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REPORT

ON

UPPER ATMOSPHERE WIND AND TEMPERATURE STRUCTURE AT SONMIANI DERIVED FROM THE ROCKET-GRENADE EXPERIMENTS CONDUCTED DURING 1965-67

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I. INTRODUCTION

Since 1962 SUPARCO has been launching sounding rockets with sodium payload for studying the wind structure of the stratosphere and mesosphere (Rahmatullah 1962). It was therefore quite natural to extend the upper atmospheric studies to include temperature measurements. The grenade technique has been successfully employed for temperature studies of the upper atmosphere by NASA scientists (Stroud et al, 1956) in the U.S.A. and by British scientists (Bowen et al, 1964) from University College, London. A manual describing the rocket grenade experiment (Nordberg and smith, 1962) has also been prepared by NASA.

In the rocket grenade experiment a dozen or more grenades flown on a rocket are timed to explode at regular intervals from about 25 km to 90 km and the times of explosions are precisely recorded. The sound from the grenade explosions is picked up by an array of microphones placed in close proximity to the range and the time of arrival of sound from the grenades is recorded at each microphone. The time taken by the sound from each grenade explosion to reach the various microphones is a function of the temperature of the intervening layers of the atmosphere.

The experiment requires accurate determination of the grenade burst position. NASA scientists have used DOVAP tracking for this purpose, whereas British scientists have made use of ballistic cameras with star background for triangulating the grenade position. The DOVAP technique can be used any time in day or night, but the photographic method can be used only at night. The latter has the distinct advantage that it does not depend on any expensive tracking facility. It was, therefore, decided to adopt the British method for conducting the grenade experiment from Sonmiani range in Pakistan.

The grenade experiment has been conducted under a tripartite cooperative agreement between SUPARCO, NASA and BNCSR. Negotiations on the cooperative programme were initiated during the visit of Sir Harrie Massey to Karachi in September 1962. The details of the experiment were worked out in several meetings held off and on during 1963-64 between Dr. G.V. Groves of University College, London, and Mr. M. Rahmatullah, Director of SUPARCO. As Pakistan had then only Nike-Cajun/Apache launching facilities at the Sonmiani Range, NASA's cooperation in the acquisition of rockets was deemed necessary for the success of the project. Dr. I.H. Usmani, Co-Chairman, SUPARCO, wrote to Mr. A. Frutkin, Assistant Administrator, NASA soliciting his assistance in the procurement of rocket hardware for the grenade experiment.

After protracted correspondence a meeting was held at SUPARCO headquarters in Karachi on 21st January 1965 between the representatives of the three space research organisations to work out the modus operandi of the experiment and to apportion responsibilities to the participants as outlined in the Memorandum of Understanding signed on 18-1-1965 (Annex-II). Dr. G.V. Groves represented BNCSR. SUPRACO was charged with the responsibility of coordinating the conduct of the experiment, operating the launching site and associated facilities and reducing the data. BNCSR agreed to provide the six grenade payloads, loan all the ground equipment essential for the conduct of the experiment and assist Pakistan in the operation and maintenance of the equipment and in reducing the data. NASA agreed to provide six Nike-Cajun/Apache vehicles and also promised continued technical assistance in the maintenance of the U.S. equipment loaned earlier.

II. DETAILS OF EXPERIMENT

The first grenade experiment as outlined in the Memorandum of Understanding was conducted on April 29, 1965. Since then the remaining five planned launchings have been conducted as shown in the following table:

Date	Time (U.T.)	Rocket Type	Payload	Experiment	Remarks
29.4.65	1732	Nike-Cajun (REHBAR VII)	Grenade (Zimney)	Wind & Temperature 30-90 Kilometers.	Successful
30.4.65	1837	Nike-Cajun (REHBAR VIII)	-do-	-do-	Partly Successful
24.3.66	1531	Nike-Cajun (REHBAR XI)	Grenade (British)	-do-	Successful
27.3.66	1712	Nike-Apache (REHBAR XII	-do-	-do-	Successful
26.4.66	0012	Nike-Apache (REHBAR XIII)	Grenade + T.M.A. (British)	Winds 30-140 Kilometers Temperature 30-90 Km.	Grenade failure, TMA successful
29.11.67	0106	Nike-Apache (REHBAR XIV)	-do-	Winds 30-140 Kilometers, Temperature 30-90 Km. shock-wave measurements.	Partly successful

The first two experiments were carried out with grenade payload manufactured by the Zimney Corporation of California, U.S.A. The first firing was successful when nine out of 12 grendaes were ejected and their flashes were recorded on ballistic cameras installed at four stations, Uthal, Naka Khari, Hab Chowki and Karachi as shown in Fig. 1. Due to the peculiar terrain at Sonmiani range it was considered advisable to split up the microphone network into two distinct arrays with separate recorders located at Sonmiani range and Hab Chowki as shown in Figs. 2(a) and 2(b).

The second launching on 30th April 1965 was partly successful as only two flashes were recorded optically and four acoustically. The other two flashes were outside the field of view of the ballistic cameras. On the basis of the acoustic data of the four ejected grenades it was inferred that the vehicle had encountered unduly large drag due to malfunction of the payload resulting in the loss of altitude and failure of the experiment.

The second campaign for the grenade experiment was organised in March/April 1966 in which the grenade payload developed by the University College, London, was used. Rehbar XI was launched on 24 March 1966 wherein 20 out of 25 grenades were ejected. The performance in case of Rehbar XII was even better when 23 grenades were ejected. With Rehbar XIII a composite Grenade-TMA payload developed by U.C.L. was used. This was the first firing of the composite payload with the Nike-Apache rocket. In this payload the first 20 grenades were timed to eject from 30 to 87 Km for acoustic recording, while the last five were planned to be ejected about 90 km for glow experiments. TMA was released between 80 and 135 km. The experiment was only partially successful as no grenades were ejected, but TMA was released as planned. Investigations with the payload brought out the fact that the acceleration encountered in the flight of the rocket caused a break in the timer circuit.

The final launching of the composite grenade-TMA payload with Rehbar XIV was done on November 29, 1967. In addition to the wind and temperature measurements, photo-optic and photo-electric measurements of velocity of grenade burst shock waves in TMA Trial were also planned. The payload performed well, but the ledex apparently failed to step first time abnormally delayed the ejection of the grenades. The TMA part was a complete success except that the late ejection of the grenades affected the shock wave pattern.

III. GROUND EQUIPMENT

The deatils of the ground equipment used in connection with the grenade experiment are summarised below.

1. S.R. MK1 Hot Wire Microphones

The theory of the rocket grenade experiment requires that the time of the grenade flash and the acoustic signal originated from the grenade explosion should be recorded very accurately. The choice of the microphone is governed by two considerations. Firstly it should be sensitive enough to record the weak acoustic signal from the grenade explosions which are timed to occur at various heights ranging from 25 km to 90 km. Secondly the microphone should be capable of identifying the weak acoustic signal from the noise caused by natural pressure fluctuations. S.R. MK1 hot wire microphones which had been used in earlier rocket grenade experiments at Woomera were used in Pakistan. S.R. MK1 is essentially a Helmholtz resonator with an enclosed volume of 9000 cm^3. The air oscillates between the enclosed volume of the resonator and the ambient atmosphere. In the neck or throat of the resonator a hot wire element, which consists of fine platinum wire of about 6 microns diameter is placed. The resistance of the element when hot, is about 300 ohms. It is kept at just below red heat by passing a D.C. current through it and because of its low heat capacity, it readily changes temperature, when the air in the neck of the resonator is in motion. Inner resonators are coupled internally to the main Helmholtz resonator of the S.R. MK1. A mechanical cross-section of S.R. MK1 is shown in Fig. 3. It has proved reliable in the grenade experiment and has demonstrated its insensivity to moisture having operated from a water fitted pit. A detailed study of the S.R. MK1 microphone has been made by Dr. R.W. Procunier (1966) at University College, London. He has also designed a multiplex system for accoustic recording to be used in conjunction with an S.R. MK1 microphone array. The system proved its efficiency in the grenade experiments performed at Sardinia in 1965.

2. Flash Detector

The initial time of detonation of the grenades is obtained by means of a ground-based optical flash detector, which is connected to one of the channels of the recording unit. The high output from the grenade flashes is sufficient for night time detection and has a broad spectrum peaking at about 1 micron.

The flash detector was assembled at University College, London. It uses a 6097 B photo-multiplier, the output from which is coupled to Cathode follower (CV 4014 valve) and finally connected to the recorder. The photo-multiplier is blue-green sensitive covering the range 0.3 to 0.7 microns and has a sensitivity of 70 micro-amps/lume. The 11 dynodes require a maximum interchange potential of 100 volts. The circuit of the photo-multiplier is given in Fig. 4.

All power supplies to the flash detector unit were furnished from a unit manufactured for this purpose by E.M. Wareham (Measuring System) Ltd. Hertfordshire, on behalf of University College, London.

The unit was designed to supply an unstabilised D.C. output of 300 V at 20 mA positive with respect to the ground and a negative output of 1200 V stabilised to 1%. It could also supply 6.3 or

+ V a.c. at 2-1/2 A with one side grounded. Silicon semi-conductor rectifiers were used in preference to valves. The construction of the unit allowed for the possibility of operation under conditions of high humidity and ambient temperatures upto 60°C. The operating voltage for the unit was 200-260 V 40 to 60 c/s.

3. Recording Equipment

The ground equipment (Fig. 5) for recording the sound waves picked up by the microphones and transmitted on wires consist of four units described below.

(a) Power Supply Unit: The power supply unit derives its initial supply from a 12 volt battery and suitably develops this, so that the unit provides all the power supplies for both the amplifier and Recorder units.

The positive side of the 12 volt battery is connected to a switch which, on closing, supplies the filaments of all valves in the amplifier unit, the heater of all valves in the Recorder Unit and the anode volts for the valve maintained vibrating bar.

The power supplies of 135 volts, 300 volts and 500 volts (nominal) are obtained by means of the H.T. Vibrator Unit. The 135 volt supply from the power supply unit provides the H.T. voltage for all valves in the seven channel Amplifier Unit.

The 300 volt supply furnishes the anode supply for the amplifier valve and power output stage in the Recorder Unit.

The 500 volts D.C. supply is obtained from one winding of the H.T. Vibrator Transformer after rectification by metal rectifiers. This provides the current for the recorder pens. A voltmeter is provided and a selection switch allows for all the voltages to be measured.

The vibrator and associated transformer, choke etc. are mounted on a metal base. The vibrator is of plug-in type and can readily be replaced when necessary.

(b) Lines Test Unit: All lines from the microphones are connected to the Lines Test Unit, which allows for the employment of any number upto seven microphones. The switching arrangement allows for the following operations:

1. Any line or lines to be tested for insulation and continuity.
2. Any or all of the seven microphones to be switched over to the Recorder Unit.
3. Current for the hot wire microphones to be measured and adjusted for lines of different resistance.
4. Two screw adjustments to adjust the zero reading of the meter when being used as an ohm meter.

Sockets are provided for cables to connect the microphone circuits to the Amplifier Unit and to connect the unit to the microphone battery.

(c) Amplifier Unit: The Amplifier Unit is designed to amplify individually the input from each microphone before it is applied to the coil of its corresponding pen at the Recorder Unit. There are eight channel amplifiers (seven working and one spare) and all are identical. Each amplifier has three stages of push-pull amplification as shown in Fig. 6. The frequency response of each amplifier is linear within 3 dB betwe n 10 & 80 C/S, when the signal source impedence equals 1500 ohms or less.

By means of gain controles each channel amplifier can be adjusted, so that the pen deflections on the recording paper can be kept to a reasonable amplitude for reading of the record. Each dial is calibrated from 0-10 over 270° and change of gain for each division is about 6 dB.

The input from each microphone is connected to the primary winding of an input transformer. Two resistors of identical valve are connected in series across this winding and earthed at their common point in order to balance the input with respect to earth. The input impedence is independent of the gain control setting. Connections to each amplifier are made through a twelve pin socket secured to the front panel and an appropriate plug fitted to the front of each amplifier chassis. All the amplifiers are interchangeable, and each is held securely in place by a spring clip.

