CHAPTER 6

PILOT BALLOON OBSERVATIONS

6.1 **<u>Introduction</u>**. The methods available for tracking balloons in upper wind measurement can be divided into optical-theodolite and radio methods. The latter include radio direction finding, primary and secondary radar techniques and the use of stable radio transmissions (NAVAIDS). In radio-balloon observations (rabals), the balloon used for the radiosonde ascent is tracked with a theodolite in the same manner as that of a pilot balloon. Rabals differ from pibals in that the height data necessary to compute the position of the balloon at one-minute intervals are taken from the radiosonde observation. Double theodolite pibals are non-routine observations and are taken when there is a need for great accuracy for research or other purposes. **In this chapter however, only the single optical-theodolite method will be discussed.**

6.2 **<u>The Pibal Observation</u>**. In a pilot balloon observation (pibal), a balloon which is inflated with either hydrogen or helium to provide a fixed free lift is tracked visually with an optical theodolite. The height of the balloon at successive minutes is not measured, but is a pre-computed value based on the average of a large number of flights triangulated by two theodolites. These results are shown in Columns two and four of Table 6-1. In any individual observation, however, local turbulence may alter the ascension rate and the balloon may actually be higher or lower than the assumed altitude. At one-minute intervals during the ascent, the azimuth and elevation angles of the balloon with reference to the point of observation are read from the azimuth and elevation scales on the theodolite. Computations of the positions of the balloon at selected minutes and, consequently, computations of directions and speeds of movement of the balloon at selected intervals, are derived by trigonometry. The height to which the balloon can be tracked is governed by many factors, such as the speed of winds aloft, which might take it beyond the range of the theodolite; the intervention of an obscuring medium, such as cloud, between the balloon and the observer; and the bursting point of the balloon. Tracking the balloon during a night observation is accomplished by attaching a small, self-illuminating light stick or a small battery-powered lighting unit to the balloon. The single theodolite method ***should*** be used for taking all routine pibals.

6.3 **<u>Selecting the Site</u>**. The site of the observing equipment is regarded as the point of observation. The point of observation ***shall*** be selected with a view that reduces to a minimum the probability of loss of data due to interference by fixed obstructions such as buildings, trees, towers, etc. Angular elevations of obstructions around theodolite sites, with the exception of small pipes or masts, ***should not*** exceed 6° above the horizontal plane.

Table 6-1. Pibal Time vs. Height Table

MINUTE	Assumed HT ABOVE SFC (METERS) 30gram/100gram	SECONDS	ASSUMED HEIGHT(FT) 30g/100g
0			SURFACE
1	216/350	60	700/1150
2	414/670	120	1350/2200
3	612/980	180	2000/3200
4	801/1285	240	2630/4300
5	990/1585	300	3250/5400
6	1170/1880	360	3850/6200
7	1350/2170	420	4430/7100
8	1530/2455	480	5350/8050
9	1710/2740	540	5600/9000
10	1890/3020	600	6200/9900
11	2070/3300	660	6800/10800
12	2250/3580	720	7400/11750
13	2430/3855	780	8000/12650
14	2610/4130	840	8550/13550
15	2790/4405	900	9150/14450
16	2970/4675	960	9750/15300
17	3150/4945	1020	10300/16200
18	3330/5215	1080	10900/17100
19	3510/5485	1140	11500/18000
20	3690/5755	1200	12100/19000
21	3870/6025	1260	12700/19800
22	4050/6296	1320	13300/20650
23	4230/6565	1380	13900/21500
24	4410/6835	1440	14500/22400
25	4590/7105	1500	15000/23300
26	4770/7375	1560	16600/24200
27	4950/7645	1620	16200/25000
28	5130/7915	1680	16800/26000
29	5310/8186	1740	17400/26850
30	5490/8455	1800	18000/27800

Note: This Table is valid for an ascent rate of approximately 300 meters per minute. To achieve this the following Combined Inflation Nozzle and Counterweight free lift values are recommended.

