| 118.0 | 321.4 | 90.0 | 70.3 | -56.2 | 54.3 | -71.8 |
| 119.0 | 323.6 | 87.9 | 70.8 | -52.2 | 55.8 | -68.0 |
| 120.0 | 327.9 | 80.5 | 68.1 | -42.8 | 55.5 | -58.2 |
| 121.0 | 332.7 | 73.0 | 64.9 | -33.5 | 54.7 | -48.4 |
| 122.0 | 344.4 | 61.6 | 59.3 | -16.5 | 53.4 | -30.6 |
| 123.0 | 352.0 | 54.9 | 54.4 | -7.7 | 50.8 | -20.9 |
| 124.0 | 355.4 | 50.7 | 50.6 | -4.1 | 48.0 | -16.4 |

WIND COMPONENTS

UP

N–S ○

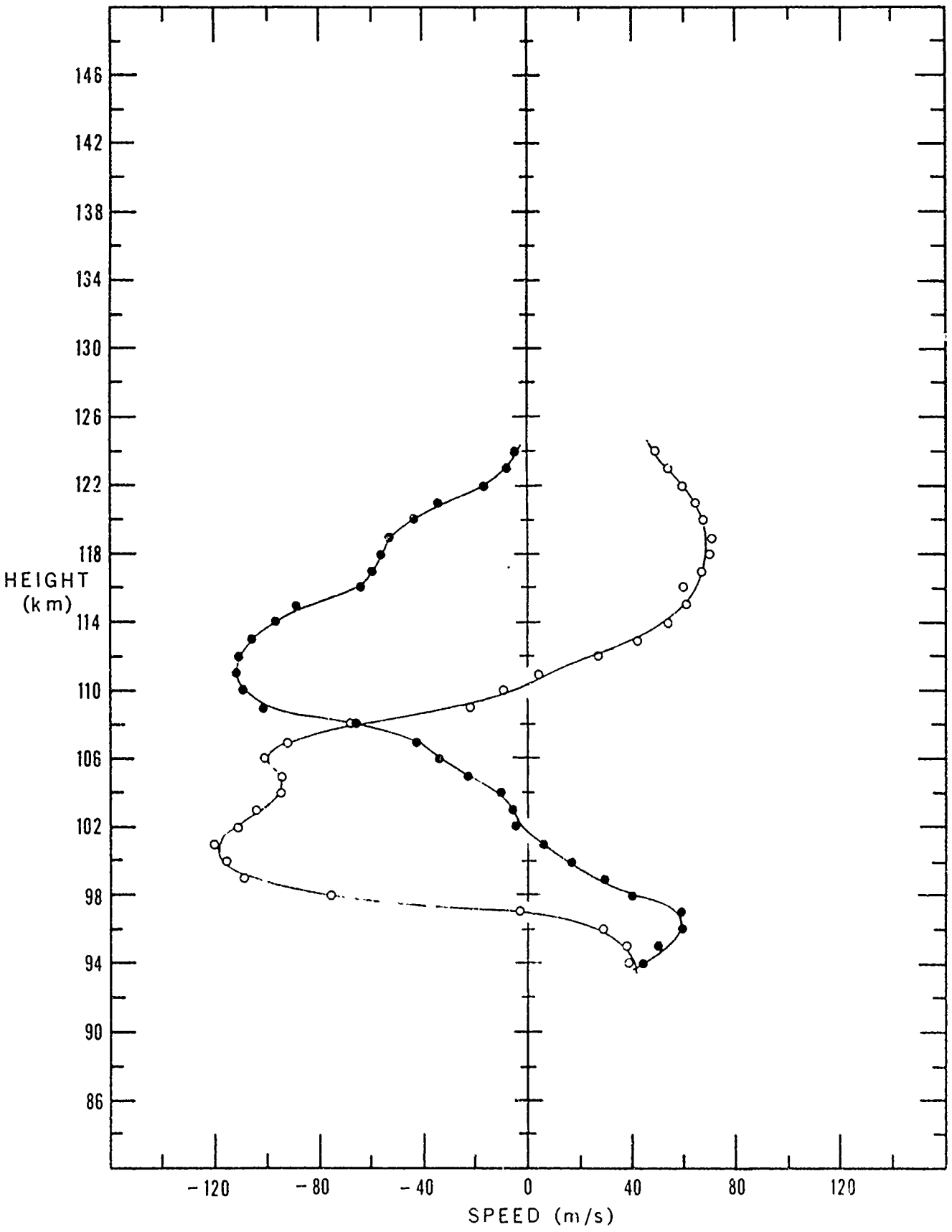
E–W ●

TRAIL NO. Y8

19:52:01 MST

27 OCTOBER 1966

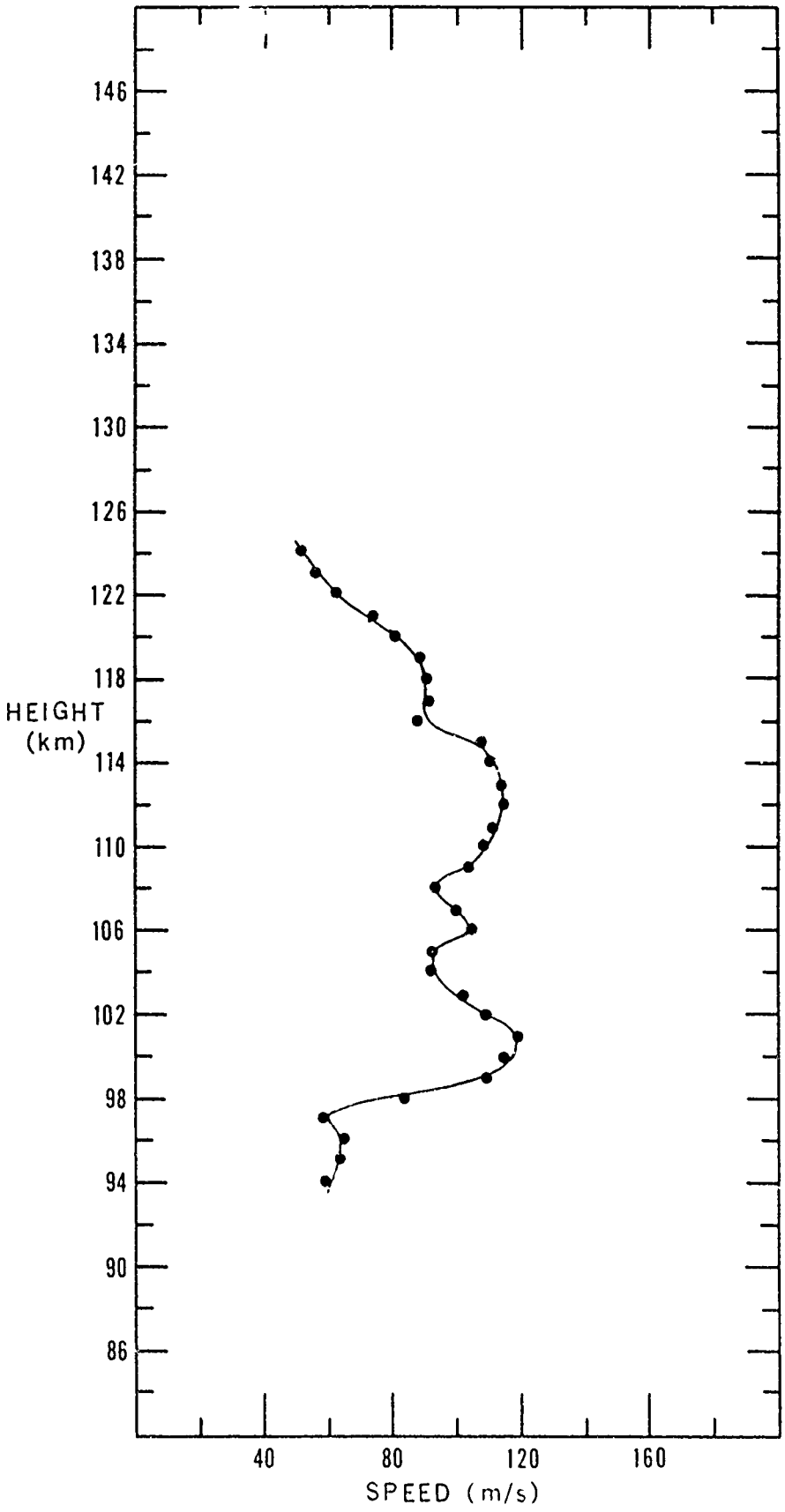
H.A.R.P. YUMA



WIND SPEED

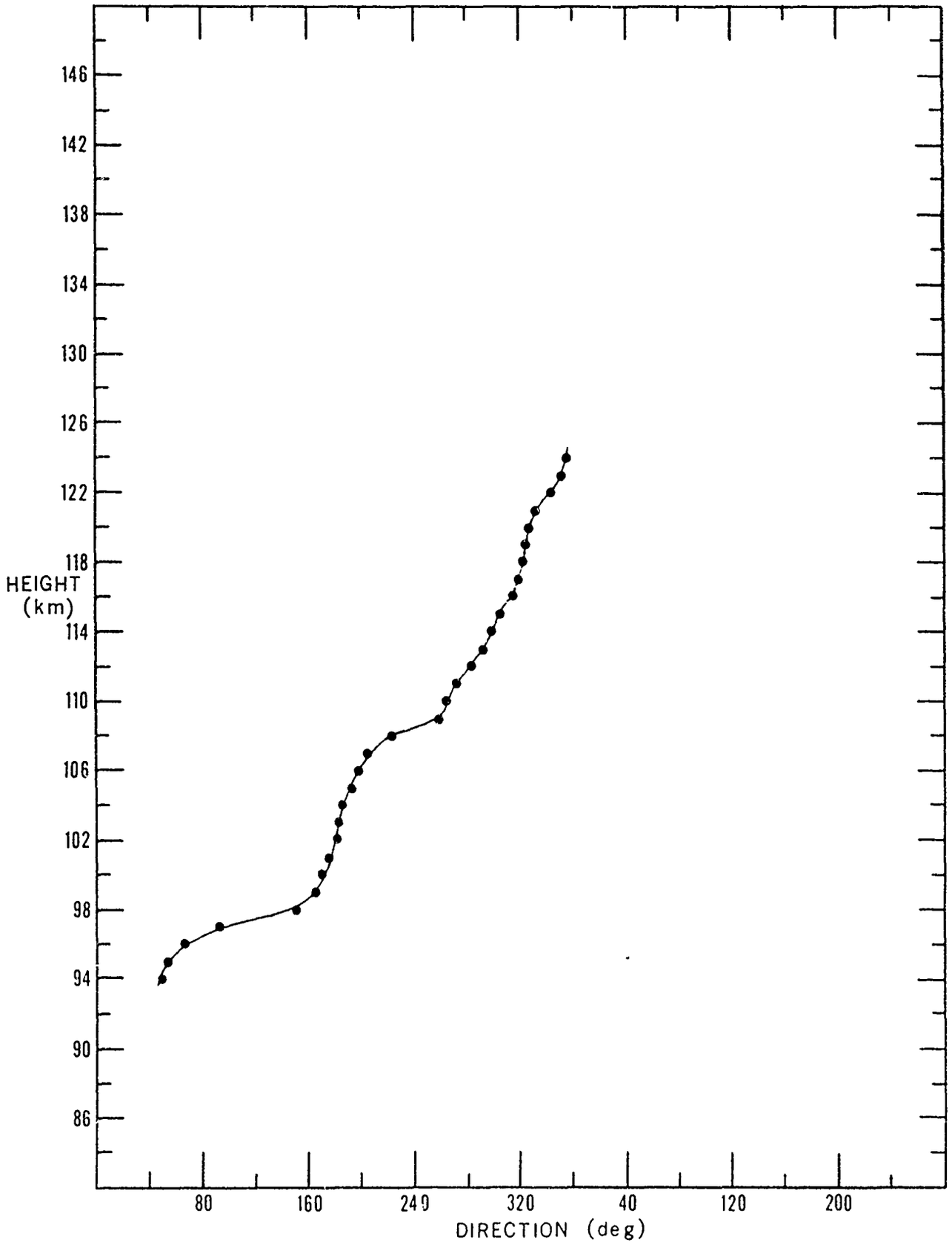
• UP

TRAIL NO. Y8
19:52:01 MST
27 OCTOBER 1966
H.A.R.P. YUMA



WIND DI`ECTION