4. Recorder Unit

The seven pen recorder is utilised to record the difference in time of arrival of the sound wave at various microphones and the time at which grenade flashes occur. Hence one of the channels is connected to the flash detector and one is used as a time base. This leaves only five channels for the microphones at each station.

The recording is made on Teledeltos paper. This paper has a metallised backing and a chemically treated front surface. The paper is supported in the Recorder Unit on an earthed metal roller, which is situated immediately beneath the pen tips which bear on it. When the Recorder Unit is in operation, the paper is drawn over the roller and current flows from the pen tips which marks the surface of the paper with a thin clear black trace. On the front of the recorder unit is mounted a press button which, when pressed, releases a catch and allows the recorder to be withdrawn from its carrying case for reloading with paper, pen adjustment, etc.

The paper is driven through a two speed gear box by a three phase synchronous motor, and the speed can be changed by means of a gear change c ontrol knob mounted on front of the Recorder. This speed control has three positions, HIGH - NEUTRAL - LOW. Inthe Neutral position the gears are disengaged.

At high speed the paper is driven through the Recorder Unit at a speed of 13.5 cm/sec. and at low speed at 6.75 cm/sec. The output from each channel of the Amplifier is connected to its corresponding coil unit on the Recorder system. The coil units are numbered from the centre outwards i.e. No. 1 is the pen nearest to the centre ofthe Recorder Unit. The moving coil units are mounted side by side between the poles of horse-shoe magnet and each coil is identical.

Each coil unit carries a light pen, which is 5 cm in length and is made of extruded duralumin. A short length of iridio-platinum wire projects at right angles from the end of the pen and bears upon the surface of the teledeltos paper. A spring keeps the pen bearing upon the surface of the paper at a pressure of 0.25 g $\pm$ 0.1 g. In order to facilitate the insertion of a new roll of paper the pens may be raised by means of a lever. Each pen is insulated from its associated moving coil and is connected through a 220 K decoupling and current limiting resister to the 500 volt supply. The' average resistance of the paper is 5000 ohms and the current for each pen is approximately 2 mA. Since the paper resistance is small compared with the 220 K ohms, any variation in the paper resistance will make no appreciable change in the pen current, and the 'blackness' of the trace will remain substantially uniform.

The sensitivity of the complete coil and pen unit is such that a deflection of 1 cm is obtained when 150 mA d.c. passes through the coil. The natural frequency of the unit is 75 c/s. The frequency response of the pen system is flat between 3 dB from 5 to 75 c/s. The three phase synchronous motor for the paper drive is controlled by a valve maintained oscillating bar to give a high degree of accuracy in paper speed. It is most important that there should be no vibration in the paper speed during operation, otherwise time errors could be introduced resulting in inaccurate record. The block diagram of the motor circuit is given in Fig. 7. The bar oscillates in the transverse mode and is made of an alloy 'Ni-Span C'. The length is critical as it determines the frequency of oscillation. It is such that the bar oscillates at a frequency of 300 c/s.

5. Cameras

SUPARCO has used K-24 cameras for photographing the grenade burst positions and the TMA trail from the optical stations established for the grenade experiment. The magazine of the camera houses film of 5-1/2" width and 56' length and the picture size is 5" x 5". The focal length of the camera is 178 mm with focal numbers: F/2.8, 4, 5.6, 8, 11 and 16.

IV. OUTLINE OF THE METHOD OF COMPUTATION

The general theory of the grenade experiment has been worked out by Dr. G. V. Groves (1956). As the wave length of the acoustic disturbance is short compared with atmospheric scale height, propagation is treated by geometric optics. It is assumed that the wind components are small compared with the speed of sound and the variation in the speed of sound with height is also relatively small.

The basic principle of the theory is illustrated in Fig. 8. The sound from grenade explosion at A is recorded by an array of microphones (M_1, M_2, M_3 .... M_n) with positions denoted by X_i, Y_i, Z_i, etc. The position of the microphones and the camera station is determined by accurate survey.

If the disturbance is travelling with a velocity c through a medium moving with three components u, v, and w in the x, y and z direction, and T_i, is the travel time from A microphone M_i, it is possible to determine u, v, w and C when the number of microphone used is 4 or more.

The travel times from the grenade burst position A are defined in terms of u. v. z. the three wind components, C the speed of sound at height Z in the following form:

$$U = \int_0^z u \, d z \; , \; V = \int_0^z v \, d z \; , \; W = \int_0^z w \, d z$$

$$C = \int_0^z c \, d z$$

Groves (1956) has shown that under the above assumptions the following equation is satisfied:

$$\left(U + \frac{X_i \; Z_i}{T_i} \right)^2 + \left(V + \frac{Y_i \; Z_i}{T_i} \right)^2 + \left(W + \frac{Z_i}{T_i} \right)^2$$

$$= C^2 \; (1 + \varepsilon) \qquad (1)$$

ε stands for certain small order terms which account for less than one percent correction.

The second and higher order effects arises from:

1) the supersonic velocity in the neighbourhood of the explosion.

2) refraction effects

3) departure of the microphones from a horizontal reference plane. The higher order terms have also been worked out in detail by Groves (1956, 1957, 1965).

If we confine ourselves only to first order effects ε can be neglected and equation (1) can be written as

$$C^2-U^2-V^2-W^2 = 2U\,\frac{\overline{X_iZ_i}}{T_i} + \overline{X_iZ_i^2/T_i^2}$$

$$+\ 2V\,\frac{\overline{Y_iZ_i}}{T_{im}} + \overline{Y_iZ_i^2/T_i^2}$$

$$+\ 2W\,\frac{Z_i^2}{T_i} + \frac{Z_i^4}{T_i^2} \qquad (2)$$

Transformation to the variable

$$S^2 = C^2 - U^2 - V^2 - W^2$$

makes the equation linear with respect to the variables U, V, W and $\frac{S^2}{2}$ since all the remaining terms

$$U = {}_0\!\int^z u\,dz\ ,\ V = {}_0\!\int^z v\,dz\ ,\ W = {}_0\!\int^z w\,dz$$

$$C = {}_0\!\int^z c\,dz$$

can be determined by the experiment. Thus four microphones determine a unique set of equations enabling us to solve for U, V, W, and $\frac{S^2}{2}$ directly.

It has been observed that the vertical component of wind W can be neglected. The equation (2) can be solved for three unknowns in which case three microphones are sufficient for a solution. But in practice it is desirable to use more than three microphones to determine U. V $\frac{S^2}{2}$ by the method of least squares. A check can, therefore, be made on errors in the data processing and standard deviation σU, σV, σC can be estimated. When U, V and C have been determined for a particular burst, it is repeated for each burst and the values of U, V, W and $\frac{dS^2}{dZ}$ are obtained as a function of altitude from which C can be determined easily by the following equation:

$$C = \frac{1/2\,\dfrac{dS^2}{dz} + uU + vV + wW}{C} \qquad (3)$$

From the speed of sound, the temperature T can be obtained by the formula

$$T = \frac{M}{\gamma R}\,C^2 \qquad (4)$$

where M is the mean molecular weight of air

γ is the ratio of specific heats

R is the universal Gas Constant.

For dry air of ground level composition

$$T = \left(\frac{C}{20.06}\right)^2$$

where C is measured in meters/second.

SCIENTIFIC RESULTS

REHBAR VII - 29.4.65

Temperature

The temperature profile obtained from the first firing (29 April '65) is shown in Fig. 9. For comparison the CIRA 1965 (10) temperature profile has been also ploted. The principal features of the temperature profile are:

1. Double maxima in the 40-50 km region.

2. The stratopause temperature at 50 km is about 23°C higher than the corresponding CIRA value.

3. The temperature at 30 km is about 20°C lower than the model.

The occurrence of double maxima in temperature profiles is also evident in some Australian firings from Woomera (31°S) and Carnavron (25°S), as reported by Rofe (11). A profile for 5 May 1961 over Wallops Island at 23.45 hours, reported by Nordberg and Smith (12), also shows pronounced double maxima. Several similar profiles also appear in a report by Peterson et al. (13).

Similarly, high stratopause temperatures, that is, high relative to the CIRA model, appear in many profiles in the same reports. In particular in Fig. 10 taken from (14), the falling sphere results show a very high stratopause temperature and very high gradients above and below the stratopause. In the absence of much other data from Sonmiani, it cannot yet be said whether this profile is truly representative of the region or whether it is an exceptional case. It must be remembered, however, that the CIRA model is based essentially on western hemisphere data.

The abnormally low temperature at 30 km is supported by results from a concurrent radiosonde release, which suggest a tropopause temperature of 180°K at about 21 km. The U.S. standard at this altitude is about 218°K (15).

Winds

The zonal wind profile as obtained from this firing together with meteorological rocket sounding results, is shown in Fig. 11(a). It is apparent from these profiles that the change from winter westerlies to summer easterilies first occurs around 50 km during mid April and gradually affects the higher levels as the month progresses. By May the summer pattern is fairly well established (16). The zonal winds about 30 km do not exhibit any systematic pattern and could be easterly or westerly depending on a particular synoptic situation.

The meridional winds as represented in Fig. 11(b) are generally less than 5 m/s below 45 km. Between 45 and 60 km they exhibit oscillatory characteristics. As an average an oscillation (N-S-N) is completed in an altitude range of about 10 km. The average meridional wind is about 10 m/s at 55 km and shows a tendency to increase with height.

REHBAR XI - 24.3.66

Temperature

The temperature profiles of the grenade firings conducted on 24.3.66 and 27.3.66 are represented in Fig. 12. The first firing is marked by a double maxima at about 40 km and 50 km respectively. The stratopause temperature is 7°C higher than the corresponding CIRA 1965 (10) temperature. Whereas the temperature at the lower maximum at 40 km is about 12°C higher than the corresponding CIRA temperature; the temperature about 50 km is, in general, lower than the CIRA temperature.

The temperature data above 58 km have been rejected due to errors involved in the interpretation of the acoustic record of the grenade explosions.

Winds
In order to study diurnal effect on the wind profile a Judi-Dart firing with copper chaff as pay-load was conducted on the morning of 25.3.66. The wind data from these two firings are presented in Figs. 13 and 14. The profile of the zonal wind exhibited marked changes at the two levels coincident with the two maxima observed in the temperature sounding obtained from the grenade firing. At other levels the variations in the zonal wind were not so marked.

The meridional wind, again, showed maximum variation in the two profiles between 40 and 50 km. Above 55 km the meridional component changed from north in the evening to south in the morning. Similar diurnal changes in the meridional wind component above 50 km have been observed by Rahmatullah and Jafri (17)' in the two Judi-Dart firings conducted on 16.2.66 at 0430 Z and 1336 Z respectively.

REHBAR XII - 27.3.67

Temperature
Fig. 12 shows the temperature profiles obtained in the second firing (27 March 1966). The broad stratopause should be noted, but apart from a general increase over the CIRA 1965 values of about 10°C the profile is not unusual.

Winds
The zonal wind profile is given in Fig. 15 and, as would be expected from a March firing, this component is predominantly westerly, reaching a maximum value of about 45 m/s at about 55 km.

The meridional component shown in Fig. 16 exhibits the oscillatory character observed in the previous firing.

REHBAR XIII - 26.4.66

T.M.A. Wind
The wind profile from TMA represented in Fig. 17 indicates that the wind steadily decreased between 96 km and 99 km from about 60 m/s to 40 m/s. Then it sharply increased to 103 m/s at 103 kms. which was the principal maximum in this case. In general the principal maximum occurs between 100 and 105 km and is characterised by strong wind shears. The wind speed above the principal maximum decreased to about 40 m/s at 115 km but rose, again, to 71 m/s at 121 km.

The direction of the transport vector was initially directed to ENE but changed to ESE at the principal maximum. It changed, again, to NE at 111 km and finally became SSE at 121 km.

In the sodium vapour experiment conducted on May 7, 1967 the principal maximum reported by M.S. Ahmad (18) was 111 m/s at 102 km. The direction of the transport vector at the principal maximum was NE in this experiment, whereas in the TMA experiment it was ESE.