		Helium	Hydrogen
30 Gram Balloons	Day	139 grams	125 grams
	Night	192 grams w/light	170 grams w/light
100 Gram Balloons	Day	515 grams	450 grams
	Night	552 grams w/light	482 grams w/light

6.4 <u>The Theodolite</u>. The type of theodolite used at either fixed or mobile land pibal stations is similar in many respects to a surveyor's transit telescope, with certain modifications made to adapt it to pibal work. A typical theodolite is shown in Figure 6-1a&b. The telescope, supported over the center of the upper plate by a yoke standard, is mounted in a manner that allows it to be rotated in both the vertical and horizontal planes; i.e., it can be turned on a horizontal axis passing through the center of the vertical circle and it can be revolved about a vertical axis passing through the center of the horizontal circle. The theodolite telescope differs from the transit telescope in that the line of sight in a theodolite is bent through an angle of 90°, which places the objective lens and the eyepiece at right angles to each other. A glass prism conveys the image from the objective lens to the eyepiece, which remains stationary in the vertical plane, as the objective lens is moved up and down while tracking the balloon. To avoid the use of two additional lenses, and a subsequent reduction in light, theodolites are equipped with non-erecting eyepieces; hence, the image appears inverted. By rotating an attached internal spiral cam the eyepiece is focused on crosshairs provided for use in centering the balloon in the field of the telescope. Measurement errors of the angles ***should not*** exceed +/-0.05°. Scale-reading errors become increasingly important at great distances and for low elevation angles and ***should not*** exceed 0.1°.

6.4.1 Optical features. Theodolites are classed as either fixed-focus or adjustable focus. The former is adjusted at the factory to focus on distant objects. The latter must be re-focused each time the theodolite is used, and usually several times during the course of an observation. In both types, the eyepiece must be focused on the crosshairs before the theodolite is used.

Some theodolites have a secondary wide-angle telescope of low magnification, which is often helpful in locating a balloon during the first few minutes of the observation. This telescope has a short-focus objective that is brought into view by means of a swinging mirror inside the unit. The focal planes of the two objectives coincide so that the same eyepiece is used, which eliminates the need to refocus. The change from one field to the other is made by means of a lever located on top of the telescope.

6.4.2 Angular Measurements. Vertical and horizontal circles, graduated in whole degrees, are provided for determining the bearing of the telescope. That is, the angles an elevated object makes with a plane tangent to the earth in a vertical plane, and with any reference point, such as true north in a horizontal plane, are read on the circles. Angles can be read to 0.1° by means of a micrometer-type tangent screw, and estimated to 0.01°. Backlash in the gearing of the circles ***should not*** exceed 0.025°. Errors in horizontal and vertical collimation ***should not*** exceed 0.1°.

Theodolites ***should*** be equipped with micrometer drums, integral with the tangent screws, for measuring angles to 0.1°. These drums ***should*** be graduated to 0.1°, and the graduations ***should*** be numbered from 0 to 9, inclusive. The reading ***should*** be taken in whole degrees if taken from the graduated circles, and to 0.1° from the micrometer drum.

6.4.3 Other Features. Gunsights ***should*** be mounted on each end of the telescope. They ***should*** be adjusted so that when the telescope is aimed correctly at a balloon it will be within the field of the theodolite and can be viewed by looking through the eyepiece. The gunsights ***should*** be a combination of short sights and folding sights.

