

Methods of measuring winds and temperatures in the upper atmosphere with small rockets

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ABSTRACT. The Indian Meteorological Rocket Launching Programme was initiated at Thumba on 14 July 1964. During the following six months seven Judi-Dart rockets and eleven test rockets were fired. The chaff payload released from the Judi-Dart rockets were tracked by an MPS-19 radar system. The data thus collected were reduced following a method which is a simple adaptation of the India Meteorological Department graphical technique.

This paper includes a description of the Judi-Dart and test rockets as well as the radar system. The method of data reduction employed at Thumba is explained with an actual example. A comparison is drawn between this method and the one employed in the U.S.A. (Wallops station).

A few remarks are added on the present International ROCOB Code in the light of the experience gained at Thumba.

A brief survey is also included of techniques of measuring winds and temperatures with small meteorological rockets which are currently in use in other countries and some of which may be adopted at Thumba in future.

1. Introduction

The measurements of winds and temperatures in the stratosphere and mesosphere are carried out using small meteorological rockets. Various types of payloads such as chaff, parachute and falling sphere are used. An accurate determination of winds and temperatures in stratosphere and mesosphere regions, the understanding of which is becoming increasingly important for reasons such as the evaluation of the interaction between the troposphere weather and the stratospheric circulation, the needs of modern high altitude supersonic aircraft etc is possible with the help of these small meteorological rockets.

2. Small Meteorological Rockets

Various types of meteorological rockets are in use in different countries for the investigation of the atmosphere from 25 to 70 km. The main types are —

- (a) American : Hasp, Judi-Dart, Arcas
- (b) British : Skua

(c) Japanese : MT-135, MT-160.

A good review of U. S. Met. Rocket network activities is given by aufm Kampe and Lowenthal (*see ref.*).

At Thumba the rocket that has been so far used is the Judi-Dart.

Prior to the launching of meteorological rocket, a test rocket is generally fired mainly for the purpose of checking the radar system. The test rocket used at Thumba is the "Folding Fin" type—48 inches in length and 2.75 inches in diameter (Fig. 1 a). As this rocket is used only for test purposes, the head does not contain any payload material. The body of the rocket is filled with the solid propellant. The tail assembly is composed of four fins which are folded during storage, but eject into position during flight. This rocket is fired from the "Tubular Launcher" which is mounted underneath the Judi-Dart Launch Tube on the I-beam of Judi-Dart Launcher on Launch-pad No. 4 at Thumba. This "Folding Fin" test rocket takes off at 41 g. It is found to attain



Fig. 1(a). Test Rocket

a height of 5.9 km when launched at 75° elevation. The impact point of the test rocket is about 4.64 km offshore. As test rockets travel very fast and also as the duration of their flight is small (70 seconds for 75° launch), no wind weighting is carried out. However, when the surface and low level winds are very strong, an azimuth correction is made from a simple empirical relationship.

3. Judi-Dart rocket

The Judi-Dart rocket is manufactured by the Rocket Power Inc. The Judi-Dart consists of the Judi-motor and the dart which contains the payload (Fig. 1 b).

The Judi-motor is 66 inches long and 13 inches in diameter. The diameter of the tail end, however, is 5.3 inches. The propellant used (as per Judi-Dart Vehicle information published by the Rocket Power Incorporated) is "a polysulphide fuel together with ammonium perchlorate oxidiser, 'Cast-in-Case' type grain, bonded to the motor case interior surfaces". The motor weighs 24 pounds. It is used to carry darts of different dimensions and weight. The motor is capable of carrying a $6\frac{1}{2}$ pound dart to 73 km and a dart of 10 pounds to an altitude of 65 km (vertical, sea-level launch in both cases). The peak acceleration is 200-250 *g* depending upon the weight of payload. The booster (motor) burns out in 1.9 seconds. The velocity at burn-out is 5000 ft per second with the 10-pound dart and 6000 ft per second with the $6\frac{1}{2}$ pound dart. The altitude at burn-out is 4000 and 6000 ft respectively.

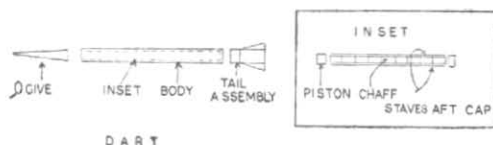


Fig. 1(b). Judi-Dart Rocket

After burn-out the booster travels at a smaller speed than the dart because of higher air drag on it. It rises up to a height of 5000 ft (heavier dart) or 7000 ft (lighter dart), before it begins to fall. During descent it quickly attains a terminal velocity of 30 ft per second and reaches the earth's surface in 160 seconds (heavier dart) and 240 seconds (lighter dart).