REHBAR XIV - 29.11.67.

T.M.A. Wind
The wind profile based on TMA trail, represented in Fig. 18, shows that the wind at 94 km is 42 m/s, but decreases to 17 m/s at 98 km. Thereafter the rise in wind speed becomes rather steep with 98 m/s wind recorded at 108.5 km. Above that level the wind steadily decreases to 75 m/s at 110 km and to 7 m/s at 115 km. It shows a slight rise above that level.

The direction of transport vector is SE to begin with, but steadily changes to NW at the principal maximum. It becomes west at 111 km and steadily backs to SSE at 115 km.

The result from this firing when compared to the sodium firing conducted in May 1967 (18) brings out some interesting features. The principal maximum in spring and autumn is located at

105 ± 5 km. From the meagre data so far available it appears that the wind speed at the principal maximum usually exceeds 100 m/s. Comparing the results from the spring and autumn firings a major change has been observed in the direction of the transport vector. In May the direction of the transport vector at the principal maximum is E or NE, whereas in November it is directed to NW. This seems to be the major difference between the spring and autumn wind circulation in the mesosphere in subtropics.

The results from the above grenade launchings have been presented at COSPAR International Space Science Symposia and have been published in SPACE RESEARCH VIII (19) and X (20). The data of Grenade/TMA are given in Annex-I.

CONCLUSION

The grenade-TMA firings conducted in 1965-67 bring out the following important features regarding the stratospheric circulation in the subtropics:

1. The temperature pattern during the month of March/April at Sonmiani is characterised by higher temperature than the corresponding CIRA 1965 value. This increase in the temperature varies considerably from firing to firing from as low a value as 7°C and as high a value as 23°C.

2. Double maxima in temperature has often been observed in Sonmiani during spring. Major changes in temperature profile have been observed over a period of 72 hours.

3. In March the zonal wind is predominantly westerly reaching a maximum value of about 45 m/s at 55 km.

4. The meridional component exhibits oscillatory character between 45 and 60 kms.The diurnal changes in the meridional component above 50 km were observed as reported in the earlier Judi-Dart firing.

5. The change from winter westerlies to summer easterlies first occurred around 50 km during April and gradually affected higher levels as the month progressed. By May the summer pattern was fairly well established.

6. The height of the principal maxima at Sonmiani is located at 105 ± 5 km. In autumn the wind at the principal maxima is below 100 m/s and is directed to NW, in spring it is of the order of 118 m/s but directed to E or NE.

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ANNEX - I

REHBAR 7 - APRIL 29, 1965

H	DELTAH	U	SIGMAU	V	SIGMAV	C	SIGMAC	T	SIGMAT
30.73	4.03	0.9	2.4	-9.6	4.7	293.8	1.8	214.8	2.6
34.93	4.39	1.1	1.9	-9.6	3.6	309.4	1.4	238.2	2.1
38.41	2.57	4.8	3.7	-4.6	6.9	319.7	2.7	254.3	4.3
41.39	3.39	0.2	2.6	-0.9	4.8	331.8	1.9	273.9	3.1
45.67	5.16	-2.7	2.1	1.0	3.9	328.3	1.6	268.1	2.6
50.80	5.10	10.8	2.8	14.4	5.1	343.8	2.1	294.0	3.6
55.50	4.30	-8.7	4.6	8.0	8.4	331.4	3.6	273.3	6.0
58.92	2.55	-19.1	7.6	26.6	13.9	313.0	6.0	243.7	9.4

REHBAR 11 - MARCH 24, 1966

H	DELTAH	U	SIGMAU	V	SIGMAV	C	SIGMAC	T	SIGMAT
32.05	3.67	-8.3	1.8	6.9	3.2	305.4	1.1	232.1	1.6
35.11	2.44	-12.7	2.7	8.1	4.6	324.8	1.6	262.4	2.6
37.53	2.41	-11.3	2.5	10.1	4.2	327.7	1.5	267.1	2.4
40.45	3.43	-8.8	2.4	20.8	4.9	327.8	1.7	267.3	2.7
43.31	2.28	20.5	4.1	-20.2	8.0	315.0	2.7	246.9	4.3
45.54	2.19	-5.5	3.2	-8.3	5.3	327.3	1.9	266.5	3.1
47.71	2.14	-4.7	4.4	-3.1	7.2	332.7	2.6	275.3	4.3
49.83	2.10	-1.7	5.5	3.1	9.0	333.2	3.3	276.2	5.5
51.90	2.03	-6.6	7.7	-0 .4	12.6	327.2	4.7	266.3	7.6
53.91	1.98	21.5	7.6	-31.6	12.3	313.9	4.6	245.2	7.2
55.86	1.93	13.2	3.6	-34.6	5.8	318.5	2.2	252.3	3.5
57.76	1.88	-9.0	2.6	-36.5	4.2	320.6	1.6	255.6	2.6
59.62	1.84	-11.9	5.3	-72.8	8.4	298.5	3.3	221.6	4.8

REHBAR 12 - MARCH 27, 1966

H	DELTAH	U	SIGMAU	V	SIGMAV	C	SIGMAC	T	SIGMAT
37.77	3.03	-12.0	2.8	-6.1	4.4	322.3	1.4	258.4	2.3
40.74	2.91	-4.8	4.3	-2.6	6.8	326.5	2.2	265.2	3.6
43.64	2.89	-2.9	5.0	-10.2	7.9	332.7	2.6	275.3	4.3
46.51	2.84	-6.8	4.3	-18.7	6.7	333.7	2.2	277.0	3.7
49.32	2.78	-7.5	3.8	-16.4	5.9	333.0	2.0	275.8	3.3
52.10	2.78	3.1	5.2	-20.6	7.9	333.0	2.7	275.8	4.5
54.82	2.67	7.5	6.1	-49.7	9.4	328.1	3.2	267.8	5.3
57.54	2.76	-4.0	4.2	-48.7	6.4	326.1	2.2	264.6	3.6
60.25	2.67	-19.1	4.7	-47.1	7.0	323.4	2.5	260.1	4.0
63.51	3.85	-26.0	4.1	-42.3	6.2	315.0	2.2	246.9	3.5
66.70	2.54	-4.4	7.5	-38.2	10.9	306.3	4.0	233.4	6.1
69.87	3.80	2.3	5.4	-14.0	8.0	308.4	2.9	236.6	4.5
75.94	4.17	6.2	2.8	-3.8	4.2	298.0	1.6	220.9	2.4
81.27	2.30	25.7	10.1	49.5	15.1	299.8	5.7	223.6	8.5

REHBAR 13 - APRIL 26, 1966

Height (Km)	Wind Speed (M/s	Direction Transport Vector (degrees)
96.18	59.15	64.14
97.00	50.01	72.30
98.50	40.36	101.87
99.14	40.50	118.99
100.00	53.00	121.89
101.70	77.83	125.32
103.42	102.63	126.78
104.00	97.08	124.51
106.00	78.27	114.54
108.00	62.80	99.15
111.98	55.94	50.35
113.00	49.82	58.54
115.00	41.34	82.63
117.00	42.72	110.56
119.90	58.77	139.96
121.70	70.73	148.94

REHBAR 14 - NOVEMBER 29, 1967

Height (km)	Wind Speed (m/s)	Direction Transport Vector (degrees)
93.80	43.29	162.50
94.00	41.76	163.30
95.00	33.54	169.70
96.00	26.04	181.10
97.00	19.60	199.36
98.00	16.98	227.49
99.00	18.92	257.80
100.00	24.68	276.90
101.00	32.57	287.88
102.00	40.71	294.68
103.00	49.24	299.17
104.00	58.52	303.15
105.00	67.83	305.10
106.00	76.40	307.02
107.00	85.42	308.34
108.00	94.17	309.18
108.50.	98.51	309.61
109.00	90.34	308.71
110.00	74.79	307.94
111.00	59.40	306.10
112.00	44.10	302.97
113.00	28.17	297.48
114.00	13.82	282.53
115.00	7.64	191.31
116.00	20.59	150.95
116.40	27.12	147.19

ANNEX - II

MEMORANDUM OF UNDERSTANDING BETWEEN THE PAKISTAN SPACE & UPPER ATMOSPHERE RESEARCH COMMITTEE, THE BRITISH NATIONAL COMMITTEE ON SPACE RESEARCH, AND THE UNITED STATES NATIONAL AERONAUTICS & SPACE ADMINISTRATION

The Pakistan' Space & Upper Atmosphere Research Committee (SUPARCO), the British National Committee on Space Research (BNCSR) and the United States National Aeronautics & Space Administration (NASA) affirm their mutual interest in obtaining wind, temperature and other meteorological information between 50 and 150 kilometers by rocket soundings using the 'grenade' technique. These agencies agree to cooperate in a joint project of launchings from Sonmiani Beach, Pakistan, during the International Quiet Sun Year.

Each agency will use its best efforts to discharge the following responsibilities:

1. SUPARCO responsibilities

a) Coordinate conduct of experiments.
b) Prepare and operatellaunching site and associated facilities.
c) Assemble and launch sounding rocket vehicles.
d) Reduce resulting data.

2. BNCSR responsibilities

a) Assist in the conduct of experiments.
b) Provide six 'grenade' payloads compatible with the NASA Nike-Cajun or Nike-Apache vehicle.
c) Provide on loan, all special ground equipment needed, including twelve microphones, one recorder, four or five cameras, and two flash detectors.
d) Train SUPARCO personnel in the acquisition and reduction of the meteorological data and in the operation and maintenance of U.K. - supplied equipment.
e) Provide, as feasible, continuing technical assistance in the operation and maintenance of U.K. - supplied equipment.

3. NASA responsibilities

a) Provide six Nike-Cajun or Nike-Apache vehicles (these include two Cajuns already supplied)
b) Provide, as feasible, continuing technical assistance in the operation and maintenance of U.S. equipment previously loaned under cooperative agreements between the U.S. and Pakistan, which will be utilised in this programme.

Each agency will bear the cost of discharging its respective responsibilities including travel by its personnel and the transportation of the equipment which is its responsibility.

Each agency will designate a Project Manager to assure proper coordination with the others.

Copies of the raw data obtained will be the common property of all three parties, reduced data will be made available to the three parties within 5 months, and all results will be published in open literature or otherwise made available to the world scientific community.

Amendment to Memorandum of Understanding
By B. N. C. S. R.

1. NASA to provide two grenade payloads compatible with Nike-Cajun if arrangements can be made for these to be launched in spring 1965 in which case BNCSR will undertake to replace these payloads with similar ones acceptable to NASA.

2. Delete 2(c) and replace by "Provide on loan eight microphones and associated recording equipment and two flash detector".