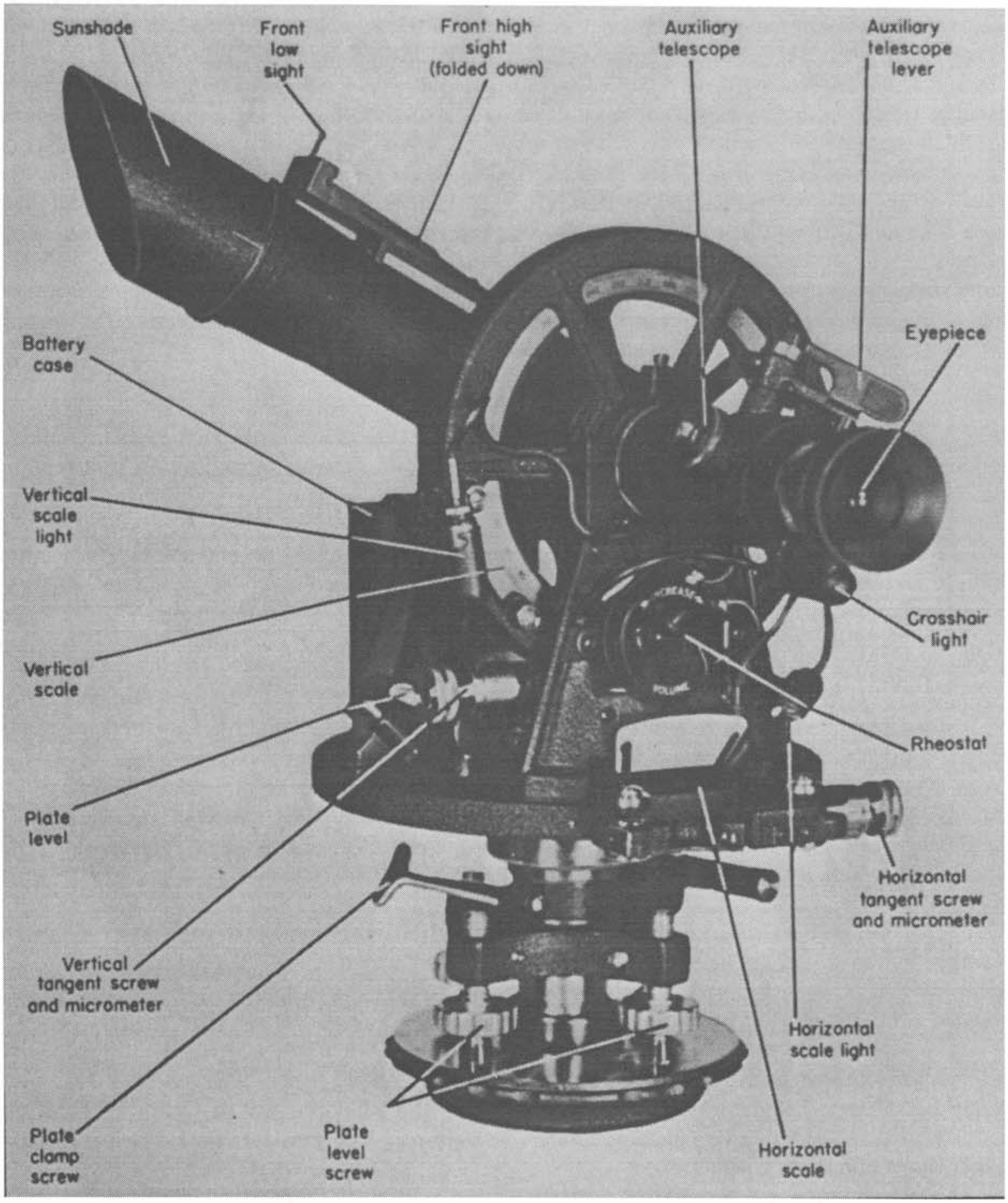

Figure 6-1a. Theodolite of the type used at land stations.