• UP

TRAIL NO. Y8
19:52:01 MST
27 OCTOBER 1966
H.A.R.P. YUMA



YUMA

TRAIL NO. Y9
27 OCTOBER 1966

21-46-01 MST

UPTRAIL

| ALTITUDE (KM) | WIND DIRECTION (DEG) | WIND SPEED (M/S) | WIND COMPONENTS (M/S) GEOGRAPHIC N-S | GEOGRAPHIC E-W | MAGNETIC N-S | MAGNETIC E-W |
|---|---|---|---|---|---|---|
| 90.0 | 303.2 | 31.5 | 17.3 | -26.4 | 10.3 | -29.8 |
| 91.0 | 311.7 | 26.1 | 17.4 | -19.5 | 12.1 | -23.2 |
| 92.0 | 313.9 | 22.8 | 15.8 | -16.5 | 11.3 | -19.9 |
| 93.0 | 318.1 | 10.9 | 8.1 | -7.3 | 6.1 | -9.1 |
| 94.0 | 93.6 | 12.6 | -0.8 | 12.5 | 2.3 | 12.3 |
| 95.0 | 122.0 | 18.4 | -9.8 | 15.6 | -5.7 | 17.5 |
| 96.0 | 162.9 | 23.7 | -22.6 | 6.9 | -20.2 | 12.3 |
| 97.0 | 190.9 | 27.3 | -26.8 | -5.2 | -27.3 | 1.6 |