Several types of darts (also called Rocket Heads) are manufactured by the Rocket Power Inc. Two of the types used are —

- (a) The Chaff Dart, 40 inches long, $1\frac{1}{8}$ inches diameter, weighing $6\frac{1}{2}$ pounds.
- (b) An Instrumented Dart, $13\frac{3}{8}$ inches, weighing 10 pounds.

Each dart consists of three parts—the ogive, the body and the tail. The tapering portion at the forward end is called ogive and this houses the fuse which will be described later. The body is the cylindrical portion approximately 26 inches long. It houses the payload assembly and a piston which drives the payload from the body. The tail section of the dart has a maximum diameter at the fins of $27\frac{3}{8}$ inches. During launch, the rocket motor gets a spin because its fins move in the "rifle groove" inside the Judi-Launcher. The cant of the fins of the dart maintains its spin thereby giving it axial stability in flight. The tail section is

attached to the body by means of three shear-pins 120° apart—these shear off at the time of payload ejection due to the movement of the pistons and the staves, thereby detaching the tail assembly from the dart.

The dart, after the motor burn-out, at about 2 seconds, continues to rise rapidly and attains its peak altitude in about 2 minutes. The altitude attained is, as mentioned earlier, 240,000 ft (73 km) for $6\frac{1}{2}$ pound payload and 215,000 ft (65 km) for 10-pound payload (vertical, sea-level launch).

4. Fuse

The fuse is contained in the ogival section of the dart. It initiates the detonation of the expelling charge which drives the piston, thereby ejecting the payload at a pre-determined stage of flight. The fuse may be of the "mechanical type" or of the "pyro-technique type". In the mechanical type, time setting is possible. There is a spring-driven clockwork containing an escapement and timing disc with a graduated scale from 12 to 120 seconds. Before launching the rocket, time setting is done by means of a special small wrench.

It is the second type of fuse — the pyro-technique delay fuse — which has been used so far at Thumba. In this case an electrical circuit is closed when the rocket takes off. This initiates the burning of a primary charge pyro-technique delay tube. This tube contains a mixture such as tungsten powder, barium chromate, potassium perchlorate and diamantene earth which burns slowly along its length. The rate of burning and the length determine the payload ejection time. When the pyro-technique delay tube burns to its end, it ignites the explosive charge which drives the piston. As there is no time setting arrangement in the pyro-technique delay tube, the ejection altitude cannot be selected. However, the requirements of most experiments are satisfied if the payload ejection occurs close to peak altitude. It may also be mentioned that owing to the small vertical velocity near apogee the dart

remains within a kilometre of peak for several seconds; hence a precise time setting mechanism is not too important. The Judi-Dart rocket used at Thumba is expected to reach apogee when fired at 78° at about 130 seconds and the fuse setting is 135 secs.

5. Payloads

(1) Chaff

For determination of wind, the types of payloads used are (1) Chaff, (2) Parachute and (3) Falling sphere — passive or active. Chaff payload may consist of metallised nylon or copper in the form of ribbons or cylindrical wire of various diameters. The choice of a particular type is made depending upon the altitude region to be explored. The fall velocity in the particular region should be appropriate. If it is too large, it will not be possible to detect wind shears. If it is too small, the time required for following it will be excessive — moreover during its fall, the chaff would go on dispersing and after a certain time, it would not be possible to follow it. As a result of a number of experiments with various types of chaff made in United States of America, the following conclusions have been arrived at. For the region below 30 km, .010-inch cylindrical copper chaff has acceptable fall rates. In the region 30 to 60 km, .005-inch diameter copper chaff is most suitable. For altitudes above 60 km, metallised nylon chaff is to be preferred. At Thumba, since the exploration is intended to be carried out, for the present, in the region 30 to 60 km, .005-inch diameter cylindrical copper chaff is being used.

The chaff is cut to a length equal to half the wavelength of the tracking radar. Thus for the S-band radar (2830 mc/s, $\lambda = 10.6$ cm) in use at Thumba the length of chaff used is 5.3 cm or 2.1 inches. The chaff is packaged in cartridges each containing several tons of thousands of filaments. These cartridges are first cut open with a knife in a direction parallel to their axis and placed between two semi-cylindrical staves and inserted into the dart. During

the payload ejection, the staves come out of the body of the dart and separate, thereby freeing the chaff. The chaff forms a cloud which is tracked by ground based radar.

