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Meteorological support for two-stage rockets at Thumba

M. S. V. RAO and D. N. SIKDAR

Meteorological Office, Thumba

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ABSTRACT. The Equatorial Rocket Launching Station at Thumba became operational on 21 November 1963. Six large meteorological rockets — Nike Apache with sodium vapour payloads and four Nike Apache rockets with magnetometer-payloads were fired up to the end of 1964.

The meteorological support given to the NikeApache firings is described. For all these firings complete wind weighting procedure was carried out. The method followed is explained with an actual example.

A brief description giving an idea of the rockets and the scientific information collected from them is also included.

1. Introduction

Thumba Equatorial Rocket Launching Station (TERLS) was inaugurated on 21 November 1963, when the first rocket was sent up from India into space. The objective with which the launching site has been established is the exploration of the upper atmosphere up to 200 km in the first instance. The studies to be made include stratospheric, mesospheric and ionospheric wind parameters and air temperatures, magnetic parameters as well as density and temperature of neutral and charged particles in the atmosphere.

Thumba is located very close to the magnetic equator. Its latitude is 0° 24′ south (magnetic) and 0° 52′ south (geomagnetic). Its geographical coordinates, however, are latitude 8° 32′ N, longitude 76° 52′ E. The proximity of Thumba to the magnetic equator is of great importance. As is well known the equatorial electrojet passes at an altitude between 100 and 160 kilometres over the magnetic equator. Thumba is the first equipped rocket station from which scientific investigation of the equatorial electrojet could be carried out.

The facilities available at Thumba include launch-pads, block-house, rocket assembly and storage buildings, a 200-ft meteorological tower, balloon launching facilities, an MPS-19 radar system, a telemetry trailer and single station DOVAP system. An electronic computer, a shake-table for vibration test, MI-4 helicopter and a sea-rescue motor launch for range surveillance are being currently added.

Six sodium vapour experiments have been conducted so far at Thumba yielding meteorological data, up to a height of 200 km (Bhavsar and Ramanuja Rao 1964). Four rocket-borne magnetometer experiments conducted by Dr. Cahill have further established the nature of the equatorial electrical currents in the ionospheric E region (Cahill — *see ref.*; Singer, Maple and Bowen 1951; Cahill 1959). Six meteorological rockets launched in 1964 have given valuable information about the equatorial stratosphere and mesosphere (Rao and Chandrasekharan 1965).

It should be mentioned here that at present there are some gaps in the exploration of the atmosphere over tropical regions from the surface upto 200 km which need to be filled up. The first of these occurs between the highest level reported by radiosonde and the lowest level of rocket sounding data. The second gap is between the highest small meteorological rocket sounding level and the lowest level of the large meteorological rocket sounding with sodium vapour payload. Remedial measures are contemplated for filling up these gaps. Better balloons with American type of radiosonde equipment are likely to be used in order to eliminate the first gap. Rocket grenade experiments conducted at Thumba would cover the second gap.

2. Experiments with two-stage rockets

The two-stage rockets used so far at Thumba is the Nike-Apache. This consists of a Nike motor as booster and an Apache TE 307 motor as a sustainer. The combination has a capability of lifting a payload of 100 lbs to 150 kilometres or a payload of 50 lbs to 200 kilometres.

Two types of payloads have been used at Thumba. In the first type, sodium with a little potassium added to it, is vaporised by means of an iron oxide - aluminium thermite mixture. The reason for adding potassium is to obtain an optically thin source for temperature measurements as