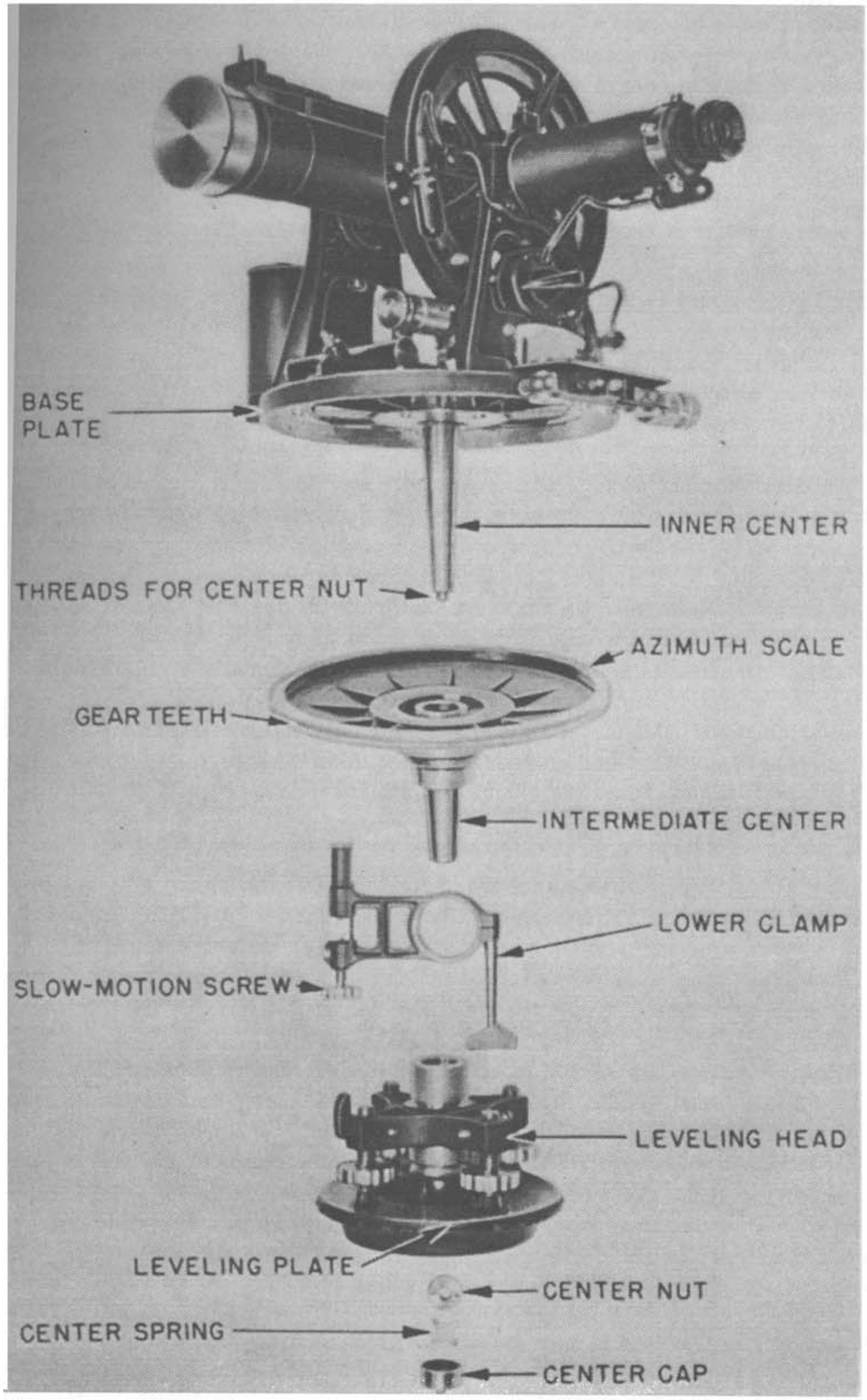

Figure 6-1b. Theodolite of the type used at land stations.

Theodolites ***should*** be equipped with lights to illuminate the crosshairs and micrometer drums when conducting night pibals. Power can be supplied by dry cells or a transformer. Theodolites ***should*** be equipped with a rheostat to control the intensity of the crosshair light, and with switches to turn off the crosshair and micrometer lights between readings. The intensity of the crosshair light ***should*** be adjusted to the lowest possible value consistent with accurate scalar readings. When there is danger of losing the balloon from the field of view, the crosshair and micrometer drum lights ***should*** be turned off between readings.

6.5 Theodolite Leveling and Orientation. When leveling the theodolite, the mount or tripod ***should*** be adjusted to a height convenient to the observer before the theodolite is leveled. The process of insuring that the base-plane of the theodolite is level involves a series of set screws controlling the orientation. Bubble levels are used to determine the orientation; when the theodolite has been leveled successfully the bubbles remain in the center of the levels as the theodolite is rotated about its vertical axis.