The advantages of chaff payload is that (a) it is more dependable than any other payload (cases of failures are few) and (b) it is very easy to acquire because it presents a large target. The disadvantages are (a) it does not provide a pin-point target. The radar beam wanders between the centres of concentration of chaff, thereby leading to inaccuracy in wind results and (b) due to chaff dispersion the signal return falls rapidly and puts a limitation on the time for which this target can be followed.

(2) Parachute

A metallised parachute with a ballast (dummy or instrumented) can be packaged into the dart and ejected near apogee in the same manner as chaff. It can be followed by ground radar and wind measurements obtained.

The advantage of using the parachute is that it offers a pin-point target—the dispersion associated with chaff does not arise, since it can be tracked for a longer time and with greater accuracy as it remains a pin-point target. The disadvantages, however, are that (a) the parachute streams or fails to open fully, (b) the parachute may be hit by the dart and damaged and (c) acquisition is more difficult than in the case of chaff because it is a pin-point target.

(3) Falling sphere

(a) *Passive*—A metallised mylar sphere called a Robinette or a plastic sphere with internal reflectors called a Robin* can be used as passive falling spheres for wind determination. Some suitable substance like isopentane crystals are packaged inside the sphere and it is placed in the dart. On ejection the sphere inflates due to the evaporation of isopentane. Its descent is tracked by radar. Experience has shown that on occasions the sphere does not inflate fully

and on some other occasions it bursts due to the violent expansion of isopentane.

Following the *passive sphere* by radar, we can obtain (a) from the drift, the wind speed and direction and (b) from the rate of fall, the density of the atmosphere.

Since the density profile is known, it is possible to obtain the temperature and pressure profiles from the equation—

$$\frac{\Delta p}{p} = \frac{\Delta \rho}{\rho} + \frac{\Delta T}{T} = -\frac{g_0 M}{R} \times \frac{\Delta Z}{T} \frac{1}{(1+Z/a)^2}$$

where, a = radius of the earth

g_0 = gravity at the surface of the earth

provided the value of p or T at one height (say the lowest point of parachute data) is known. Regarding the accuracy of the results, the reader is referred to Leviton and Wright (1961)

(b) *Active*—The *active falling sphere* is a solid sphere (a common type has a diameter of 7 inches) which has an accelerometer built into it. The principle of it is as follows. Inside the sphere a small piece of solid falls freely under gravity in an evacuated hollow space. As soon as it touches the floor of the sphere it is pushed up by a special device. The instant when the piece starts its descent and the instant when it touches the base of the sphere are telemetered to the ground. From a comparison of the rate of fall of the sphere falling through air (tracked by radar) and the rate of fall of the piece falling freely under gravity inside the falling sphere, the drag on the falling sphere and hence the density of the ambient atmosphere are obtained.

6. Instrumented payload

The instrumented payload consists of a temperature sensor such as tungsten wire (used in U. K.) or a bead thermistor (used in U. S. A.). The type that will be used initially at Thumba is the American bead type thermistor (Wagner 1961). A ceramic

*Robin stands for Rocket Balloon Instrument

bead ten mil* diameter is aluminized, or glass coated and painted with krylon, to ward off radiation. This has a high negative temperature coefficient. This is connected by means of one mil platinum-iridium wires to a blocking oscillator. When the outside temperature changes, the changing resistance of the thermistor varies the frequency of the blocking oscillator, the frequency being inversely proportional to thermistor resistance. The pulses generated by the blocking oscillator are amplified and used to plate-modulate an oscillator. The power supply is a six-volt nickel-cadmium battery. The output of the transmitter is fed to an antenna system which includes the container of the instrument package and the length of stranded copper wire which also serves to suspend the instrument package from the parachute. The effective length of the antenna system is carefully related to the wavelength of the frequency of transmission. The radiated peak power is more than 1 watt. Periodically, the thermistor is disconnected from the blocking oscillator circuit and a precision reference resistor is put in its place. This eliminates errors resulting from variations in the pulse repetition frequency (p.r.f.) due to causes such as depletion of battery voltage changes in the operation of components of the instrumented package due to change in environments etc, by providing in-flight calibration. It should further be added that the instrumented package contains a baroswitch operating at a predetermined pressure level. At a particular pressure, the switch closes. This causes the reference resistance to be changed.