| 98.0 | 202.2 | 33.2 | -30.8 | -12.6 | -33.0 | -4.6 |
| 99.0 | 201.2 | 38.4 | -35.8 | -13.9 | -38.1 | -4.7 |
| 100.0 | 181.1 | 40.3 | -40.3 | -0.7 | -39.2 | 9.2 |
| 101.0 | 162.4 | 34.9 | -33.2 | 10.6 | -29.6 | 18.4 |
| 102.0 | 169.4 | 29.6 | -29.1 | 5.5 | -26.9 | 12.5 |
| 103.0 | 272.0 | 52.0 | 1.8 | -52.0 | -11.1 | -50.8 |
| 104.0 | 287.8 | 77.4 | 23.7 | -73.7 | 4.8 | -77.3 |
| 105.0 | 291.0 | 88.7 | 31.8 | -82.9 | 10.4 | -88.2 |
| 106.0 | 294.6 | 101.3 | 42.2 | -92.1 | 18.2 | -99.7 |
| 107.0 | 297.7 | 113.7 | 52.9 | -100.7 | 26.5 | -110.6 |
| 108.0 | 304.4 | 121.4 | 68.6 | -100.1 | 41.8 | -113.9 |
| 109.0 | 305.3 | 122.1 | 70.6 | -99.6 | 43.9 | -113.9 |
