Paper 7

A Unique Insight into National Mapping's Programs

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ABSTRACT

In an era before instant information, communication and location, the Division of National Mapping (Natmap), the Federal Government's civilian mapping agency, utilised then state of the art technology and processes in support of its mapping programs. Aerial photography, acquired by contractors and Natmap, was the primary data source. Accurate extraction of the map information from this photography required that the photography be 'controlled' both horizontally and vertically. This required that the relatively sparse continental scale horizontal and vertical control networks be intensified. The *Aerodist* program produced the framework for the required horizontal control intensification while the vertical control came from the *Laser Profiling* program. How it was, how it was done and how it was reported is contained in three included documents providing a unique insight into this part of Natmap's mapping role.

BIOGRAPHICAL NOTES

<u>Carl McMaster</u>
After training as a surveyor under the article system, Carl joined the Division of National Mapping in 1962 where for the next 23 years he worked on field surveys and map sheet compilation. This work involved conducting field trials with the *Aerodist* airborne electronic survey system and its subsequent introduction into the operations of the national mapping program.

In 1986 Carl moved to the Australian Centre of Remote Sensing (ACRES) where he led the agency's expansion from the acquisition and processing of early Landsat data through to higher resolution imagery. From 1994 until 2001 he managed the Australian subsidiary of the French satellite company Spot Image.

<u>Paul Wise</u>
Paul holds a Masters Degree in Remote Sensing from the University of NSW, as well as qualifications in surveying from the Royal Melbourne Institute of Technology and in aerial photography from the ITC in the Netherlands.

Paul has worked in the surveying, mapping and remote sensing industry for nearly 40 years including 15 years with the Division of National Mapping. During his time with National Mapping he undertook field and office work associated with ground marking, control surveys using *Aerodist* and *Laser Terrain Profiler*, aerial photography, and map sheet completion and revision.

A Unique Insight into National Mapping's Programs

Introduction

As the Federal Government's civilian mapping agency the Division of National Mapping (Natmap) had the responsibility for producing the major part of Australia's 1:250 000 scale and 1:100 000 scale mapping requirements.

In the 1960's the national horizontal and vertical control networks were sparse and would need to be intensified to meet the accuracy and time demands of this mapping. Furthermore, the control would have to suit aerial photography as the primary data source.

How it was, how it was done and how it was reported is contained in the three included documents reproduced by kind permission of the publishers and copyright holders. By letting these documents 'speak for themselves' it is considered that they provide a unique insight into this part of Natmap's mapping role.

Setting the scene

Aerial photography was the foundation of Natmap's mapping programs. From the 1950s this photography was acquired by Defence, Contractors and Natmap. The resulting maps were a product of the photography controlled by the best horizontal and vertical information available at that time.

In the era described, 1:80 000 scale aerial photography was the primary data source. Mapping information was extracted from this photography using overlapping pairs (a 'stereo-model') of photographs in stereoplotters with horizontal and vertical control required for each stereo-model.

A number of 1:250 000 scale map areas were selected to form a "block" using whatever control was available. An assembly of slotted templates was then used to graphically determine the positions of the horizontal control, at the stereo-model level.

Until the 1960s the primary geodetic survey networks supplemented by astronomic observed and identified survey marks provided the horizontal control with barometric heighting and 3rd order level traverses for the vertical control.

To accelerate the mapping program Natmap (in parallel with the Army Survey Corp) implemented the Aerodist program from the mid-sixties with block perimeter control from the 1st and 2nd order Geodetic Control networks with a 1º latitude by 1º longitude (sometimes 30' by 30') grid of 'Aerodist stations'. The Aerodist system was essentially an airborne EDM system purchased from the South African Tellurometer manufacturers. Aerodist measurements enabled the spheroidal distance between, usually non-intervisible, ground stations to be calculated, with the final coordinates on the Australian Geodetic Datum, emerging from a least squares fit to the surrounding geodetic control.

Vertical control was generally provided by acquiring a continuous profile of the terrain from which height points at the stereo-model level could be extracted. Early profiling was obtained using radar technology. Later Natmap introduced and operated its own purpose-built Laser Terrain Profiler providing more accurate height data due to the narrower 'beam' of the laser as compared with the radar. For example if the radar sampled an area on the ground 100 m in diameter then from the same altitude the laser's sampling area would be less than 1 m.

The laser profile acquisition program was undertaken such that bench marks on the 3rd order National Levelling network could be used to relate the profiles, and any point on them, to the Australian Height Datum. Less intense profiling was used where semi-analytical methods provided the final vertical control values.

While Natmap employed then state of the art technology in its data gathering role it is important to note that the overwhelming majority of its data 'reduction' was manual. These processes, whether it be cutting and laying slotted templates, deciphering Aerodist charts, or calculating profile heights while labour intensive, also allowed errors to be 'trapped' and 'isolated' as they occurred. Errors did not accumulate such that they compromised the final product. For example if a template did not move freely or the assembly did not sit 'flat and without strain' it indicated that that a template or templates had a problem and the control etc should be checked and new template(s) cut until the problem was resolved. If a specific Aerodist block adjustment had large residuals then charts could be re-examined or the data sheet rechecked. Heights from the Laser profiler were selected in pairs, enabling the identification of an erroneous height calculation.

As the mapping program proceeded during the early 1970s, stereo-model control was also provided by in-house analytical aerotriangulation. By the 1980s the template assembly technique had been phased out and replaced by contract analytical aerotriangulation.

For operational purposes the accuracy of the maps produced was measured by their 'completeness' (fidelity of representation and description of the topographic features represented) and 'metric quality' (the correct geographical positioning of the topographic features represented).

Completeness surveys were carried out by air and ground methods in an effort to ensure the topographic features depicted were correctly represented and labelled.

In an era before Global Positioning metric quality was ascertained on a sampling basis. Within a block of maps based on common horizontal and vertical control a representative 1:100,000 scale map was selected and the positions of 'check' points independently established by ground survey and compared with the map coordinates for the same features.

Suffice it to say that as far as it could be proved, Natmap maps met the established map accuracy criteria of the time.

Introducing the original documents

The technology and processes used for the compilation of maps from aerial photographs, by Natmap and its predecessors, is described by Dave Hocking in the first document (Annexure A). His paper 'Natmap early days, map compilation from aerial photographs 1948 - 1970s', was previously published in The Globe. His paper also references the other two documents reinforcing the relationship of the three documents.

Natmap's Aerodist program is detailed by Carl McMaster in Natmap's Technical Report. No 27, 'Division of National Mapping Aerodist Program' (Annexure B). This program was responsible for providing horizontal control for 1:100 000 scale mapping over slightly more than half Australia and extended the survey network to various reefs and islands.

Finally the Laser Profiling program which provided vertical control for the photogrammetric plotting for over one third of Australia is described by Paul Wise in Natmap's Technical Report No. 26, 'Laser Terrain Profiling' (Annexure C).

Concluding remarks

In the last half of the 20th Century, Natmap's programs, in cooperation with Defence and the States, unquestionably resulted in a legacy of accurate topographic maps leading to the current digital mapping era based on satellite based imagery and positioning.

For its part, Natmap utilised the then state of the art technology and processes as described in the attached documents to complete its map control and compilation programs. By letting these documents 'speak for themselves' it is considered that they provide a unique insight into this aspect of Natmap's role.

Acknowledgements

The Authors gratefully acknowledge the following:

> the Australian Map Circle for their written permission to reproduce Dave Hocking's paper as published in The Globe #47 (1998) titled Hocking, D, 'Natmap early days, map compilation from aerial photographs 1948 - 1970s', p. 16-34;
>
> verbal permission from the copyright holder's estate, through Mrs Iris Hocking, to reproduce Dave's article as part of their paper. Our sincere thanks go Iris and hope the incorporation of his paper represents a fitting tribute to Dave;
>
> the Commonwealth of Australia, through Geoscience Australia for written permission to reproduce the two Natmap technical reports 'Division of National Mapping Aerodist Program' Technical Report No 27, copyright © Commonwealth of Australia, Geoscience Australia, (1980), and 'Laser Terrain Profiling' Division of National Mapping Technical Report No. 26, copyright © Commonwealth of Australia, Geoscience Australia, (1979); and
>
> so as not to leave anyone out, all those who worked for or with Natmap, for their contribution to mapping Australia.

ANNEXURES

ANNEXURE A
Hocking D.R. (1998) 'Natmap early days, map compilation from aerial photographs 1948 - 1970s', The Globe, 1998, #47, p. 16-34.

ANNEXURE B
McMaster C. G. (1980) 'Division of National Mapping Aerodist Program' Technical Report. No 27, Copyright © Commonwealth of Australia, Geoscience Australia, (1980).

ANNEXURE C
Wise P. J. (1979) 'Laser Terrain Profiling' Division of National Mapping Technical Report No. 26, Copyright © Commonwealth of Australia, Geoscience Australia, (1979).

