COMMONWEALTH OF AUSTRALIA

DEPARTMENT OF NATIONAL DEVELOPMENT

DIVISION OF NATIONAL MAPPING

TECHNICAL REPORT NO. 4

ASTRONOMIC OBSERVATIONS WITH THE KERN DKM3a AND WILD T3 THEODOLITES

by

A. G. BOMFORD

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CONTENTS

FIGURES

* Note original figures 4, 6 and 9 were closely cropped, causing some loss of text.

1. INTRODUCTION:

1.1 This report is a guide for astronomical field parties in the Division of National Mapping. It sets out the experience gained up to 1st May 1965 in making precise astronomical observations with the Kern DKM3a and Wild T3 theodolites, using the following methods :

Azimuths by Sigma Octantis.

Almucantar longitudes, both impersonal and by stop-watch.

Latitudes by meridian or circum-meridian altitudes of FK4 stars.

Some mention is made of Position Lines. Theoretical astronomy is excluded. It is intended to publish details of the electronic computer programs separately. No mention is made of administrative matters, vehicles, communication radios, or camp equipment. These matters are of great importance to parties in the field, but are outside the scope of this report.

1.2 While the writer commends all the practices described, it will not be supposed that he developed them all himself. His aim has been to consolidate the experience of many observers, in both the Division of National Mapping and the Royal Australian Survey Corps.

1.3 All the electronic computer programs referred to in this report were written by the author in Fortran 3600 for the Control Data Corporation 3600 computer owned by the Commonwealth Scientific and Industrial Research Organisation in Canberra.

1.4 Almucantar longitudes were used 50 years ago to fix part of the border between South and Western Australia. The method seems little known outside Australia. The computation of predictions, which was previously tedious, presents no difficulty with an electronic computer. With a geodetic theodolite, stop-watch and transistor radio, the method gives pleasingly consistent results, the standard deviation of pairs of stars averaging 0".8. With a moving-wire eyepiece micrometer, personal equation is reduced, if

not eliminated, but the standard deviation of the results is not improved.

1.5 Circum-meridian latitudes of FK4 stars have been found thoroughly satisfactory. The standard deviation of pairs of stars observed with the DKM3a theodolite averages 0".6. Owing to the weakness of the Boss catalogue in the southern hemisphere, the Talcott method is at present not only less convenient, but less accurate.

1.6 Azimuths by Sigma Octantis are convenient for all Australian latitudes. Greater errors occur in observing the RO light than in observing the star. In Australia, we are not blessed with Polaris, which can be observed during twilight, when shimmer is reduced and refraction is changing sign. With Sigma Octantis, it is essential to start observing the instant the star can be seen in the telescope: the quantity of the RO light often deteriorates rapidly. Reciprocal observations are made simultaneously from both ends of the azimuth line. Reciprocal Laplace azimuths often differ by about one second, but the effect of lateral refraction is reduced, if not eliminated, in the mean.

1.7 No written words, however detailed, can take the place of practical instruction, and this report is intended to supplement, rather than replace, the practical training of new observers. After their initial course of instruction, observers may benefit by having this report with them in the field, and perusing it from time to time. They are likely to find some points which they have hitherto failed to appreciate, and may find some points which they still fail to understand. They should then seek advice from an experienced observer. Experienced observers, in turn, may find parts with which they disagree, even parts which are plainly wrong. Discussions and suggested innovations are welcome, particularly if the aim is to simplify existing equipment and procedures. Suggestions involving an increase in complexity and expenditure, while not necessarily unwelcome, are less likely to be adopted.

2. PREDICTIONS:

Latitudes and Longitudes

2.1 Before going into the field, the party leader must arrange for the electronic computation of his star predictions, using programs ALMUPRED for almucantar longitudes, and MERIPRED for circum-meridian latitudes. These programs run on the CDC 3600 computer.

2.2 A sample data sheet is shown in Figure 1. The same cards may be used for both programs.

On the first and every alternate card:-

Enter the name of the station, and any other information wanted on the output, in columns 3-70.

Column 72 affects program MERIPRED only. If left blank, altitudes are listed. If "1" is entered, vertical circle settings for the Wild T3 on Face Left are listed. If "2" is entered, (altitudes + 270°) will be listed, as required by the DKM3a and many other instruments on Face Right.

On the other cards, enter:-

The date for which the predictions are required.

The latitude and longitude of the station, to a minute of arc or such lesser accuracy as may be available. In Australia, no signs are required. North of the Equator or west of Greenwich, enter "N" and "W" respectively in columns 17 and 27.

The altitude limits in the meridian, for latitudes. With the DKM3a, stars are observed between 50° and 90°. With the T3, the limits are 30° to 60°.

The altitude of the almucantar circle, for longitudes. At altitudes higher than 35°, star pairs become infrequent, and time is wasted sitting around. Lower than 35°, it may be difficult to see out of the 10' x 10' observing tent without partially dismantling it. For the DKM3a, 35° is therefore

GEODETIC SURVEY OF AUSTRALIA

ALMUCANTAR AND MERIDIAN STAR PREDICTIONS

PROGRAMS **ALMUPRED** AND **MERIPRED**

Name of Station, Notes, etc. — Style

3 4 5 6	9 10	13 14	17 18 19 20	22 23	26 27 28	30 31	34 35	37 38	41 42	44 45	48 49 50	52 53	56 57	59 60	62 63	65 66	69 70	72
HØNEYSUCKLE		DKM3A		ØVER	MIDNIGHT													2
1965	04	10	148	58	35	35	90	50	35	00	10	00	21	00	25	00	100	
Year	Month	Day	E/W Longitude		N/S Latitude	Upper Limits of Altitude		Lower	Deg Almucantar	Min	E/W Hrs Time Zone	Min	Hrs Start	Min	Hrs End	Min	Serial No. of Day of Year	
ØRRØRAL			T3															1
1965	04	11	148	57	35	38	60	30	35	00	10	00	18	00	23	30	101	

NOTES:

1. This form may be used for either ALMUPRED or MERIPRED. The same cards may be fed into either program. Columns 34-38 and 72 refer to Meripred, and columns 41-45 to Almupred.
2. All entries in columns 3-70 of the top cards are reproduced on the output.
3. Style. Column 72 determines the style of the predicted altitudes on Meripred. If a "1" is entered, circle readings for a Wild T3 on face left are listed. If a "2" is entered, circle readings in the range 270-360 are printed, as for a DKM3a on face right. Any other entry, including a blank, gives altitudes in the range 0-90.
4. If "+" or "N" is entered in column 26, the latitude is taken north. If "+" or "W" is entered in columns 17 or 48, the longitude or time zone is taken west. Any other entry gives south latitudes and east longitudes. In Australia, these boxes are best left blank. Enter degrees and minutes only for latitudes and longitudes.
5. Predictions may be for any period up to 24 hours, and may continue over midnight. Entries in columns 62-63 must then exceed 24.
6. The serial number of the day of the year, columns 69-71, is given in many desk diaries. Jan 1 = 1, Dec 31 = 365, or 366 leap year.

/MISC/65/396 3

FIGURE 1

recommended, but for the T3 in a smaller shelter, work procedes more rapidly at 30°.

The Local Standard Time for the beginning and end of the predictions. Predictions can be for up to 24 hours, and can continue over midnight; in the latter case, the finishing time will exceed 24 00.

The local time zone: for example, in eastern Australia, 10 00. West of Greenwich, a "W" must be entered in column 48.

The serial number of the day of the year: Jan 1 = 1 Dec 31 = 365 or 366. These numbers are given on many desk diaries in common use.

2.3 Entries which do not fill the boxes must be right-justified, as blanks are read as zeroes. This is automatically achieved, and some convenience for the punch girls results, if left-hand zeroes are entered; for example, for the month of January, enter "01".

2.4 On receipt of the predictions, check that the latitudes and longitudes actually fed into the computer were correct. It is inconvenient to discover an error of this sort in the field when expecting to start observations.

2.5 Hand in the electronic predictions with the field books, however tattered they may have become. They are the only means the computers have of detecting and rectifying incorrect star numbers.

Azimuths

2.6 For azimuths, it is advisable to compute the hour angle of Sigma Octantis for a suitable time and date near the start of observations. For example, at 7 p.m. E.A.S.T. on 1965 Feb 1 in $30^{\circ}00'$ S, $146^{\circ}00'$ E:

Hour Angle (W) = Long E - RA + Local Time + N + R_o

$$
\begin{array}{rrr}
= & +\ 9 & 44 \\
 & -20 & 32 \\
 & +19 & 00 \\
 & -10 & \\
 & +\ 8 & 45 \\
\hline
= & 6 & 57 \\
\hline
\end{array}
$$

Here R_o is for midnight from the Sun Tables of the Star Almanac, or from Table II of "Apparent Places"; the increment in R since Greenwich midnight can safely be ignored.

Then Altitude = (South Lat) + (Codec x cos t)

$= 30^o + (54'36") \times (-.246) = 29^o47'$

Azimuth $= 180^o + (\text{codec} \times \sin t) \times (\sec \text{altitude})$

$= 181^o\ 00'\ 54"$

If observations are not made on the expected time and day, the hour angle changes about one hour per hour of time, and 3.94 minutes per day, increasing in both cases if observations have been delayed. The calculations involving sin t and cos t can be avoided by using published graphs.

3. TECHNICAL EQUIPMENT:

3.1 At the end of this section, there is a list of technical equipment. It is not suggested that every party need take every item listed. The aim is to provide the party leader with a check list, so that nothing that he does need is overlooked.

3.2 Theodolites used for stop-watch almucantar observations must be fitted with graticules having 5' intersections on the vertical hair; and the alidade bubble on all theodolites must be graduated at approximately 2mm intervals.

3.3 On hills to which access is by foot only, first-order azimuths and latitudes, and very satisfactory second-order longitudes, may be observed with only the equipment marked with an asterisk.

3.4 Before going into the field, check the following :

Check all the lights on the theodolite.

Check that all contacts on the impersonal micrometer are registering sharply on the chronograph.

Check that the chronoscope and chronometer work properly together.

Check that the chronometer is missing the 59th second, and is making on the whole second, and breaking on the half.

Check that you have a complete set of leads, with appropriate plugs or clips; that all joints are soldered; and that all leads are electrically sound.

Check that the stride and plate bubbles are in good adjustment.

3.5 Instruments frequently get damp with dew. If put away damp at night, dry them and thoroughly air them the following morning. Similarly, tents may sometimes have to be struck when damp or wet. Dry them out at the first

opportunity. If stored damp, they can ferment and rot in a few days.

3.6 CHECK LIST

*Kern DKM3a with Tripod Levels Lighting set and batteries Spare lighting unit Lead to micro eyepiece Travelling case Pack frame	or	*Wild T3 with Tripod Lighting set Reflector for alidade bubble Pack frame

Time Signal Receiver, Labtronics, Type 21, with dipole aerial, earth, and leads to battery; or
*Transistor Radio.

Chronometer, clockwork, Mercer or Nardin, with condenser across the terminals, and leads to chronoscope and chronograph; or
*Watch with seconds hand.

Chronoscope, Labtronics, with leads to battery and time signal receiver.

Chronograph, Favag, two pen, with tapes, batteries, and leads to time signal receiver. For use with Labtronics receivers, the ordinary Favag chronograph needs to be modified, so that the power output from the receiver goes straight to the pen, instead of actuating the make-and-break.

*Stop-watch, reading to 1/10th sec., with split twin second hands.

*Pocket watch for use with the predictions. Tempo timer, or "pinger".

*Torch; thermometer and barometer (if altimeter, take I.C.A.N. tables); binoculars; prismatic compass; 100 ft. tape.

Observing tent, with poles, pegs and guys.

Booker's table and two chairs; booking light.

Wet batteries, bell cells for lamps, and small batteries for torches, lights, Favag, etc. Spare globes for torch and lamp.

Lamp, helio and tripod. Time swich. Two plumb-bobs.

Small theodolite and tripod for reference marks.

*Field books, predictions, access notes, station descriptions, record cards. Maps. De-misting tissues.

Computing machine. Natural or logarithmic tables. Computing forms. Data sheets.

Star Almanac and "Apparent Places".

Axe, shovel, sledge hammer; copper tubes, cement, plaster; wooden pegs, brace and bit; metal pegs, adaptor; soldering iron, cored solder, spare clips; cellotape, wrapping tape.

4. SETTING UP:

The Tripod

4.1 Set the theodolite centrally over the station mark whenever possible. When this is not possible, set up over any existing mark. If no existing mark is suitable, construct a permanent mark of brass set in concrete.

4.2 For almucantar longitudes, particularly with a stop-watch, it is convenient to set up the instrument so that two foot-screws lie in the meridian, with the other to the east or the west. The tripod legs should be set similarly.

4.3 The tripod is to be rigidly emplaced. On rock, drill holes to give the feet a positive grip. On earth or gravel, drive wooden or metal pegs firmly into the ground, and drill the tops to receive the tripod. In all cases, encase the footings liberally with plaster of paris. Leave the tripod plastered in until observations are complete.

4.4 Centre the instrument to less than a centimetre, much less on short lines. On the DKM3a, the circular bubble on the centre spike is convenient. Check that it is in reasonable adjustment by rotating it round the spike, and adjust it when necessary. Note the height that suits you best: about nine inches less than your own height.

Reference Marks and Eccentric Stations

4.5 Whether the instrument is central or eccentric, observe a round of angles on Face Left and Face Right to all reference marks, and tie into a true azimuth - either a distant mark or Sigma Octantis. Record the height of the instrument, and observe vertical angles to all marks. Tape slope distances from the trunnion axis in preference to horizontal distances. If the instrument is eccentric, make similar observations from the trig or from another eccentric mark and compute the reductions on the spot, to ensure the

observations are free from blunders and ambiguities. At every station, draw a free-hand sketch in the field book showing all the marks at the station. This diagram need not be a work of art, but draw it on the spot; diagrams drawn from memory some days later are worse than useless. Read a magnetic bearing from the trig to the eccentric station as a check on gross errors.

4.6 On all documents the name of the station is to be followed by the word "TRIG", "ECCE", "RM 2", etc, as the case may be.

Observing Tents

4.7 For impersonal observations, use the 10' x 10' observing tent. Set up the timing equipment on a table, and let both the observer and the booker have chairs. Make stop-watch observations inside a tent whenever it is possible to get one to the site.

Azimuth Lamp

4.8 Set the light to the distant station over the trig point whenever possible. When this is not possible, either ray it in by theodolite precisely on line to the distant station to less than 1cm, and much less on short lines; or set it over an existing eccentric or reference mark. Record the location of the light shone to each distant station very clearly in the azimuth field book, and mark it on the sketch, even if this information has already been transmitted by radio to the distant observer. When aligning the lamp, do not rely on the sights, which are nearly always out of adjustment. If it is not possible to "talk the light on" over the radio, check the alignment with extreme care using a piece of card. Reduce the power to the lamp towards last light. Ideally, it should always appear to the observer like a 4th or 5th magnitude star.