For the Pakistan Space & Upper Atmosphere
Research Committee

Sd/- I.H. USMANI

For the National Aeronautics & Space Administration

Sd/- Hugh L. Dryden

For the British National Committee on Space Research

Sd/- H.S.W. Massey

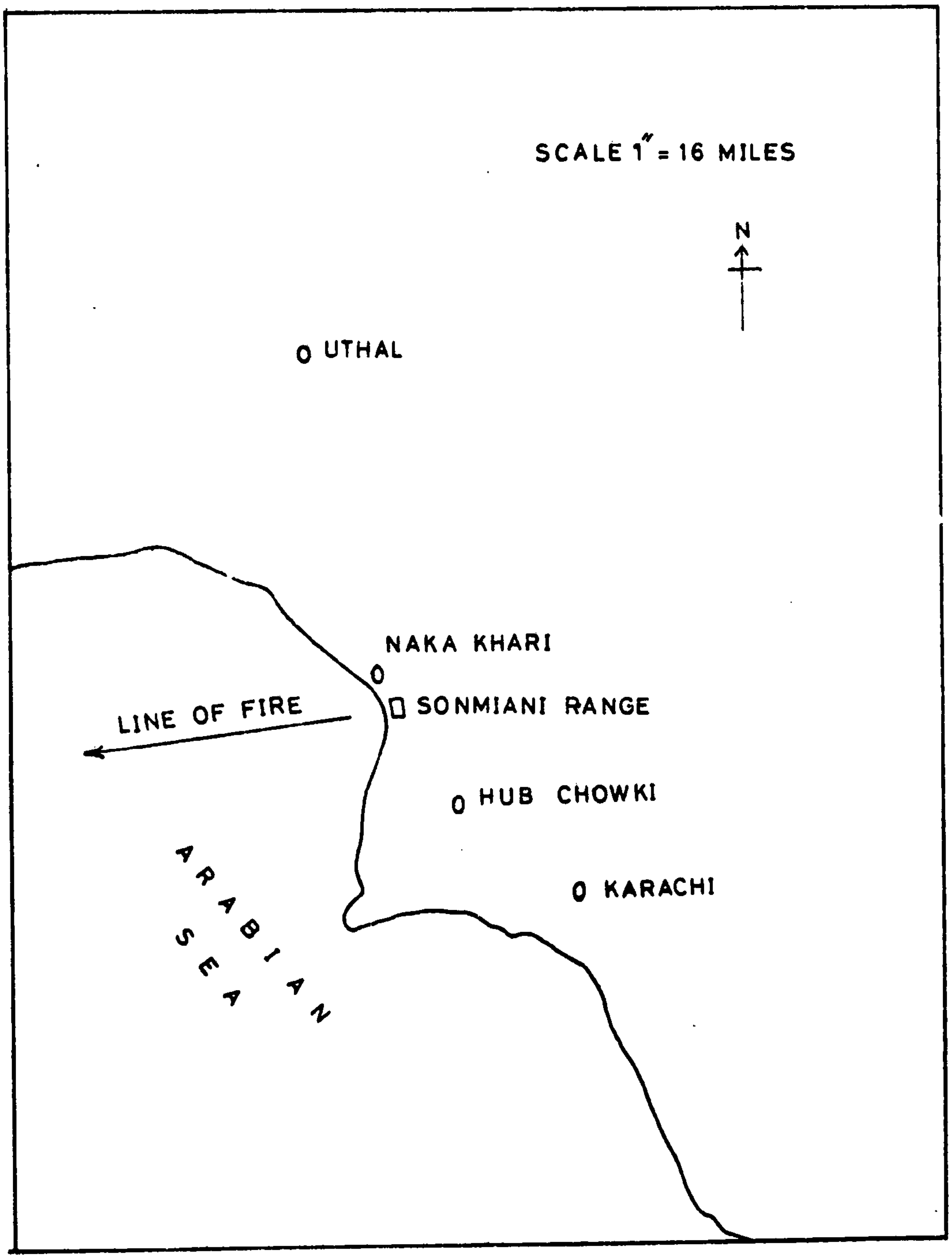

FIG 1 MAP SHOWING BALLASTIC CAMERA NETWORK.

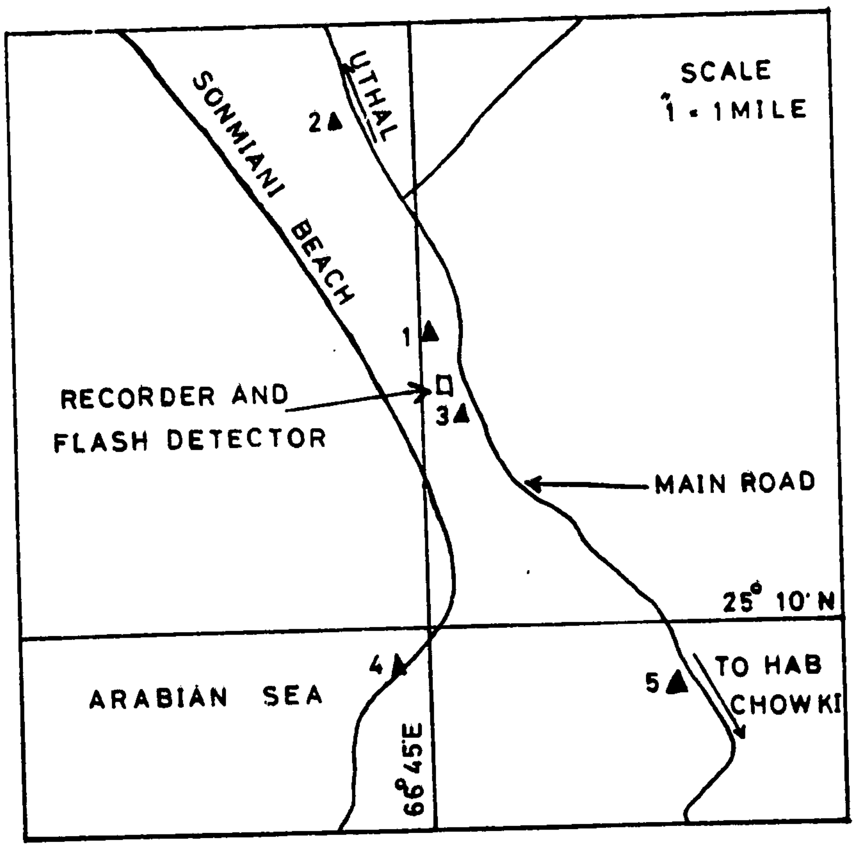

FIG.2.(a). MICROPHONE ARRAY AT SONMIANI.

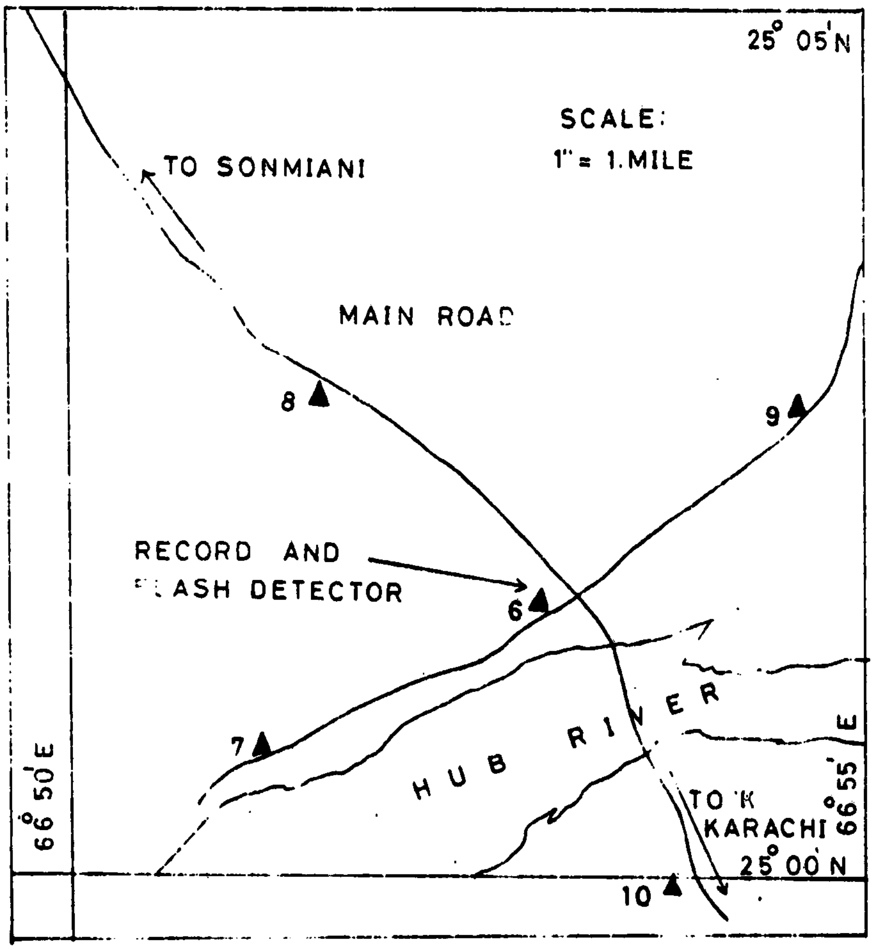

FIG.2(b) MICROPHONE ARRAY AT HUB CHOWKI.

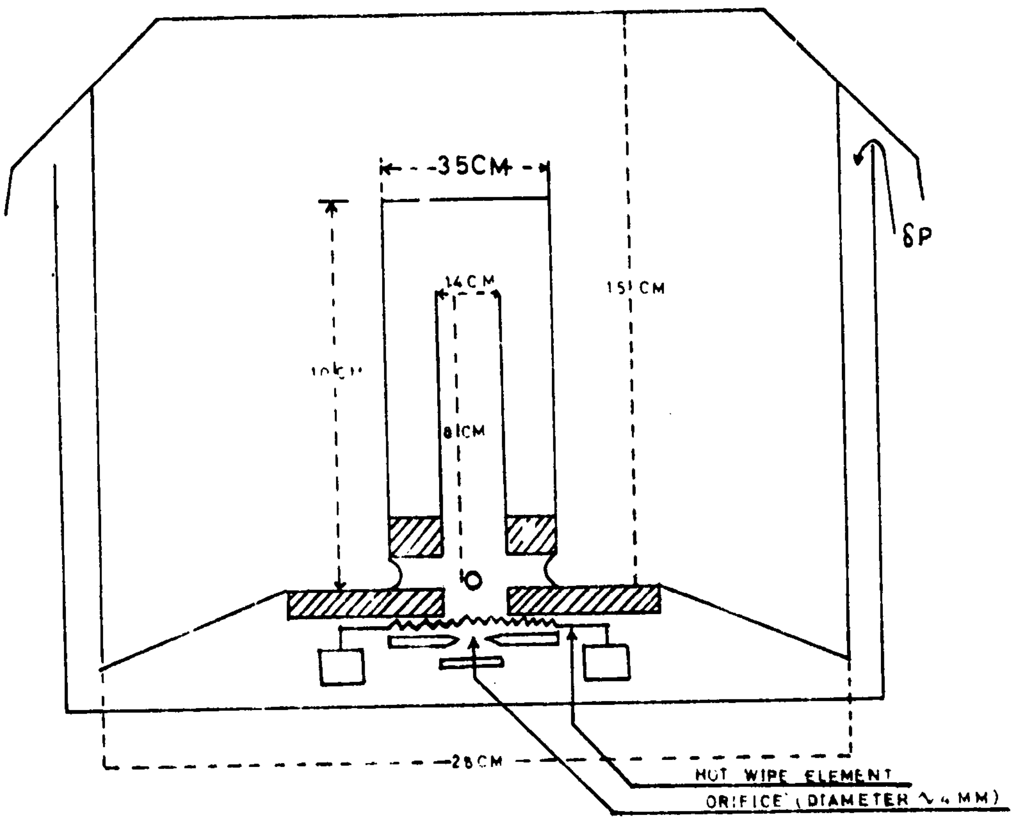

FIG.3 SRMK I CONSTRUCTION.