ANNEXURE A

NATMAP EARLY DAYS, MAP COMPILATION FROM AERIAL PHOTOGRAPHS 1948 – 1970s

David R. Hocking

This paper describes the methods used to compile maps from aerial photographs, commencing 50 years ago, by the National Mapping Section / Office as it was variously known in those early days before becoming the Division of National Mapping (Natmap). Some of these products were : aerial photo indexes, mosaics, radial line plots, slotted template assemblies, 'shift & trace' or Zeiss Sketchmaster or Wild A6 plotted map compilation sheets. These map-substitutes and planimetric small scale maps at 1:253 440 and 1:250 000 were urgently needed by users, such as Natmap surveyors and geo-scientists who wanted information about the country they were working in and needed to record their findings as accurately as possible in relation to the terrain. With the first priority special mapping needs being satisfied, a more precise method of slotted template planimetric adjustment of very large blocks of aerial photos for horizontal position at 1:100 000 scale was introduced in the 1960s. Vertical control for the 20 metre contour interval specified for the 1:100 000 scale topographic map series was obtained using airborne radar/laser terrain profiling along the sidelaps of the aerial photo coverage. Stereoplotting of map detail and contouring from stereoscopic models formed from overlapping aerial photos using Kern PG2 and Wild B8 instruments is described.

Aerial photographs, until recently, have been the main provider of topographic information for a national mapping program. Satellite imagery is now being used to revise major features of the small scale, 1:250 000 data base. The high resolution, 1 metre ground sample distance, satellite imagery expected to be available during 1998/99 will be used to upgrade the medium and large scale, 1:100 000 and 1:25 000 data bases. Aerial photography will continue to be used for the large scale project mapping needed for engineering, mining, construction, and so on and, no doubt, both digitized aerial and satellite imagery will be used on some projects.

Dave Hocking is part-time Executive Director of The Association of Aerial Surveyors, Australia Inc. (AASA). After WWII Dave worked for nearly 38 years with the Division of National Mapping on the field and office tasks needed for the compilation of maps.
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During the past 80 years the major events in the imagery available for mapping Australia at small and medium scales are:

- The 1:50 000 scale Fairchild K17 camera aerial photos obtained from 25 000 feet by RAAF, 87 PR (Photo Reconnaissance) Squadron, 1947 - 1953. These photos provided the basic data for the 1:253 440 and 1:250 000 R502 map series.
- The 1:80 000 scale Wild RC9 or RC10 camera aerial photos taken from 25 000 feet and obtained by Natmap using contractors during the 1960s and 1970s. These photos provided the basic data for the 1:100 000 series and the 1:250 000 National Topographic Map Series.
- The eagerly awaited availability in 1998/99 of 1 metre high resolution images from the Space Imagery Eosat (SIE) 'Ikonos 1' satellite. This imagery will provide the basic data for up-grading medium and large scale data bases.[1]

[1] See www.spaceimage.com for more details.

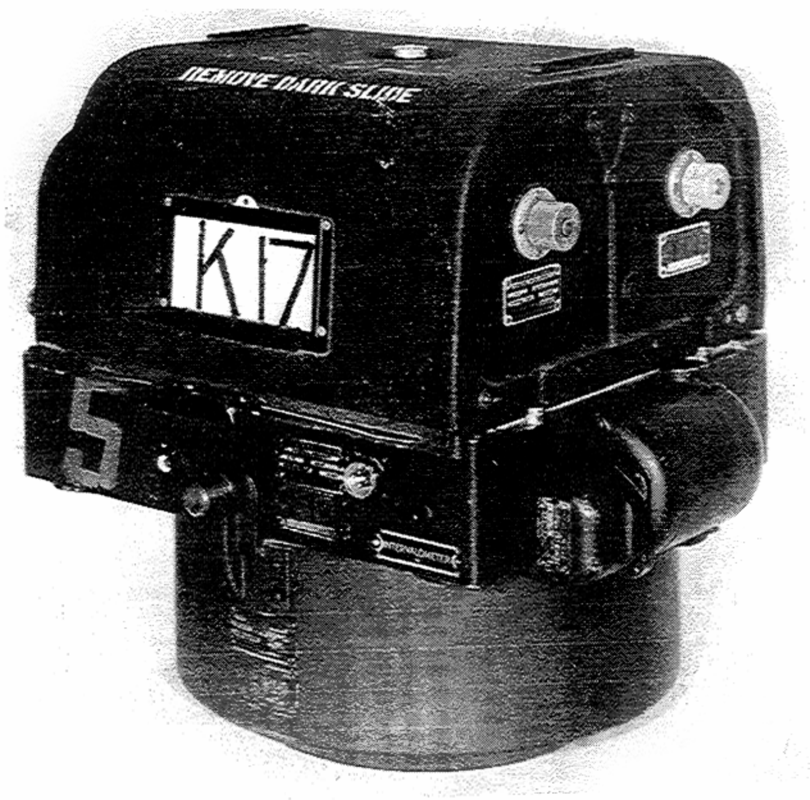


Fig. 1. Fairchild K17 aerial photography camera.

SUMMARY OF AERIAL PHOTOGRAPHY DEVELOPMENT IN AUSTRALIA

1920s After the First World War some general purpose cameras were used and photos taken with the camera held over the side of the aeroplane.

1924 RAAF, Royal Australian Air Force, first areas for mapping, using a P18 plate camera which had a 4"x 5" format.

1927 RAAF, F8 (Eagle I), 100 exposures on film, 7"x 8¼" format with 8¼" lens. Ca. 19 000 square miles photographed in eastern Australia.

1930 RAAF, F8 or Williamson Eagle III.

1936 RAAF, Williamson Eagle IV, 7"x 9" format. Commercial aerial survey companies started operating.

1939 RAAF photographed areas for NAS – (Aerial Geographical and Geophysical) Survey of Northern Australia.

Second World War 1939-45

1940 RAAF used Eagle IV to photograph large areas of Australia.

1942–45 US Air Force acquired small scale reconnaissance photography with simultaneous exposures of three cameras, one vertical, two oblique depressed 30 degrees, one port and one starboard normal to the flightline, to cover strategic areas of Australia.

1943 RAAF obtained the Fairchild K17, 9 x 9 / 6 inch, wide angle (90 degrees) Metrogon lens cameras. (Fig. 1)

1944 Victoria and Tasmania set up state government aerial survey agencies to provide photogrammetric services. Aerial photography obtained by commercial companies.

1945-53 Demand increases with RAAF using the Fairchild K17, 9 x 9 / 6 inch and, later the Williamson OSC (Ordnance Survey Camera).

