Report on Aerodist Surveys carried out by the Australian Division of National Mapping since 1963*

B. P. LAMBERT

Australia

Presented by

J. V. BULEY

The Division's Aerodist equipment was mounted in a helicopter and subjected to preliminary trial during 1963. In the latter half of 1963 and during the 1964 field season it was successfully used on line crossing trilateration surveys.

This year the equipment has been transferred to a fixed-wing aircraft and after trilateration survey is now about to be used to obtain position-controlled photography.

This paper describes the Aerodist work carried out by the Division and concludes with an estimate of the likely resultant accuracy.

Introduction

The Division's Aerodist equipment was mounted in a helicopter and subjected to preliminary trial during 1963. In the latter half of 1963 and during the 1964 field season it was successfully used on line crossing trilateration surveys.

This year the equipment has been transferred to a fixed wing aircraft and after further trilateration survey is now about to be used to obtain position-controlled photography.

This paper describes the Aerodist work carried out by the Division and concludes with an estimate of the likely resultant accuracy.

1963—Equipment Trials

For familiarization purposes the equipment, consisting of a two-channel system, was first mounted in a motor vehicle and tested on the

* This report has been prepared by officers of the Division of National Mapping, Department of National Development, Australia.

ground in mid-1963 for line crossing techniques over a length of approximately 36 miles (58 km). The result came within $\pm 1\frac{1}{2}$ metres of the Tellurometer measurement for the whole line.

The equipment was next mounted in a Bell 47J helicopter with the 2 master units and attached aerial control boxes, the pen recorder, triode and junction boxes mounted inside the cabin. The antennae were bolted on a rigid platform fixed externally to the rear skids of each side of the helicopter.

A number of test lines varying from 58 to 203 km were then measured in Victoria. Two of these lines had previously been directly measured with the Tellurometer and the following comparative results were obtained:

Line	Geodetic length (G) (metres)	Aerodist			A–G
		Length (A) (metres)	No. of meas.	Spread of meas.	
Bacchus Marsh – Geelong	58 155·94	58 155·4	18	5·2	−0·5
Porndon – Monmot Hill	75 201·35	75 203·2	4	5·6	+1·9

1963—Operational Surveys

Production work was then undertaken in Central Queensland with the objective of measuring, by line crossing technique, the sides and diagonals of a series of 1° × 1° quadrilaterals which were to be fitted into a surrounding first-order survey.

Two pairs of ground stations were used and were moved by road vehicles; each vehicle being equipped with a 25-watt h.f. Transceiver for both ground-to-ground and ground-to-aircraft intercommunication.

Some difficulties were experienced with the helicopter which, at times, had to operate at altitudes of 2100 m when lines greater than 150 km were measured but only minor equipment troubles were encountered and these were easily attended to by field personnel.

Over a 6-week period thirteen quadrilaterals were measured including four comparisons with first-order Tellurometer traverses. The average number of crossings was five.

Most ground stations were fixed for elevation by third-order levelling but in some instances it was necessary to resort to careful barometric work.

In all operational work the practice has been to compare continuously with the surrounding first-order survey in order to determine any index error or any performance variability in the Aerodist equipment and the following comparisons were obtained during the 1963 survey.

Line	Geodetic length (G) (metres)	Aerodist			A–G
		Length (A) (metres)	No. of meas.	Spread of meas.	
Noakes Lookout / Bluff	125 935·02	125 935·3	3	0·7	+0·3
Staircase / Planet	91 522·87	91 519·9	7	3·6	−3·0
Staircase / Dawson	145 816·62	145 817·3	4	4·7	+0·7
Dawson / Holly	127 947·21	127 945·8	5	3·7	−1·4

At this time the 'atmospherics' at the airborne station were obtained by holding an Assman–Lambrecht psychrometer in the slipstream and then making rapid readings inside the cabin.

1964 Surveys

In 1964 a third master channel was obtained and the three masters were mounted in the helicopter; this third channel did not function satisfactorily and was not used operationally.