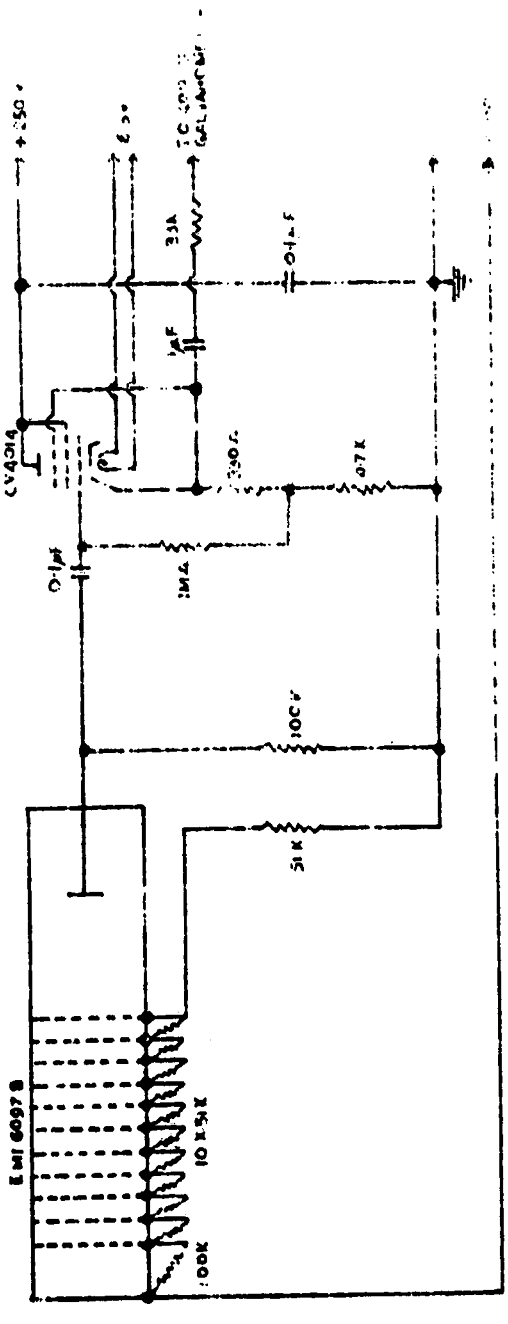

FIGURE 4 6097B FLASH DETECTOR CIRCUIT

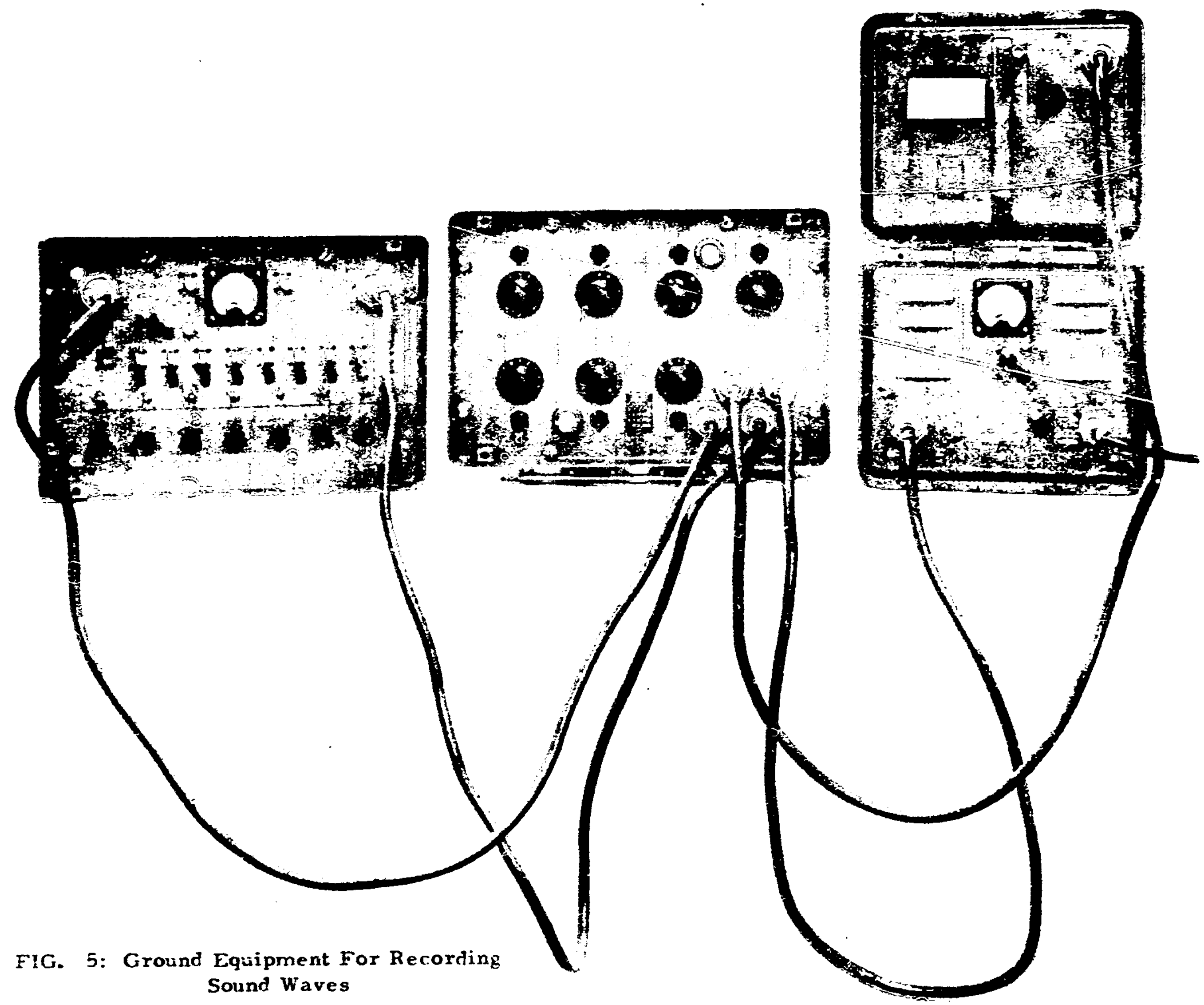

FIG. 5: Ground Equipment For Recording Sound Waves

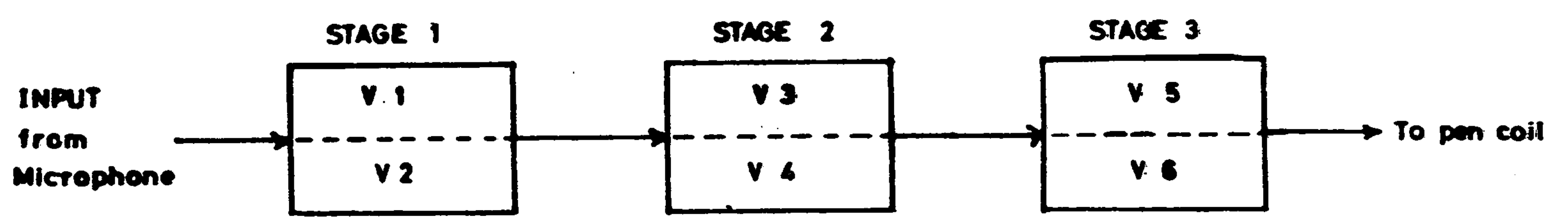

FIG.NO.6. BLOCK SCHEMATIC DIAGRAM OF A CHANNEL AMPLIFIER.

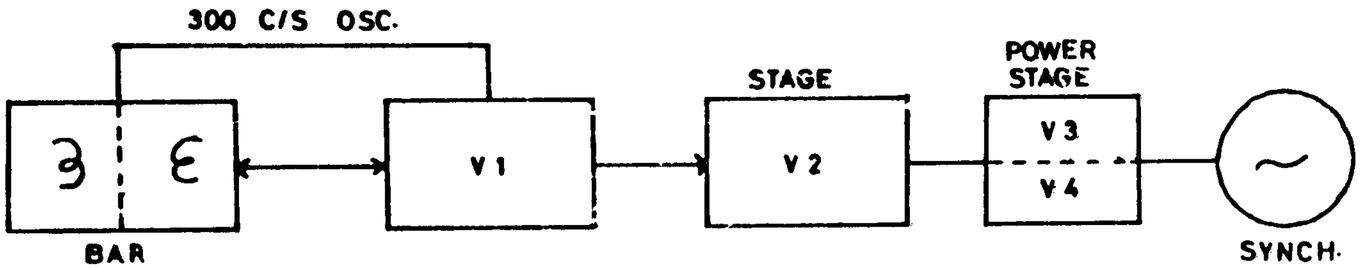

FIG NO 7 BLOCK SCNEATIC DIAGRAM OF MOTOR CIRCUIT.