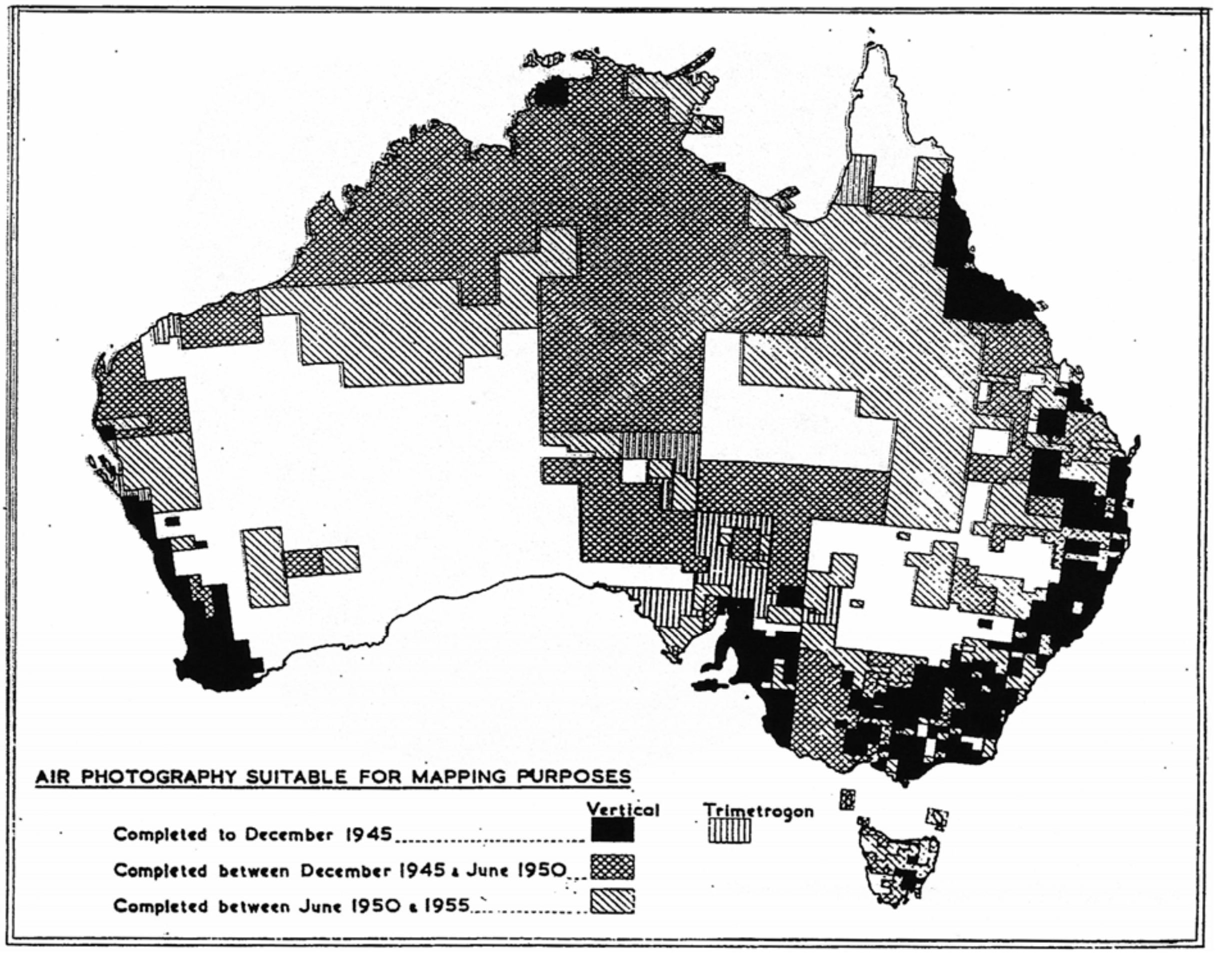


Fig. 2. Aerial photography suitable for mapping purposes to 1955.

Civilian agencies use the Williamson Eagle IX, 9 x 9 with a choice of 6, 8¼ , 10, 12 or 14 inch focal length lens. In 1948, the RAAF 87 (PR) Squadron photographed ~ 650 000 square km in northern Australia. Until 1954 all aerial photography work for the Commonwealth was done by the RAAF, ~ 3.25 million km^2. (Fig. 2).

1954-59 Commercial companies acquired aerial photography for the Commonwealth.

1960 Natmap purchased Wild RC9, 230 x 230 / 88 mm superwide angle SWA (120 degrees) camera. Initially, the RC9 camera was hired to the successful contractor, but contractors such as Adastra Airways, Civil Aerial Surveys, Kevron Aerial Surveys and Queensland Aerial Survey Co. soon purchased their own SWA cameras, either Swiss Wild or German Zeiss.

1976-80 High altitude 12 500 m 'Lear Jet' Wild RC10, 150 mm (1:80 000) and 88 mm (1:140 000) scale photography.

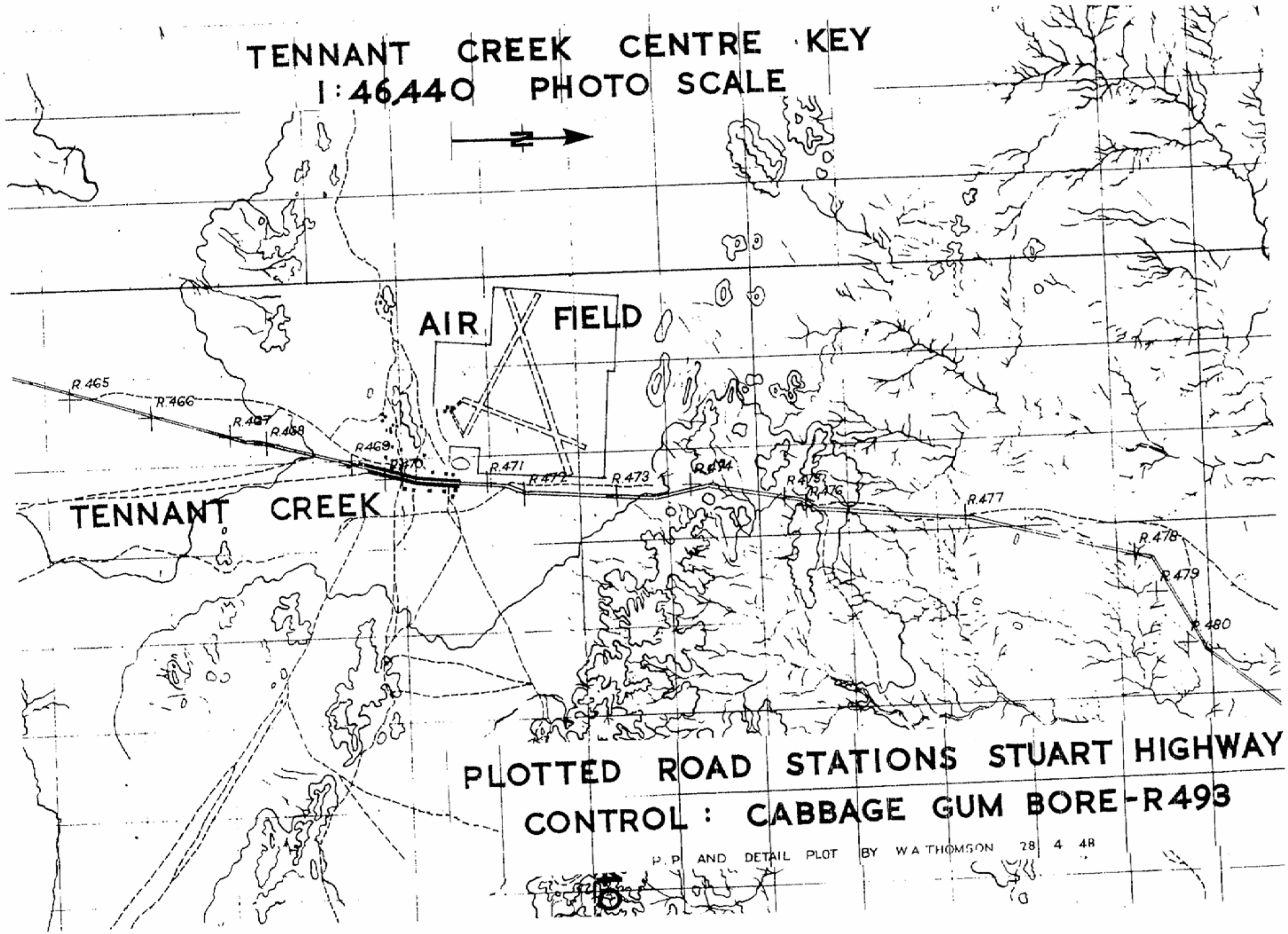
1970–98 Commonwealth, State and Territory mapping and geo-spatial information agencies increased their use of commercial aerial survey companies for aerial photography, photogrammetric, survey and mapping services.[2]

High resolution Satellite Imagery

The Earthwatch, 'Earlybird' 3 metre, high resolution imaging satellite was unfortunately lost in space.[3] Space Imaging Eosat's, 'Ikonos' 1 metre, high resolution imaging satellite was due to be launched in 1998, but has been delayed until mid-1999.[4]

Fig. 3. (On next page). Part of the principal point and detail plot of the Tennant Creek centre key run at 1:46 440 photoscale. Original plot in 1948 on 'Kodatrace'.

[2] See www.ozemail.com.au/~aasa for more details.
[3] See www.digitalglobe.com
[4] See www.spaceimage.com



TENNANT CREEK CENTRE KEY
1:46440 PHOTO SCALE
N
AIR FIELD
TENNANT CREEK
R.465
R.466
R.467
R.468
R.469
R.470
R.471
R.472
R.473
R.474
R.475
R.476
R.477
R.478
R.479
R.480
PLOTTED ROAD STATIONS STUART HIGHWAY
CONTROL: CABBAGE GUM BORE-R493
P.P. AND DETAIL PLOT BY W.A THOMSON 28 4 48