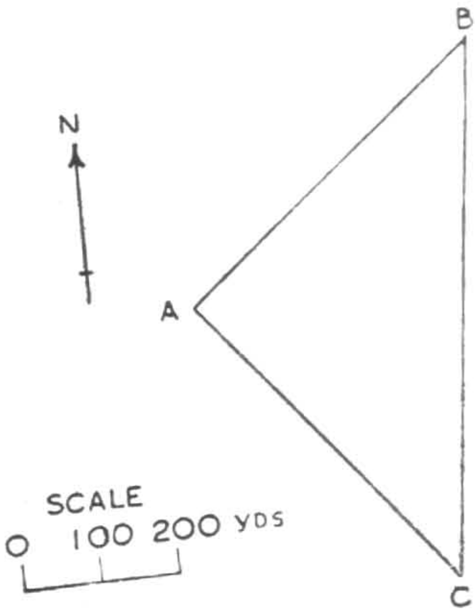

Fig. 1. Lay-out of theodolite pillars at Thumba

well as a brighter cloud. This payload is carried aloft and ignited by an electrically fired squib activated by a preset timer. The vapour that is ejected forms a trail which is visible due to the resonance scattering of sunlight by the sodium or potassium atoms. This is photographed from a number of camera sites (such as Palayamkottai, Cape Comorin, Kodaikanal, Trichur and Kottayam). The time of firings is such that the region above 50 km is well illuminated whereas the cameras remain in shade, *i.e.*, evening or morning twilight. By carrying out triangulation from the photographs, winds are determined. In one of these firings, a temperature measuring equipment was set up, by Prof. Blamount at Cape Comorin to determine spectroscopically the neutral gas temperature at ionospheric altitudes.

The second type of payload was a proton precision magnetometer along with a d.c. Langmuir probe, an aspect sensor, densitometer. The magnetometer measured the magnetic field and the Langmuir probe estimated the electron density.

Future firings from Thumba may overcome the main limitation of the sodium vapour firing, *viz.*, observations being confined to twilight hours, by using as payload some such material as trimethyl aluminium $(CH_3)_3$ Al. The glow from trimethyl aluminium can be observed at any time in the night but this can be produced only upto an altitude of about 160 km. Puffs from the glow of aluminium casings of the Grenade Rocket could also be utilised for wind speed and diffusivity evaluations.

3. Meteorological support for rocket launchings

(*i*) *Weather briefing* — Forecast has to be supplied from 2–3 days in advance giving the local weather at the launching station and also at the camera sites. Detailed weather briefing based on latest synoptic charts is to be provided. Particular emphasis is laid on the factors which influence the chance of photography of luminescent vapour clouds at the various camera sites such as the prevailing and the expected visibility and cloud conditions. A rough criterion is that the cloud cover should not exceed 3 oktas, but the important consideration is that there should be no cloud in the direction in which the camera has to be directed to photograph the sodium vapour trail.

(*ii*) *Wind weighting* — This is important for attaining the desired altitude and to keep close to the desired impact point from range safety considerations. In order to carry out wind-weighting it is necessary to know the wind profile from the surface upto about 60,000 ft. As the wind-weighting factors are very high at low levels, great accuracy is needed in determining low level winds.

For this purpose a 200-ft meteorological tower with facilities for mounting Distant Indicating Wind Instruments (D.I.W.E.) at 33, 58, 83, 100, 136, 156 and 200 ft has been erected at Thumba. In addition, a meteorological pole 60 ft high is located, close to the Launch Pad No. 2, on which wind instruments are mounted at heights 33 and 58 ft. The D.I.W.E. consisting of a cup generator anemometer and wind vane is of India Meteorological Department manufacture. The current generated by the cup generator anemometer is fed on to a D.C. meter after rectification. The range of the speed meter is 0–80 knots or 0–20 knots, the accuracy being $\pm$ 1 knot. The direction indicator is of the Selsyn Desyn type. The direction meter has graduations at intervals of 5° of the compass. The accuracy of the direction reading is $\pm 2°$.

The winds from surface up to 200 ft are obtained from the meteorological pole and the meteorological tower and recorded at intervals of 15 minutes from T—3 hrs* up to T+15 minutes for the sake of final monitoring. In this manner the low level winds are obtained at Thumba with sufficient accuracy to meet the needs of the large meteorological rockets which have a high sensitivity to wind particularly in the lowest portions of their flight trajectory.