Crossover co-axial switches were fitted to enable the master stations to operate through either of the antennae and thereby enable line crossings to be made in both directions.

Use was made of a prototype psychrometer that had been developed by the Applied Physics Division of the Commonwealth Scientific and Industrial Research Organization. It embodied a vented and baffled venturi to reduce the velocity of air flow and prevent dynamic heating effects. The depression of the wet bulb was determined by means of thermocouples and the output was amplified to a suitable display by means of a d.c. amplifier. These data were referenced to an insulated mercury-in-glass thermometer inside the aircraft and readout was by means of a switched meter.

The first operations in 1964 were unsuccessful and the Aerodist equipment had to be returned for workshop servicing but after complete re-alignment the original two masters worked satisfactorily with only minor interruptions. However, operations with the third master were again unsuccessful.

Over a period of nine weeks eighteen new stations were established in a 1° quadrilateral pattern and 110 lines measured with an average of seven crossings to each line. On sixteen lines comparisons were made with the first order Tellurometer traverse. These comparisons are tabulated on page 360.

1965 Surveys

This year the equipment has been transferred to an Aero Commander 680 E fixed wing aircraft in which the antennae are fitted at the end of rotatable axes and are about 2 ft clear of the fuselage. A simple lever moves them to a vertical position in flight and to a horizontal position for landing and take off.

A commercially manufactured version of the CSIRO psychrometer has been fitted into one window spacing of the aircraft and the three masters, the pen recorder and ancillary equipment have been mounted against the rear bulkhead of the cabin.

Some weeks were spent re-aligning and testing the equipment before it was taken into the field for operational work. (It is now standard procedure to do this and actually check the equipment over a known line before proceeding to the field for operational work.)

On return to the field, once again, the original two masters operated satisfactorily with minor maintenance but the third master was unsatisfactory.

In a period of eight weeks seventy-seven lines were measured with seven to ten crossings each and comparisons were made with eleven Tellurometer traverse lines.

On completion of this operation the aircraft returned to headquarters for installation of positioning camera equipment consisting of a Wild Horizon Camera geared to a Vinten vertical camera and the whole linked with ground sighting device.

The aircraft has now just left for the field where it is intended to try and obtain horizontal positional control for mapping operations. Tentatively this is planned to consist of ground trilateration stations at the 30-minute graticule intersections and controlled photography at the remaining 15-minute intersections.

To the present only the following of this year's comparison lines have been computed (see table on page 363):

Line	Geodetic length (G) (metres)	Aerodist			A–G
		Length (A) (metres)	No. of meas.	Spread of meas.	
Bendemeer / NMC 51	84 098·28	84 095·8	8	5·1	−2·5
Antares / NMC 51	151 715·33	151 709·3	Rejected (poor trace)		−6·0
Antares / Bendemeer	113 410·44	113 408·0	7	3·9	−2·4
Antares / Wingebar	107 161·75	107 161·6	5	6·6	−0·2
Wingebar / Bendemeer	172 321·70	172 319·1	5	3·2	−2·6
Wingebar / Woorut	97 991·95	97 991·6	5	2·5	−0·3
Woorut / King Jack	107 481·00	107 481·9	6	2·9	+0·9
Woorut / Kaputar	153 018·14	153 017·8	3	2·6	−0·3
King Jack / Kaputar	86 185·39	86 183·5	7	7·6	−1·9
Kaputar / Gragin	100 100·43	100 099·2	8	2·7	−1·2
Gragin / Carpet Snake	88 028·32	88 026·8	7	7·5	−1·5
Carpet Snake / Gammie	124 679·69	124 678·2	6	4·9	−1·5
Gammie / Fair Hill	117 400·96	117 399·4	7	5·0	−1·6
NMC 51 / E 355	106 536·52	106 536·4	7	1·9	−0·1
E 355 / Bendemeer	156 100·02	156 099·3	7	4·3	−0·7
Mitchell / Bassett	96 221·76	96 222·9	5	3·2	+1·1