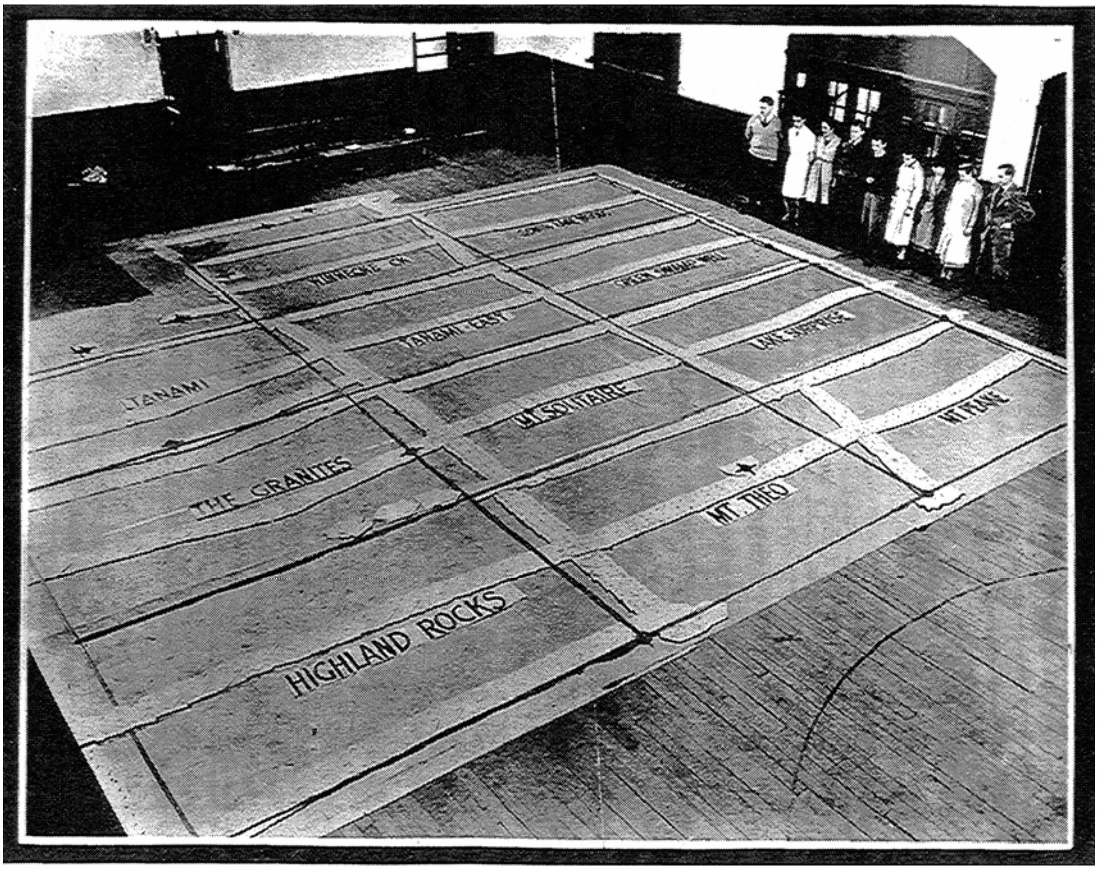


Fig. 4. Slotted template framework for a block of 'four mile' mosaics north-west of Alice Springs. Gregory Hall, Chapel Street, St. Kilda, c. 1950.

K17 AERIAL PHOTOGRAPHY

In 1947 a 'Four-mile to the inch', 1: 253 440 scale map area of 1 degree latitude x 1½ degrees longitude was covered by 15 runs of 40, K17 aerial photos taken from 25 000 feet with 60% forward lap and 25% side lap, a total of about 600 photos for stereo cover or 300 for non-stereo coverage. When Natmap field survey work started in 1948, aerial photos were scarce with a single set, the field set of matte photos, being shared between the Natmap and CSIR (Commonwealth Scientific and Industrial Research) field parties. Reliable maps did not exist and field workers had to lay out the photos in a rough shingle mosaic to get some idea of the country they were working in. Laying out hundreds of photos in the field was a challenging task with any sort of a breeze blowing!

The Tennant Creek Reconnaissance Map, produced in 1948 by W.A. (Alan) Thomson and K.O.(Ken) Johnson, was the earliest compilation by Natmap using the photogrammetric method of radial line plotting of map detail from aerial photos. (Salt 1933) (Fig. 3)

Photo Indexes were prepared by plotting aerial photo centres on the best available base map and joining these to form the runs of photos. Runs were labeled with the first and last photos numbered and every fifth photocentre along the run. Photo coverage was then checked for compliance with coverage and overlap specifications.

Photo Mosaics in this era were usually prepared by laying a framework of slotted template runs at photo scale (1:46 500) between survey control points. Ideally, control would be identified on Runs 1 and 15 and East and West Key Runs. (Fig. 4) The slotted template positions would be pricked through to the kraft paper base sheets, the photos laid over the framework positions with the other photos used to fill in the gaps by matching

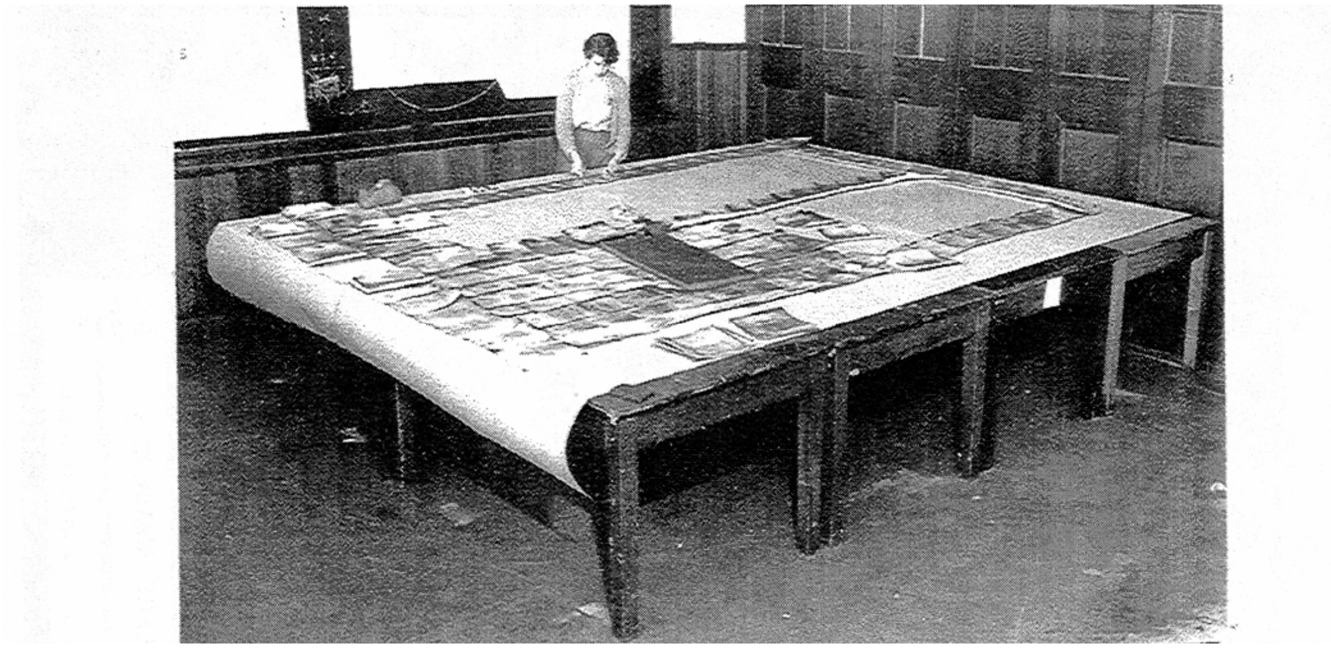


Fig. 5. Preparing a shingle mosaic.

detail. (Fig. 5) This was known as a shingle mosaic with Run 1 overlapping Run 2 and so on. Run and photo numbers were added, major detail annotated and then the shingle mosaic was photographed in six sections, (Fig. 6) mosaiced at 7 miles to an inch, and enlarged to 4 miles to an inch. (Fig. 7)

These 1:253 440 (4 miles to the inch) scale photomaps were produced for use as a base for geological, soil, timber, aeronautical, geographical and other maps. The photomaps were prepared from unrectified aerial photographs controlled by slotted template plotting based generally on astronomical fixations. (NMO 1955 Map Catalogue)

SLOTTED TEMPLATE ASSEMBLY

A photograph is not a map. However, on a near vertical perspective photograph of terrain with gentle slopes, directions from the photocentre to points of detail on that photo can be considered true radial directions. This is the basis of radial line plotting and the Slotted Template Assembly (STA) method of extending control points for mapping from aerial photographs.

In ‘Point Selection’, photocentres and points of detail, called pass points, tie or wing points, were selected and transferred to the overlapping photos along the run and to the adjoining runs. Ideally, some survey control points were selected as pass points.

In ‘Template Making’, the photocentre and pass points were pricked through from the photo on to the template material, such as exposed x-ray film. A hole was punched at the photocentre and slots cut, using a ‘Cassella’ slotted template cutter, through the pass points and transferred photocentres to represent the radial directions. The slotted templates were annotated with the run number and photo number then trimmed.