The Theodolite

4.9 Set up the instrument in good time, an hour or more before observations are due to begin, to allow time for the tripod to settle and temperatures and bubbles to stabilise. Prior to sunset, the instrument must be

completely shaded. Centre the slow-motion screws. Check the focus of the eyepiece, telescope and micrometer. Perfect focus is essential for accurate observations. There must be no parallax between the eyepiece and the object lens, and the circles must appear in sharp focus without straining the eye.

4.10 Check that the lights are satisfactory well before dusk. Use the lighting-sets supplied with the instrument, to ensure that the correct current is obtained. Do not use globes of incorrect voltage: brighter lights may be obtained initially, but the wiring is likely to burn out.

Initial Levelling

4.11 Level carefully, so that the vertical axis is within 5" of the true vertical in all azimuths. Check that the instrument is stable and the bubbles are floating centrally before observations begin. On the DKM3a the plate bubble is very sensitive, and can be used for the initial levelling if it is in good adjustment. Otherwise, it is convenient to use the stride level. It is wise to have the alidade bubble adjusting screw graduated, or marked with a file cut or strip of tape, to indicate its central position. The bubbles will stay in good adjustment for long periods provided the lock nuts are really tight. Readjustments with tight lock nuts takes patience, but if well done is seldom necessary.

Lengths of Bubbles

4.12 Before mounting the stride and Horrebow bubbles, set them to between 20 and 25 divisions in length. As the temperature falls, the bubbles increase in length, so they should initially be set slightly short. The double Horrebow bubble may be mounted before azimuths are observed; the single Horrebow bubble may not, as the instrument is out of balance and the stride bubble will not remain central.

5. AZIMUTHS BY SIGMA OCTANTIS:

5.1 Except in northern New Guinea, azimuths are determined by observing Sigma Octantis, which forms a perfect target in the telescope.

Observing at Dusk

5.2 It is always desirable, and frequently essential, to start observations at sunset, the instant the star can be seen in the telescope, and to stop within an hour or so. If the quality of the RO light deteriorates badly, additional observations may do more harm than good.

Simultaneous Reciprocal Observations

5.3 Azimuth observations are now nearly always made simultaneously with reciprocal observations from the distant station. Strict simultaneity zero by zero is not required. It suffices if observations start and finish at the same time. In hot weather, one must get on an finish the observations as soon as possible after sunset, without wasting time talking on the radio. In broken cloudy weather, observations at one end should not be discontinued just because the star at the far end has gone temporarily into cloud.

Double Pointings

5.4 In Australia, the greatest single source of inaccuracy is the bisection of the RO light, which even in the twilight period is sometimes large and woolly, and usually gets worse. The system of double pointings is therefore used on both the Wild T3 and Kern DKM3a. Observe and book two pointings to the RO, throwing off the horizontal slow-motion and the micrometer between pointings. Make two timed pointings to Sigma Octantis. A single reading of the stride or plate level suffices, but the level may be read at each pointing if preferred. Change face. Make two timed pointings to Sigma Octantis, read the level, make two pointings to the RO, change zero, and repeat.

Number of Zeroes

5.5 Aim for 12 zeroes of double pointings from each end of the line on each of two evenings. If a party is at a station more than two nights, take additional sets of 6 zeroes each evening. Do not leave a station with less than 12 zeroes of double pointings, of which at least six are on a different evening to the remainder. If observations are single ended, the minimum number of zeroes is raised to 18.

Preparations

5.6 Set up in good time; level carefully; start the stop-watch; check the lights on the instrument and at the RO; set the first zero; and look for the star soon after sunset. As soon as the star is seen, give the booker an approximate altitude and azimuth, leave the cross hairs on the star, and make the first time-check. Sigma Octantis will move very little, and any movement there is should accord with its hour angle. It is not impossible to compute observations to the wrong star, but identification is often difficult and the labour is great.

Stop-Watch

5.7 Start the stop-watch at an exact half-hour. Do this well before sunset, so that if the half-hour is missed, there is another opportunity without delaying observations. A tempo timer is a useful reminder. The stop-watch and the booker's clock should preferably agree within a second or two, and both should be deliberately set about 10 seconds fast. Wind a paper clip around the main button of the stop-watch so that it is impossible to stop it accidentally in the dark. Check the watch against the radio time signals immediately before and after every set of six zeroes, and record the observations in the spece provided in the field book - see Figure 2. At each time-check, read the decimal of the second five times and take the mean. The whole second is best checked by both the observer and the booker looking at the face of the watch as the minute signal is heard. On azimuths, the whole second is of greater importance than the decimal, and it must be checked beyond doubt, either from Lyndhurst, or from the start of the five minute tone on WWVH. Beware the false bleep transmitted on 10 m/c at about the 59.4 second of each minute, believed to come from JJY.

INITIAL DATA for Pages 4–9

Station: BEACON HILL TRIG R.O.: PRARIE HILL ECCE

Date: Year, Month, Day, & Decimal (G.M.T.) 1964 07 17·4

Observers Initials, Instrument Type & No. R. SCOTT. WILD T3 29967

Level: Value per Division 6·5 Secs. Readings per Zero 4 Hence Constant: 1·62

South Latitude: — East Longitude: —

Right Ascension: Declination: —

Sidereal Time at 00 Hours G.M.T.

Watch started at 1730 about 5 seconds fast.
At 1745 by WWVH, the watch read 15 04·9

TIME CHECKS

Watch: Make, Type & No. Hever No 5437 Time Zone: −10 (E.A.S.T)

Time by Radio Lyndhurst	Stopwatch Readings						Mean	Correction Fast or Slow
1800	·7	·7	·6	·7	·8	By eye, −4·8	−4·70 ✓	Fast
1825	·6	·6	·5	·6	·6		−4·58 ✓	
1855	·4	·5	·4	·5	·4	By eye, −4·5	−4·46 ✓	

Position of Light shown to Other Station: Set on line to Prairie Hill Trig.

Sketch on Page 15

Observer: R. SCOTT Recorder: J. M. CARLISLE

Weather: Mild; no cloud; slight easterly breeze.

Visibility: Excellent.

Figure 2: Initial Data for T3 azimuth observations.

Figure 3: A page of T3 azimuth observations with double pointings.

Station BEACON HILL TRIG Reference Object PRARIE HILL ECCE

Day & Date 1964 JULY 17, Friday Initial Data on Page 2 Star: Sigma Oct.

No of Zero	Horizontal Circle: Reference Object	Horizontal Circle: Star	Time: Approximate	Time: Stopwatch	Vertical Circle	Level E	Level W	Chord ~~to Arc~~
L	00 00 05·4	02 18 47·0	18 03 08	03 07·8 ✓	101 1858			Sum
L	06·0	45·7	3 40	3 39·3 ✓		5·6	4·1	9·7
R	180 00 02·7	182 18 40·3	5 16	5 15·8 ✓				
R	02·6	38·6	5 48	5 47·3 ✓		4·1	5·6	9·7
	16·7	171·6		17 50·2		9·7	9·7	
		85·8						
1	00 00 08·35 ✓	02 19 25·8 ✓		18 04 27·6 ✓	22·40	+0·0 ✓		
R	240 00 24·5	242 18 54·5	18 09 09	09 08·0 ✓				
R	24·1	52·6	9 47	9 45·6 ✓		4·1	5·7	9·8
L	60 00 26·8	51·7	11 06	11 05·6 ✓				
L	27·0	51·7	11 37	11 36·1 ✓		5·8	4·0	9·8
	102·4	210·5		41 35·3		9·9	9·7	
		105·25						
2	60 00 51·2 ✓	242 19 45·25 ✓		18 10 23·8		+0·2 ✓		

It is the end, rather than the start, of this bleep which, marks the minute. Wind the watch fully after every time-check.

Zeroes

5.8 Observe in sets of six on the following zeroes, which divide the circle and the micrometer into equal parts :

	DKM3a	T3
FL	00 00 25	00 00 05
FR	210 01 15	240 00 25
FL	60 02 05	120 00 45
FR	270 02 55	210 02 15
FL	120 03 45	90 02 35
FR	330 04 35	330 02 55

On the DKM3a, the micrometer is increased by 50" and the circle by 30° between zeroes. On the T3 the micrometer is increased by 20" and the circle by 60°. On succeeding sets, the degrees should be increased by 10° on all zeroes. After setting a new zero, unclamp the horizontal circle, and rotate the instrument once in the correct direction - see paragraph 5.9.

Swing

5.9 On face left, swing right; on face right, swing left. On the DKM3a, this is automatically achieved if when changing face one transits the telescope first, and then always swings the object glass away from the observer.

Observing

5.10 Obey all the usual rules for observing first-order horizontal angles. For all observing, but particularly for night work, the practice of using the right eye for the telescope and the left eye for the micrometer is recommended. Intersect the RO and the star with the same part of the vertical hair, close to, but not on, the horizontal hair. Use either the single or the double hair, but not both. Always make the final adjustment to the horizontal slow-motion and to the micrometer in a clockwise direction.

Practice intersecting the light quickly and decisively, without dithering. If the RO light is rolling and woolly, this is not easy; but a precise intersection of a moving light is impossible however much care is taken, and fiddling about is not likely to do much good. The final setting of the hair and the micrometer must nevertheless be made with all possible precision. The art of observing consists of reconciling these two conflicting requirements. A satisfactory speed for single pointings is a pointing a minute, a set every half hour. With double pointings, a set should not take more than 40 minutes.

5.11 To find the star and the RO, have the booker predict the settings, and use the circles. It is convenient to set the vertical circle first. When the star is seen, say "Star seen"; then "Coming . . . Up!" as the intersection is made and the stop-watch is pressed. Read the watch, and as soon as the booker has read back, release the hand. Read the level, always reading the east end first. With the DKM3a, the booker must immediately take the difference of the two readings and record the bubble length as a check against mis-readings. With the T3, the two readings are checked by adding them together and recording the sum. Then read the horizontal circle.

5.12 Avoid breathing on the bubbles. If there is condensation, wipe the bubbles and object glass delicately with de-misting tissues; then check the levels. If there is heavy dew, lay a handkerchief over the instrument whenever there is a pause in observations.

Wind

5.13 If a high wind is blowing through the window of the observing tent directly from the RO, the stride on the DKM3a may chatter on its mounting and be difficult to read. If it is not feasible to postpone observations, it can be carefully chocked with wedges of folded paper.

Vertical Angles

5.14 Read a vertical angle to the star at the beginning and end of every set. Observations to the nearest minute on one face suffice, but the alidade bubble must be at least approximately central.

5.15. Read a vertical angle to the RO light once per night, for the deviation of the vertical correction.

Booking

5.16 Sample pages of the field book are shown in Figures 2 and 3. Use a new book at each station. The booker needs his wits about him. He has to :-

Read a clock by eye when the observer says "Up!" and record his reading, as a check on gross errors on the stop-watch. Errors of 30 seconds are easy to make.

Check the bubble readings and record the bubble length.

Read back all observations as soon as he has written them down.

Have the next vertical and horizontal reading ready. The vertical settings on FL and FR do not change appreciably during a set. The horizontal setting increases by 30° per zero.

Levelling

5.17 The DKM3a must be levelled between sets, and more often if the stride readings are not satisfactory. The end of the bubble with the lower number should read approximately the same on both faces. If some zeroes have had a large stride correction, over-level in the opposite direction, the aim being that the algebraic sum of the stride corrections for an evening's work should be close to zero. The mean azimuth is then independent of the bubble value. On the T3, the plate bubble should be thrown off and re-centred, using a foot-screw, every three zeroes.

Abstracting Observations

5.18 The time signals should be graphed the following morning at the latest. Connect each point to the next by a straight line. Abstract mean levels and angles in the field book, in the field. The azimuth data sheets should also be completed in the field. A party should not delay just to

complete data sheets, but periods of cloudy or wet weather should be put to good use. The best drill is for the booker to make the original reductions, and for the observer to check them.

Electronic Data Sheets

5.19 A sample data sheet for program SIGMA is shown in Figure 4. The 1-card must define both the station and the RO, and is completed once only for every station. For the second and subsequent nights, a 2-card is optional, and a 3-card obligatory. A 2-card may be inserted anywhere in the deck when it is desired to have a comment printed on the output.

The computer will assume latitudes to be South unless "N" or "+" is inserted in column 36 of the 3-card, and will assume longitudes and the time zone to be East unless "W" or "+" is inserted in boxes 49 and 75. In Australia, these boxes can therefore be left blank, though "S" and "E" or "-" may be inserted if desired.

On the 4-cards, the degrees should be those observed on face left. One or two decimals of a second of arc may be inserted as desired. Only one decimal of a second of time may be inserted. Altitudes (not circle readings) must be interpolated to the nearest minute and entered for each zero.

Bubble: For the plate bubble on the T3, which is deemed to be numbered outwards from the centre, enter the sum of the east end readings, minus the sum of the west end readings. For the stride on the DKM3a, which is numbered consecutively from one end, enter the sum of the end readings when the zero end is in the west (i.e., instrument Face Left) minus the sum of the end readings when the zero end is in the east (instrument on Face Right).

Read also the notes printed on the form.

GEODETIC SURVEY OF AUSTRALIA

AZIMUTHS BY SIGMA OCTANTIS

PROGRAM **SIGMA**

2 4 Station and RO

1 LA PEROUSE TRIG RO COUNSEL TRIG — Red card

4 Observer, Instrument, etc

2 G.J.CRUICKSHANKS WILD T3 18573

	4 GMT Date & decimal	19 Bubble Rdgs	29 Const	NS36	38 Latitude	EW49	51 Longitude	63 R_o=GST at GMM	75 EW Zone
3	1965 02 18·60	6·50 4	1·62		43 30 27		146 44 38	9 50 58·7	-10 00

	4 Direction to RO	18 Direction to Star	32 Chron Times (1)	(2)	(3)	(4)	62 Error F_{S+}^{-}	69 Bubble	76 Altitude	
4	00 00 09·20	261 15 33·00	23 52 27·7	83·7	227·3	257·9	-11·6	- 0·4	42 39	✓
4	240 00 49·40	141 14 05·50	24 00 00·1	40·2	114·2	144·1	-11·6	- 1·2	42 39	✓
4	120 00 27·60	21 12 51·60	24 05 59·7	84·5	172·4	198·8	-11·6	- 0·2	42 40	✓
4	210 00 30·40	111 09 05·10	24 15 27·4	63·6	125·4	154·5	-11·7	- 0·3	42 40	✓
4	90 01 10·20	351 08 04·50	24 20 53·2	76·2	163·0	193·4	-11·7	+ 0·1	42 41	✓
4	330 01 51·20	231 06 59·80	24 26 36·0	64·3	154·1	183·3	-11·7	- 0·9	42 42	✓
4										
4										
5										

Do not punch blank 4-cards.