*T *minus* and T *plus* refer to count down procedure, T=0 is the precise rocket firing time

The winds from 200 to 5000 ft are determined at Thumba by the Double Theodolite method. Three pillars have been erected at positions A, B and C as shown in the sketch (Fig. 1). The arms AB and AC are at right angles to each other and measure 500 yards. Depending on the direction of the wind, the balloon is released either at B or C and it is followed by two theodolites located at A and C or A and B respectively. The base line is chosen so that it is as far as possible normal to the expected direction of balloon drift. A telephonic communication system has been arranged between the three pillars and the central plotting room. The theodolite at pillar A is set to true North while the other theodolite is oriented so that its azimuth reading is 360° when pointing towards A. When the balloon is released, azimuth and elevation angles are recorded at A and only azimuth angles are recorded at the other theodolite post. These readings are taken at intervals of 15 secs during the first $1\frac{1}{2}$ minutes, at intervals of 30 seconds between $1\frac{1}{2}$ and 3 minutes and thereafter at every minute. The readings are passed on telephone to the plotting room where they are immediately plotted on a special board. From the two azimuth readings it is an easy matter to obtain the trajectory of the balloon (because the base line is known). From this trajectory the horizontal range at any instant can be obtained, and from the elevation figure at the same instant (obtained from the theodolite A readings), the height is inferred. Proceeding further in the usual manner for pilot balloon computation, the winds at various levels up to 5000 ft are computed, far more accurately than by the single theodolite tail method. The pilot balloon observations by the Double Theodolite method are made at intervals of half an hour from T—3 hrs up to T+30 minutes.

Winds above 5000 ft up to 60,000 ft are obtained from specially arranged rawinsonde ascents made at T—5 hrs and T—3 hrs. These ascents are made from Trivandrum, which is a few miles away from Thumba.

Putting together the tower observations, pilot balloon observations and rawinsonde observations a vertical wind profile is constructed (Fig. 2). The next step is to read off the mean winds in various layers and proceed to carry out wind weighting.

The wind weighting is carried out a number of times prior to each rocket launching from the data mentioned above. The basis for "Wind Weighting" is the determination of the displacement of the impact point due to the unit wind in a thin layer. This effect will naturally vary from layer to layer according to its position and it may be termed

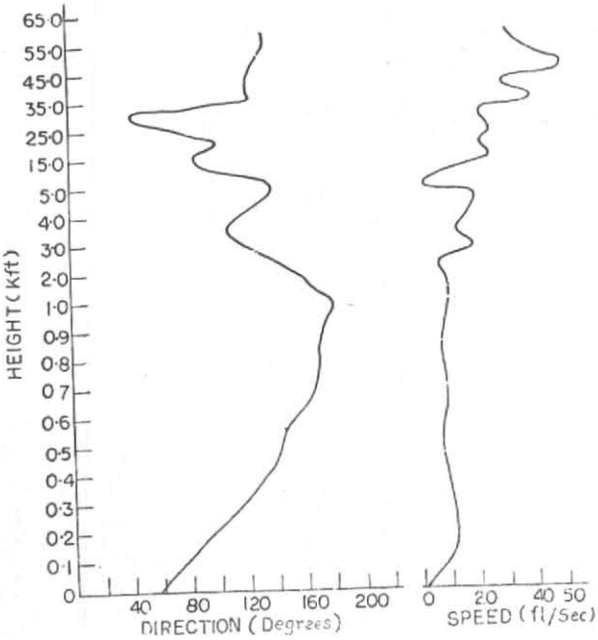

Fig. 2. Vertical wind direction and speed profiles over Thumba at 0414 IST on 12 January 1964

"Weighting Factor". The wind weighting followed at Thumba is based upon the method developed by Lewis (1949). Following more or less closely his arguments, it can be shown that the displacement of the impact point suffered by the rocket due to its upward passage through a thin horizontal stratum is given by the expression,

$$\delta_{pq} = -\frac{1}{w_p}\int_{t_p}^{t_1} w\, e^{\int_{t_p}^{t}(g/w)dt} + \frac{1}{w_q}\int_{t_q}^{t_1} w\, e^{\int_{t_q}^{t}(g/w)dt} + (t_q - t_p) + \left[-\frac{e^{\int_{t_p}^{t_1}(g/w)dt}}{w_p} + \frac{e^{\int_{t_q}^{t_1}(g/w)dt}}{w_q} \right] \times \left\{ w_1\,(t_2 - t_1) + \int_{t_2}^{t_3} w\, e^{\int_{t_2}^{t}(g/w)dt} \right\} \quad (1)$$