After the theodolite has been leveled, it ***should*** be oriented about its vertical axis by rotating it until the reading of the azimuth scale is the same as that of an orientation point with respect to true north. The azimuth tangent screw ***should*** be engaged with the base plate. Because the azimuth scale on some theodolites *may* be read at two positions, the theodolite ***shall*** be oriented with reference to the position to be used during the subsequent observations. The base-plate clamp screw ***should*** be loosened and the base plate turned about its vertical axis until the telescope is trained approximately upon the reference point of orientation. The base plate ***should*** be locked to the vertical axis by tightening the base-plate clamp screw. If the reference point is not at the intersection of the crosshairs, the necessary vertical adjustment ***should*** be made with the elevation tangent screw, and the azimuth adjustment with the slow-motion base-plate screw. This final azimuth adjustment ***should not*** be made with the azimuth tangent screw, because to do so would change the orientation of the theodolite.

6.6 Focusing the Theodolite. The theodolite eye-piece ***should*** be focused by turning the aperture disk to obtain maximum sharpness of the crosshairs. The telescope itself ***should*** be focused by use of the eyepiece sleeve-adjustment screw to obtain maximum sharpness of a distant object. The telescope ***should*** be re-focused during the observation whenever the balloon or lighting device appears blurred.

6.7 General Test. A general test ***should*** be conducted upon receipt of the theodolite and every three months thereafter to determine whether the theodolite requires adjusting by a laboratory technician. The test ***should*** determine if any alignment problems, such as confusion of horizontal and vertical angle change, exist. A satisfactory test involves sighting on a chosen object about 120 meters (400 feet) from the theodolite and recording the indicated angles. A change of both angles by 180 degrees and a re-reading of the indicated angles will normally produce identical readings. If the resulting difference is more than 0.2° in either azimuth or elevation individual agencies ***shall*** make the appropriate adjustments or corrections to insure that the theodolite is functioning within standards.

6.8 The Observation. Before starting a pibal observation, the observer ***shall*** become familiar with weather conditions prevailing at that time and those expected during the course of the observation. The type of observation, the time required for preparation of equipment, and station requirements ***should*** all be considered while preparing for the release.

6.8.1 Release Time. Insofar as possible, pilot balloon release times (actual times of observation) ***shall*** be scheduled as close as possible to H-30 minutes, where H is one of the standard times; eg: 0000, 0600, 1200, 1800 UTC. The release time of the pibal observation ***shall not*** fall outside of the time range from H-45 to H, a period known as the release window. For all non-standard observation times, the release window, in regard to the record time of the observation, is from 30 minutes before to 29 minutes after the assigned hour of observation.

6.8.2 Theodolite Preparation. The theodolite to be used in taking a pibal ***should*** be set up and adjusted in accordance with instructions outlined in para. 6.5. Particular attention ***shall*** be directed to the requirement for proper leveling and orientation of the theodolite with respect to established reference points before the observation is started. Accurate orientation of the theodolite with respect to true north is an essential preliminary to the observations of azimuth and elevation of the moving balloon. Lights for illuminating the crosshairs and micrometer drums ***shall*** be turned on and checked prior to night releases.

6.9 <u>Balloons</u>. All pilot balloons used in taking winds-aloft observations are spherical shaped films of natural (latex) or synthetic rubber (neoprene), which are inflated with a lighter-than-air gas (hydrogen, or helium.) The film thickness of the inflated balloons is extremely small, and the balloons are very delicate. The smallest cut, bruise, or scratch sustained during storage or preflight preparations will seriously affect the altitude at which the balloon will burst; therefore, the requirement for careful handling of the balloons cannot be overemphasized.

Balloons ***should*** be stored in their original sealed containers and, if possible, in a warm room at temperatures not exceeding 120°F (50°C). They ***should not*** be placed immediately adjacent to large electric generators or motors because these create ozone, which is detrimental to neoprene. Since balloons deteriorate with age, they ***should*** be used in the order of their production dates to avoid excessive aging. If balloons must be stored at below-freezing temperatures, they ***should*** be returned to a temperature of 18°C or higher for a period of 12 hours or more before removal from their containers. This practice will avoid any damage that they might receive when removed from containers and unfolded while cold. No part of the balloon except the neck ***should*** be touched with the bare hands. When it is necessary to handle any portion other than the neck, soft rubber gloves, soft cloth gloves, or some other non-abrasive material ***should*** be used.