The instrumented packages in use in U. S. A. operate either on 403 mc/s or 1680 mc/s. The ones that are going to be used at Thumba will be of the latter type.

7. Rocket Assembly and Launching

In the rocket assembly building, the rocket and dart are weighed separately and their centre of gravity determined. The static margin (distance between centre of gravity

and centre of buoyancy) of the dart is verified. The dart and rocket are transported in a special vehicle with a muffler and spark arrester to the launch-pad. At the launch-pad, if a mechanical fuse is being used, the time is set. The rocket and the dart are then coupled with a shearing pin. The electrical circuits of the launcher and the fuse are checked. The rocket and dart are loaded into the launcher. Accurate azimuth and elevation settings are calculated. The elevation is checked by means of an Inclinometer. The final connections to the ignitor (and fuse, if necessary) from the firing switch box are made. (At Thumba, the firing switch box is located in the Computer Van of the MPS-19 radar system). The count-down then begins. At Zero-Time, the remote firing switch is closed.

8. Range Safety

No wind weighting can be carried out for the Judi-Dart rocket which has a very high acceleration. However, one has to ensure that the burnt-out booster does not fall back on land. The booster, as has been mentioned earlier, falls with a terminal velocity 30 ft/sec for a period of 160 seconds in the case of the heavier dart and 240 seconds in the case of the lighter dart. Therefore, from a knowledge of the wind from surface up to the height at which the booster begins its descent, it would be possible to determine the drift of the booster.

The impact zone for the Judi-motor is a circle of radius 6-9 kilometres depending on the payload weight centred at a distance of 400-600 metres from the launcher in the direction of firing. The impact zone of the dart is a circle of radius 30-45 kilometres depending on the weight of the payload, centered round the impact point. For safety clearance purposes it is best to treat the entire area in between the two circles, obtained by drawing the common tangents to them, as a safety zone—this will also take into account the dropping of the tail section of the dart etc.

*One mil is one thousandth of an inch

9. Ground equipment

The radar system consists of a radar van which houses the transmitter, receiver and power supply console and display units. A parabolic antenna mounted on a pedestal can be raised or lowered into the radar van through a hatch in the ceiling. Its primary function is to acquire and automatically track in range, elevation and azimuth, a target and supply position data to the computer van. An optical tracking system (open sight) which aids visual acquisition of the rocket is also provided. When a test rocket is fired it is followed by the optical tracker to which the radar antenna is slaved. As soon as the rocket is acquired, an operator inside the radar van switches over to the automatic mode. The radar is provided with three A-scopes used for the ranges 2000 yards, 3200 yards and 400,000 yards, and a P.P.I. scope. In the computer van, the computing tracking equipment transforms the information into an x-y plot or a slant range *vs* altitude on a plotting board, together with a number of plots on subsidiary recorders. These recorders can provide altitude-time, horizontal range-time, azimuth-time, or slant range-time curves. The general characteristics of the MPS-19 radar are briefly as follows —

Transmitter frequency	= 2700–2900 mc/s
Peak power	= 0.5 watts
Beam width	= 5 degrees
Antenna	= 8 ft parabolic
Maximum range	= 360,000 yards
Pulse repetition frequency (p.r.f.)	= 300–2000 c.p.s
Pulse width	= 0.8 μ s

Slewing and tracking rates

In range —	
slewing	= 18,000 yards/sec
tracking	= 8000 yards/sec
Elevation —	
slewing	= 72 deg/sec
tracking	= 20 deg/sec

Azimuth —

slewing	= 72 deg/sec
tracking	= 40 deg/sec

In the computer van, surface wind measuring equipment and a firing box have been positioned with a view to centralising the operational controls.

10. Ground telemetry

The telemetry receiver is essentially a pulse integrating meter with a recorder. A voltage proportional to the pulse frequency is developed and this is balanced in a potentiometer arrangement with a servo-mechanism. Thus as a result of the incoming signal, a pen is displaced proportional to the voltage and, therefore, to the pulse repetition frequency and traces a curve on a moving paper. High speed paper recording is provided for.

Telemetry receivers are mainly of two types, the first is AN/SMQ-1 operating on 400–410 mc/s. The second is the GMD-equipment. GMD-1 or GMD-1B can receive signal from 1680 mc/s transmitter. This is the type that is proposed to be employed at Thumba. GMD-2 is a recent development which can receive both 403 mc/s and 1680 mc/s signals.

11. Data reduction

For data reduction the method used at Thumba was an adaptation of the India Meteorological Department pilot balloon computation technique.