4	10	00	12·60	271	02	18·80	24	37	06·5	38·7	101·2	150·2	-11·7	+ 0·0	42	43	✓
4	250	00	43·40	150	58	55·00	24	50	27·5	58·3	142·6	165·0	-11·7	- 0·4	42	44	✓
4	130	01	22·70	30	57	54·80	24	36	23·7	51·3	131·5	165·4	-11·7	+ 0·0	42	45	✓
4	220	00	27·60	120	54	55·20	25	04	04·4	39·0	104·1	127·6	-11·7	- 0·2	42	46	✓
4	100	01	13·40	00	53	43·40	25	18	21·5	54·4	126·7	152·1	-11·7	- 1·3	42	48	✓
4	100	01	13·40	00	53	43·40	25	10	58·8	87·6	174·7	209·1	-11·7	+ 0·3	42	47	✓
4	340	01	51·00	240	52	28·80	25	18	21·5	54·4	126·7	152·1	-11·7	- 1·3	42	48	✓
4																	
5																	

OTE: The date and decimal must be in GMT. At 20.00 E.A.S.T, the decimal is (20-10)/24=0.4.
If the bubble value is 6" per div, and four ends are read, enter 6.00 4 1.50.
Chron times must be in Local Standard Time and may exceed 24 hours. If only two times are read, (3) and (4) are left blank.
The curvature correction, right ascension and declination are computed internally.

M/MISC/65/148

FIGURE 4

6. LONGITUDES - STOP-WATCH ALMUCANTARS:

6.1 Impersonal observations made with the micrometer eyepiece on the DKM3a are described in Section 7. It is there assumed that the reader is familiar with the stop-watch observations described here in Section 6.

6.2 Stop-watch longitudes can be observed with either the DKM3a or the Wild T3. Only the theodolite, stop-watch, and transistor radio are required. The theodolite must have a graticule with five horizontal wires five minutes of arc apart, and have 2mm graduations on the alidade bubble. The standard deviation of the results will often be no greater than observations made with the impersonal micrometer, but the results are burdened with the observer's personal equation, for which it is necessary either to determine or assume a value. For this reason, the observations are classed as second order.

Calibration for Personal Equation

6.3 Personal equation is determined by observing stop-watch longitudes at a station whose longitude has already been determined impersonally. The minimum observation to give a single reliable determination would be 8 pairs on each of three or preferably four nights; but as personal equation is not a constant quantity, and the calibration stations (except Mount Stromlo) are not free from error, it is in practice determined by making the normal observation of 8 pairs on two nights at a calibration station before the first and after the last stop-watch station, and at intervals of about 5 stations in between. On a new traverse, Laplace stations are customarily observed in pairs, with impersonal observations at one end of the line, and stop-watch observations at the other. Calibration involves a delay of two nights while the stop-watch party visit the impersonal station, but is not otherwise inconvenient. On geoidal sections, where one-night observations are made at every station along an existing traverse, impersonal longitude stations will be found every four lines or so, which the stop-watch party occupy like any other station.

6.4 In the past, many stop-watch longitudes were observed without determining personal equation. For these stations, a standard delay of $0^s.088$ was adopted; but this

LONGITUDE PREDICTIONS FOR
HONEYSUCKLE DKM3A OVER MIDNIGHT

DATE	LONGITUDE	LATITUDE	ALMUCANTAR	ZONE	PERIOD	DAY
1965 4 10	E 148 58	S 35 35	35 0	E 10 0	21 0 TO 25 0	100

STAR	MAG	EAST	WEST	TIME	NOTES
1365	6.4	83 15		21 3.6	
1165	5.5		265 54	21 6.2	
1369	5.7	88 40		21 7.9	
243	2.0		272 13	21 8.8	
1385	5.4	98 57		21 19.4	
1371	4.6	80 55		21 22.7	
257	=1.6		274 2	21 27.9	
249	4.5		265 11	21 33.4	
556	3.4	97 52		21 37.4	
1391	6.0	92 29		21 39.9	DOUBLE MAG 8.9 DISTANT 20 SECS
271	4.1		275 37	21 43.6	
1387	5.3	84 47		21 46.9	
548	2.9	84 51		21 47.0	
1404	6.8	99 48		21 53.0	
559	4.7	90 14		21 58.6	
1192	5.8		278 24	21 59.7	
270	3.1		264 1	22 3.3	
273	2.0		260 30	22 14.5	
1405	6.7	83 33		22 21.4	
1407	5.9	85 51		22 22.4	
1202	5.1		277 13	22 22.6	
1197	5.7		269 49	22 26.8	
1413	5.0	90 6		22 28.4	
592	3.0	99 3		22 30.0	
288	4.5		266 11	22 30.5	
577	4.0	83 4		22 34.8	
1415	5.1	90 48		22 38.5	
594	2.5	94 15		22 39.6	
1212	4.6		271 42	22 46.6	
597	2.9	90 18		22 51.5	DOUBLE MAG 5.1 DISTANT 13 SECS
1204	3.5		262 39	22 51.7	
311	5.1		275 28	22 53.2	
607	3.1	98 22		22 53.4	VARIABLE
1419	5.5	85 37		22 54.8	
1417	4.7	82 20		22 58.7	
616	1.2	99 31		22 59.7	VARIABLE 1.2 TO 5.2
308	2.9		263 26	23 8.6	
1221	5.6		263 48	23 25.4	DOUBLE MAG 7.9 DISTANT 41 SECS
1430	5.8	82 46		23 29.4	
1437	7.6	93 14		23 30.4	
624	5.0	87 25		23 32.6	
1447	6.2	99 40		23 36.8	
1229	6.1		267 50	23 38.3	
1231	5.9		271 59	23 41.3	DOUBLE MAG 6.3 DISTANT 67 SECS
644	3.4	97 37		23 55.3	
1449	6.1	87 15		23 59.5	
1457	4.3	96 29		24 1.5	
1242	5.8		269 51	24 1.8	
364	5.0		277 40	24 15.8	
1463	4.9	93 3		24 24.4	
1243	4.9		261 13	24 25.9	
1247	5.2		267 56	24 26.2	
658	3.6	84 6		24 34.5	
1261	4.7		279 33	24 36.9	
373	5.2		270 56	24 42.6	
1470	6.3	86 40		24 53.6	
682	4.0	92 13		24 56.1	
692	2.9	98 16		24 60.0	

COMPUTED 08/09/65. TIME FOR THIS JOB 4.4 SECONDS.

rather arbitrary assumption detracts from the precision of the observations, and for second-order observations, personal equation must be determined by calibration. With a new team, it is no use hoping to train and calibrate at the same time. The training observations must be discarded; then the party can calibrate; and then useful observations may begin.

Number of Pairs

6.5 For Laplace observations, whether stop-watch or impersonal, the aim should be 16 pairs, 8 on each of two nights. The minimum is 12 pairs, with not less than 6 pairs on each of two nights. For geoidal sections, 8 pairs on one night suffice.

Predictions

6.6 Predictions are prepared electronically, see Section 2, and Figure 5. It is unlikely that observations will be made on the exact day for which predictions have been prepared. Instead of altering the predictions, it is convenient to set a pocket watch to "Prediction Time". If observations are late, the stars will be early, and the watch must be set fast. Occasionally predictions are made for a place some way from the actual observation station. Differences in longitude are easily allowed for: if observations are made 15 minutes of arc eastwards of the predicted point, the stars will appear one minute of time early. Changes in latitude are not easily allowed for exactly, but if the observation point is north of the predicted point, the azimuth of east stars will have to be increased, and west stars decreased. In contrast to latitudes, there is not much to gain by selecting pairs in advance. Any east star can be paired with any west star, provided a pair is observed within 20 minutes of time. With practice, stars predicted within 2 minutes of each other can be successfully observed. Stars brighter than magnitude 2.0, and observations through thin cloud, are both better avoided, but are better than no observations at all.

Time Signals

6.7 A sample page from an observation book is shown at Figure 6. The procedure is similar to paragraph 5.5, but the

FIGURE 6

Stop watch started about 10^s fast at 1830.
At 1835 by WWVH, the watch read $05^m 09.7$

TIME CHECKS

Day and Date 1964 SEPT. 3 Thursday

Time Signal WWVH

Time Zone −10 00 E.A.S.T

Radio Time	Stopwatch Readings	Mean	Radio Time	Stopwatch Readings	Mean
1935	09.3 FAST BY EYE				
1936.5	.30, .25, .30, .25, .35, .30.	09.29 ✓			
1942	.35, .25, .35, .25, .35, .25	09.30 ✓			
1951	.35, .40, .35, .35, .35, .30	09.35 ✓			
1955	09.3 FAST BY EYE				
2000	.40, .35, .35, .40, .40, .40	09.38 ✓			
2004	.35, .40, .35, .35, .45, .40	09.38 ✓			
2009.5	.40, .50, .45, .35, .45, .45	09.43 ✓			
2010	09.4 FAST BY EYE				
2019	.45, .45, .45, .40, .45, .45	09.44 ✓			
2024.5	.45, .45, .45, .50, .45, .40	09.45 ✓			
2030	.45, .50, .45, .45, .50, .45	09.47 ✓			
2040.5	.55, .55, .55, .55, .60, .60	09.57 ✓			
2046	.60, .50, .60, .55, .55, .60	09.57 ✓			
2049	.60, .60, .60, .55, .60, .55	09.58 ✓			
2050	09.6 FAST BY EYE				

Figure 6: Stop-watch time checks for longitudes.

FIGURE 7

Figure 7: T3 stop-watch almucantar longitudes - a page of east stars.

Station CARPET SNAKE TRIG Day and Date 1964 SEPT. 3 Longitude ~~Latitude~~

Page	353		Star No. 1597		Pair No. 1				Aspect EAST					Baro
Clock	19 47 42		48 04		48 26		48 48		49 11					
Bubble	0.0		−0.1		−0.7		−0.7		0.0			−0.30		
S/Watch	17 45.65 ✓		18 07.70 ✓		18 29.80 ✓		18 52.25 ✓		19 14.85 ✓		19 48 30.05			
Vertical Circle														
Page	353		Star No. 861		Pair No. 2				Aspect EAST					Temp.
Clock	20 01 05		01 27		01 50		02 12		02 35					
Bubble	−0.2		0.0		0.0		+0.2		+0.6			+0.12		
S/Watch	01 09.35 ✓		01 31.65 ✓		01 53.90 ✓		02 16.45 ✓		02 38.90 ✓		20 01 54.05			
Vertical Circle														
Page	358		Star No. 873		Pair No. 3				Aspect EAST					Baro.
Clock	20 06 51		07 13		07 35		07 58		08 20					
Bubble	0.0		0.0		−0.3		0.0		+0.1			−0.04		
S/Watch	06 55.10		07 17.30		07 39.60		08 02.25		08 24.75		20 07 39.80			
Vertical Circle														
Page	361		Star No. 1612		Pair No. 4				Aspect EAST					Temp.
Clock	20 22 11		22 33		22 56		23 18		23 40					
Bubble	0.0		−0.2		−0.3		−1.0		−0.2			−0.34		
S/Watch	22 15.75 ✓		22 37.90 ✓		23 00.25 ✓		23 22.30 ✓		23 45.10 ✓		20 23 00.26			
Vertical Circle														

Figure 7: T3 stop-watch almucantar longitudes - a page of east stars.

watch is read to $0^s.05$, the mean of the five tocs is taken to $0^s.01$, and the aim is to take a time check between every star. If two stars follow in quick succession, a time signal may be omitted; but if two stars are more than say 8 minutes of time apart, it is best to take two checks, one at the start and one at the end of the interval. Wind the stop-watch immediately after every time-check. Graph the time signals the following morning at the latest, joining each point to the previous one by a straight line. If correct procedures are being followed, the graph will be reasonably smooth; a jagged graph is a warning that either the stop-watch needs repair, or, more likely, that it is not being kept fully wound, or is not being carefully handled. The aim is to be able to interpolate on the graph to $0^s.01$ with reasonable confidence.

Starting Observations

6.8 Longitudes are usually observed immediately after azimuths. Time signals, particularly WWVH, tend to get worse during the evening. If the Horrebow bubble is not already fixed to the DKM3a, set the bubble length to between 20 and 25 divisions, and attach it. Level the instrument carefully. The DKM3a is used on Face Right and the T3 on Face Left. On the T3, the eyepiece prisms may be used. Set the horizontal circle in the meridian as well as possible. Set the telescope to the altitude of the almucantar plus the estimated refraction, which can be found from page 60 of the Star Almanac.

For the 30° almucantar,	about	300°	01'	30"	on the DKM3a,
	or	105	00	22	on the T3.
For the 35° almucantar,	about	305	01	20	on the DKM3a,
	or	107	30	20	on the T3.

Clamp the vertical circle firmly, and avoid touching the vertical slow-motion or the alidade bubble adjusting screw throughout the observations. On the DKM3a, level the Horrebow bubble approximately, clamp it, and centre it using the fine adjustment screw. Check that the bubble remains reasonably stationary in all azimuths. If it moves, relevel the instrument using the foot-screws only. When the instrument is level, recentre the bubble. Unless accidently touched, it should not need readjustment throughout the observations. Correct any subsequent dislevelment on the foot-screws only.

6.9 Look for a trial star of fair magnitude, to test the predictions, the prediction watch, and the azimuth and altitude settings. Stars come into view about two minutes before the predicted time. The DKM3a reverses, but does not invert, so that east stars rise and west stars fall. The T3 both reverses and inverts. If no star is seen, check the setting of the prediction watch, and the meridian and altitude settings. If nothing is wrong, see if the stars come into view 4 minutes late, or 4 minutes early. The previous prediction program was sometimes imperfect in this respect. As a last resort, look for a bright star in the sky, follow it over the open sights, and see in what azimuth and at what time it cuts the almucantar. Adjust the horizontal circle or the prediction watch accordingly. If all else fails, do position lines, see Section 9.

6.10 Swing on to the predicted azimuth of the first star. It is convenient to set the micrometer to 00' 00", and set the azimuths using the main circle only. Check the levels. If imperfect, adjust the ex-meridian footscrew. Great delicacy of touch is required on the DKM3a. The footscrews may be touched at any time. When using the Horrebow bubble, there is no theoretical objection to using the vertical circle slow-motion, but when using the alidade bubble, as on the T3, it is disastrous to touch either the vertical circle slow-motion or the alidade bubble slow-motion, so it is safer to use only the footscrews on all instruments. The Horrebow bubble may only be touched between pairs of east and west stars, and if accidentally touched within a pair, that pair is ruined.

Observations

6.11 Stars are timed by stop-watch to $0^s.05$ as they cross the five horizontal wires in the graticule. When the star comes into view, say "Star seen", to relieve the booker's anxieties. On the DKM3a, the Horrebow bubbles are read, east ends first, before the first hair and after the last. If there is a crisis, it is permissable to delay the initial bubble readings until after the first or second hairs, when the bubbles have stabilised. On the Wild T3, the alidade bubble is recorded for each hair, and is moved fractionally, using the ex-meridian footscrew, between hairs. For the sign of the bubble reading, see paragraph 8.5. Ideally, the alidade bubble readings should range between ± 0.5 divisions, and the sum of the five readings should be close to zero. Observations are then independent of the value of the bubble,

and there is no danger of incorrect readings being obtained from a sticky bubble. Let the star cross the hairs just to the right of the vertical hair, adjusting the horizontal slow-motion between each hair.

6.12 In Australian latitudes, the interval between the hairs is about 22 seconds, during which the observer has to :-

Shout "Up!" and press the stop-watch at the precise instant that the star crosses the hair.

On the T3 only, read the alidade bubble and touch the ex-meridian footscrew.

Read the stop-watch, and when the booker has read back, release the second hand.

Adjust the horizontal slow-motion to bring the star back close to the vertical hair.