| 110.0 | 306.9 | 123.3 | 74.1 | -98.6 | 47.5 | -113.8 |
| 111.0 | 311.4 | 123.0 | 81.3 | -92.3 | 56.1 | -109.5 |
| 112.0 | 331.0 | 110.5 | 96.7 | -53.5 | 80.6 | -75.7 |
| 113.0 | 338.5 | 103.3 | 96.1 | -37.8 | 83.8 | -60.3 |
| 114.0 | 343.8 | 94.4 | 90.7 | -26.3 | 81.4 | -47.8 |
| 115.0 | 350.7 | 83.9 | 82.8 | -13.5 | 76.9 | -33.5 |
| 116.0 | 353.6 | 73.8 | 73.3 | -8.2 | 69.0 | -26.0 |
| 117.0 | 355.8 | 63.5 | 63.4 | -4.7 | 60.3 | -20.2 |
| 118.0 | 357.3 | 52.7 | 52.6 | -2.5 | 50.4 | -15.4 |
| 119.0 | 356.2 | 38.7 | 38.6 | -2.6 | 36.8 | -12.0 |
| 120.0 | 356.0 | 28.3 | 28.2 | -2.0 | 26.8 | -8.9 |
| 121.0 | 352.4 | 20.4 | 20.2 | -2.7 | 18.9 | -7.6 |
| 122.0 | 8.2 | 12.7 | 12.6 | 1.8 | 12.7 | -1.4 |