Line	Geodetic length (G) (metres)	Aerodist			A–G
		Length (A) (metres)	No. of meas.	Spread of meas.	
Noake's Lookout / Bluff	125 935·02	125 935·3	10	7·8	+0·3
Gammie / Fair Hill	117 400·96	117 398·5	10	3·6	−2·5
Texas / Gammie	95 254·09	95 251·3	11	6·2	−2·8
Fair Hill / Bluff	91 006·94	91 005·8	11	3·9	−1·1

Reduction of Data and Computations

Charts from the line crossing measurements are examined, pairs of distances extracted and a graph plotted. Groups of ten measurements are then selected at equal intervals on each side of the minimum point and these twenty-one readings are computed on a standard programme to give, by least squares, the best fitting parabola.

There is a large volume of work in the extraction of data from the graphs, therefore an order has been placed for a chart reader that will readily convert data into digital form.

Every perimeter has been connected by Tellurometer traverse to the surrounding first-order survey and the computation of geodetic co-ordinates will be by a programmed least-square variation of co-ordinates technique in which the perimeter stations will be held fixed.

Operational Functioning

There is no doubt that knowledgeable and skilled servicing is required in order to keep the Aerodist equipment operational. (This has been provided by the Australian agents.) Each year it has taken some weeks, at the start of the survey season, to get the equipment functioning but once it has started to function properly very little further trouble has been encountered in the field when operating two master stations for line-crossing measurements. It has just not been possible to get the third master to operate satisfactorily.

Analysis of Results

It has been accepted that the errors in the first order Tellurometer traverses are negligible in comparison with the errors of the Aerodist measurements.

A general analysis indicates that in the range approximately 100 to 150 km the size of the errors was fairly constant and from all twenty-five comparisons so far made with the geodetic survey an index correction of $+0{\cdot}9$ m has been determined.

The residuals of each observation have been brought to unity weight and a statistical analysis of these unity weight observations gives a standard deviation of $\pm 3{\cdot}5$ metres for a single line-crossing measurement.*

The corrected measurements and their equal unity weights are tabulated in the Appendix.

Likely Precision

It has been concluded, that if in the course of 1-degree quadrilateral-type trilateration nine satisfactory crossings are obtained per line over a period of at least two days, the standard deviation of measurement will be $\pm 1{\cdot}2$ m which is the equivalent of ± 12 and 8 parts in 10^6 respectively on the orthogonals and diagonals.

It is expected that these ratios will be improved by the large number of conditions introduced in the course of fitting the trilateration to a complete perimeter surround but that they will be adversely affected by the strains introduced by the adjustment of the national geodetic survey.

In this survey the average length between junction points is 200 miles and loop mis-closures have averaged 2 parts in 10^6 while the preliminary computation of the main network, based on equal weighting for azimuth and length, has resulted in adjustments between traverse junction points of an average of 0·4 seconds of arc for azimuth with a maximum of 1·4 seconds, and of 1·8 parts in 10^6 for length, with a maximum of 6 parts in 10^6.

It is hoped that the finally adjusted lengths of the Aerodist 1 degree trilateration network will have a standard deviation of ± 10 parts in 10^6 provided these networks are restricted to a block of about 4° of longitude × 4° of latitude throughout the continental area of Australia.

* A similar treatment of the comparisons reported in 'Aerodist Test Project' (*The Canadian Surveyor*, September 1964) gave a standard deviation of $\pm 2{\cdot}7$ m for a single line-crossing measurement.