With practice, this is easily done in about 12 seconds, giving the observer about 10 seconds in which to relax between hairs; but new observers on their first night usually need practice. After the last hair, read the Horrebow bubble on the DKM3a, and immediately swing on to the azimuth for the next star. If time allows, take a time signal; and wind back the horizontal slow-motion, otherwise it will run out during an observation.

Booking

6.13 Use a new book at every station. Use a pen which suits your hand. Some modern biros are very satisfactory, particularly for chronograph tapes, but some cheap biros are practically illegible and should be avoided. Pencil is not permitted. See the sample pages from the field book, at Figure 7 for the T3, and Figure 8 for the DKM3a. It is convenient, but not essential, to book east stars on the left hand pages, and west stars on the right. With an inexperienced observer, or in cloudy weather, it is wiser not to insert the pair numbers until observations are complete. The pair numbers are merely a guide to the computer which star to pair with which.

6.14 In many ways, the booker runs the operations, and he should allow the observer to relax as much as possible. The booker selects the stars, tells the observer when and

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Station TIDBINBILLA ECCE	Day and Date Friday 1964 Aug. 21					Longitude ~~Latitude~~	
Page 351	Star No. 854	Pair No. 4		Aspect E			Baro
Clock	20 24 19	20 24 44	20 25 08	20 25 32	20 25 56		
Bubble	E 6·7 W 31·7	108·4 135·8		5·3 30·3	108·0 135·3		−1·5 ✓
S/Watch	24 21·95 ✓	24 46·15 ✓	25 10·25 ✓	25 34·40 ✓	25 58·60 ✓	20 25 10·27 ✓	
Vertical Circle	Δ 25·0	27·4		25·0	27·3		
Page 349	Star No. 849	Pair No. 5		Aspect E			Temp.
Clock	20 32 50	20 33 ~~19~~	20 33 38	20 34 ~~03~~	20 34 26		
Bubble	E 4·8 W 29·8	108·0 ~~135·2~~		4·5 ~~29·5~~	107·8 135·1		+5·3 ✓
S/Watch	02 53·60 ✓	~~03 17·30~~ ✓	03 40·85 ✓	~~04 04·75~~ ✓	04 28·30 ✓	20 33 40·92 ✓	
Vertical Circle	Δ 25·0	~~27·2~~		~~25·0~~	27·3		
Page 353	Star No. 1597	Pair No. 6		Aspect E			Baro.
Clock	20 48 22	20 48 46	20 49 09	20 49 33	20 49 57		
Bubble	E 6·7 W 31·7	108·8 136·1		6·8 31·8	108·9 136·0		−6·8 ✓
S/Watch	18 23·55 ✓	18 47·30 ✓	19 10·95 ✓	19 34·90 ✓	19 57·75 ✓	20 49 10·89 ✓	
Vertical Circle	Δ 25·0	27·3		25·0	27·1		
Page 361	Star No. 1612	Pair No. 7		Aspect E			Temp.
Clock	21 22 32	21 22 56	21 23 19	21 23 43	21 24 07		
Bubble	E 6·8 W 31·7	108·9 136·3		6·4 31·4	109·0 136·3		−6·8 ✓
S/Watch	22 33·45 ✓	22 57·20 ✓	23 20·70 ✓	23 44·60 ✓	24 08·35 ✓	21 23 20·86 ✓	
Vertical Circle	Δ 24·9	27·4		25·0	27·3		

37

Station Vertical Circle checked	Day and Date and found to read 305 01 20·2					Longitude ~~Latitude~~	
Page 218	Star No. 1369	Pair No. 4		Aspect W			Baro
Clock	20 20 27	20 20 51	20 21 15	20 21 39	20 22 03		$E^e - W^w$
Bubble	E 31·4 W 6·4	136·1 108·8		32·1 7·0	136·4 109·2		−7·4 ✓ −0·3
S/Watch	20 30·25 ✓	20 53·85 ✓	21 17·60 ✓	21 41·35 ✓	22 05·00 ✓	20 21 17·61 ✓	
Vertical Circle	Δ 25·0	27·3		25·1	27·2		
Page 229	Star No. 1390	Pair No. 5		Aspect W			Temp.
Clock	20 38 55	20 39 ~~19~~	20 39 43	20	20 40 32		$E^e - W^w$
Bubble	E 31·0 W 5·9	136·2 ~~109·0~~		31·5 ~~6·5~~	136·5 109·2		−5·8 ✓ −1·7
S/Watch	08 56·60 ✓	~~09 20·80~~	09 44·70 ✓	MISSED	10 33·45 ✓	20 39 44·92 ✓	
Vertical Circle	Δ 25·1	~~27·2~~		~~25·0~~	27·3		
Page 227	Star No. 1387	Pair No. 6		Aspect W			Baro.
Clock	20 45 31	20 45 55	20 46 19	20 46 42	20 47 05		$E^e - W^w$
Bubble	MISSED			32·1 7·1	136·2 109·0		−4·4 ✓ −0·4
S/Watch	15 32·00 ✓	15 55·80 ✓	16 ~~40~~ 19·40	16 43·40 ✓	17 07·35 ✓	20 46 19·59 ✓	
Vertical Circle	Δ			25·0	27·2		
Page 240	Star No. 577	Pair No. 7		Aspect W			Temp.
Clock	21 27 02	21 27 28	21 27 52	21 28 15	21 28 40		$E^e - W^w$
Bubble	E 30·8 W 5·8	135·6 108·3		31·0 5·9	135·6 108·3		−1·3 ✓ +0·9
S/Watch	27 05·50 ✓	27 29·55 ✓	27 53·35 ✓	28 17·30 ✓	28 41·15 ✓	21 27 53·37 ✓	
Vertical Circle	Δ 25·0	27·3		25·1	27·3		

Figure 8: DKM3a stop-watch almucantar longitudes, using double Horrebow bubble.
On pair 5, the fourth hair was missed on the West star.
On pair 6, there was insufficient time to read the bubbles prior to observation.
The length of the bubble has been booked in the box marked "Vertical Circle".

where to look for them, and decides whether or not there is time to take a time signal.

6.15 When the observer says "Star seen", and not before, write the page and star number in the field book. Errors in transcribing the star numbers are easy to make; while not disastrous, they cause trouble in the office. With the Horrebow bubble, check and record the bubble lengths immediately, and tell the observer at once if he has made an error. It is very easy for the observer to make gross errors if there is dew on the bubbles. Read and record the chronometer or a pocket watch when the observer says "Up!" and record the stop-watch and T3 bubble readings. Read back all observations as soon as they have been written down. If a hair is missed, write "MISSED" in the relevant box. As soon as a star is completed, give the observer the azimuth setting for the next star. If it should be in view, say "Should be in view. Magnitude 4.6. No time signal". Otherwise say "In view in two minutes. Time signal first", and switch on the radio.

Checking the Levels on the DKM3a

6.16 On the DKM3a, when each pair is completed, the booker checks the levelling of the instrument as follows. From the first east-end bubble reading to the east star, subtract the last west-end bubble reading to the west star, and book the difference, called "E^e-W^w", plus or minus. See Figure 8. The aim is for the algebraic sum of these values for a night's work to be zero; the longitude is then independent of the bubble value. If the booker sees that the algebraic sum is creeping up, he should advise the observer to adjust the footscrews so that there is slight over-compensation in the other direction. If the booker keeps the observer informed of the E^e-W^w value each time a pair is completed, it is easy to keep the theodolite very finely levelled.

Missing Hairs

6.17 If a hair is missed:

(a) The observations for the symmetrical hair must be omitted or cancelled. If the first or last hair is missed, use the centre three; if the second or fourth, use hairs 1, 3 and 5; if the centre hair is missed, use the other four.

EODETIC SURVEY OF AUSTRALIA

ALMUCANTAR LONGITUDE COMPUTATION

PROGRAM **ALMUCOMP**

1 Station, Instrument, Observer, etc. 56

LA PEROUSE ASTRO ECCE GJ CRUICKSHANKS DKM3-A85584

59 Limit

Date: 1 Year	6 Mth	9 Day	Altitude: 13 Deg	16 Min	19 Sec	Latitude; N+/S-: 23 Deg	27 Min	30 Sec	Time Zone; W+/E-: 36 Hr	40 Min	R_o=Sid. Time at 0 hr UT: 44 Hr	47 Min	50 Seconds	Bubble 58 Value
1965	02	12 ✓	35	00	00 ✓	-43	30	27.4 ✓	-10	00 ✓	9 ✓	27 ✓	19.334 ✓	0.3 ✓

1 Page	5 Star	10 E/W	12 ±Bubble Reading	18 Hr	21 Mn	24 Seconds Mean Time	30 +Slow/-Fast Chron Error	37 Hr	40 Mn	43 Seconds Right Ascension	50 Deg	54 Mn	57 Seconds Declination; N+/S-
173	421 ✓	E ✓	- 1.2 ✓	21 ✓	43 ✓	41.93 ✓	-10.44 ✓	11 ✓	09 ✓	56.649 ✓	-22 ✓	38 ✓	02.52 ✓
45	102 ✓	W ✓	+ 1.4 ✓	21 ✓	38 ✓	29.17 ✓	-10.45 ✓	02 ✓	49 ✓	26.265 ✓	-21 ✓	09 ✓	05.40 ✓
169	1283 ✓	E ✓	+ 2.6 ✓	21 ✓	47 ✓	45.52 ✓	-10.44 ✓	10 ✓	58 ✓	04.631 ✓	-18 ✓	06 ✓	42.99 ✓
48	1085 ✓	W ✓	+ 4.7 ✓	21 ✓	58 ✓	46.24 ✓	-10.43 ✓	3 ✓	00 ✓	50.224 ✓	-23 ✓	45 ✓	53.97 ✓
182	1305 ✓	E ✓	- 4.4 ✓	22 ✓	07 ✓	36.25 ✓	-10.42 ✓	11 ✓	46 ✓	59.296 ✓	-26 ✓	33 ✓	15.18 ✓
57	1100 ✓	W ✓	+16.4 ✓	22 ✓	10 ✓	52.78 ✓	-10.41 ✓	3 ✓	34 ✓	41.150 ✓	-17 ✓	35 ✓	07.74 ✓
176	431 ✓	E ✓	+ 5.9 ✓	22 ✓	15 ✓	01.73 ✓	-10.41 ✓	11 ✓	23 ✓	08.385 ✓	-17 ✓	29 ✓	28.94 ✓
57	1099 ✓	W ✓	+ 0.8 ✓	22 ✓	23 ✓	14.68 ✓	-10.39 ✓	3 ✓	32 ✓	13.972 ✓	-21 ✓	45 ✓	11.44 ✓
180	1301 ✓	E ✓	+13.3 ✓	22 ✓	32 ✓	23.85 ✓	-10.37 ✓	11 ✓	42 ✓	59.636 ✓	-18 ✓	09 ✓	20.69 ✓
60	140 ✓	W ✓	+ 0.7 ✓	22 ✓	41 ✓	46.23 ✓	-10.35 ✓	3 ✓	45 ✓	20.089 ✓	-23 ✓	21 ✓	21.86 ✓
193	471 ✓	E ✓	+ 9.2 ✓	23 ✓	04 ✓	09.10 ✓	-10.30 ✓	12 ✓	32 ✓	32.945 ✓	-23 ✓	12 ✓	09.04 ✓
69	161 ✓	W ✓	+ 8.4 ✓	23 ✓	06 ✓	26.15 ✓	-10.29 ✓	4 ✓	19 ✓	07.141 ✓	-20 ✓	43 ✓	32.07 ✓
196	1329 ✓	E ✓	+ 4.1 ✓	23 ✓	12 ✓	42.93 ✓	-10.28 ✓	12 ✓	46 ✓	01.951 ✓	-24 ✓	39 ✓	36.51 ✓
66	153 ✓	W ✓	- 4.0 ✓	23 ✓	15 ✓	01.26 ✓	-10.27 ✓	04 ✓	04 ✓	10.589 ✓	-27 ✓	45 ✓	02.58 ✓
			-			.	- .			.	-		.
			-			.	- .			.	-		.

'ES:
1. Entries which do not fill the boxes must be right-justified, as blanks are read as zeroes.
2. Signs must go in the columns indicated, the printed minus signs being altered to plus signs as necessary.
3. Decimal points can be inserted in any column of the bubble value and bubble reading boxes.
4. Page number entries are optional.
5. Star numbers, right ascensions and declinations may be punched automatically by program STARCORD.
6. Star pairs whose computed longitude is more than LIMIT seconds of time from the mean of the remainder are excluded from the computed mean, range and standard deviations. If the Limit box is left blank, a value of $0^s.2$ is used. A decimal point may be inserted anywhere in the limit box.
7. The Chron Error is on Local Standard Time. If it exceeds 99.99 seconds, the minutes of the Time Zone entry may be adjusted to bring the Chron Error under 60 seconds.
8. R_o must be for 0 hr UT on the date shown, to which Chron Times must also refer. If observations continue over midnight, Chron Times may exceed 24 hrs.
9. Computations must be separated by a "MORE DATA" card with an "M" in column 10. The last station must terminate with an "End of Run" card only, which has an "R" in column 10.

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FIGURE 9

(b) Observations for the same hairs must be struck out for the other star in the pair.

(c) Count a pair with missing hairs as half a pair only; if the program requires eight pairs, they could consist of 7 perfect pairs, plus two pairs with missing hairs.

Checking the Vertical Circle Setting

6.18 After every four pairs, and at the end of observations, check the vertical circle setting, and record it on the top right hand page of the field book:

"Vertical circle checked and found to read ....."

See Figure 8. If the setting has changed more than 2", complete a pair, and then re-set it to the original value. If during the observation of a pair, the vertical circle slow-motion or the alidade bubble adjusting screw are touched on the T3, or the Horrebow bubble adjusting screw is touched on the DKM3a, the pair is ruined.

Reductions in the Field

6.19 Graph the time signals the following morning at the latest. Check and tick the stop-watch readings against the clock, looking for errors of 30 seconds and 30 minutes. Use a desk machine with back transfer to form the means of the five stop-watch readings, and check that the mean is close to the reading for the centre hair. On the T3, mean the five alidade bubble readings. On the DKM3a, with the single Horrebow bubble, form (80.0 - (sum of four end readings)). With the double bubble, form (560.0 - (sum of eight end readings)). In the office, this job is best done on an adding printer. The bubble value must be divided by 4, or by 8, respectively, before entry on the data sheet.

6.20 Enter the data on a sheet for program ALMUCOMP. For an example see Figure 9. Read the notes at the foot of the form. In the field, the latitude, bubble value, right ascensions and declinations should be left blank; they are best entered in the office. Enter the star numbers on a data sheet for program STARCORD - see Section 10.

7. LONGITUDES - IMPERSONAL ALMUCANTARS WITH THE DKM3a:

7.1 First-order observations are made using the impersonal micrometer eyepiece, chronometer, chronoscope, chronograph and a time signal receiver. The reader is assumed to be familiar with second-order observations made with a stop-watch, which are described in Section 6. Details which are common to both methods are not repeated here.