| 123.0 | 32.8 | 5.9 | 5.0 | 3.2 | 5.6 | 1.9 |
| 124.0 | 96.6 | 5.4 | -0.6 | 5.4 | 0.7 | 5.4 |
| 125.0 | 124.3 | 10.3 | -5.8 | 8.5 | -3.5 | 9.7 |
| 126.0 | 131.1 | 14.9 | -9.8 | 11.2 | -6.7 | 13.3 |
| 127.0 | 133.6 | 20.7 | -14.3 | 15.0 | -10.2 | 18.1 |
| 128.0 | 134.3 | 26.2 | -18.3 | 18.8 | -13.1 | 22.7 |
| 129.0 | 134.9 | 32.8 | -23.2 | 23.2 | -16.8 | 28.2 |
| 130.0 | 136.4 | 38.8 | -28.1 | 26.7 | -20.7 | 32.8 |
| 131.0 | 138.3 | 44.0 | -32.9 | 29.3 | -24.7 | 36.5 |
| 132.0 | 140.3 | 53.0 | -40.8 | 33.9 | -31.2 | 42.9 |
| 133.0 | 143.4 | 62.6 | -50.2 | 37.3 | -39.5 | 48.5 |
| 134.0 | 146.8 | 70.8 | -59.2 | 38.7 | -47.9 | 52.1 |
| 135.0 | 147.9 | 72.2 | -61.2 | 38.4 | -49.9 | 52.3 |