Thirty-gram balloons ***should*** be used for land pibal observations that extend to 4600m (15,000 feet.) Hundred-gram balloons ***should*** be used for pibal requirements above 15,000 feet when a strong possibility exists that the 30-gram balloon would be lost before attaining that altitude. The balloon color is a matter for the observer to decide. In general though, a white balloon ***should*** be used with a clear sky, a black balloon with low or middle overcast, and a red balloon with high overcast or with a white or gray background. It will usually be found that when haze, dust, or smoke are present in a cloudless sky, a white balloon will remain visible longest because the sun shining upon it above a lower layer of haze creates scintillation that is absent when colored balloons are used. **Chapter 3 of this Handbook *should* be referred to for standards regarding balloon pre-release and release procedures.**

6.10 Night Pibal Lighting Units. Tracking a pibal at night can be made possible by attaching a lightweight, self-illuminating or battery-operated lighting unit to the balloon. No lighting unit ***should*** be used for a release more than 15 minutes after the unit has been activated. The lighting unit ***should*** be activated just prior to the release in accordance with accompanying manufacturer's instructions.

6.11 Train Assembly. Attachments ***should not*** be made to pilot balloons used in observations taken during daylight hours. At night, attach the lighting unit directly to the balloon with a length of cord. The length of the train ***should*** generally be limited to 2 meters (6 feet).

6.12 The Release. The timing device ***shall*** be started at the same instant as the balloon release. When the balloon is released 100 meters (300 feet) or more from the observation point, the azimuth bearing and distance from the point of release ***shall*** be noted.

A surface wind observation ***shall*** be taken at the release point no more than 5 minutes before the balloon is released.

Whenever the release point is below the level of the theodolite or whenever the released balloon is forced below the level of the theodolite by a downdraft, the time that the balloon re-ascends to the level of the theodolite ***shall*** be regarded as the time of release, and, if possible, the timing device ***should*** be reset accordingly. To minimize the error as much as possible in such instances, the time of release ***should*** be adjusted to the nearest whole minute. That is, if the balloon descends for less than one-half minute after the actual time of release, no adjustment in time ***should*** be made. If it descends for one-half minute or more, but less than a minute and a half, the time of release ***shall*** be regarded as the actual time of release plus 1 minute**.** In this case, angles read at the end of the second minute after the actual release of the balloon ***shall*** be ascribed to the first minute. The azimuth bearing of the theodolite ***should*** be read at this point and the distance between the balloon and the theodolite estimated. These values ***should*** be recorded when the distance is 100 meters or more. The speed of the surface wind should aid in making the estimation.

6.13 Errors Encountered in Tracking the Balloon. The time of any jar suffered by the theodolite ***should*** be noted since this is the most common cause for a shift in orientation. If the difference in orientation is less than 0.3°, the observation ***shall not*** be corrected. If difference is 0.3° or more, and the time of the shift is known, successive readings ***should*** be corrected by applying the amount of the difference and entering the corrected values above the original entries. If the time of the shift is not known, the observation ***shall*** be discarded and another started as soon as possible within the time constraints specified in para. 6.12.

6.13.1 Extraneous Light. The interference encountered in night pibals from extraneous light entering the objective lens ***should*** be reduced by using the theodolite sun shield. When light from an extraneous source enters the observer's eyes directly, a shield ***should*** be improvised from a piece of cardboard or other material cut with a U-shaped slot and mounted over the yoke standard. Authority ***should*** be obtained whenever possible to turn off all lights that are a persistent source of annoyance and that are not essential to local operations while a night pibal is being taken.