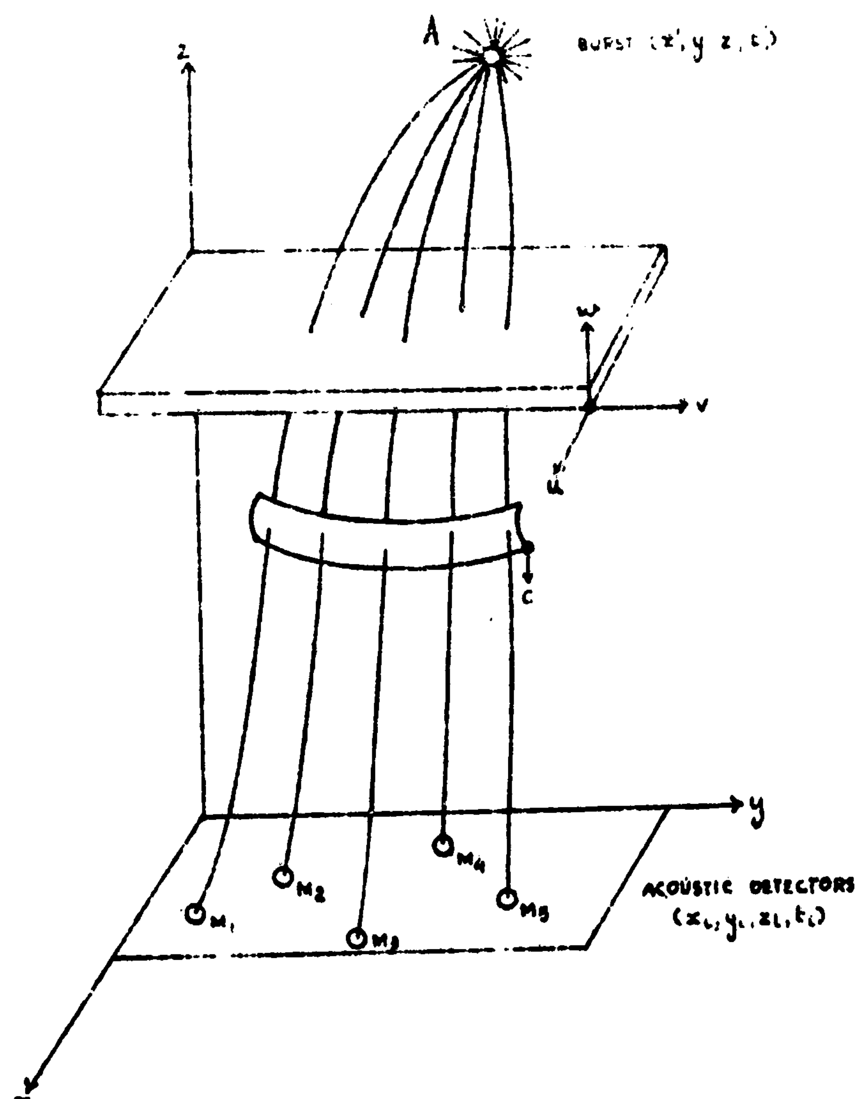

FIGURE 8 CO-ORDINATES OF BURST

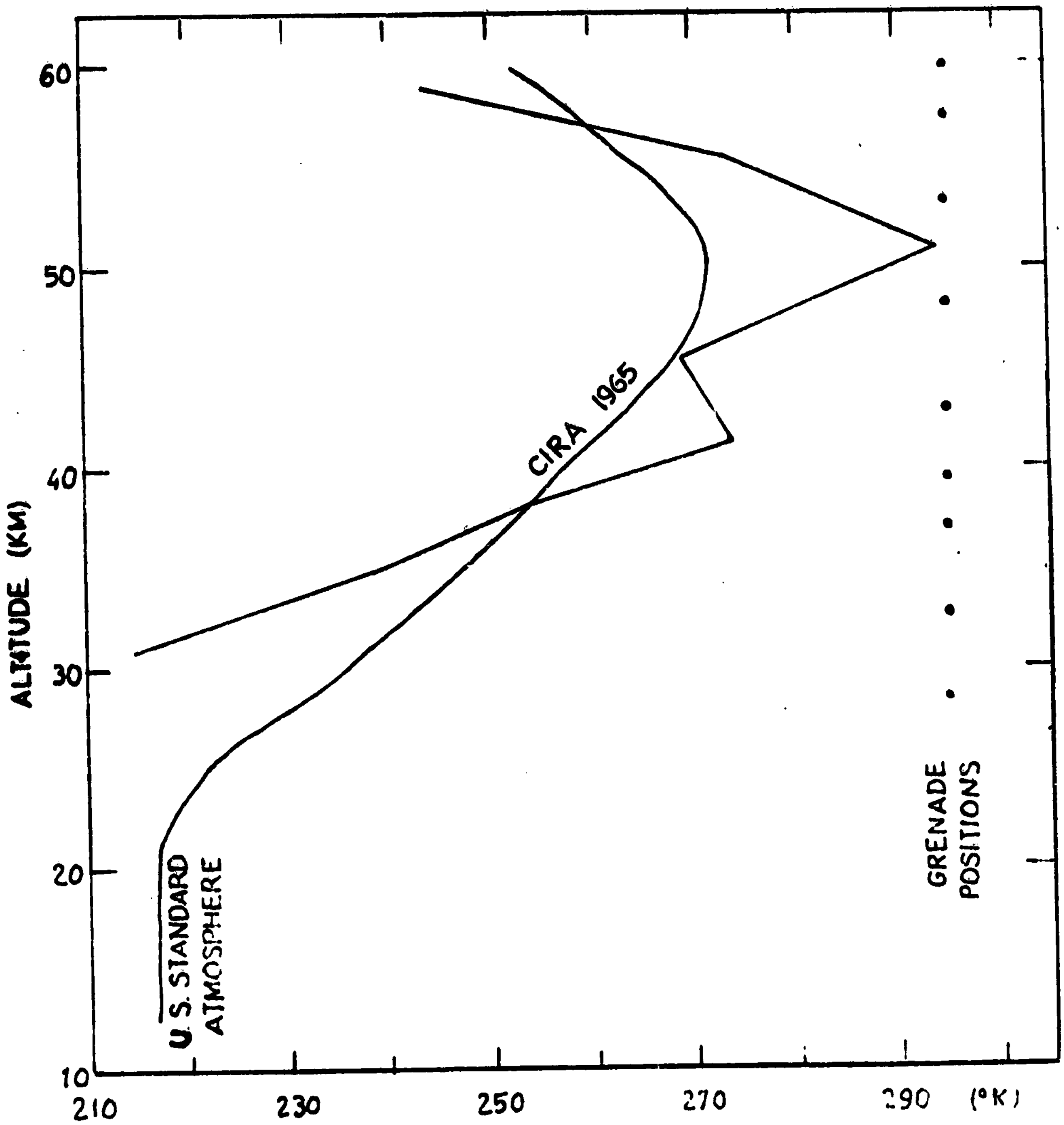

Fig. 9. Temperature sounding 29 April 1965.

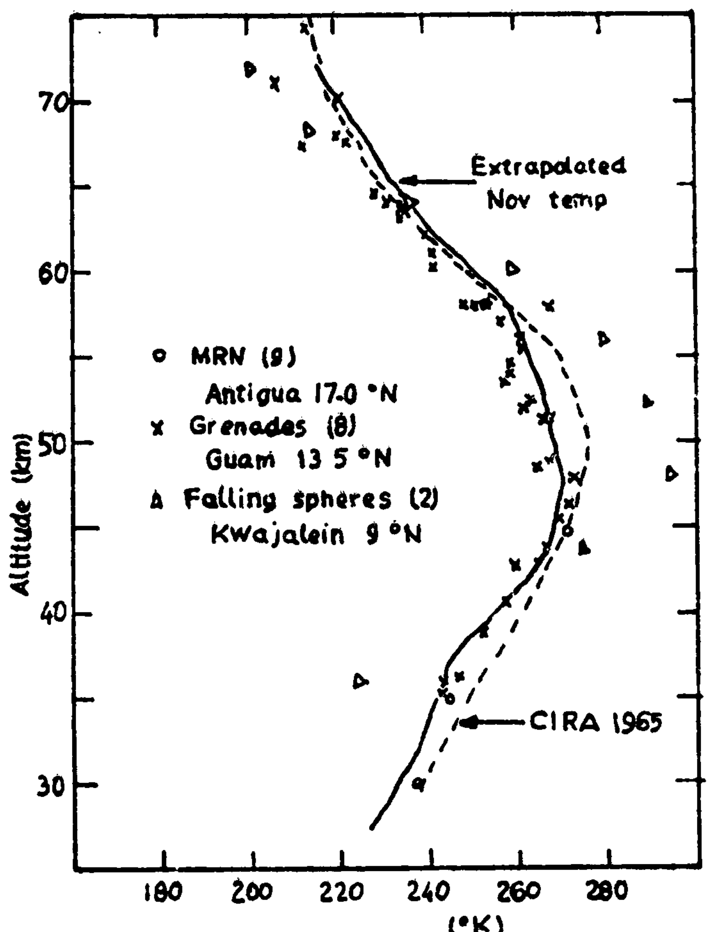

Fig. 10 Comparison of observed temperatures at three tropical locations with extrapolated 15°N profile for November (5). CIRA 1965 15° latitude November profile has been added for comparison.