WIND COMPONENTS

UP

N–S o

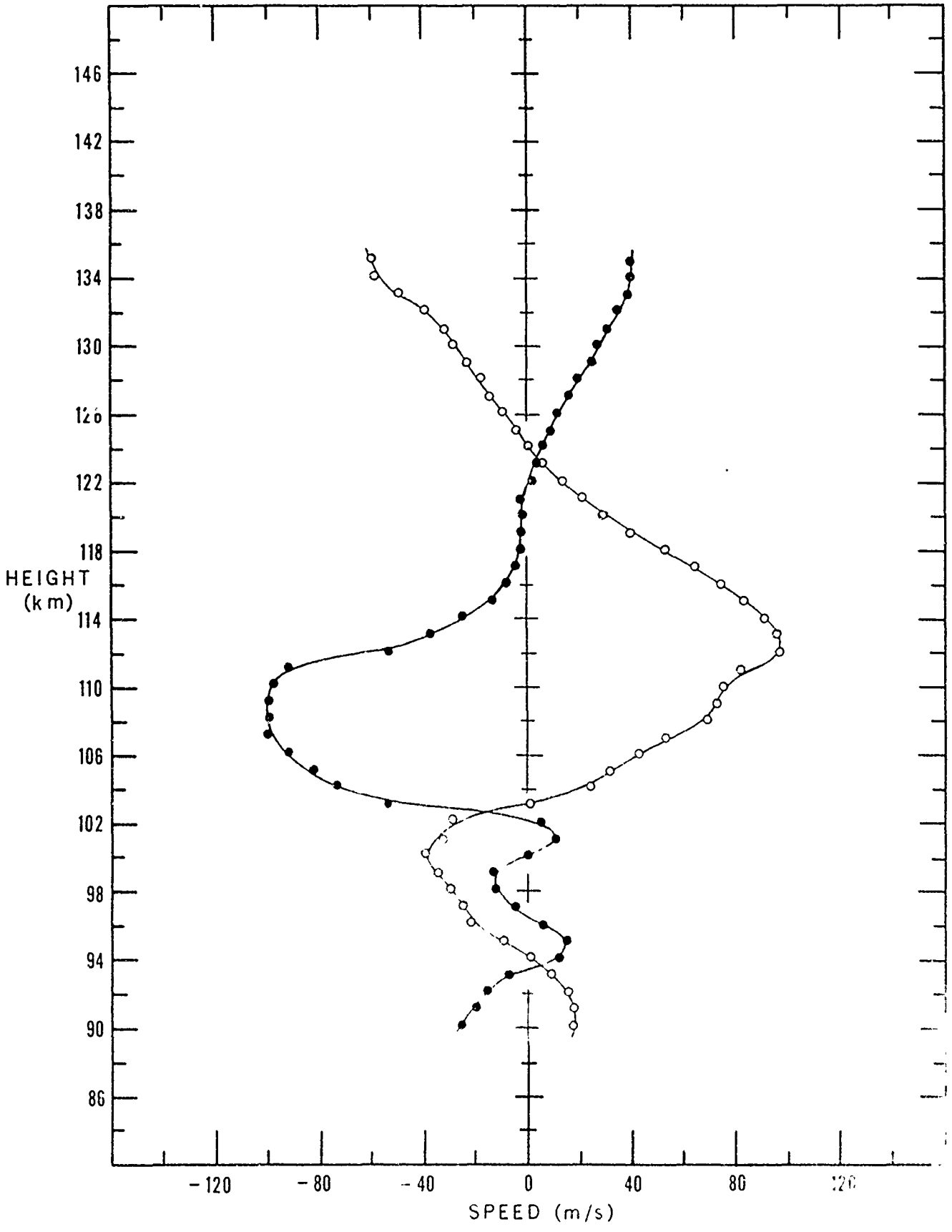
E–W •

TRAIL NO. Y9

21:46:01 MST

27 OCTOBER 1966

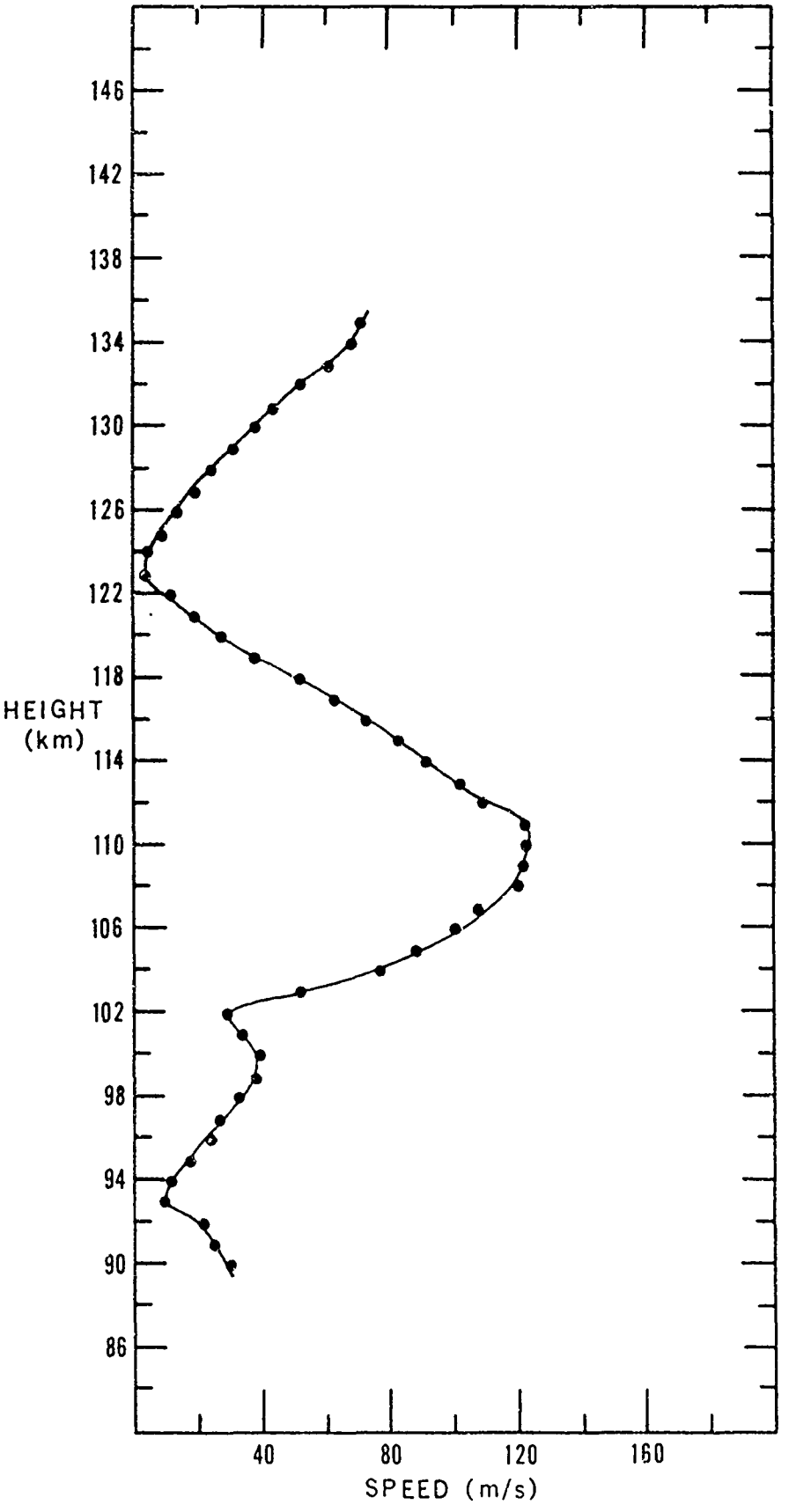
H.A.R.P. YUMA



WIND SPEED

• UP

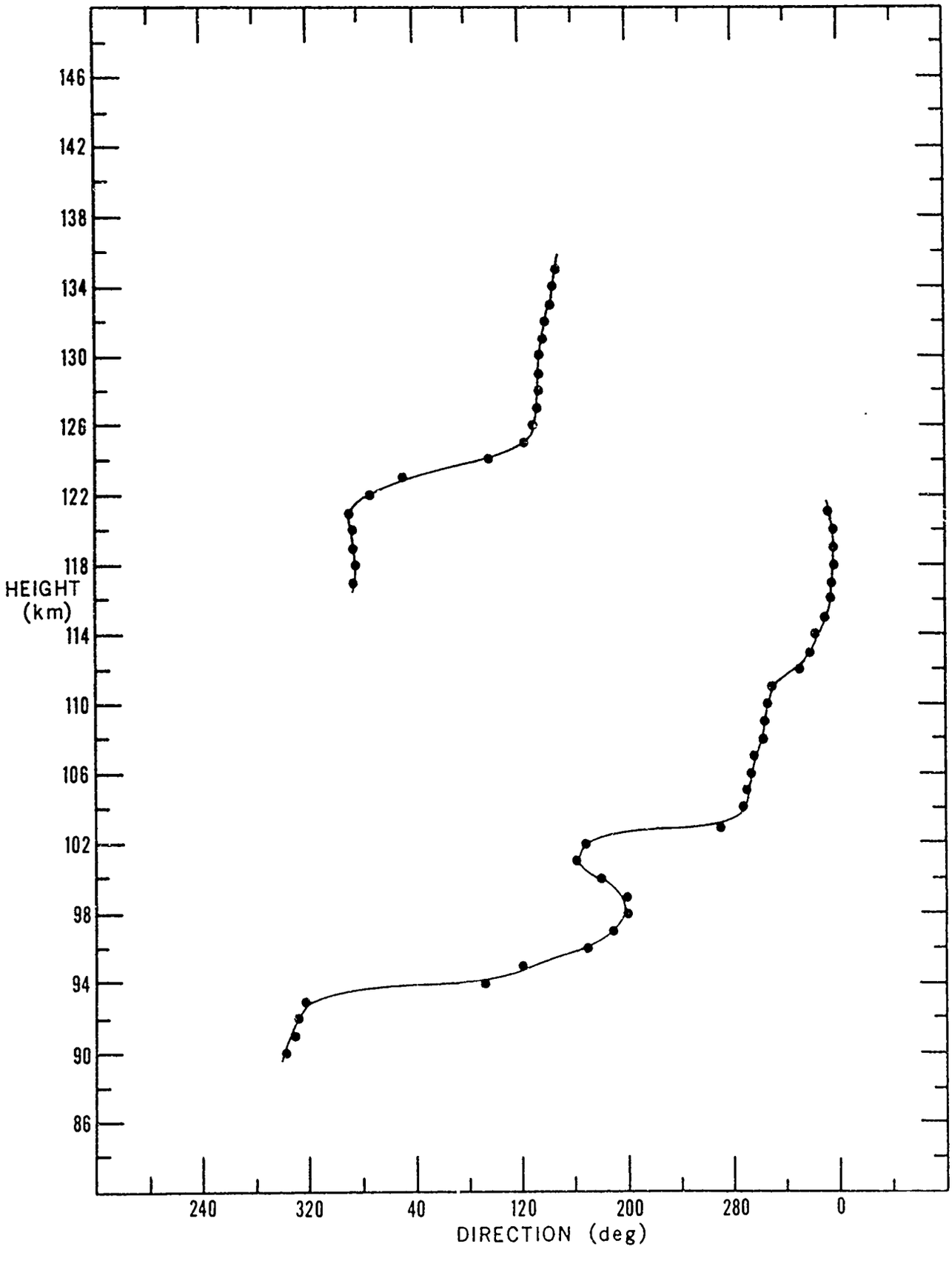
TRAIL NO. Y9
21:46:01 MST
27 OCTOBER 1966
H.A.R.P. YUMA



WIND DIRECTION

• UP

TRAIL NO. Y9
21:46:01 MST
27 OCTOBER 1966
H.A.R.P. YUMA



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Atlanta, Georgia

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Robert L. Fuller

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13. ABSTRACT

On the night of 26 October 1966, two luminous trails were produced between 87km and 160km by the release of tri-methyl-aluminum from projectiles fired from a smoothbore sixteen-inch gun located at Yuma Proving Ground, Arizona (114.2°W, 32.8°N). Two additional trails were produced on the night of 27 October 1966. These trails were photographed by cameras located at Yuma and Gila Bend in Arizona and at Blythe, California, and have been analyzed to yield wind profiles. This report contains the tabulated wind data for all four trails together with plots versus altitude of wind components, wind speed, and wind heading.

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|---|---|---|---|---|---|---|
| | ROLE | WT | ROLE | WT | ROLE | WT |
| HARP<br>High Altitude Research Project<br>Ionospheric Winds | | | | | | |

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