‘Template Assembly’ involved drawing a rectangular coordinate grid at the nominal photo scale, for example 1:46 500, on the assembly base board and plotting the survey control points. Studs were fixed at control points and templates laid between the control points, along the runs and adjoining runs with floating studs at the photo centres and in the slots. The slotted template assembly (STA) was laid flat without strain the positions of the photo centres and pass points were

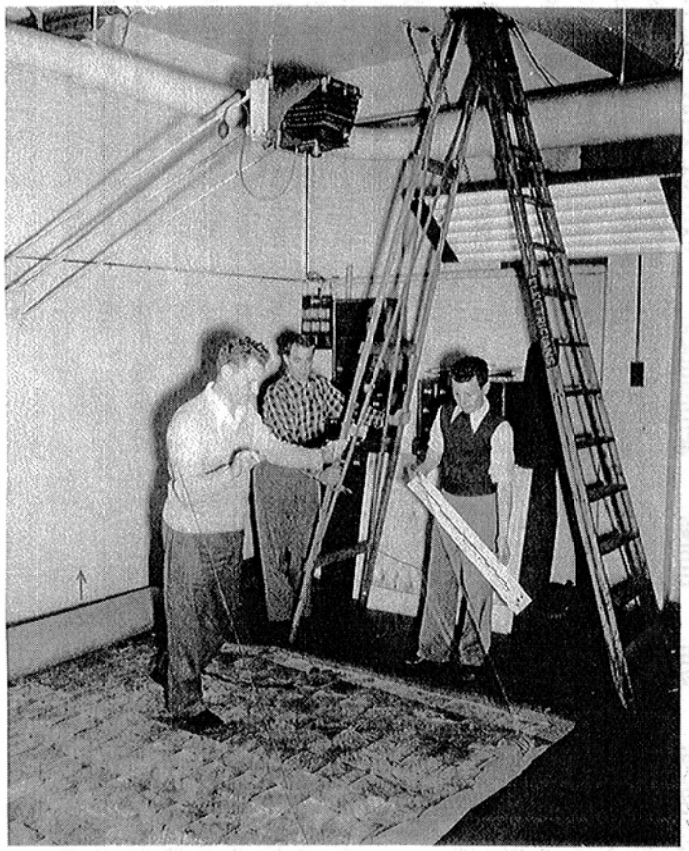


Fig. 6. Overhead camera set up to photograph a section of a 'four mile' mosaic. **Fig. 7.** One of six sections of SG-52-04 Lake Amadeus (Amadeus 5048).

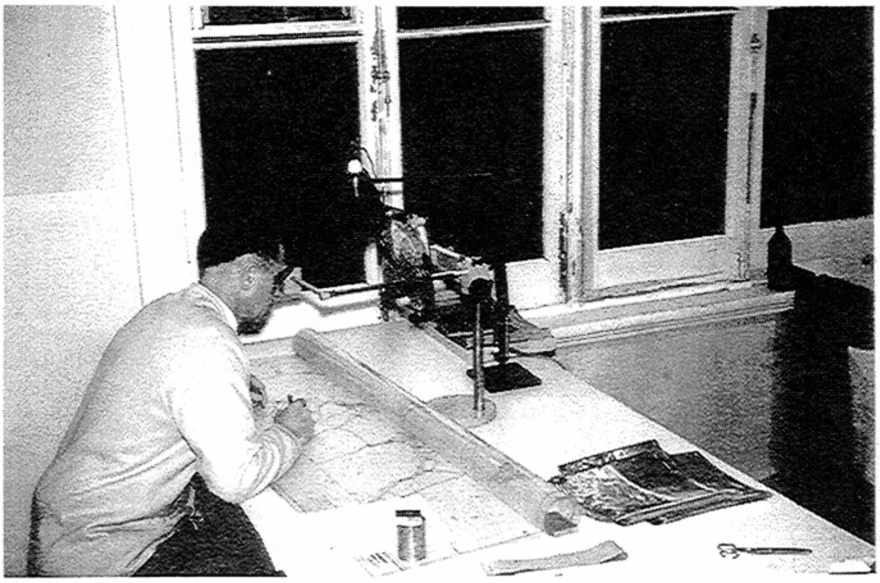


Fig. 8. Using Zeiss Sketchmaster to transfer map detail annotated on the aerial photo to the compilation sheet.

pricked through the holes in the centre of the studs to the base compilation sheets. The templates were taken up, STA positions circled, photo centres labeled and the index to adjoining sheets shown on the drafting film map compilation sheets together with the control points, grid ticks and map sheet corners. (Hocking 1967)

PLOTTING MAP DETAIL

Overlapping photos were viewed stereoscopically and map detail, interpreted, selected and marked up with coloured inks within the lines joining the pass points. Map details were transferred to corresponding positions on the compilation base sheet by 'the shift and trace method' which meant matching the points on the photograph to the STA points on the map compilation base sheet and tracing off the marked up detail. (Salt 1933) It is important to realize that there was more than a 5 to 1 (1:46 500 to 1:253 440) reduction between the compilation scale and the final map scale. Later, Zeiss sketchmasters were used to transfer annotated photo detail to map compilation sheets more quickly and more accurately. (Fig. 8)

Some indication of the elevation of the terrain was given by plotting spot heights derived from aneroid barometer readings in the field. The spot heights were obtained about every four miles (one inch on the map) along roads, tracks, at creek crossings, homesteads, aerodromes, high ground etc. (Hocking 1985)

The 1:253 440 Planimetric Series was drawn on the Transverse Mercator Projection in zones 5 degrees wide with origins at intersections of parallel of latitude 34°S with the Central Meridian of each zone. These planimetric maps were produced for some special priority areas of Australia, showing all types of natural and cultural features, including railways, roads, tracks and towns. Relief was indicated by spot heights and hachures. (NMO, 1955 Map Catalogue)

TOPOGRAPHIC MAPPING

'Precise' Slotted Template Assembly (STA) for 1:100 000 Planimetry

A most significant improvement occurred in 1960 with the introduction of the super wide angle, Wild RC 9 camera taking 1:80 000 scale photos which meant that less than 200 photos (stereomodels) covered a 1:250 000 map area compared with the 600 needed with K17 photo coverage. During the 2 or 3 years transition from K17 to RC9 photos an obvious disadvantage was that photo interpretation of map detail was more difficult on the smaller scale 1:80 000, RC9

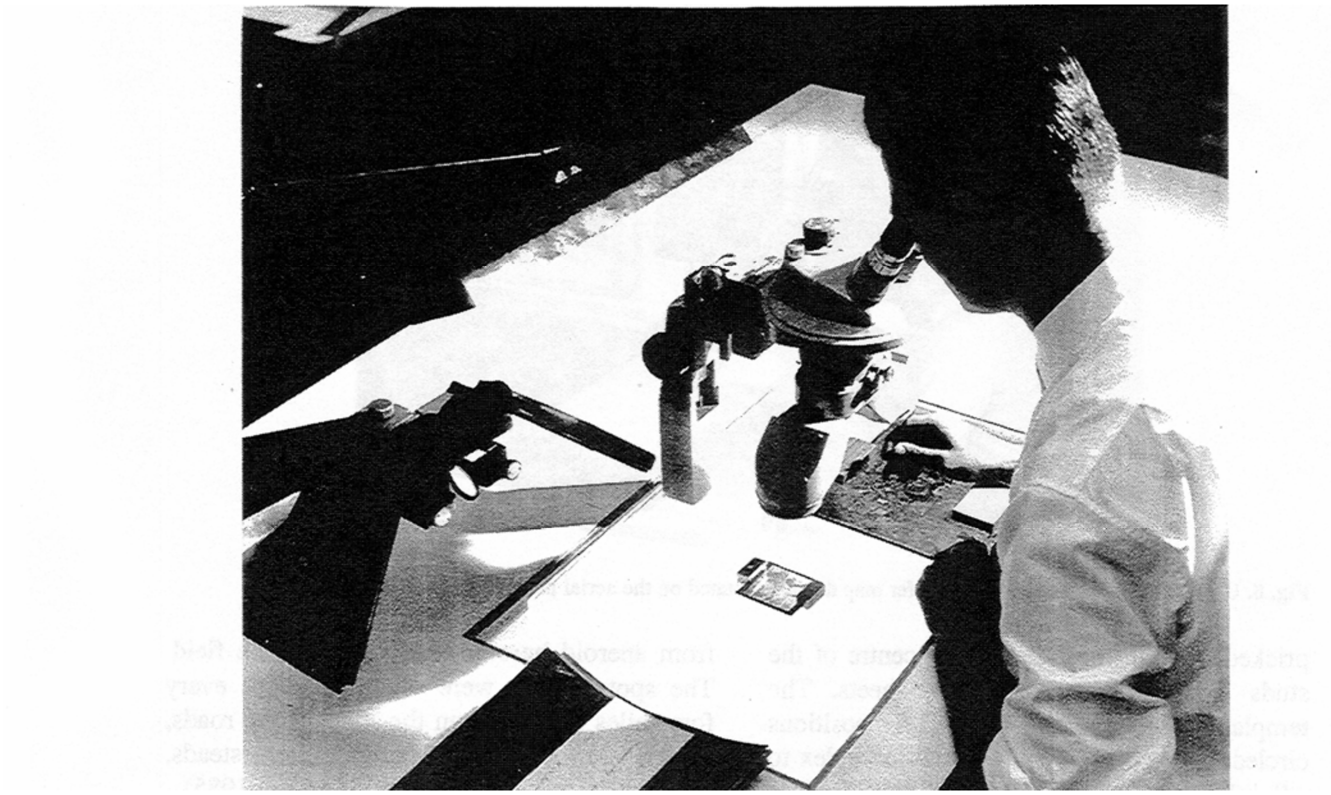


Fig. 9. Transferring survey control information from the spot photo to the mapping photography using a Bausch & Lomb Zoom 95 Differential Stereoscope.

photography. However, most Natmap operators were well experienced and soon able to cope with the smaller photo-scale.