δ_{pq} = horizontal displacement into wind of point of fall *due to wind of unit velocity* in a stratum entered at time t_p and left t_q

w_p — vertical velocity of the rocket at time t_p

w — vertical velocity of the rocket at time t

g — acceleration due to gravity

w_q — vertical velocity at time t_q

Further the displacement of the impact point during the downward passage of the rocket through the same stratum is given by the expression —

$$\delta_{q'p'} = -(1/w_{q'}) \int_{t_{1'}}^{t_3} w\, e^{\int_{t_{q'}}^{t} (g/w)dt} + (t_p - t_{q'})$$

$$+ \frac{1}{w_{p'}} \int_{t_{p'}}^{t_3} w\, e^{\int_{t_{p'}}^{t} (g/w)dt} \qquad (2)$$

The symbols have the same meaning except that the dashes indicate the downward motion of the rocket (Fig. 3).

The "Wind Weighting Factor" and the "Unit Wind Effect" are obtained for the various altitudes by adding algebraically the displacements due to all the terms on the right hand side of the equations 1 and 2.

Actually the wind weighting factors computed in the above manner have to be empirically adjusted slightly in the light of actual experience. From dispersion studies made in the United States the wind factors have been revised and these are utilised at Thumba.

4. Wind Weighting Computation

For the actual computation we start with the following four basic data —

(*i*) Data of wind speed and direction from ground up to 55,000 ft collected in the manner described earlier,

(*ii*) A curve of wind sensitivity against altitude (or weighting factor against altitude) for the vehicle and for the particular configuration* in use,

(*iii*) A curve of "Payload Weight" against "Unit Wind Effect".

(*iv*) The "Tower Tilt Factor".

The last three items, *i.e.*, Unit Wind Effect, Wind Sensitivity and Tower Tilt Factor are determined by theoretical calculations followed by empirical adjustments in the light of practical experience.

The atmosphere is divided into layers (slabs) of suitable thickness. The slabs chosen are clear from col. 1 of the computation table (Table 1). The mean wind direction and speed in each of these slabs are read out from the graph in Fig. 2 which represents the combination of the meteorological pole, meteorological tower, pilot balloon and rawin data. These are entered in cols. 2 and 3 of the computation table. The N-S and E-W components of velocity are then calculated and entered against the appropriate slabs in cols. 4 and 5. The weight factors are shown in col. 6. The cols. 7 and 8 are the results of the wind components in the slabs multiplied by the respective weight factor.

Adding algebraically the weighted wind components for all these slabs from ground up to the top, the components of "Ballistic Wind" are obtained. By vectorially combining these components the direction and speed of the Ballistic Wind are computed.

In the actual example chosen, the Nike-Apache rocket carried a payload of 60 pounds and had a clear configuration. The values of the Unit Wind Effect (U.W.E.) and Tower Tilt Factor (T.T.F.) used are also shown in Table 1. The effective azimuth and elevation as desired by the Project Scientist are also shown in Table 1. The Ballistic Wind is then multiplied by U.W.E. to get the "Wind Displacement". The "Desired Impact Range" is then calculated by multiplying the effective zenith angle (complement of the effective elevation) by the Tower Tilt Factor.

As shown graphically in Fig. 4 the "Wind Displacement" is then subtracted vectorially from the "Desired Range". Thus we obtain the "Apparent Impact Point". The direction of this point relative to the "Launcher Point" gives the required "Launcher Set" azimuth. Next, the distance between the Apparent Impact Point and the Launch Point is measured from the graph in Fig. 4. Dividing this distance by the Tower Tilt Factor we get the corrected "Zenith Angle", the components of which give the required "Launcher Set" elevation.