Chronometer

7.2 The chronometer is fitted with electrical contacts, across which a filter is fitted which prevents the chronometer being heard on the radio:

In addition, it is advisable to fit a large 1 micro-farad condenser externally across the terminals. At the first station, check to see that the chronometer is making on the exact second and breaking on the half. Check that the 59th second of each minute is the second that is omitted, not the 60th, and record in the field book that this is so. Alterations can be made by removing the glass and delicately rotating the second-hand clockwise on its friction mount. Wind the chronometer nightly at the conclusion of observations. Stop the chronometer before moving to the next station. A daily rate of up to 10 seconds is no disadvantage: the test of a good chronometer is the constancy, not the size, of its rate. Rates above 10 seconds per day are perhaps better adjusted.

Chronoscope

7.3 Check that the chronoscope is working before leaving the office. It is a delicate instrument that needs to be handled with care.

7.4 The chronoscope reads only fractions of a second. The whole second must be unambiguously recorded :-

(a) on the Favag Chronograph if the signal is strong enough.

(b) by eye, by both the observer and the booker independently, immediately before and after the longitude observations, and at least hourly in between.

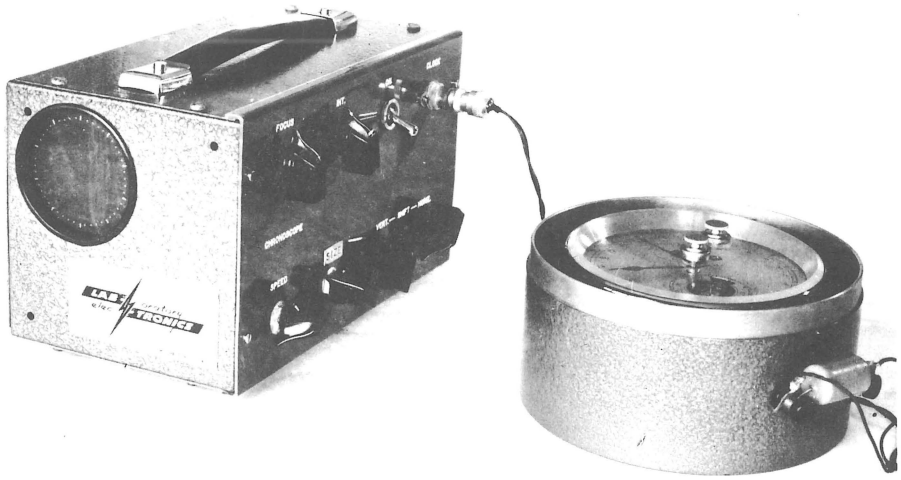
7.5 Connect the chronoscope to the chronometer and the time signal receiver and switch on. Set the trace on the chronoscope exactly CENTRAL and exactly CIRCULAR. Adjust the focus and brightness so that the clock break can be clearly seen, and adjust the speed until it is within 0.05^s of the zero position at 12 o'clock, and nearly stationary. See Figure 10. Adjust the fine tune on the radio until the tocs can be heard with maximum clarity, and dim the brightness of the trace until the tocs can be clearly seen. The leading, anti-clockwise, edge of the signal is the exact second. Read and book five clock tocs and five radio tocs alternately to $0^s.005$, take the means to $0^s.001$, and subtract the clock from the radio. Enter the whole second by extrapolation, check it at least hourly, check by eye that the fraction of a second is not visibly incorrect, and make a record whenever a check is made. Then switch the chronometer from the chronoscope to the Favag. The chronoscope and the chronograph must not be connected in parallel across the terminals of the chronometer. A time-check can be made in less than two minutes when the signal is clear. Take a signal whenever gaps in the program allow, and at least every 30 minutes. Use the same signal throughout the night. If this is not possible, and one or two WWVH signals, say, are included in a batch of Lyndhurst, label them very clearly so that corrections for transit time can be applied.

Chronograph

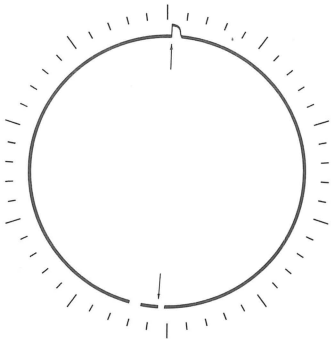
7.6 For use with the Labtronics time signal receivers, the Favag chronograph needs to be modified so that the radio operates the relay directly, without drawing power from the batteries. Ensure that this has been done, so that the Favag may be used if the chronoscope fails in the field. Check that the pens are aligned without visible pen equation, and run a short length of tape to ensure that the pens are registering cleanly and the marks have steep leading edges. Some chronographs have been modified so that the tapes can

LABTRONICS CHRONOSCOPE

for the comparison of chronometers with radio time signals.



Clock : $0^{s}.005$



Radio : $0^{s}.510$

Chronoscope Time Signals

Day & Date: Mon. 13th July 1964
Station : Boveys Lookout

Chronoscope: Labtronics No. 126
Chronometer: Mercer No. 20518
T.S. Radio : Labtronics Type 21 No. 15

At 1927 hrs. by WWV the chronometer read 19 hrs. 27 mins. 09.4 sec. by eye

Time	Chronometer Readings					Mean	WWV Readings					Mean	Mean
1943	.000	.000	.000	.995	.995	.998	.525	.525	.525	.525	.525	.525	-9.527 Fast
2015	.010	.010	.010	.010	.010	.010	.735	.735	.740	.735	.740	.737	-9.727 "
2024	.000	.000	.000	.000	.000	.000	.770	.770	.770	.775	.775	.772	-9.772 "
2040	.010	.010	.010	.010	.010	.010	.885	.890	.890	.890	.890	.889	-9.879 "
2054	.000	.000	.000	.000	.000	.000	.960	.960	.960	.965	.960	.961	-9.961 "
2058	.000	.000	.000	.000	.000	.000	.990	.990	.995	.995	.995	.993	-9.993 "

Visual check at 2100 hrs. showed chron 10.0 secs. fast

2113	.000	.000	.000	.000	.995	.999	.080	.085	.085	.085	.085	.084	-10.085 Fast
2127	.000	.000	.000	.000	.000	.000	.190	.190	.190	.190	.190	.190	-10.190 "

be wound and stored on 9mm cine reels, and this is recommended.

Tapes

7.7 Some red tapes are difficult to read. Black tapes are more satisfactory. Two stations can usually be recorded on one single tape, but carry ample spares. At both ends of every tape, reading inwards, record :

Station name and number.
Date, and time of start or finish.
Observer and Booker.
Chronometer number and chronograph number.
Pen equation.
Time signal.

In general, the more information that is recorded on the tape, the better.

Pen Equation

7.8 Join the chronometer to both terminals of the chronograph, and record about 15 seconds of pen equation before and after every evening's observations. If the chronoscope is in use, have the clock connected to the back pen the first night, and to the front pen the second night. Any residual pen equation will then tend to cancel in the mean of two nights work. If time signals are being recorded exclusively on the Favag chronograph, keep the clock on the back pen throughout, and pen equation will cancel. With the modified Favag, it is not possible to record radio time signals on the back pen.

Favag Time Signals

7.9 Time signals are now only recorded on the Favag to check the whole second on the chronograph in a permanent and unambiguous manner. However, the observer should be thoroughly familiar with the procedure, so that the Favag may be used if the chronoscope breaks down.

7.10 Connect the chronograph to the chronometer and to

the time signal receiver (the LO Z terminals), and tune the receiver very carefully for maximum clarity. In Australia, Lyndhurst will usually record with no difficulty. To record WWVH, it is often necessary to adjust the relay level and the limiter very carefully so that the pen is just thrown by a toc, and returns afterwards. Ten unambiguous WWVH tocs are sufficient; they are most easily obtained during the fourth minute of each five minute period. Periods when BPV is on the air are to be avoided for accurate time-checks, but are often the most satisfactory for gross checks on the whole second.

Time Signal Receiver

7.11 The Labtronics Type 21 is now in use. Use a dipole aerial, for which the total length should be 468 feet divided by the frequency in megacycles. Cut this length in half, and join each half to an insulator. Connect a shielded twin lead of 75 ohms impedance to each half at the insulator, and connect the other end to the red terminals on the receiver. The aerial should be high, horizontal and at right angles to the direction to the transmitter. Connect the earth terminal to a spike struck in the ground, which is best kept damp. The Type 21 receiver has an internal battery which must be removed when exhausted. An external 12 volt battery is normally used. The internal battery may not operate the chronoscope satisfactorily.

7.12 Use Lyndhurst whenever it is audible. In 1965, the frequencies are :

GMT	E.A.S.T.	kcs	kcs	kcs
1200-2200:	10 p.m. - 8 a.m:	5425	7515	
2200-1200:	8 a.m. - 10 p.m:		7515	12005

When Lyndhurst is inaudible owing to the displacement of the ionosphere, use WWVH, which is usually clearest on 10 mcs. For accurate work, the short five minute periods when BPV is on the air are easily detected by the sharp peeps overriding the WWVH tocs, and are to be avoided. The time signal receiver is designed to filter out JJY. If late in the evening it seems impossible to obtain a satisfactory signal, do not despair. Try again five minutes later; the conditions may have changed remarkably for the better.

Eyepiece Micrometer

7.13 Before and after tracking longitude stars, it is necessary to release the clamp, and turn the whole eyepiece through exactly 90°, firmly up against the stops, and clamp it again. Longitude stars are tracked in altitude, not in azimuth. Connect the micrometer lead to the pins on the eyepiece, connect the other end to the chronograph, switch the latter to "Stars", and rotate the micrometer slowly and listen for the pen to click. If no action, check the micrometer switch, and check the connections. Switch on the light for the micrometer graduations, and adjust the brightness. If no light, check the bulb is not loose or broken.

7.14 The micrometer has 120 divisions to each revolution. The revolutions are numbered as follows. The centre hair is numbered 10. The outer hairs are numbered 5 at the micrometer eyepiece side of the telescope eyepiece, and 15 at the other side. The intermdeiate hairs correspond to 7.5 and 12.5. Thus by reading the divisions on the drum, and looking at the position of the moving hairs in the eyepiece, both revolutions and divisions can be read. There is a contact which actuates the pen at the 0, 12, 24, 36, etc., division - 10 per turn - with an additional contact at 5, between 0 and 12, which identifies the zero mark. Each revolution corresponds to about 2 minutes of arc, so that each division is about 1", which is why the drum is numbered in this way.

Observations

7.15 Set up the instrument and check the predictions as in paragraphs 6.8-6.10. When the star comes into view, say "Star seen" to relieve the booker's anxieties. Read the Horrebow bubbles (always east end first) when the star is near the outer hairs. It is permissable to omit the initial bubble readings if there is a crisis. An accurate azimuth setting is important. The star must cross the almucantar as close as possible to the centre hair, well within 2 minutes of arc on average. This can be achieved quite easily, by watching where the star cuts the outer hair, and adjusting the azimuth accordingly. Track the star with the double hairs, and make sure that they are at the correct end of the field of view to start with. Stars are tracked between the

two inner wires. Before starting to track, give the booker the micro reading - usually about 7.40 or 12.80. This is recorded on the chronograph tape, and helps the tape reader identify the other contacts. Say "Chron on!" about five seconds before the star crosses the hair, and say "Tracking!" when tracking starts. The booker checks that the pen is recording, and if it is, says "Tracking" back. Intense concentration and much practice is required to keep the star central between the two hairs right the way across the field of view. Only the contacts between 8 and 9.5 and between 10.5 and 12 are actually computed. This gives the observer some five seconds to lock on to the star, and some ten seconds while the star is crossing the centre hair when some inattention due to blinking or even a sneeze is not disastrous. When the star crosses the final hair, say "Tracking stops". Do not say "Chron off"; tracking only occupies about 45 seconds, and the booker may have to let the chron run on for another 15 seconds in order to record a minute mark. When the booker is ready, give him the micrometer reading, and read the bubbles. Immediately set the azimuth of the next star. If it is on the same side, wind the moving hair back. Take a time signal if possible, and if there is time to spare, sit down and relax. Tell the booker you are in his hands, and it is then his responsibility to get you back on the instrument in time for the next star. Is is particularly easy to miss stars when there has been a long gap of say 15 minutes. A tempo timer is useful.

Booking

7.16 See paragraph 6.13 and 6.14, and the sample page of the field book at Figure 11. As with stop-watch observations, the aim should be for the booker to run the operation, and let the observer relax as much as possible. As soon as a surveyor is confident that the booker can take a time signal with 100% reliability, he can let the booker read the chronoscope if he wishes. The observer must invariably check the whole seconds.

7.17 When the observer says "Star seen", the booker records the star number in the book and on the tape. Errors in transcribing star numbers are easy to make, and while not disastrous, they cause trouble in the office. Write the micrometer readings on the tape, and the initial bubble readings in the field book. Immediately check and record the bubble lengths. When there is dew, it is very easy for the

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Station	COUNSEL TRIG		Day and Date	Saturday 1965 Feb. 13				Longitude · ~~Latitude~~					
Page	153		Star No.	373		Pair No.	1		Aspect	E			Baro
Clock													
Bubble	E 4·4	W 27·8	103·3	128·0			4·9	28·2	103·3	128·0			
S/Watch													
Vertical Circle	Δ 23·4		24·7				23·3		24·7				
Page	163		Star No.	399		Pair No.	2		Aspect	E			Temp.
Clock													
Bubble	E 1·8	W 25·0	102·1	127·0			0·7	24·2	102·3	127·2			
S/Watch													
Vertical Circle	Δ 23·2		24·9				23·5		24·9				
Page	167		Star No.	1280		Pair No.	3		Aspect	E			Baro.
Clock													
Bubble	E 6·8	W 30·0	106·2	131·0			6·7	30·1	106·2	131·1			
S/Watch	Instrument releveled before this star.						Star faint: 6·9 mag only.						
Vertical Circle	Δ 23·2		24·8				23·4		24·9				
Page	171		Star No.	419		Pair No.	4		Aspect	E			Temp.
Clock													
Bubble	E 4·9	W 28·4	104·9	129·7			4·8	28·2	104·8	129·8			
S/Watch													
Vertical Circle	23·5		24·8				23·4		25·0				

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Station	Vertical circle set		Day and Date	at 305° 01' 20"				Longitude · ~~Latitude~~					
Page	21		Star No.	1036		Pair No.	1		Aspect	W			Baro
Clock													
Bubble	E 32·8	W 9·5	132·7	108·0			33·1	9·8	133·0	108·2	$E^e - W^w$		-5·4
S/Watch													
Vertical Circle	Δ 23·2		24·7				23·3		24·8				
Page	40		Star No.	1071		Pair No.	2		Aspect	W			Temp.
Clock													
Bubble	E 31·5	W 8·2	132·4	107·8			31·8	8·3	132·5	107·9	$E^e - W^w$		-6·5
S/Watch													
Vertical Circle	Δ 23·3		24·6				23·5		24·6				
Page	32		Star No.	1055		Pair No.	3		Aspect	W			Baro.
Clock													
Bubble	E 32·5	W 9·1	133·2	108·3			32·6	9·1	133·4	108·4	$E^e - W^w$		-2·3
S/Watch													
Vertical Circle	Δ 23·4		24·9				23·5		25·0				
Page	34		Star No.	78		Pair No.	4		Aspect	W			Temp.
Clock													
Bubble	E 28·5	W 5·1	130·1	105·1			28·8	5·3	130·1	105·2	$E^e - W^w$		-0·4
S/Watch													
Vertical Circle	Δ 23·4		25·0				23·5		24·9				

Figure 11: Pages of impersonal almucantar longitude observations.
Only the Horrebow bubble readings are recorded in the field book.

observer to make gross errors in reading the bubbles. If there is not time to read the bubbles, write "Missed". Wind the Favag after every star, and cultivate the knack of switching it on first go; it is very easy to switch it on half speed, which is no good. Say "Tracking" as soon as the pen is seen to be working. While the star is tracking, watch for the whole minute, and record for example "2032" on the tape. Every star must have a minute marked. Do not switch off the Favag until this has been done. If the minute is forgotten, it is much easier and better to take another star than try and fix the computations in the office.