Film diapositives (0.10 mm thick) were printed using a U4A projection printer fitted with a 7000 metre flying height correction plate for earth curvature, air refraction and RC9 lens distortion. Point marking was done using 8x or 10x magnification stereoscopes and either orange ‘Letraset’ or black ‘Mecanorma’ rub-down dot and circle point marks to avoid pricking or drilling holes in the film diapositive.

Spot photos of control points were available to allow positive identification of survey control on the diapositives. To obtain spot photos, the control points were marked on the ground, then using a Hasselblad camera near vertical photos were taken at 500, 1500 and 3000 feet above ground. Using a Bausch and Lomb Zoom 95 Differential Stereoscope the control was then transferred from the larger to the smaller scale photographs which provided an accurate position on the mapping photos of the control point. (Fig. 9) This technique was a vital requirement in order to maintain map accuracy.

Control for 1:100 000 mapping was based on the Australian Geodetic Datum 1966. However, in the period leading up to the adoption of AGD66 a provisional datum based on the ‘165’ figure (semi-major axis 6 378 165 m) compared with the adopted ‘160’ m provided coordinates sufficiently accurate for 1:100 000 scale mapping.

Control point density was ideally half a degree around the perimeter with one degree spacing of control within the block. However, the control point density usually averaged between a half and one degree network of geodetic control (Ford 1979) and airborne Tellurometer ‘Aerodist’ control. (McMaster 1980).

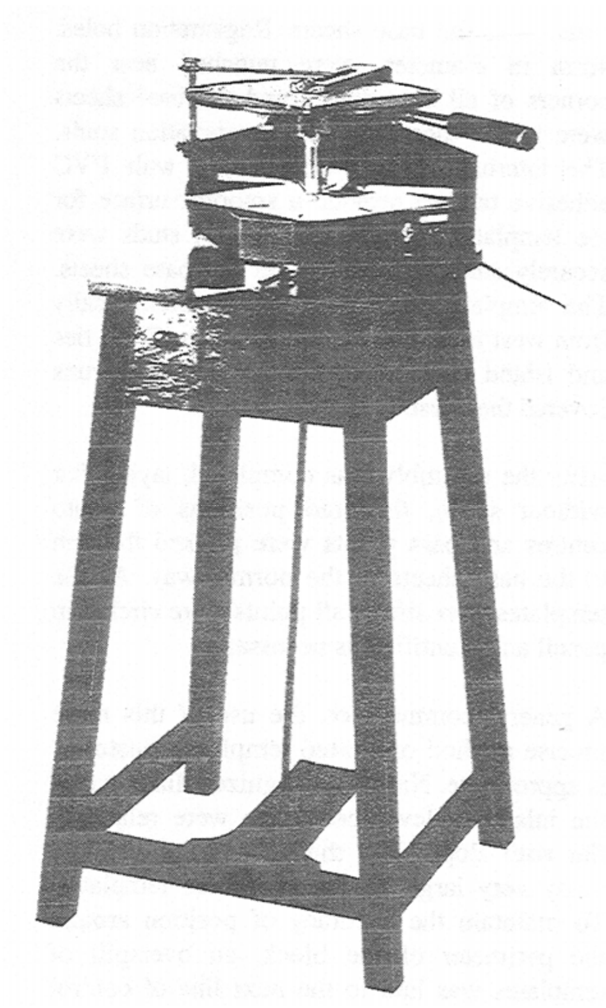


Fig. 10. ‘South African’ Pattern Slotted Template Cutter with upper (photo) stage and lower (template) stage with the facility to change template scale.

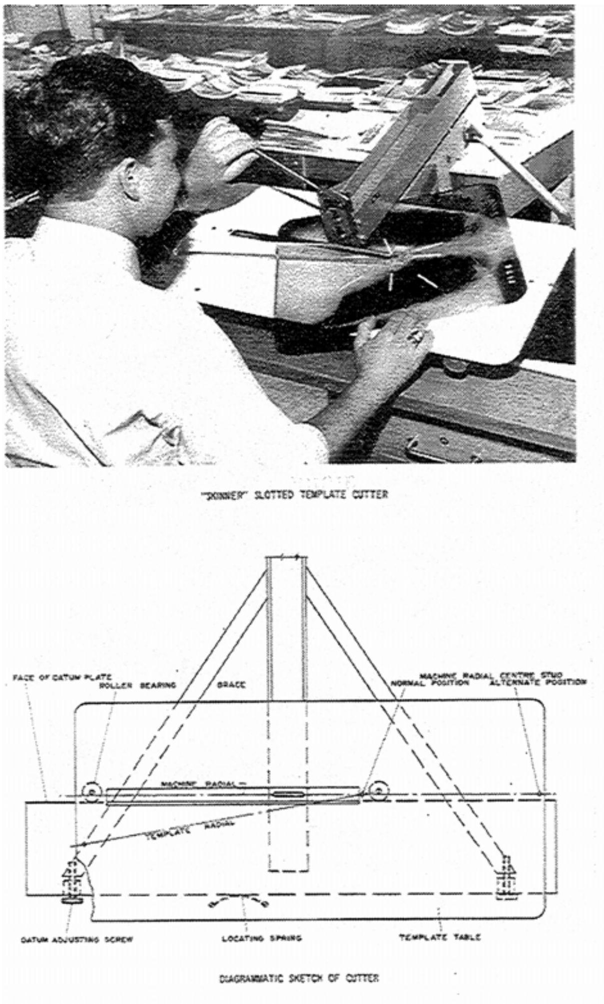


Fig. 11. ‘Skinner’ Slotted Template Cutter with constant radial offset and facility to change template scale, usually from 1:80 000 to 1:100 000.

Using the ‘South African’ pattern slotted template cutter, normal templates were made from 0.35 mm thick white ‘Flovic’ blanks with a pre-punched centre hole. (Fig. 10) Azimuth templates were made from 0.35 mm thick clear ‘Cobex’ using the ‘Skinner’ constant radial offset slotted template cutter. The ‘Skinner’ cutter facilitated changing the template scale, usually from 1:80 000 to 1:100 000. (Fig. 11) Azimuth templates were used to reduce the bowing of a run of templates by bridging with the direction of the photo centre 2 photos distant marked on every second photo. This was done by using the second of three successive photos and accurately transferring the photo centres of the first and third photos to the middle photo.

These transferred image points were joined with a fine line and image points along this line transferred to the first and third photos. Then on the first and third photos a line was drawn radially from the photo centre points through these marks. Every second template was an azimuth template and every other a scale template. (Gamble 1950) This technique is analogous to strengthening azimuth in a survey traverse by reading the angle at station 1 to 3 and at station 3 to 5.

Stereo templates were used occasionally to locate templates firmly at control, to get a strong fix on a control point; for example, where the control point was close to the base line and a strong radial intersection was not possible.

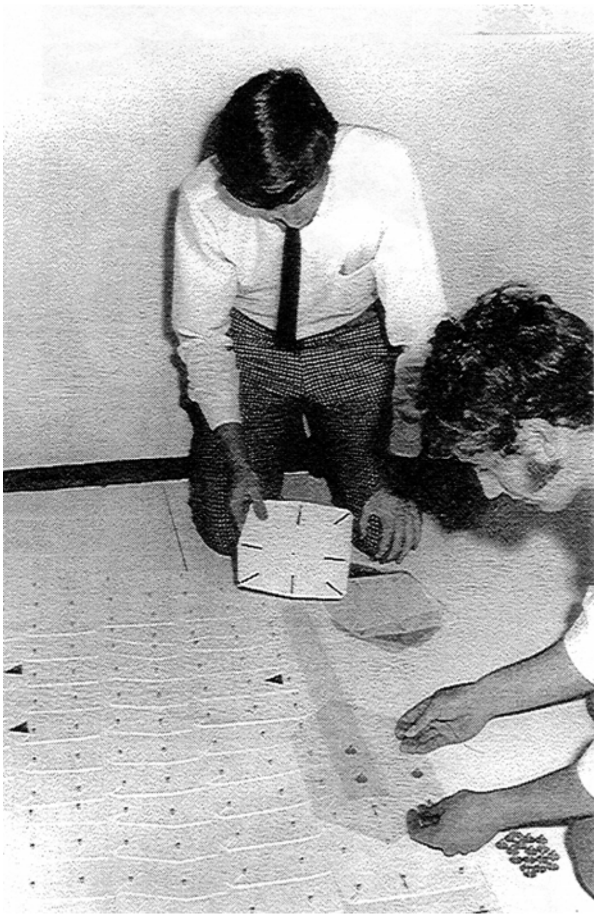


Fig. 12. Laying white 'Flovic' plastic templates and clear 'Cobex' plastic azimuth templates.