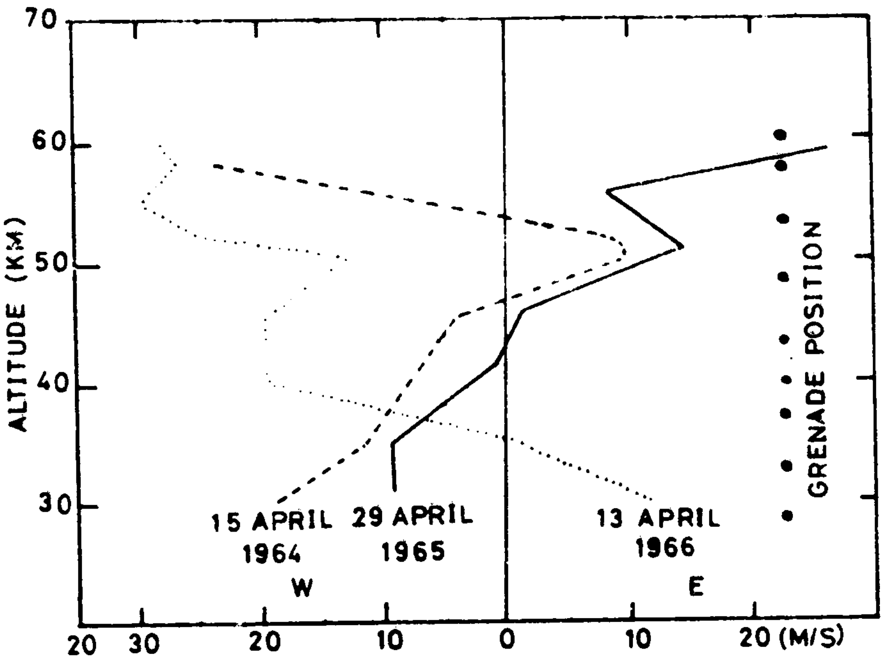

FIG.11(a). ZONAL WIND PROFILES IN APRIL

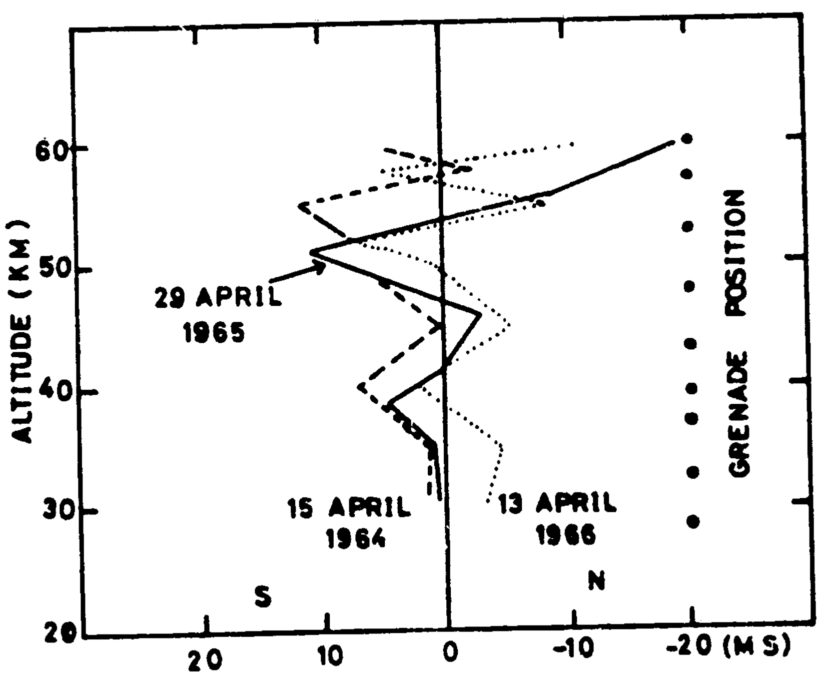

FIG.11(b). MERIDIONAL WIND PROFILES APRIL

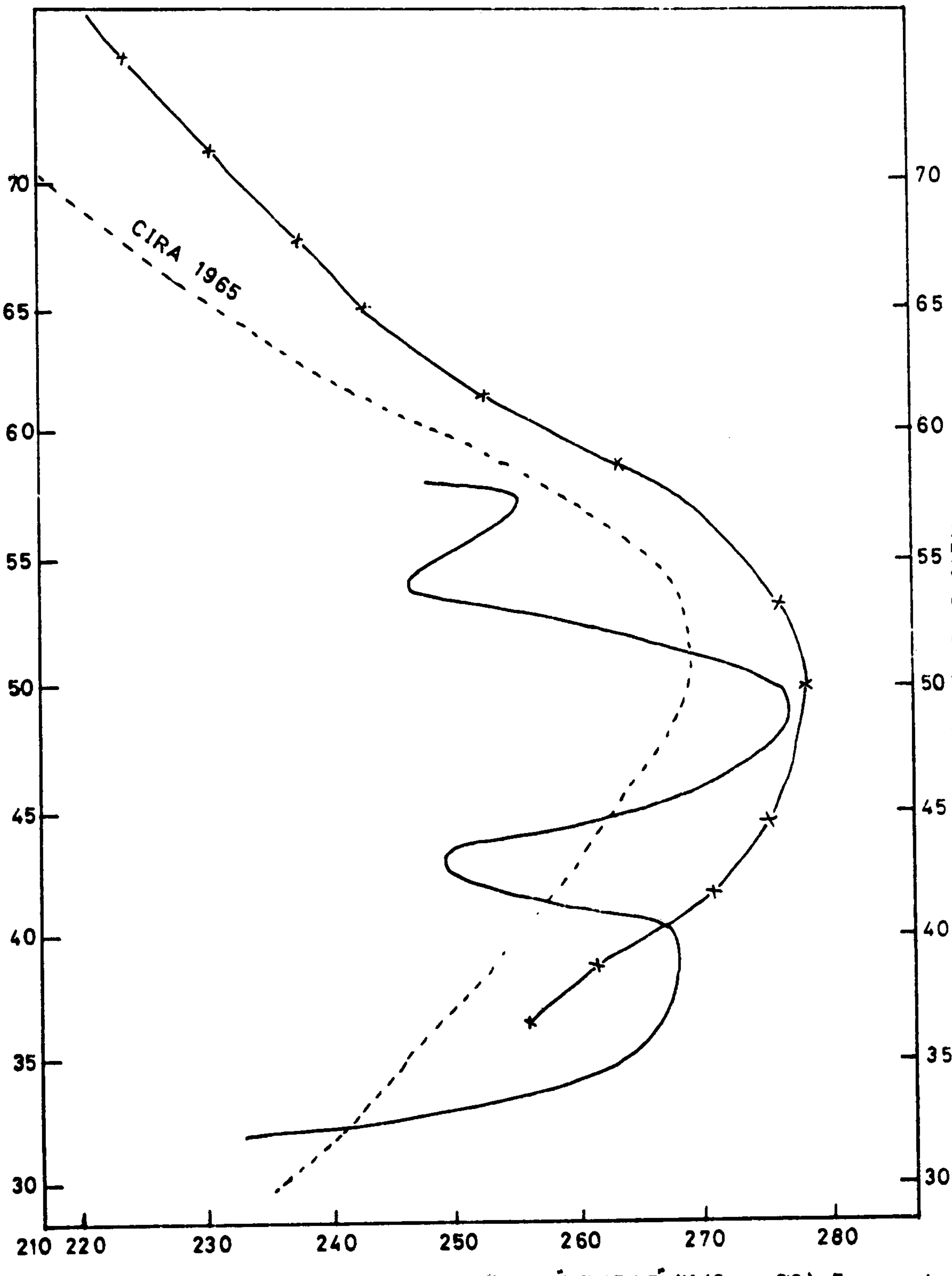

FIG.12. TEMPERATURE PROFILE FROM REHBAR XI (2 -66) Temperatuare °K

24-3-66 ———————— GRENADE DATA

- - - - - - - - - - - - CIRA 1965

27-3-66 x———x———x———x GRENADE DATA

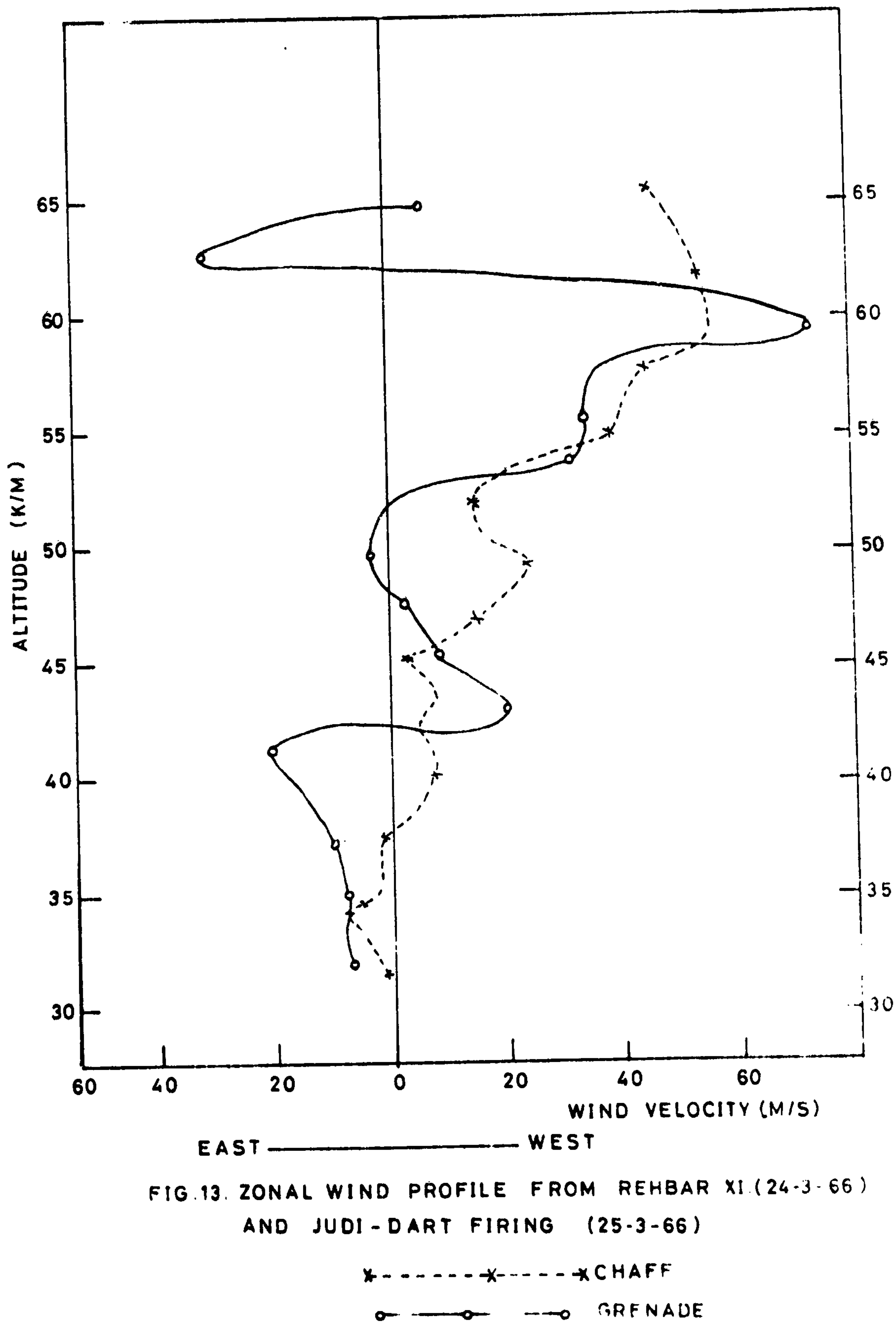

FIG.13. ZONAL WIND PROFILE FROM REHBAR XI (24-3-66) AND JUDI-DART FIRING (25-3-66)

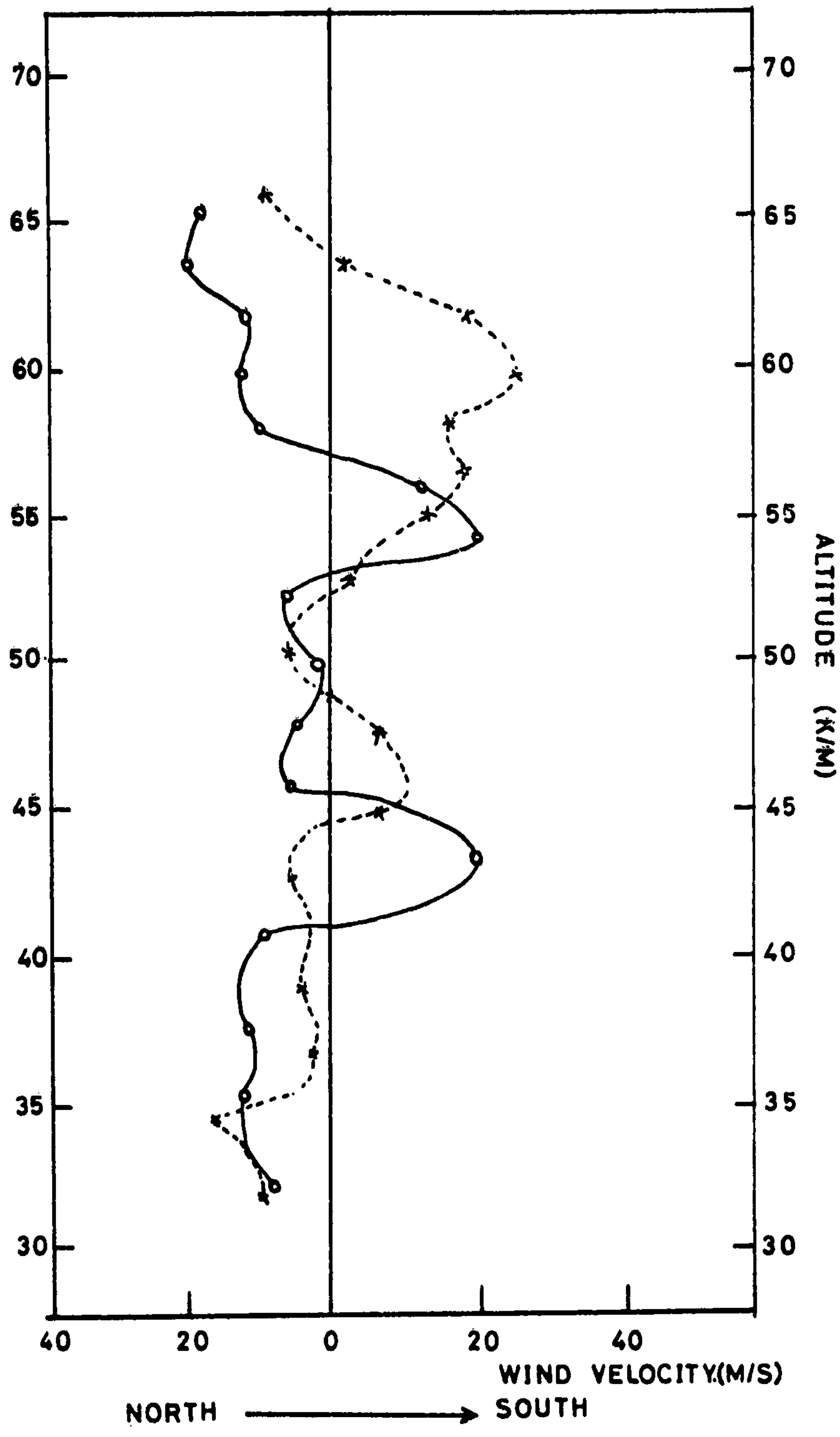

FIG.14. MERIDONAL PROFILE FROM REHBAR.XI.(24-3-66) AND JUDI DART FIRING. (25-3-66)