6.13.2 Sun in Field. **THE OBSERVER'S EYES WILL BE PERMANENTLY DAMAGED BY LOOKING DIRECTLY AT THE FOCUSED SUN IMAGE THROUGH THE THEODOLITE. THEREFORE, THE OBSERVER MUST USE EXTREME CAUTION FOLLOWING THE BALLOON WHILE IT IS NEAR THE SUN'S ANGULAR BEARING, AND NEVER TRACK THE BALLOON ACROSS THE SUN'S DISK.**

6.13.3 Confusion of Stars With the Lighting Device. When taking night observations, it is often possible to distinguish the lighting device from stars only by the relatively rapid movement of the former. When angular changes are small, the difficulty is correspondingly greater. If the light that is being tracked does not appear to diminish in brilliance with time, and if it moves from east to west with an angular change of about 1° in 4 minutes, it is probable that a star is being tracked.

6.14 Termination. Immediately upon the termination of a sounding, a preliminary accuracy check ***should*** be made of both the equipment and the observed data. A determination ***should*** be made as to whether the orientation of the theodolite has remained unchanged during the observation. Any reference point of known bearing ***should*** be sighted upon and the indicated azimuth angle read on the theodolite. If there is a difference between the indicated angle and the true bearing of the reference point, the difference is the amount that the theodolite has shifted during the observation.

6.15 Preliminary Inspection of Data. All pibal observations ***should*** be continued as long as possible up to 4600m (15,000 feet) above ground level, except when the agency specifically requests that an observation be continued to a higher level, when the pibal is taken in lieu of a scheduled rawinsonde observation, or when the official in charge of the station deems an extended observation desirable.

If the observed data are not known to be inaccurate but some reason exists for questioning their validity, the observation ***should*** be evaluated and filed for transmission. If severe or unusual weather exists in the vicinity of the station during the pibal observation, a verifying pibal ***should*** be taken as soon thereafter as possible, within the time limits specified in para. 6.12. Occasionally during a pibal, a balloon will develop a leak that markedly affects its ascension rate. This condition will usually be recognized by a sudden and rapid decrease in the elevation angle. Whenever a leaking balloon is suspected, a second release ***shall*** be made as soon as possible within the time constraints specified in para. 6.12.

The second pibal ***should*** be evaluated and, if necessary, a correction filed with the transmitted data. If a correction message is sent, the ascension number ***shall*** be assigned to the second pibal and the first discarded. If no correction message is sent, the verifying pibal ***shall*** be discarded.

6.16 Criteria for Satisfactory Observations. A pibal ***should not*** be taken whenever low clouds or other phenomena would prevent the observation from reaching 900m (3,000 feet) above the surface, unless specifically requested by the area or local forecaster, or whenever the station is within an area described in a severe weather warning or watch. Pilot balloon observations extending to less than 300m (1,000 feet) above the surface ***shall not*** be transmitted. Very light rain or very light rain showers, and occurrences of restrictions to vision that do not reduce the visibility to zero, are not in themselves regarded as sufficient justification for omission of a pibal observation. A pibal observation ***shall not*** contain more than 5 consecutive minutes of missing data. If this occurs and an observation is required, the flight shall be terminated and another pibal taken.

Whenever a pibal is lost from the field of the theodolite less than 10 minutes after release and the weather conditions or circumstances of the loss are such that a longer observation is possible, another pibal ***should*** be started immediately. The longer observation ***shall*** be used for all record and transmission purposes, and any record of the shorter observation ***should*** be discarded.

A loose base-plate clamp will necessitate a second observation if the duration of the flight prior to the loosening does not meet the requirements for a satisfactory observation unless the exact time of its loosening, and the amount of error, can be definitely determined and the observation corrected.

Another pibal ***shall not*** be required whenever the balloon is lost less than 10 minutes after release because of the following conditions:

- When the balloon entered the base of, or was obscured by, clouds and it seems unlikely that another pibal would extend to 10 minutes or more.
- Obstructions to vision, provided there is reasonable certainty that a longer observation could not be secured with a different color balloon.
- Obscuration by fixed obstruction, when the path of the balloon is so low as to render the success of another observation improbable.
- Disappearance at a horizontal distance of 10 kilometers or more in daytime and 7 kilometers or more at night, and the exact reason is not known (loss of the balloon will be ascribed to distance).

6.17 Pibal Evaluation. Evaluation of pibals taken at fixed or mobile land stations ***shall*** be accomplished by projecting the path of the balloon to a horizontal plane tangent to the surface of the earth through the observation point. The evaluation of wind speed and direction involves the trigonometric computation of the minute-to-minute changes in the plan position of the balloon. Computer software specifically designed for these computations is available and ***should*** be used in lieu of manual computation with plotting boards and graphs.