First we start with the altitude-time strip chart provided by the computer of the radar system — a specimen of this is given in Fig. 2. In this chart the pen moves along the base line. But at intervals of 30 seconds, for a short instant of time, the scale is magnified 10 times and this results in the pen describing a spike. By noting the position at the end of a particular spike on the chart an accurate value of height can be deduced. It should be mentioned that the chart was set to move at a speed 24 inches per hour. To give an example of height determination

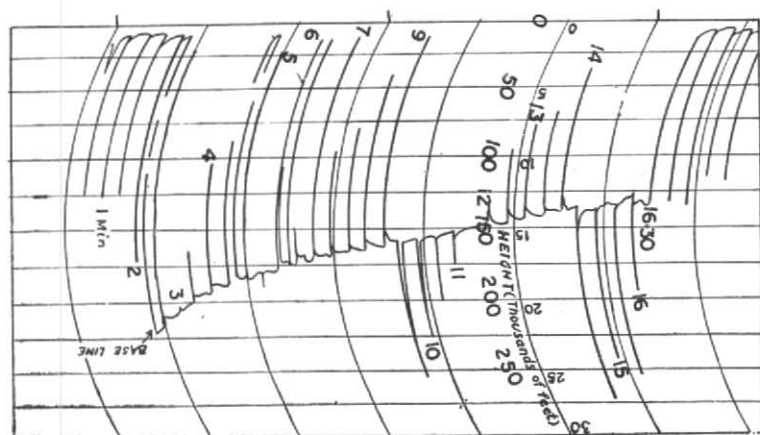


Fig. 2. Altitude — Time strip chart

Judi — Dart, INCOSPAR No. 11-04

Time : 0601 GMT, Date : 19 Aug 1964

from the chart, we may look at the reading at $4^m 0^s$. The base line reading is between 175,000 and 200,000 ft. The end of the spike is at 10,500 ft. So instead of reading exactly the position of the base line, at 4 minutes, which would give only a coarse value, advantage is taken of the fine reading of 10,500 ft provided by the spike and by adding this to 175,000 ft corresponding to the lower of the two thick horizontal lines on either side of the base line on the chart, the precise height of 185,500 ft is obtained. In this manner, it is possible to obtain height at various instants of time. One important difficulty which arises in such interpretations is, however, worth mentioning. This arises from the wandering of the base line. It would be sometimes misleading merely to gauge between which two thick horizontal lines, the base line lies, and accepting the lower value for determining the final height, by adding to it the value corresponding to the end of the spike. Thus at minute eleven, the base line is between 150,000 and 200,000 ft whereas the fine reading is 17,300 ft. If we accept these figures as they are, this

would give a value for the height of 167,300 ft which would be certainly erroneous. The actual figure in this case is 142,300 ft as is evident when the height-time curve is referred to. This is because the base line, which should have been close to 150,000 ft between the two horizontal thick lines at 125,000 ft and 150,000 ft has slightly wandered and lies between 150,000 ft and 175,000 ft. This wandering can be only detected and allowed for by exercising care during the continuous process of reading and evaluation of the height-time strip chart, in a manner to eliminate an abrupt jump by 25,000 ft.

After obtaining the correct heights at various instants of time a height-time curve is drawn. An example of this is given in Fig. 3. (The height figures have been converted into kilometres on the height-time graph).

Next, we take the x - y plot provided by the computer van. When we take two points at a short-time interval, the direction of the line joining them gives the direction of the wind at the middle of the interval. By

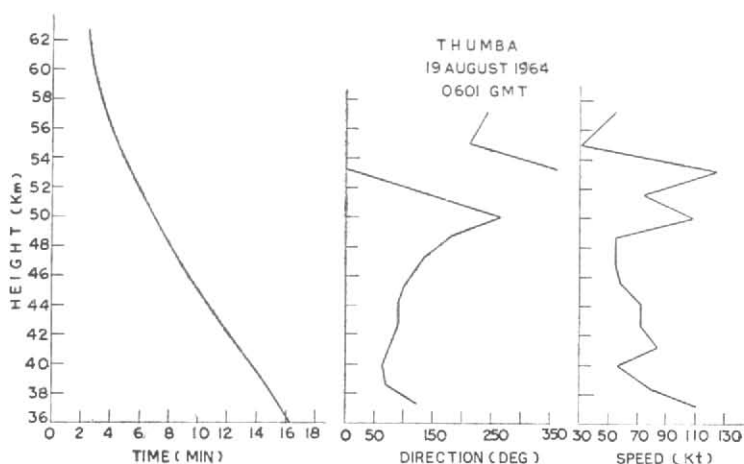


Fig. 3. Height-Time-Direction-Speed curves

measuring the distance between the two points and multiplying it by the scale of the $x-y$ chart, the horizontal displacement of the chaff during the interval is obtained. On dividing this by the duration of time between the two points, the wind speed corresponding to the middle of the interval is derived.