7.18 When the Favag is switched off, record the micrometer reading on the tape, followed by two transverse lines. Record and check the bubble readings, and give the observer the next star setting. If it should already be visible, give him the magnitude. Otherwise say "Into view in about 3 minutes". Take a time signal if time allows. At the conclusion of each pair, check the levelling of the instrument as in paragraph 6.16, and after every four pairs, check and record the setting of the vertical circle as in paragraph 6.18.

7.19 After the last star take a time signal on both the chronoscope and the Favag; check the whole seconds by eye; run some pen equation, and complete the record on the tape. The observer should unclamp the eyepiece, and turn it through 90°, firmly up against its stops, into the position for latitudes and azimuths. It is better to leave the micrometer contacts in contact with the drum, not to switch them off. The Horrebow bubble must be taken off and the counterweight replaced before the instrument is put away, but there is no objection to making azimuth or latitude observations with the double bubble on.

Reductions in the Field

7.20 Chronoscope time signals should be graphed as soon as possible. Beyond seeing that the records in the field book and on the tape are clear and complete, no other work need be done in the field. Both the bubble readings and the tapes are best processed on an adding printer in the office.

Reductions of Bubble Readings

7.21 Use an adding printer. With the double bubble, the number to be entered on the form is (560 - (sum of 8 bubble readings)). With the old single bubble, the number is (80 - (sum of 4 bubble readings)). If one set of bubble readings have been missed in the field, subtract the other set twice.

Reading the Tapes

7.22 Find the minute mark, and confirm from the field book that the 59th second is the one that is blank. Use a centimeter rule to mark in the 10, 20, 30, 40 and 50 seconds along the tape. From the micrometer readings at the ends of the tape and the "05" contacts, find and mark the "00" contacts on the tape, and mark off the sections from 8.0 to 9.4 and from 10.6 to 12.0.

7.23 Set the tape under a tape reader, with a piece of card along side it, so that

(a) the tape can slide under the reader without disturbing it

(b) the tape is held at the correct part of the scale, and at right angles to it.

The tape is read to 1/10th second only, but systematic errors must be avoided. There are about 1000 contacts to read per station, and it is necessary to work fast and accurately on smooth, mass-production principles. The tape reader must be used with the engraved side downwards to avoid parallax. Slide the tape until the left side of a contact is under the centre hair of the tape reader, and count the tenths of a second left-wards from the centre hair to the left edge of a chronometer second. Count and check the whole second, and enter the second and decimal on an adding printer. Slide the tape to the next contact.

The Adding Printer

7.24 Clear the machine. Record the star number, non-add, followed by a blank line. Record the first five contacts, and a total A; then the next five, with a total B; then the next five, with a sub-total C; this completes the 15 contacts on one side of the centre hair. Record the centre contact,

10.0, non-add. Add in the next five contacts, and form the total E, which will be the sum of ten contacts, five on either side of the centre hair. Record the next five contacts, add in B, and form the total F. Record the last five contacts, add in A, and form the sub-total G. Look at the list, and make the following checks :

(a) Each contact reading should be about 1 second from its neighbours. With a poor observer, there may be some variety in the intervals, but nevertheless, gross errors in tape reading are easily spotted.

(b) The totals E, F and G should be similar to each other and to the centre hair reading. The allowable range depends on the standards of the observer, but as a guide, it is safest to re-read any group for which the mean of ten contacts differs from the others by $0^s.1$.

If these checks are satisfactory, add to the sub-total G still on the machine the totals E and F, divide the sum by three mentally or by hand, and subtract this mean three times. The final sum should be zero or $0^s.01$. Enter the mean on the ALMUCOMP data sheet, adding the hours and the minutes from the tape.

7.25 With a difficult tape, where the tocs cannot be identified with certainty, proceed as in USC&G Special Publication No.237, p.44, adding the contacts in pairs.

8. LATITUDES:

Type of Observation

8.1 Meridian or circum-meridian altitudes of FK4 stars are observed. The Talcott method has many advantages, but requires the use of the Boss catalogue in which the standard error of stars in the Southern Hemisphere is now reputed to exceed 1". When a more accurate catalogue is published, the Talcott method may once again be used.

Selection of Stars

8.2 Stars are predicted electronically, see Section 2. With the DKM3a the altitude limits are 50°-90°; with the T3, 30°-60°, and the eyepiece prisms are recommended. Stars are paired north and south within 4° of altitude and 20 minutes of time. Lower transit stars may be used when available. Stars brighter than 2.0 magnitude are better avoided. In contrast to longitudes, it is advisable to select pairs in advance, trying to find a partner among the many north stars for each of the rarer south stars. With the T3 and the old IBM 7090 predictions, it is necessary to convert predicted altitudes to circle readings for the selected stars. If predictions have been made out for a point some distance away, changes of both latitude and longitude are easily allowed for; longitudes as in paragraph 6.2. If the true latitude is north of the prediction latitude by 1 minute, north stars will be higher by 1' and south stars lower by 1'.

Number of Pairs

8.3 Twelve pairs of stars are the minimum for a first order station; sixteen pairs are welcome. Observations on a single night are acceptable, but eight pairs on each of two nights should be the aim. For geoidal sections, and at T3 stations where latitudes are required only for Sigma Octantis computations, six pairs on one night suffice.

Number of Shots per Star

8.4 Near the zenith, it is important that both the instrument and the star lie very close to the meridian when

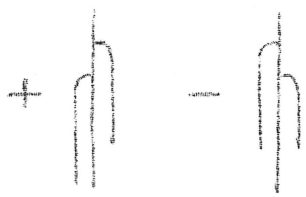
the altitude is measured, and only a single shot is taken. At lower altitudes, additional circum-meridian altitudes are measured, up to a maximum of six. The following table may be used as a guide :

Altitude	No. of Shots	Maximum Interval from Transit, in Time
90-80	1	4 seconds
80-70	2	20 seconds
70-60	3	1 minute
60 and lower	6	3 minutes

It is better to obtain few shots to many stars, than many shots to few stars. Stars transitting within one minute of each other can be observed with practice.

Alidade Bubble

8.5 The bubble is graduated, one division being about 5" of arc. The bubble is read to one tenth of a division, but there is no accuracy to spare, and care must be taken. The sign of the bubble is defined thus :



DKM3a on Face Right

T3 on Face Left

- viewed from the telescope eyepiece in both cases. The total difference between the ends of the bubble is estimated and booked. It need seldom exceed 0.5 divisions, and if when swinging from north to south the bubble is found to be more than one division out, relevel the instrument at the next convenient pause.

Time Signals

8.6 Use a stop-watch, exactly as for azimuths, see paragraph 5.6. Record time signals immediately before and after observations, at least once in the middle, and once every half hour if observations are protracted. Check and

record the whole second, as well as the decimal, on each occasion. Use the pages provided in the field book. Rewind the stop-watch after each time signal.

Observations

8.7 If the setting of the horizontal circle and the prediction watch have not already been tested on longitudes, check a bright star as in paragraph 6.9 before starting. For observations at high altitudes, set the zero of the horizontal circle in the meridian within 15". If a geodetic azimuth is not available, either compute an azimuth from Sigma Octantis, or avoid observations at the highest altitudes. For observations below 70°, which includes all T3 observations, the azimuth is not critical. Make all observations on face right with the DKM3a, and on face left with the T3.

8.8 Set the predicted reading on the vertical circle, and swing into the meridian, north or south. Find the star, say "Star seen", and depending on the altitude of the star and the time available, decide how many shots to take. If only one, and the succedding star follows quickly, centre the alidade bubble and the micrometer approximately in advance. Then set the telescope carefully on the zero of the horizontal circle, and observe the star as it crosses the centre wire. If taking several shots, for each shot say "Coming ...", intersect the star, press the stop-watch and shout "Up!". When the booker has recorded the approximate time, read the stop-watch, and when he has read back, free the second hand. Read the bubble and read the circle. After reading the circle, move the alidade bubble fractionally, using the alidade bubble adjusting screw. Ideally, the bubble readings should range between +0.5 and -0.5, and the mean should be close to zero. The danger of a sticky bubble is then averted, and the mean altitude is independent of the bubble readings. Move in azimuth between shots so that the star is always observed just to the right of the vertical hair. A shot every 30 seconds should be the aim. The degrees and minutes of altitude need only be read on the first and last shots. After the last shot, immediately set the telescope for the next star. Periodically rewind the horizontal slow-motion, else it will run out during the observation of a star.

Refraction

8.9 Record temperatures and pressures. The thermometer must be hung where it indicates the true external air termperature. With the DKM3a it is therefore best hung outside the tent, and read by the observer, who can reach over the wall for it. With the T3 in a small shelter, the booker can read the thermometer provided it is hung where it is not affected by his breath or his lamp. The temperature and pressure have to be entered on the data sheet for each star. It suffices to read the pressure every half hour, but the temperature should be read at least once per pair, and once per star if it is falling rapidly and stars forming pairs are observed in irregular order. Read the temperature to the nearest degree fahrenheit. If altimeters are used instead of barometers, record the readings in feet, and convert to pressure in inches, in the field book, using ICAN tables. Barometers and altimeters are very unreliable. It is best to read a battery of three, and to calibrate them against a mercury barometer at least once per journey.

Booking

8.10 Use the field book in which longitudes have been recorded. For a sample page, see Figure 12. It is desirable to book north stars on the left page, and south stars on the right.

8.11 Read and record a clock when the observer says "Up!" to guard against gross errors on the stop-watch. Read back all observations after they have been written down. Check that the vertical circle reading agrees with the predictions. When a star is complete, immediately give the observer the aspect and altitude of the next star. If it should be in view, say "Transits in about 1 minute. Magnitude 4.6". Otherwise say "Start observing in about 3 minutes". During gaps in the program, it is the booker's responsibility to get the observer back on the instrument in good time; a tempo timer is useful. If a time signal is due, and there is time before the next star, switch on the radio.

Station COUNSEL TRIG	Day and Date Sunday 1965 Feb. 14					~~Longitude~~ Latitude
Page 150	Star No. 366	Pair No.		Aspect NORTH		~~Baro~~
Clock	00 23 51	24 25				47°
Bubble	-0·1	-0·1				27.65
S/Watch	23 36 9	24 10·5				
Vertical Circle	344 09 21·8	344 09 22·5				
Page 154	Star No. 377	Pair No.		Aspect NORTH		Temp.
Clock	00 38 53					47°
Bubble	+0·3					27·65
S/Watch	08 37·9					
Vertical Circle	352 16 03·6					
Page 155	Star No. 1260	Pair No.		Aspect NORTH		~~Baro~~
Clock	00 43 44	44 23				47°
Bubble	0·0	0·0				27·65
S/Watch	13 29·1	14 09·0				
Vertical Circle	340 39 49·0	340 39 50·4				
Page 156	Star No. 381	Pair No.		Aspect NORTH		Temp.
Clock	00 49 28	00 50 06	00 50 43	51 16		47°
Bubble	-0·1	-0·1	-0·1	-0·2		27·65
S/Watch	19 13·2	19 57·8	20 28·0	21 01·3		
Vertical Circle	328 43 58·0	328 43 59·3	59·0	328 43 57·7		

Station BEACON HILL TRIG	Day and Date Friday 1964 July 17						~~Longitude~~ Latitude
Page 260	Star No. 1440	Pair No. 1			Aspect NORTH		Baro
Clock	21 16 51	17 14	17 36	18 02	18 27	18 53	69° 1180+30
Bubble	-0·3	0·0	+0·4	+0·1	-0·1	0·0	1190+10
S/Watch	16 50·6	17 13·3	17 35·8	18 01·3	18 27·2	18 52·8	MEAN
Vertical Circle	111 12 30·5	111 12 30·3	29·2	29·0	29·7	111 12 29·0	1205
Page 263	Star No. 635	Pair No. 2			Aspect NORTH		Temp.
Clock	21 30 20	30 48	31 09	31 29	32 00	32 24	69°
Bubble	-0·2	-0·1	0·0	+0·3	0·0	-0·9	
S/Watch	00 19·8	00 47·7	01 09·3	01 29·2	01 59·9	02 23·9	
Vertical Circle	117 10 19·8	117 10 19·7	20·0	19·2	18·8	117 10 19·2	
Page 265	Star No. 1451	Pair No. 3			Aspect NORTH		Baro.
Clock	21 36 37	37 05	37 39	38 10	38 31	39 07	69° 1180+30
Bubble	-0·9	-0·7	-0·3	0·0	+0·9	+1·0	1180+10
S/Watch	06 36·5	07 05·2	07 38·8	08 09·3	08 30·6	09 06·8	MEAN
Vertical Circle	119 36 06·1	119 36 06·1	05·4	04·3	02·5	119 36 00·5	1200
Page 265	Star No. 641	Pair No. 4			Aspect NORTH		Temp.
Clock	21 40 25	40 55	41 23	41 46	42 13	42 41	68°
Bubble	+0·4	-0·6	-0·3	0·0	0·0	+0·2	
S/Watch	10 24·8	10 54·8	11 22·3	11 45·5	12 12·7	12 41·3	
Vertical Circle	111 08 00·3	111 08 02·6	02·2	01·7	00·9	111 06 58·7	

Figure 12: Field book pages for Latitudes
a) DKM3a at top
b) Wild T3 below

Reductions in the Field

8.12 Graph the time signals the following morning at the latest. Check and tick the stop-watch reading against the clock, looking particularly for errors of 30 seconds and 30 minutes.

8.13 Enter the data on forms for the electronic program LATCOMP; see Figures 13 and 14 for an example. Read the notes on the first form. It is particularly helpful to the punch girls if left hand zeroes are entered. Observations equal to zero should be entered "+0.0", as negative zeroes and blanks are printed blank on the output. The latitude, longitude, bubble value, right ascensions and declinations should not be entered in the field. Circle readings do not have to be converted to altitudes before entry on the form. Seconds both of time and of arc, will frequently exceed 60. With the T3, if the minutes of circle reading change, they increase by 2; nevertheless, the entry for seconds should increase by 60 only:

If for	105	18	59.1	one has entered	105	18	59.1
then for	105	20	01.2	enter	105	18	61.2

For negative entries, ink over the printed minus sign, to make them clearer to the punch girls. Enter the star numbers on a data sheet for program STARCORD. If latitudes and longitudes have been observed consecutively on the same night, a single STARCORD sheet may be used for all stars. See Section 10.