*Configuration : The arrangement by addition or omission of auxiliary equipment of a particular rocket which makes it differ from others of the same model for example, Clean configuration, DOVAP configuration, Turnstile antenna configuration

TABLE 1

Table of Ballistic Wind Computation

Equatorial Rocket Launching Station, Thumba

Model : Nike Apache : INCOSPAR No. 10·03
NASA No. 14·131

Date : 12 January 1964
Release Time : 0414 IST

Wind Run No. III

Altitude (feet)	Direction (degrees)	Velocity (FPS)	Velocity N—S	Velocity E—W	Weight Factor	Weighted wind	
						Velocity N—S	Velocity E—W
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
0— 50	062	2·0	·94	1·76	·103	+·10	+·18
50—100	070	7·0	2·39	6·58	·123	+·30	+·81
100—200	082	10·2	1·42	10·10	·141	+·20	+1·42
200—300	106	11·5	3·17	11·05	·087	—·28	+·96
300—400	125	10·0	5·74	8·19	·056	—·32	+·46
400—500	138	8·0	5·94	5·35	·044	—·26	+·24
500—600	146	7·1	5·89	3·97	·037	—·22	+·15
600—800	163	8·2	7·84	2·40	·057	—·45	+·14
800—1K	174	8·0	7·96	·84	·039	—·31	+·03
1— 2K	170	9·8	9·65	1·70	·099	—·96	+·17
2— 3K	138	12·0	8·92	8·03	·047	—·42	+·38
3— 4K	115	15·5	6·55	14·05	·029	—·19	+·41
4— 5K	130	14·4	9·26	11·03	·018	—·17	+·20
5—20K	166	14·0	3·86	13·46	—·003	+·01	—·04
20—46K	097	30·0	3·66	29·78	—·005	+·02	—·15
46—50K	127	48·0	28·89	38·33	·087	—2·51	+3·33
50—55K	130	40·5	26·03	31·02	·044	—1·15	+1·36
				Ballistic Wind Components :		—6·61	+10·05

Ballistic Wind

Velocity	FPS 12·02
Direction	123°

U.W.E. : 1·436 NM/f.p.s.

T.T.F. : 10·8 NM/degree

	Effective	Launcher Set
Azimuth	270°	275°
Elevation	80°	78°·7

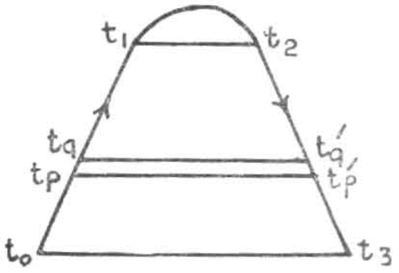

Fig. 3

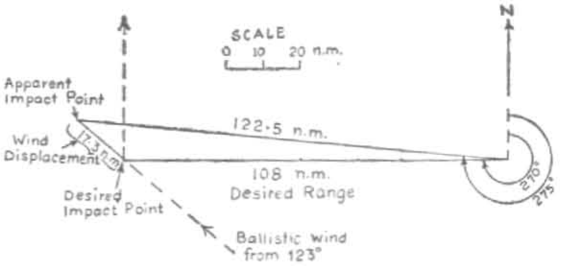

Fig. 4. Graphical computation of wind displacement

Thus the final figures of corrected Launcher settings passed to the ramp were—

Azimuth setting :	275°
Elevation setting :	78·7°

The above example is a reproduction of an actual wind weighting performed by the authors for the Nike-Apache launch at Thumba on 12 January 1964.

5. Safety Limits

When certain limits are exceeded for (*a*) surface wind, (*b*) ballistic wind and (*c*) the azimuth shift due to wind weighting, a rocket such as Nike-Apache is not fired. As a result of dispersion analysis made at Wallops Island, the following safety limits have been fixed at that launching site — (1) Surface wind exceeding 20 mph, (2) Ballistic wind exceeding 25 mph, (3) Azimuth exceeding $\pm 30°$.

At Thumba, population density, vegetation, number density of animals and of fishing craft within the "Danger Zone" of the range impose serious limitations, more severe than at Wallops. Therefore, until a proper dispersion analysis can be made it would be advisable to keep the surface wind maximum at 20 mph, the maximum launch elevation angle at 82° and the maximum azimuth shift at 25°.

6. Acknowledgements

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