Wind direction and speed ***shall*** be evaluated for each minute for which actual or interpolated angular data are available using a 2-minute interval with a 1-minute overlap procedure.

6.17.1 Missing Data. At a minimum, when angular data are missing for 3 minutes or less and accurate data bound this stratum both above and below, interpolate for the missing angular data. If three minutes or less are missing or in error at the beginning of the pibal, a best estimate for the interpolated minutes ***should*** be used by using the reading changes of the following good minutes and the observed flight of the balloon after release.

6.17.2 Errors. For theodolite observations, the wind errors vary markedly with range, elevation and azimuth, even when the errors of these parameters remain constant.

In single-theodolite ascents the largest source of error is the uncertainty in the rate of ascent. This may be due partly to incorrect inflation and partly to vertical currents in the air. The proportional error of the assumed mean rate of ascent introduces a like proportional error in the height and, with modification by the elevation angle, a proportional error in wind speed.

Errors in the measurement of the mean wind in a shallow layer arise partly from errors in the assumed height of the layer. The latter errors result in the measured wind being attributed to the wrong level and are not usually serious unless the height is derived for an assumed rate of ascent. Height measurements are affected more by systematic errors, such as those arising from incorrect leveling of the equipment, than by random errors of observation.

When upper-wind data are required in mean layers up to one kilometer thick, corresponding to three or four minutes of the ascent, it is usual to smooth the reading over this period. This procedure reduces the errors to nearly one-half of those for pairs of observations at one minute intervals, provided the errors are perfectly random.

6.18 The Pibal Message. Instructions for coding the pibal message for transmission are found in Appendix E-I.

The height of the pibal balloon is assumed and given in Columns 2 or 4 of Table 6-1. However, WMO standards require that the coded message for a pibal observation include wind information at the height of standard isobaric surfaces (para 5.2.1). The height for these standard isobaric surfaces ***should*** be determined using the following methods:

- At stations taking rawinsonde observations in addition to pibal observations, use the pressure-altitude curve from a current rawinsonde observation to determine the heights of the constant pressure surfaces for the pibal observation.

- At stations taking pibal observations only, use tables of mean monthly heights of constant pressure surfaces. If mean monthly heights are not available, use U.S. Standard Atmosphere geopotential heights. (Ref. 15) (See Appendix D for method of computation.)

6.19 Theodolite Care and Adjustments. Special care ***should*** be taken to avoid any situation that might result in the theodolite being dropped or otherwise subjected to a severe jolt. In addition, theodolites ***should*** be cared for and adjusted by following the specific recommended guidelines that are listed in the following paragraphs:

- A clean cloth or lens tissue ***should*** be used to remove dust from the objective lens and the eyepiece. The lens ***should*** be kept covered when the theodolite is not in use. A sunshade ***should*** be used to protect the lens from the direct rays of the sun.

- In order to retard oxidation, the graduated circles and micrometer drums ***should*** be coated with a clear lacquer. A thin film of oil applied with a lint-free cloth may help keep the scale surfaces clean.

- The theodolite ***should*** be inspected frequently for loose screws or parts.

- The bearing surfaces on the theodolite ***should*** be lubricated occasionally with a small amount of anemometer or machine oil to keep them operating smoothly. Neither the worm gears nor any element of the optical system ***should*** be lubricated.

6.20 Storage Between Observations. If the theodolite is adequately covered and not accessible to unauthorized persons, it need not be taken indoors between observations, provided it is not exposed to the elements. If it is taken indoors between observations, care ***should*** be taken each time it is placed on its adjustable mount or tripod to ensure that the threads holding it to the mount are properly secured and engaged, and that the legs of the tripod are properly seated in their foot blocks.

Both tangent screws ***should*** be disengaged after the observation to avoid possible damage to the worm gears if the instrument is accidentally jarred. When moved about, the theodolite ***should*** be carried by the base plate rather than by the yoke assembly.