CHAFF

GRENADE

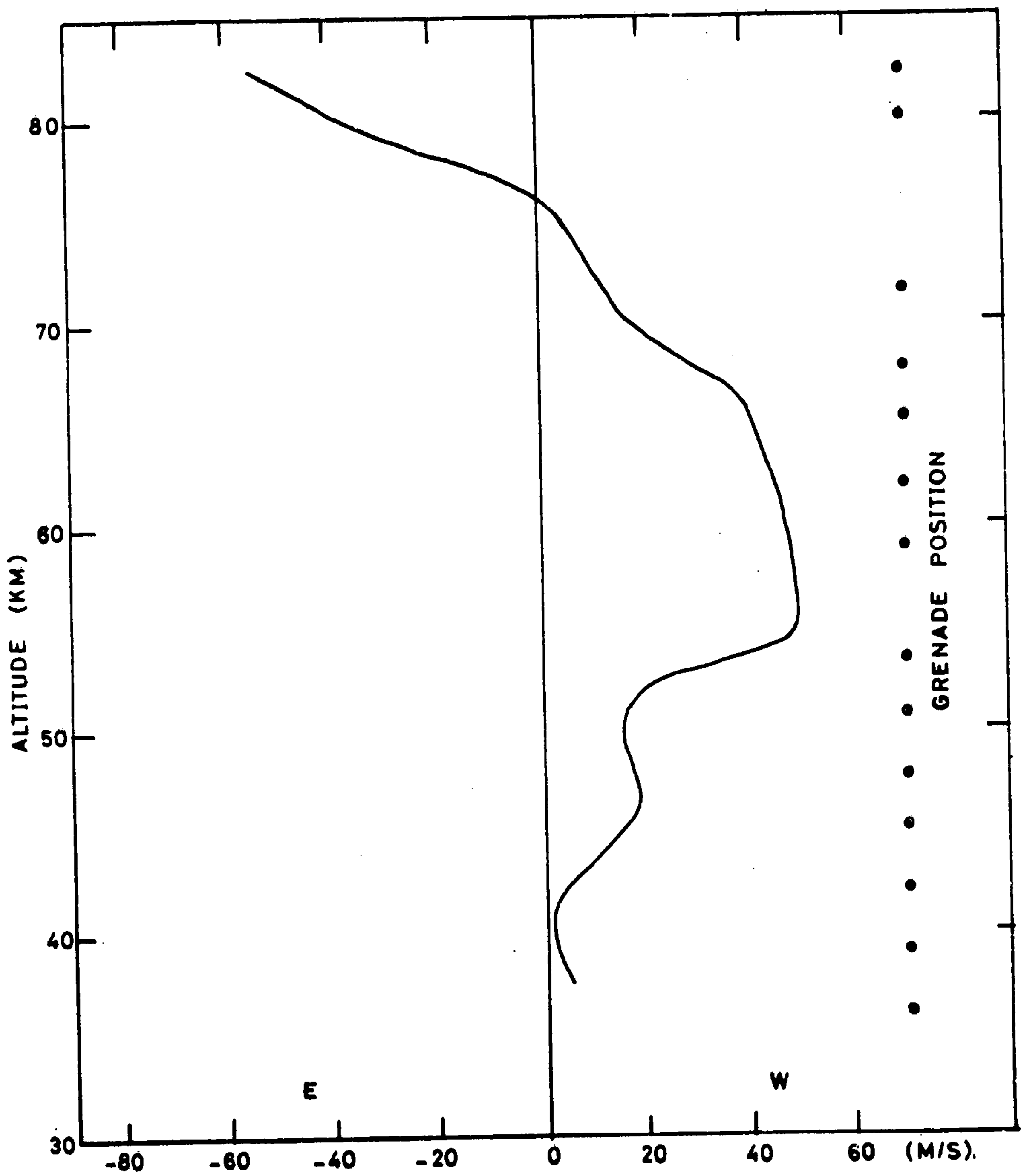

FIG.15. SONMIANI: ZONAL WIND PROFILE ON 27 MARCH 1966

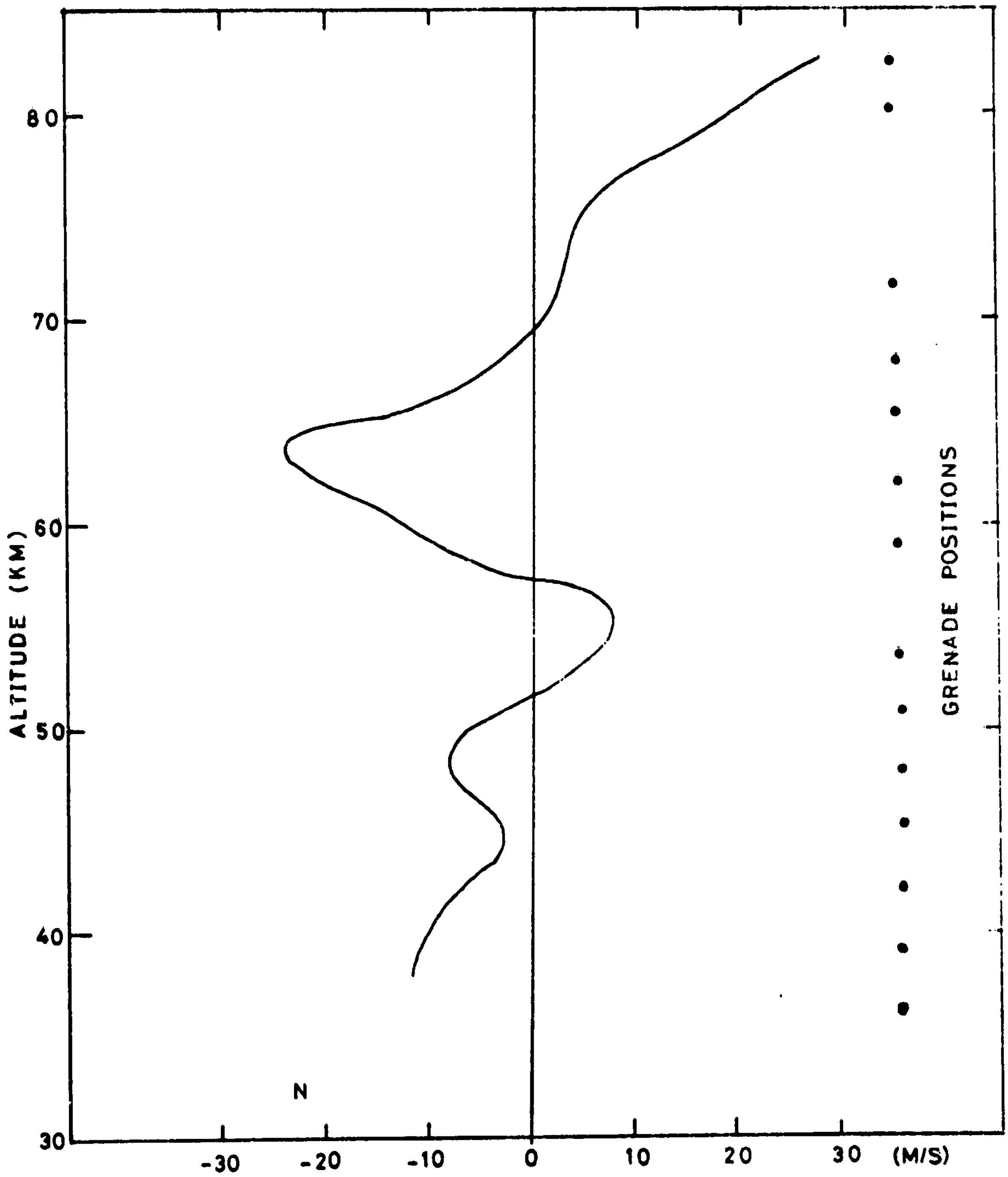

FIG.16. SONMIANI: MERIDIONAL WIND PROFILE ON 27 MARCH 1966

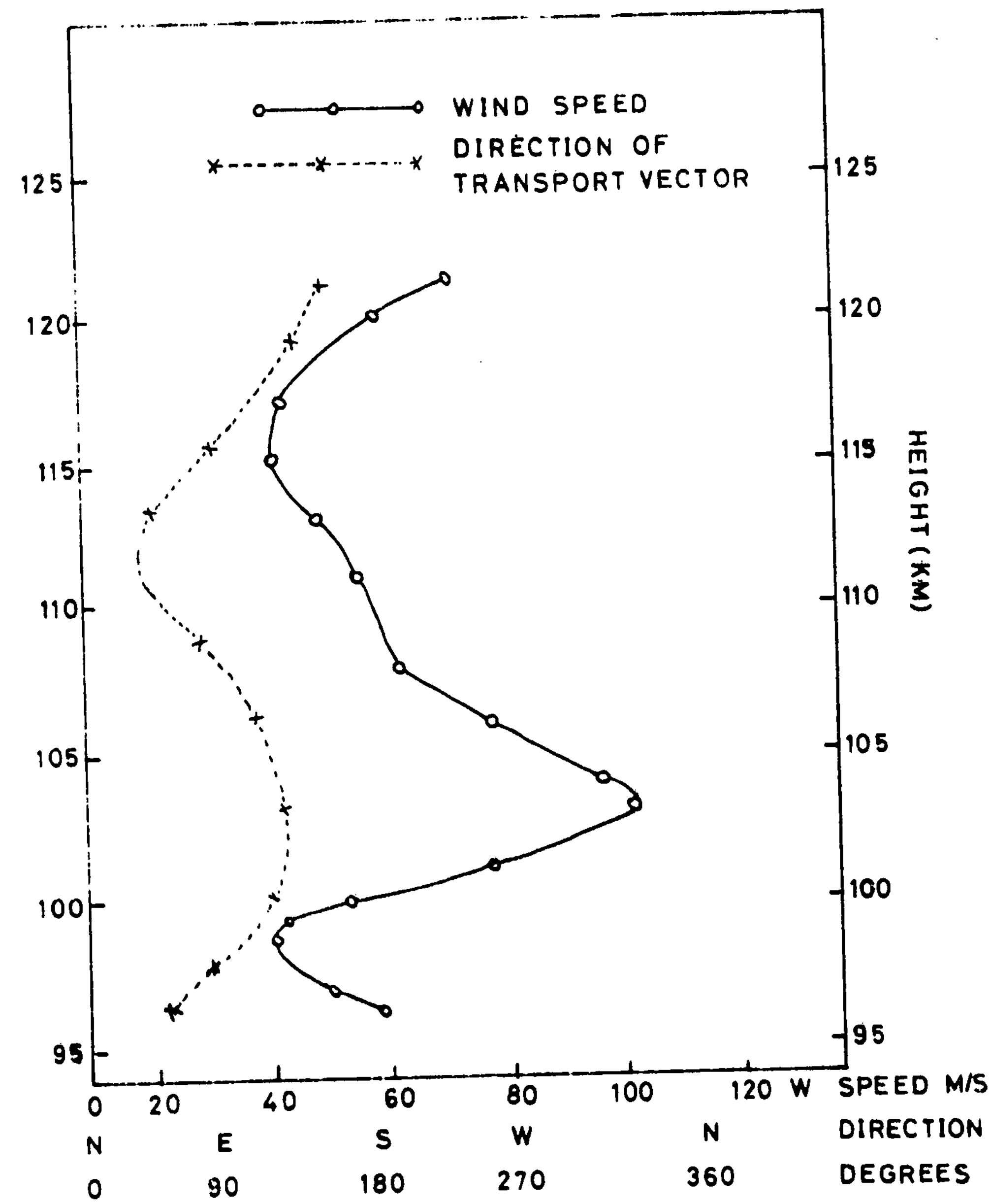

FIG.17. TMA WIND PROFILE REHBAR XIII. (26-4-66)

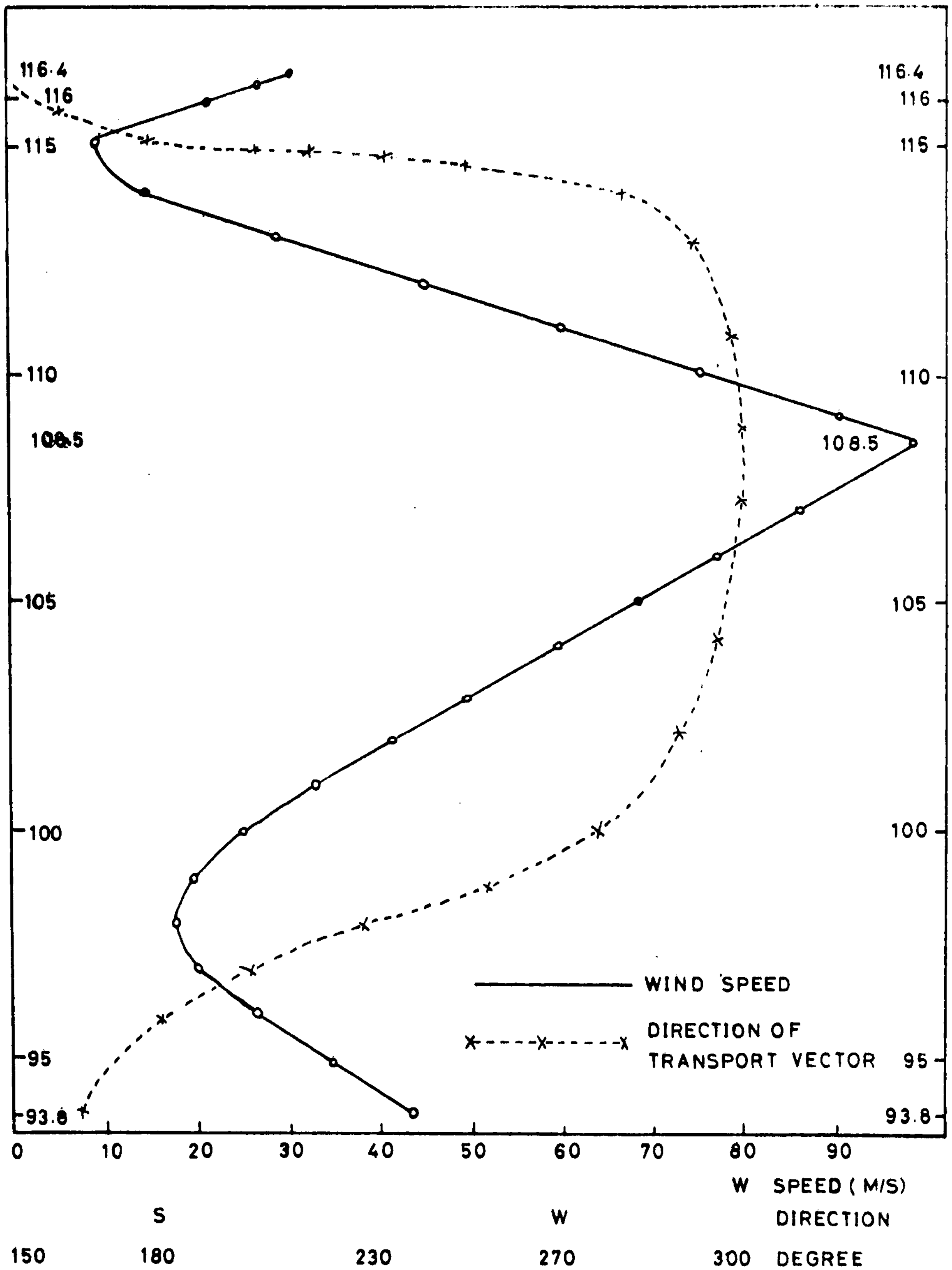

FIG.18. TMA WIND PROFILE REHBAR XIV (29-11-67)