The wind direction and speed values are plotted on the same graph sheet (Fig. 3) as the altitude-time curve. But in plotting the wind speed and direction, time is eliminated by reading out the altitude from the height-time curve at any instant (mid-point of an interval as described in the last para) and plotting the direction as well as speed directly against the altitude so obtained. Thus, the direction-altitude and the speed-altitude curves in Fig. 3 were drawn. It should be mentioned that the data thus plotted were checked whenever possible from the data of horizontal range and azimuth provided by two other subsidiary recorders in the computer van.

12. Nomographic method in U.S.A.

In Wallops station where a nomogram is used, the times corresponding to fixed altitudes are read off from the altitude-time strip chart. These are tabulated. By dividing the desired altitude interval, *i.e.*, 2 km by the corresponding time interval, the speed is obtained and tabulated. The direction corresponding to the time interval is read off directly from the $x-y$ plot and tabulated. In order to determine significant levels graphs of direction *vs* altitude, and speed *vs* altitude are drawn.

This nomographic method has the advantage that when the average of 2 km is desired, it can be read off directly without drawing any graph. On the other hand, the graphical method adopted at Thumba is far more convenient for getting wind speeds and directions for any desired slabs and also for reading off significant levels without a separate graphical analysis.

13. Preparation of ROCOB messages

On the graph-sheet representing the altitude-speed and altitude-direction curves the mandatory levels as prescribed by the International ROCOB Code, *i.e.*, 20, 25, 30 km and so on are marked off. Wind speed, and direction corresponding to these levels averaged over a slab one kilometre on either side, are determined and tabulated. Further, the wind speed and direction corresponding to the lowest altitude possible are also determined — in this case, the slab interval chosen is much less than 2 km for obvious reasons. Next, the significant levels are determined first for speed and then for direction following the criteria laid down by the ROCOB Code. These are briefly as follows.

(1) *Speed* — A departure of 10 knots or more from a linear interpolation between any consecutive levels selected for transmission.

(2) *Direction* — When the departure from linear interpolation between any two consecutive levels selected for transmission is one of the following —

- (a) 60° or more — When the average wind speed for the layer is 16 to 30 knots inclusive,
- (b) 30° or more — When the average wind speed for the layer is 16 to 30 knots,
- (c) 20° or more — When the average wind speed for the layer is 61 knots or greater.

From the determination of the significant levels in the above manner the preliminary reportable levels are found out. A further examination is carried out to see if in between any two of these preliminary reportable levels the original curve deviates by the amount specified in the criteria, thereby giving rise to further significant levels. After such examination the final reportable levels are determined.

Using the ROCOB Code, a message is prepared and transmitted.

ROCOB message prepared from rocket sounding data obtained on 19 August 1964 is reproduced below —

ROCOB 43373 1919/ 190601 37/// 62110 39///
 07712 40/// 07654 41/// 07772 45 /// 10644
 48/// 16542 49/// 20672 50/// 23944 52///
 11842 53/// 86142 55/// 23464 57/// 24520
 JJJ

It may be pointed out that in the above message, for J_n we have not always stuck to the figure 4 corresponding to 2-km slab but also employed, $J_n - 0$ (corresponding to 0—250 metres) and $J_n - 2$ (corresponding to 501—1000 metres) as was appropriate.

14. Comments on ROCOB Code

In the light of experience gained at Thumba, a few suggestions are offered with a view to improving the present ROCOB Code.

- (1) Smoothed values of wind-speed and direction at the reportable levels are preferable to 2-km means.
- (2) While the lowest level for which data are available is to be reported although it is not a mandatory level, no corresponding instruction is included regarding the highest level for which data are available when it is not a mandatory level.
- (3) Sometimes it may be of interest to report data in between successive whole kilometres of altitude. Provision for this may be made.
- (4) Under the code table 2 (symbol a) there is no code figure for MPS-19 class radar although this class of radar is commonly used for meteorological rockets.
- (5) Under code table 4 (symbol m_r) one of the unassigned numbers may be allotted to the graphical method described above.

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