APPENDIX

Line	Length (metres)	No. of meas. (n)	A–G (corrected for index error = +0·9 m)	Errors converted to unity weight $\sqrt{n}$(A–G) = V	V^2
Bacchus Marsh / Geelong	58 156	18	+0·4	1·7	2·89
Porndon / Monmot Hill	75 201	4	+2·8	5·6	31·36
Noakes Lookout / Bluff	125 935	3	+1·2	2·1	4·41
Staircase / Planet	91 523	7	−2·1	5·5	30·25
Staircase / Dawson	145 817	4	+1·6	3·2	10·24
Dawson / Holly	127 947	5	−0·5	1·1	1·21
Bendemeer / NMC 51	84 098	8	−1·6	4·5	20·25
Antares / Bendemeer	113 410	7	−1·5	4·0	16·00
Antares / Wingebar	107 162	5	+0·7	1·6	2·56
Wingebar / Bendemeer	172 322	5	−1·7	3·8	14·44
Wingebar / Woorut	97 992	5	+0·6	1·3	1·69
Woorut / King Jack	107 481	6	+1·8	4·4	19·36
Woorut / Kaputar	153 018	3	+0·6	1·0	1·00
King Jack / Kaputar	86 185	7	−1·0	2·6	6·76
Kaputar / Gragin	100 100	8	−0·3	0·8	0·64
Gragin / Carpet Snake	88 028	7	−0·6	1·6	2·56
Carpet Snake / Gammie	124 680	6	−0·6	1·5	2·25
Gammie / Fairhill	117 401	7	−0·7	1·8	3·24
NMC 51 / E 355	106 537	7	+0·8	2·1	4·41
E 355 / Bendemeer	156 100	7	+0·2	0·5	0·25
Mitchell / Bassett	96 222	5	+2·0	4·5	20·25

Line	Length (metres)	No. of meas. (n)	A–G (corrected for index error = +0·9 m)	Errors converted to unity weight $\sqrt{n}$(A–G) = V	V^2
Noakes Lookout / Bluff	125 935	10	+1·2	3·8	14·44
Gammie / Fair Hill	117 401	10	−1·6	5·1	26·01
Texas / Gammie	95 254	11	−1·9	6·3	39·69
Fair Hill / Bluff	91 007	11	−0·2	0·7	0·49

$$\sum V^2 = 276{\cdot}65$$

$$\sqrt{\frac{\Sigma V^2}{n-1}} = \sqrt{\frac{276{\cdot}65}{24}} = \pm 3{\cdot}4 \text{ m}$$

DISCUSSION

Owing to shortage of time there was no discussion of this paper.

Adjustments of Aerodist Observations

B. R. EVANS

Canada

Aerodist is a powerful tool for extending survey control rapidly over wide areas. The method of adjustment outlined in this paper is suitable for medium-sized computers with magnetic tape or disk facilities, and the paper includes a general outline of a programme to perform the adjustment.

The method is developed in connection with continuous trilateration by Aerodist, but can also be used to adjust data from other airborne measuring systems (HIRAN, SHIRAN, etc.). The paper shows how data from continuous trilateration by Aerodist and data from connecting surveys and azimuth observations can be adjusted simultaneously. The same programme can be used for fixing the positions of photo stations when Aerodist is used with fixed ground stations.

1. *Applications*

Aerodist is an electronic ranging system capable of measuring simultaneously and continuously distances to three ground points; these measurements are accurate to 5 ppm[8] for maximum distances of about 100 miles. This ability to take ranges on *more* than two ground points has opened up new possibilities in electronic surveying, particularly continuous trilateration, which for establishing horizontal mapping control is considerably faster and cheaper than ground surveys, and can be carried out in terrain where ground surveys are impractical.

Essentially, the procedure is quite simple, as illustrated in Fig. 1. By means of radio waves, an instrument in the aircraft takes continuous simultaneous ranges to three ground transmitters at prescribed time intervals (i.e. from successive points along the flight line). Then, if the positions of two of the ground transmitters are fixed and the height of the aircraft is known, the position of the unfixed ground transmitters can be calculated. This is the basic concept of continuous trilateration by Aerodist; in practice, one can fix a whole net of new ground points. It is also possible to adjust other types of surveys simultaneously with data obtained from continuous trilateration, and these data can be incorporated in the computational procedures outlined in this paper for continuous