The stereo templates were prepared from stereo instrument plots of a relatively oriented model of overlapping photos, thereby transforming the perspective projection to a parallel projection with the pass points and control point plotted at approximately STA scale. These points were pricked through to two sheets of 'Flovic' and, using the Zeiss Radial Secator RS1, slots were cut from diagonally opposite pass points used as radial centres and a (double) stereo template prepared.

Base sheets and overlay sheets were 0.1mm double-matte 'Ozatex' pre-printed with standard marginal information for 1:100 000 manuscript mapping. Grid intersections, 10 minute graticule intersections, control points and register holes were plotted using the 'Decograph' coordinate plotter. Contour and vegetation overlays were prepared as plain sheets of the same size and material as the base sheets. Registration holes, 4mm in diameter, were punched near the corners of all base sheets and the base sheets were joined together with 2 registration studs. The internal edges were covered with PVC adhesive tape to provide a smooth surface for the templates to slide on. Control studs were securely stuck in position on the base sheets. The templates were assembled systematically from west to east and north to south. Coast ties and island runs were added when W-E runs covered the coast. (Fig. 12).

After the assembly was completed, laying flat without strain, the stud positions of photo centres and pass points were pricked through to the base sheets in the normal way. As the templates were lifted, all points were circled in pencil and identified as necessary.

A general comment on the use of this more precise method of slotted template adjustment is appropriate. Natmap recognized that most of the inland undeveloped areas were relatively flat with slopes less than 5 degrees and laid many very large blocks of slotted templates. To maintain the accuracy of position around the perimeter of the block, an overspill of templates was laid to the next line of control where possible. For example, Block 6 covered 19 x 1:250 000 areas or 110 x 1:100 000 areas of the Northern Territory. (Fig. 13) Some statistics for Block 6 are:

	Block 6	Overspill	Total
No of templates	3076	704	3780
No of studs	6250	1450	7700
+ control studs	130		
+ register studs	220		
Area	315 200 km^2		379 200 km^2

It is interesting to compare the Block 6 area with the combined area of the states of Victoria and Tasmania which is approximately 300 000 km^2. [5]

[5] Some of these comments on Block 6 STA are based on a 1971 report by Mr. R.G. Foster, Supervising Draughtsman. Bob, who unfortunately died recently, was the acknowledged expert on precise slotted template adjustments in Natmap.

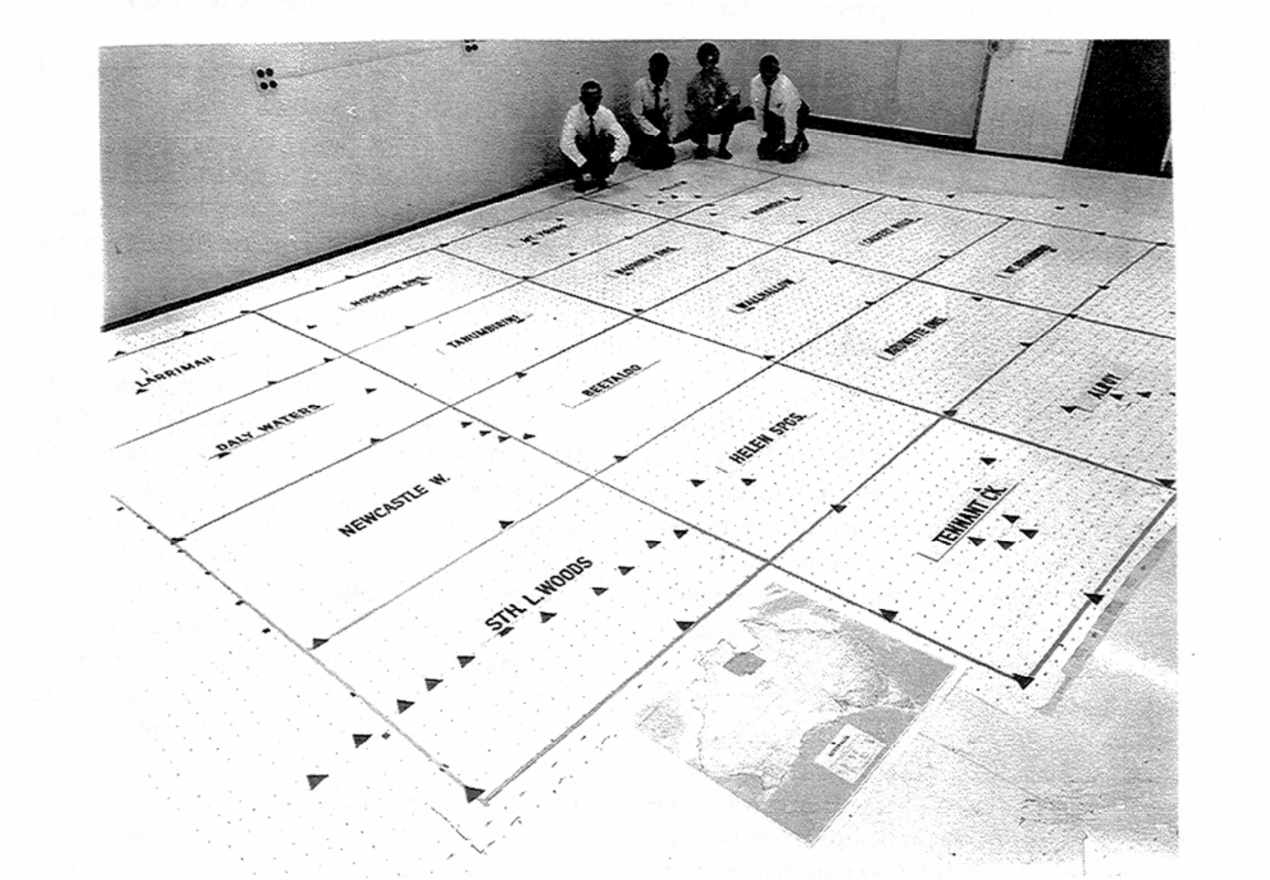


Fig. 13. Block 6, Slotted Template Assembly, Rialto Building, Collins Street, Melbourne, June 1971. This provided planimetric control for one hundred and ten 1:100 000 scale maps covering about 315 200 km^2.

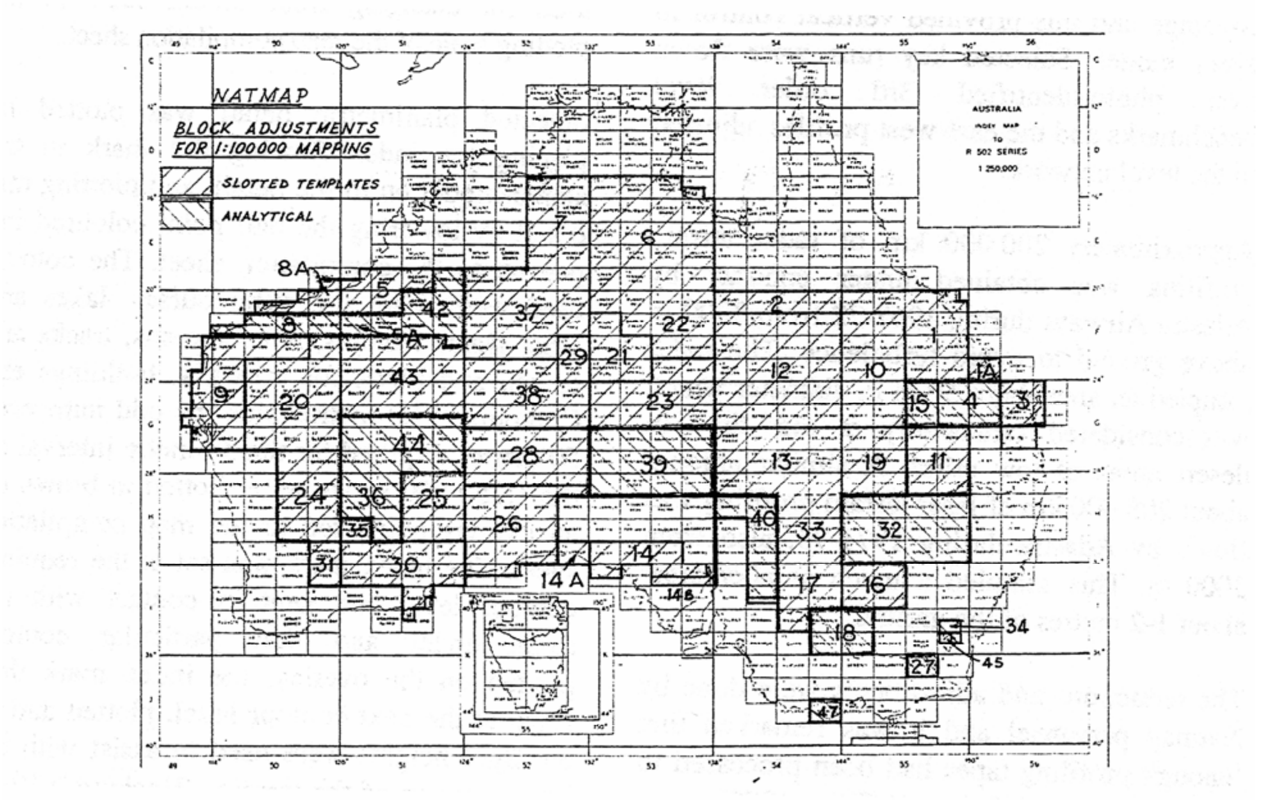


Fig. 14. Slotted template block adjustments and analytical block adjustments for 1:100 000 mapping.