GEODETIC SURVEY OF AUSTRALIA

CIRCUM - MERIDIAN LATITUDE COMPUTATION

INITIAL DATA FOR PROGRAM **LATCOMP**

1 Station, Instrument, Observer, etc	Circle Style 59	Limit 62
INNES PEAK ASTRO ECCE AG BOMFORD KERN DKM3A 87989	2	

Date 1 Year	6 Mth	9 Day	Longitude: W+/E- 13 Deg	18 Mn	21 Seconds	Latitude: N+/S- 27 Deg	31 Mn	34 Seconds	Time Zone: W+/E- 40 Hrs	44 Mn	R_o= Sid. Time at 0 hr UT 48 Hr	51 Mn	54 Seconds	Bubble 59 Value
1965	02	03	-145	35	44.6	-42	38	18.4	-10	00	8	51	50.4	4.8

NOTES:

1. Entries which do not fill the boxes must be right-justified as blanks are read as zeroes.
2. Signs must go in the columns indicated, the printed minus signs being altered to plus signs as necessary.
3. Page number entries are optional.
4. Star numbers, right ascensions and declinations may be punched automatically by program STARCORD.
5. Circle style. Insert 1, 2, 3, or 4 according to the style of the vertical circle readings entered:
   - 1: For Wild T3 ($90^\circ + D^\circ/2 + M'/2 + S''/4$)
   - 2: From 270° horizontal to 360° vertical - for T4, DKM3a or Tavistock on Face Right.
   - 3: From 90° horizontal to 0° vertical - zenith distances.
   - 4: From 0° horizontal to 90° vertical - altitudes.
6. For circum-meridian observations, the programme rejects reduced altitudes which differ from the mean of the remainder by more than 5".
7. Star pairs whose computed latitude is more than LIMIT seconds from the mean of the remainder are excluded from the mean, range and standard deviations. If the LIMIT box is left blank, a value of 2" is used.
8. The Chron Error is on Local Standard Time. If it exceeds 99.99 seconds, the minutes of the Time Zone entry may be adjusted to bring the chron error under 60 seconds.
9. R_o must be for 0hr UT on the date shown, to which Chron Times must also refer. If observations continue over midnight, Chron Times may exceed 24 hours.
10. Computation must be separated by "MORE DATA" cards with an "M" in column 10. The last station must terminate with an "END OF RUN" card only, which has an "R" in column 10.

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FIGURE 13

GEODETIC SURVEY OF AUSTRALIA

CIRCUM-MERIDIAN LATITUDE COMPUTATION

STAR DATA FOR PROGRAM **LATCOMP**

1 Page	5 Star	N/S/L 10	Chron Error 13 Slow+/Fast-	Temp 20 °F	Pressure 25 Inches
137	1230	N	−9.3	67	27.50
136	331	S	−9.3	67	27.50

	Right Ascension 37 Hr	40 Mn	43 Seconds	Declination: N+/S- 50 Deg	54 Mn	57 Seconds
	8	47	36.830	−03	18	45.13
	8	42	40.703	−78	50	10.69

Time 3 Hr Min 0013 — 8 Seconds 61811721789 — Star One 31

2 (Bubble± + 00 + 00 + 00 − 00 −)

Deg Min 32040 — 40.5 45.0 43.6

34 Hr Min 0009 — 39 Seconds 28.7 70.810 2 11.36 61.6 81 — Star Two 62

33 (Bubble± + 00 + 00 + 00 − 01 − 01)

Deg Min 32348 — 18.5 19.8 18.3 18.3 17.9

1 Page	5 Star	N/S/L 10	Chron Error 13 Slow+/Fast-	Temp 20 °F	Pressure 25 Inches
137	332	N	−9.3	67	27.50
138	336	S	−9.3	67	27.50

	Right Ascension 37 Hr	40 Mn	43 Seconds	Declination: N+/S- 50 Deg	54 Mn	57 Seconds
	8	49	03.610	−27	34	45.85
	8	54	17.543	−60	30	35.38

Time 3 Hr Min 0017 — 8 Seconds 140 — Star One 31

2 (Bubble± + 01 − − − −)

Deg Min 34456 — 15.0

34 Hr Min 0021 — 39 Seconds 238 468 — Star Two 62

33 (Bubble± − 02 − 01 − − −)

Deg Min 34207 — 339 335

1 Page	5 Star	N/S/L 10	Chron Error 13 Slow+/Fast-	Temp 20 °F	Pressure 25 Inches
143	1241	N	−9.3	68	27.50
138	1233	S	−9.3	68	27.50

	Right Ascension 37 Hr	40 Mn	43 Seconds	Declination: N+/S- 50 Deg	54 Mn	57 Seconds
	9	08	28.231	−30	13	17.46
	8	56	09.135	−59	05	35.01

Time 3 Hr Min 0035 — 8 Seconds 332 786 — Star One 31

2 (Bubble± − 02 + 00 − − − −)

Deg Min 34734 — 46.0 46.0

34 Hr Min 0023 — 39 Seconds 195 507 — Star Two 62

33 (Bubble± − 01 − 02 − − −)

Deg Min 34332 — 315 321

1 Page	5 Star	N/S/L 10	Chron Error 13 Slow+/Fast-	Temp 20 °F	Pressure 25 Inches
140	1234	N	−9.3	67	27.50
142	345	S	−9.3	67	27.50

	Right Ascension 37 Hr	40 Mn	43 Seconds	Declination: N+/S- 50 Deg	54 Mn	57 Seconds
	8	58	48.106	−41	06	59.62
	9	06	43.667	−43	17	24.38

Time 3 Hr Min 0026 — 8 Seconds 188 — Star One 31

2 (Bubble± + 00 − − − − −)

Deg Min 35828 — 162

34 Hr Min 0034 — 39 Seconds 124 — Star Two 62

33 (Bubble± − 01 − − − − −)

Deg Min 35920 — 254

MISC/64/4225

FIGURE 14

9. POSITION LINES:

9.1 When all else fails, position lines can be observed, and when skies are cloudy, observers are untrained, or predictions are not available, latitudes and longitudes can be obtained which may suffice to provide a Laplace correction to azimuths in low latitudes. Position lines are often convenient for topographic astro-fixes, but they are less good for precise work: latitudes are burdened with timing errors, longitudes with circle-reading and refraction errors, as well as personnal equation, and the results when computed are frequently disappointing. With clear skies, trained observers will always obtain better results by observing latitude and longitude separately using the more sophisticated methods described in earlier sections.

In the following paragraphs it is assumed that observations are made with a Wild T3 and stop-watch.

Selection of Stars

9.2 An observation consists of measuring four timed altitudes in quick succession to each of four stars lying approximately NE, SE, SW and NW. However, as longitudes are both more important and more difficult to obtain than latitudes, two additional stars lying east and west are included in every set. Stars in opposite quadrants should balance each other in altitude and azimuth as well as possible, and preferably be observed consecutively. Stars lower than 30° in altitude should be avoided. The important point, however, is to select BRIGHT STARS, brighter than magnitude 4.0, which are listed in the "Star Almanac". There is no guarantee that fainter stars are listed in "Apparent Places"; and even with electronic computing, the labour and expense of obtaining coordinates for Boss stars is prohibitive - it is much easier to observe bright stars only. It is desirable to identify at least one or two of the brighter stars of an evening's program, particularly if an accurate azimuth is not available. Avoid observing planets.

Number of Sets

9.3 A set of six stars will give a weaker result than one pair of latitude stars and two pairs of longitude stars.

The aim must therefore be to observe at least six sets, three on each of two nights, and more are welcome.

Personal Equation

9.4 To determine the observer's personal equation, it is necessary to make calibrating observations at a station whose astronomical longitude has been determined "impersonally". In practice, however, the quality of position line observations seldom merits the labour involved, and a standard value of $0^s.088$ for an observer's personal equation is more usually applied.

Time Signals

9.5 Since longitudes are being determined, time signals must be recorded with all possible accuracy, as in paragraph 6.7. A tenth of a second of time corresponds to 1".5 of arc in longitude, and an accuracy ten times better would be welcome. Time signals are therefore recorded between each star, 5 tocs being observed to $0^s.05$ and meaned. The whole second should be observed before and after every set. The timing of the stars in the telescope must also be done with the utmost precision, and useful observations are not likely to be obtained by an observer who is feeling sluggish and tired.

Observations

9.6 Set up, level and check the lights as in Section 4. Set the zero of the horizontal circle in the meridian as well as possible; use a geodetic azimuth if one is available, but an azimuth determined with a prismatic compass is better than nothing. The use of the eyepiece prisms is recommended.

9.7 Select a bright star, find it in the telescope, and check beyond doubt over the open sights that it is the bright star selected, not some dim unlisted companion which looks bright when seen in the telescope. Identify the star if possible, and assess its magntitude carefully. Bring the alidade bubble close to coincidence. Read an azimuth to one minute, and then make four or five pointings in succession as follows :

Set the horizontal hair in front of the star, and say "Coming . . ."

As the star crosses the hair, press the stop-watch, and shout "Up!"

Read the stop-watch, and when the booker has read back release the second hand.

Read the bubble, with the correct sign.

Read the vertical circle.

Make a small adjustment to the alidade bubble, using the alidade bubble adjusting screw. The aim should be for the bubble to move between +0.5 and -0.5, and for the mean of the four readings to be close to zero.

After the last pointing, read the horizontal circle again.

Booking

9.8 The azimuth field books are the more convenient. Rule up a blank page for the time signals. Read and record the clock when the observer says "Up!" as a check on gross errors with the stop-watch. Read back all observations after they have been written down. For each star, record the temperature to 1°F, and the pressure to 1/100th inch. Check that for each star the aspect, the magnitude and two horizontal circle readings have been recorded.

Abstracting Observations

9.9 Check, and tick, the stop-watch readings against the clock, looking particularly for errors of 30 seconds and 30 minutes. Plot a graph of the four altitudes against the four times. The four points should lie on an almost straight line. Do not worry about possible errors of less than 10 seconds, but check and if necessary discard observations which are grossly wrong. Then take out the mean time, the mean altitude, the mean bubble reading and the mean horizontal circle reading, and enter them on a data sheet for electronic computation.

Star Identification

9.10 If the orientation of the horizontal circle is unknown or uncertain, calculate a value of the azimuth a of the star from :

$$\sin A = -\frac{\Delta h}{\Delta t} \cdot \frac{1}{15.\cos \phi}$$

where h is the change in altitude and t the interval of time between the first and last pointing to the star. Provided the horizontal circle has been read for every star, it suffices to calculate the azimuth of 2 of 3 stars only, and derive the azimuth of the other from their horizontal circle readings.

9.11 Given the azimuth a, either as above, or from a known azimuth to a distant station, calculate the declination of a star from :

$$\sin \delta = \sin \phi \,.\, \sin h + \cos \phi \,.\, \cos h \,.\, \cos A$$

A slide rule or four-figure tables suffice. If the star has been provisionally identified in the field, and the computed declination confirms the field identification, that suffices. If the star's identity is completely unknown, compute its hour angle t from :

$$\sin t = \cos h \,.\, \sin A / \cos \delta$$

and then

$$RA = +t(E) + \lambda(E) + \text{Local Time} - N(E) + R$$

where N is the time zone and R is from the star almanac.

10. STAR COORDINATES:

10.1 Star coordinates (with the exception of circumpolars) are computed electronically. The object of this section is to enable a field party to fill up the data sheet for program STARCORD. When Boss stars have been accidentally observed, the data sheet for the Boss star program will be completed in the office.

10.2 See figure 15 for a completed data sheet. Read the notes at the bottom of the form. Entries on the first card are reproduced verbatim on the output. The date and decimal must be inserted in the field. The functions A, B, C, D, E and T are from p264 of the Astronomical Ephemeris; do not enter Besselian day numbers for 0 hrs sidereal time, p280, nor Independent day numbers, by mistake. They need not be entered in the field if no Astronomical Ephemeris is available. Nor is it necessary to complete the Year Card in the field. Complete boxes I and L - see notes 2 and 4. On the third card, leave box "59 Cards" completely blank. If any entry is made, even a zero, cards will be punched; and the decision whether or not to have cards punched will be made in the office.

10.3 The coordinates of stars do not change appreciably over a period of six hours or less, and as a general rule all stars observed on one evening, whether for latitude or longitude, may be entered on one form. However, if observations continue from dusk to dawn, it is advisable to compute star coordinates in two batches, using a different decimal of a day.

10.4 At the foot of the output for every batch, the following notice is printed :

> CAUTION - COORDINATES FOR DOUBLE STARS 257, 287, 291, 339, 583, 616, 793 ARE FOR CENTRE OF GRAVITY. FOR COORDINATES OF BRIGHTER COMPONENT, SEE "NOTES ON DOUBLE STARS" IN "APPARENT PLACES".

The corrections are far from negligible - exceeding 10" for No.793A - but are very easy to apply. The Notes are on page XLII of the 1965 edition of "Apparent Places". Corrections are given to both RA and Declination for the beginning and end of the year, and it is usually possible to interpolate by eye, taking care over the signs.

GEODETIC SURVEY OF AUSTRALIA

STAR COORDINATES FROM FK4 CATALOGUE

PROGRAM **STARCORD**

1 Name of Station — 56

INNES PEAK ASTRO ECCE

Besselian day numbers for 0 hrs Ephemeris Time:

1 Year	6 Month	9 Day & Dec.	15 ± A	23 ± B	31 ± C	39 ± D	47 ± E	51 ± T	59 I	61 L
1965	02	01.60	-4.409 ✓	-1.528 ✓	-12.559 ✓	+15.228 ✓	-23 ✓	+0.0861 ✓	0	5 ✓

59 Cards

Entries for following day: -4.345 ✓ -1.590 ✓ -12.806 ✓ +14.982 ✓ +0.0888 ✓

Star numbers:

2	8	14	20	26	32	38	44	50	56
419 ✓	78 ✓	421 ✓	102 ✓	1283 ✓	1085 ✓	1305 ✓	1100 ✓	1301 ✓	1099 ✓
1309 ✓	140 ✓	479 ✓	1119 ✓	471 ✓	161 ✓	1230 ✓	331 ✓	332 ✓	336 ✓
1241 ✓	1233 ✓	1234 ✓	345 ✓	1241 ✓	348 ✓	1243 ✓	351 ✓	1248 ✓	353 ✓
366 ✓	361 ✓	364 ✓	362 ✓	377 ✓	1256 ✓	1265 ✓	375 ✓	1261 ✓	385 ✓
381 ✓	391 ✓	399 ✓	393 ✓						

YEAR CARD (See Astronomical Ephemeris p.50)

1 Year	16 m	25 n	34 tan ε
1965	3.07355	1.33609	0.433647229

NOTES:

1. The Day and Decimal must be in GMT. For example, 8 p.m. E.A.S.T. = (12+8-10)/24=.42
2. Put I = 1 if RA only required. Put I = 2 if Dec only required. Otherwise leave blank or put I=0.
3. To economise in cards and computer time, enter the star numbers line by line, not column by column; but the programme works with either.
4. Put L = the number of star cards used, between 1 and 10, one card per line, up to ten stars per card.
5. All numbers must be right adjusted in their boxes, as blanks are read as zeroes.
6. Each batch of stars must be followed by a year card. The last year card must be followed by an "END OF RUN" card with an "X" in column 62.
7. Year cards and end-of-run cards will usually be available from an earlier computation.
8. Any entry in box "59 Cards" causes RA and Dec to be punched out on cards ready for programmes ALMUCOMP and LATCOMP.

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FIGURE 15

10.5 For Sigma Octantis, the RA and Declination are computed automatically by program SIGMA. Circum-polar star coordinates are thus seldom required, but when they are, they must be computed by hand. Although they are listed daily in "Apparent Places", the entries are for upper transit at Greenwich, and interpolation is not quite straight forward. Proceed as follows :

Let Y be the GMT decimal of a day, as entered on the data sheets for program STARCORD.

Compute X = RA - R_o, adding 24 hours if negative: to the nearest minute only.

Convert X to a decimal of a day, using Table V in "Apparent Places".

Let n = Y - X.

Use n to interpolate in the tables in "Apparent Places". If n is positive, interpolate forwards from the day of observation to the next day. If n is negative, interpolate backwards from the entries for the day of observation towards the entries for the previous day.

For examples, including the case when there is a double upper transit at Greenwich, see Figure 16.

Interpolation for RA and δ of Sigma Octantis

Date & Decimal of Day	1959 Jan 17·6	1959 Jul. 29·4	1959 Jul. 30·5	1959 Jul. 31·6	1959 Aug 01·7
RA } for Date	20 24 39·74	20 27 62·09	20 27 62·25	20 27 62·65	20 27 62·87
δ } for Date	−89 06 29·39	−89 06 18·06	89 06 18·34	89 06 18·90	89 06 19·19
R_o	7 42 40·9	20 23 35·9	20 27 32·4	20 31 29·0	20 35 25·5
$x = RA - R_o$ (+ 24 hrs ?)	12 42	00 04	00 00	23 56	23 52
x in days	·529	·003	·000	·997	·995
y from line 1.	·6	·4	·5	·6	·7
$n = y - x$, ±:	+·071	+·397	+·500	−·397	−·295
Previous RA	—	—	—	20 27 62·43	20 27 62·65
Previous δ	—	—	—	89 06 18·61	89 06 18·90
Following RA	20 24 39·71	20 27 62·25	20 27 62·43	—	—
Following δ	89 06 29·02	89 06 18·34	89 06 18·61	—	—
Interpolated RA	20 24 39·7	20 28 02·1	20 28 02·3	20 28 02·6	20 28 02·8
Interpolated δ	−89 06 29·36	−89 06 18·17	−89 06 18·48	−89 06 18·78	29 06 19·10

FIGURE 16

11. CALIBRATIONS:

Bubbles

11.1 Bubbles with a value of about 2" per division are very finely made and delicately mounted objects. Stresses brought about by temperature changes or shock can bring about large and unsuspected changes in their value at any time. For this reason, observations are designed so that the quantity finally computed is independent of the bubble value. Nevertheless, bubble values need to be determined, and checked at least annually. Unnumbered bubbles like the alidade bubble require a plus or minus sign which is determined by a more or less arbitrary convention. To prove beyond doubt what convention has been adopted, these bubbles are calibrated at least once per journey.

Alidade and Horrebow Bubble Calibration

11.2 Bubbles whose axes lie in the plane of the vertical circle are easily calibrated in the field. The T3 should be set on face left, and the DKM3a on face right, so that circle readings increase with altitude. Record the instrument number and face in the field book. It is necessary to prove that during the course of the calibrations the vertical axis of the instrument has not moved. For the alidade bubble, point the telescope at some target that can be finely bisected, and clamp it. The alidade bubble can then be moved with the alidade bubble adjusting screw, and dislevelment can be detected by the telescope moving off target. For the Horrebow bubble, set the alidade bubble exactly central, and clamp the Horrebow bubble to the telescope axis. The Horrebow bubble can then be moved with the vertical circle slow-motion, and dislevelment can be detected by the alidade bubble drifting off centre.

11.3 For the sign of the alidade bubble reading, see paragraph 8.5. The signs are so chosen that if the altitude read on the circle is less than the true altitude of the telescope axis, and therefore needs to be increased, then the bubble reading is positive.

11.4 To calibrate, move the bubble to one end of its run, and check that the telescope is on target, or the alidade bubble is central. Read the vertical circle and the bubble. Then move the bubble about one-sixth of its run, let it settle, and take another reading. Repeat till the bubble is at the other end of its scale. Readings can advantageously be made more frequently towards the ends of the scale, and less frequently in the middle. Check that the vertical axis has not moved, and take another series of readings back up the scale to the starting point. Make a final check on the vertical axis.

11.5 With the T3, convert the circle readings to seconds, but leave the alidade bubble readings in their original form. For each setting of the single Horrebow, form the sum of the end readings minus 40, and divide by two. With the double Horrebow, form the sum of the end readings minus 280, and divide by four. Plot a graph of seconds of altitude against bubble divisions. Draw a straight line through the points, using either a transparent ruler or a piece of thread to judge the slope of the line. Avoid simply joining up the two end points. Determine the slope of the line in seconds per division. More sophisticated methods of calculating the slope can be adopted, such as least squares; but little is gained. Avoid taking observations in pairs, calculating the slope for each pair, and taking the mean: this is equivalent to throwing away all the observations except the end ones.

11.6 With some instruments, it may be found that two separate parallel lines are obtained on the graph, one when the altitude is increasing, and the other when it is decreasing. The separation may be great, as much as 10", and is due to backlash. When this defect is found, the cure is always to make the last adjustment to the slow-motion screw in a clockwise direction, regardless of whether one needs to move the bubble up or down. Few observers do this, and with a new instrument it is not essential, but it is clearly a good habit to get into.

Stride and Plate Bubble Calibration

11.7 The DKM3a stride level can be mounted on top of the telescope of a T3, parallel to the optical axis, and bound on with masking tape. It can then be calibrated against the vertical circle just like a Horrebow level. This method is no good for plate bubbles.

11.8 Both stride and plate bubbles can be calibrated using a bubble testing bench. There is one at Mount Stromlo. It is a rigid bar of known length, on which the bubble, and even the whole theodolite, is placed, with the bubble parallel to the bar. One end of the bar is hinged. Under the other, "shims" of various accurately known thickness are inserted, the bubble being read for each. The inclination of the bar (referred to some arbitrary horizon) is then

$$\frac{(\text{Thickness of shim}) \times \operatorname{cosec} 1''}{(\text{Length of bar})} \quad \text{seconds}$$

which is plotted against the bubble readings as in paragraph 5.

The Wisconsin Method

11.9 To calibrate a stride or plate bubble in the field use the Wisconsin Method, for which the following description has been amplified from Clarke, Vol 2, 1963 edition, page 86. Set up and level the instrument carefully. Ensure that the stride or plate bubble is in reasonable adjustment, and note its reading when the instrument is level. Select a foot-screw which is close to one end of its run, and carefully align the telescope so that the centre of the object lens is over it, and clamp. Centre the alidade bubble and read the vertical circle. The plan is to move the alidade bubble adjusting screw until the screw is near the end of its run, and then re-centre the bubble using a foot-screw under the object lens. If the foot-screw is going to fall, move the alidade bubble towards it and vice versa. On the DKM3a, while throwing off the alidade bubble, look down the micrometer, and count how many pairs of twin circle graduations pass the single circle graduation. Each interval is equivalent to 5'. Re-centre the alidade bubble using the foot-screw under the object lens. Bring the stride level back to its level position by rotating the instrument slightly in azimuth. Set the horizontal circle to read zero. Check the alidade bubble is still central and if necessary adjust it using the alidade bubble adjusting screw. Read the vertical circle. Let the difference between the two vertical circle readings (plus an integral number of 5' intervals on the DKM3a) be i.

11.10 The instrument is now set with its stride or plate bubble in the level position, the horizontal circle reading

zero, and the vertical axis off level by an angle $\underline{i}$ in the plane of the telescope axis. Take a series of readings as follows. Swing off in azimuth until the stride or plate bubble is at one end of its run. Read the horizontal circle and the stride bubble. Swing back until the bubble has moved about one-eighth of its run, let it settle, and read again. Repeat until the bubble is at the far end of its run, and then take another series of readings coming back again. Convert the horizontal angles to ΔH seconds, plus or minus from the central position, and tabulate $\Delta H''$. tan $\underline{i}$. Convert the stride bubble reading to divisions by adding the two end readings, subtracting 40, and dividing by 2. Convert plate bubble reading to divisions by taking the left end reading from the right end reading and dividing by 2. See Figure 17 for an example of the booking and the reductions.

11.11 Plot a graph of $\Delta H''$. tan $\underline{i}$, and determine its slope in seconds per division, which will be the value of the bubble.

Calibration of the Micrometer Eyepiece

11.12 East stars are tracked upwards, and west stars are tracked downwards. There may be backlash in the mechanism, and in one case one edge of the contact strip throws the pen on the chronograph, and in the other case the other. We have therefore to determine a correction for what is commonly known as "Lost motion and width of contacts". This is done once a year, and is done in two parts, one preferably in the office and the other in the field.

11.13 The office test consists simply of connecting the micrometer eyepiece to the chronograph, and moving the hair through a complete rotation of 120 divisions. The pen will be thrown by the contacts at 0, 12, 24 etc. Keep an eye on the micrometer readings and an ear open for the pen. The instant the pen throws, book the micrometer reading. Then come back the other way across the same contacts, and book the micrometer reading when the pen is thrown by the other side of the contact strip. The mean width of the ten contact strips is then obtained in terms of a micrometer division.

11.14 To determine the lost motion, bring the double micrometer hair over a fixed wire from the left, and read the micrometer; then from the right, and read the micrometer. The difference in the readings is the backlash. Measure it very carefully at least two times and take the mean. Add the

Fig.17-Calibration of bubbles by the Wisconsin method.

KERN DKM3A No.103052 Stride Level No.101087

Obs. D. Cook 13.5.65

i = 05′57″ tan i = 0·00173

Horizontal circle set to 270°00′00″ initially.

STRIDE BUBBLE Length	Ends		Centre	HOR	△ H	△H″.tan i
20·8	17·0	37·8	27·4	267° 20′	−2° 40′	−16·6
20·6	16·6	37·2	26·9	267 25	−2 35	−16·1
20·7	15·5	36·2	25·85	267 40	−2 20	−14·5
20·8	14·9	35·7	25·3	267 50	−2 10	−13·5
20·7	14·3	35	24·65	268 0	−2	−12·5
20·8	13	33·8	23·4	268 20	−1 40	−10·4
20·8	11·9	32·7	22·3	268 40	−1 20	−8·3
20·8	10·7	31·5	21·1	269	−1	−6·2
21·0	8	29	18·5	269 40	+0 20	−2·1
20·7	6	26·7	16·35	270 20	+0 20	+2·1
20·8	4·7	25·5	15·1	270 40	+0 40	+4·6
20·9	4·0	24·9	14·45	270 50	+0 50	+5·2
20·8	3·6	24·4	14·0	271 0	+1	+6·2
20·8	3·0	23·8	13·4	271 10	+1 10	+7·3
21·0	2·0	23·0	12·5	271 20	+1 20	+8·3
20·9	1·5	22·4	11·95	271 30	+1 30	+9·3
21·0	1·0	22·0	11·5	271 40	+1 40	+10·4
20·9	1·4	22·3	11·85	271 30	+1 30	+9·3
21·0	2·0	23·0	12·5	271 20	+1 20	+8·3
20·9	2·9	23·8	13·35	271 10	+1 10	+7·3
20·9	3·5	24·4	13·95	271 0	+1 0	+6·2
20·9	4·8	25·7	15·25	270 40	+0 40	+4·6
20·8	6·0	26·8	16·4	270 20	+0 20	+2·1
20·9	8·5	29·4	18·95	269 40	−0 20	−2·1
21·0	10·7	31·7	21·2	269 0	−1 0	−6·2
21·0	13·0	34·0	23·5	268 20	−1 40	−10·4
21·0	14·0	35·0	24·5	268 0	−2 0	−12·5
21·0	15	36	25·5	267 40	−2 20	−14·5
21·0	15·6	36·6	26·1	267 30	−2 30	−15·6
21·0	16·0	37·0	26·5	267 20	−2 40	−16·6
21·1	16·7	37·8	27·25	267 10	−2 50	−17·7

mean to the width of the contact strips.

11.15 It remains to determine the value of a micrometer division in terms of arc, or more conveniently in terms of time for an equatorial star. This is done at a field station. At a convenient time when changing from longitude to latitude observations, turn the micrometer eyepiece back from altitude to the azimuth position, and find a star from the latitude predictions which transits in the north within 10° of the equator. Set the instrument in the meridian, and track the latitude star in azimuth from one outer hair to the other. Extreme care is required only as the star crosses the five hairs, corresponding to micrometer readings 5.0, 7.5, 10.0, 12.5 and 15.0. The value of a micrometer division is equatorial seconds is obtained from :

$$\frac{(\text{Time interval between 5.0 and 15.0 contacts})}{(15.0 - 5.0) \times 120} \times (\cos \delta \text{ for star observed})$$

The intermediate readings give checks against gross errors.

11.16 For almucantar longitudes observed within 10° of the prime vertical, instead of applying a correction to each star, we can apply a correction to the mean longitude at each station. By differentiating the basic formulae of the astronomical triangle, we obtain the well known formula :

$$\delta t = \frac{-\delta h}{\cos \phi \, . \, \sin A}$$

In our case, δt is the correction to time or longitude, which we require, brought about by an error δh in altitude caused by the width of contacts and loss motion, also expressed in seconds of time. For sin A, we may use the average value when A lies randomly between 80° and 100°, which is 0.995.

11.17 So if we let

W = Width of contacts plus lost motion, in micrometer divisions.

D = Value of one micrometer division in seconds of time.

Then the correction to the longitude of a station in latitude ϕ is :

$$\frac{W \times D}{2 \times 0.995 \times \cos \phi} \quad \text{seconds of time.}$$

12. REPAIRS IN THE FIELD:

12.1 Make no repairs or adjustments to the theodolite, unless you have been instructed what to do, and know exactly how to do it. Modern theodolites are delicate and complicated machines, and amateur attempts at repair or adjustment are seldom successful. It is not the policy to train surveyors and technical staff to be instrument mechanics. The policy is to train observers to handle, and transport, their instruments with care; and to have instruments maintained in good order by professional mechanics on their return from every journey. They will then seldom require attention in the field. When they do, the policy is to fly them back for professional repair.

Lights

12.2 Even the most modern theodolites are apt to have trouble with their lights. The Wild T3 and Kern DKM3a are no exception. The lighting system must be tested before leaving the office, and immediately on receiving an instrument back from repair.

12.3 If lights fail in the field, check the contacts, and if necessary clean with fine emery paper; check the globes, and if necessary tighten or replace. Do not use globes or batteries of a voltage higher than that recommended by the manufacturer. Brighter lights may be obtained initially, but the wiring is likely to burn out. Use solder on external joints. Despite all precautions, it still seems inevitable that from time to time the observer will have to fall back on the only infallible stand-by: reading the bubbles with the aid of a torch.