When mapping under pressure (Lambert 1963), and before massive number-crunching computers were available for large analytical block adjustments, there was a lot in favour of STA block adjustments of 2000 to 3000 models, with direct transfer of the minor horizontal control positions to the base map compilation sheets. (Fig. 14)

VERTICAL CONTROL

To plot map detail using stereo-plotting instruments, such as the Wild B8 and Kern PG 2, in which a virtual model is formed by stereoscopic observation of a pair of overlapping aerial photo film diapositives, the model must be levelled and scaled. Three vertical control points, not in a straight line, are necessary to level the model, and two horizontal control points are needed to set the correct scale.

In large scale project mapping it is common to establish the individual vertical control points by direct ground survey methods. However, for the medium scale, 1:100 000 national mapping program with 20 metre contours, the vertical control was obtained by airborne terrain profiling along the sidelaps of the aerial photo coverage and this provided vertical control in every model. Selected key runs were flown over photo-identified 3rd order level benchmarks and the east-west profiles adjusted to the level network.

Approximately 200 000 km of radar terrain profiling was obtained under contract by Adastra Airways during 1967-72 from 3000 m above ground to avoid turbulence. The radar sampled an area about 50 m in diameter which was considered satisfactory at that time in desert areas of low relief. A similar amount about 205 000 km of laser terrain profiling was flown by Adastra during 1971-75, also from 3000 m. This sampled a much smaller area, about 1-2 metres of the ground.

The reductions and adjustments were done by Natmap personnel and it was remarked that ‘enough profiling tapes had been processed to encircled the earth 5 times’! (Wise 1979)

STEREO- PLOTTING MAP DETAIL

In the 1950-60s the stereo-plotting of map detail was carried out by photo-interpretation of map detail from a stereo-model of overlapping aerial photos and transferring selected detail to the map compilation sheet. Initially, Natmap used Wild A6 and Zeiss Stereotope instruments for stereo-plotting map detail. However, the A6 was designed to plot from wide angle 150 mm / 6 inch photography, not the superwide angle 88 mm / 3.5 inch focal length aerial photos, and so the A6 was used for training and plotting planimetry only. The Stereotopes were used mostly for plotting detail for base mapping for resources surveys in Papua and New Guinea. (Fig. 15) The bulk of stereo-plotting of planimetry and contours from the super-wide angle 230 x 230 / 88 mm RC9 and later RC10 photography for the 1:100 000 mapping program was done using Kern PG2 and Wild B8 analogue stereo-plotting instruments.

The aerial photo diapositives were oriented on the left and right carriers, viewed stereoscopically and the stereo-model formed (relative orientation). The stereo-model was levelled to the vertical control and scaled to the horizontal control (exterior orientation). A pantograph was used for changing from model scale to the plotting scale of the map compilation sheet.

Selected planimetric detail was plotted by placing the index floating dot mark in the stereo-model on to the detail, and plotting that detail by lowering the ball point coloured ink pen on to the compilation sheet. The colours used were: blue for watercourses, lakes and other water features, red for roads, tracks and so on, and black for railways, buildings etc. Contours at 20 metres plus the odd numbered 50 metres required for the 50 metre interval on the 1:250 000 series were plotted in brown on an overlay registered to the map compilation sheet. The index mark was set at the required contour level and kept in contact with the stereo-model and that particular contour plotted on the overlay, the index mark then fixed at the next contour level, plotted and so

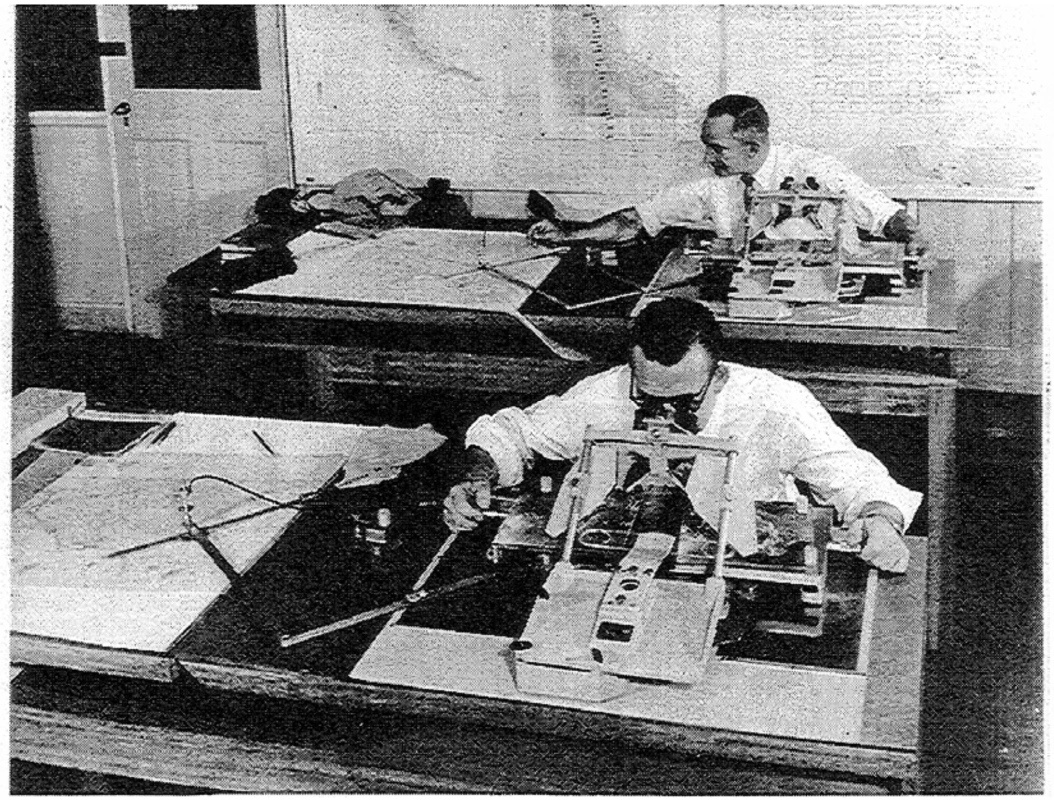


Fig. 15. Zeiss Stereotope plotting instruments.

on. Spot heights were used to assist with the interpretation of the terrain. (Hocking c.1967)

Vegetation was plotted in green on another overlay registered to the map compilation sheet. (Fig. 16, A to G) Separate overlays were used to avoid having too much map detail on one sheet. Sheets of 'Letraset' cultural symbols were prepared and used during the map compilation.

CONTRACTORS

Up to 20 private sector firms were involved at various times, under contract on such operations as aerial photography, point marking, template making and stereo plotting of map detail. These firms included: Adastra , Geosurveys, AAM Surveys, Watsons, Associated Surveys, Alpha Aerial Surveys, Aerial Surveys, Civil Aerial Surveys, Photomappers, Photec, Qasco, Aerometrex, P. Livings, Pike & Partners, Southern Aerial Surveys, GH&D, GeoSpectrum, and others.

The contract photogrammetry was considered to be a successful operation for both Natmap and the contractors. Putting work out to contract forced Natmap staff to prepare unambiguous specifications of the work to be done and this proved to be a most demanding yet useful exercise in sorting out various procedures for compiling maps. It is well known that it is difficult enough for separate sections working in the same building to follow the same procedures, let alone different firms scattered all round Australia.

The contractors' staff learnt to compile medium scale maps from aerial photographs and, in addition, contract mapping provided a base load of work for the firms involved. Further more, and most importantly, these mapping contracts increased the pool of skilled people available to do map compilation work in the event of a national emergency. It is worth noting that many of these firms continue to operate in the private sector.

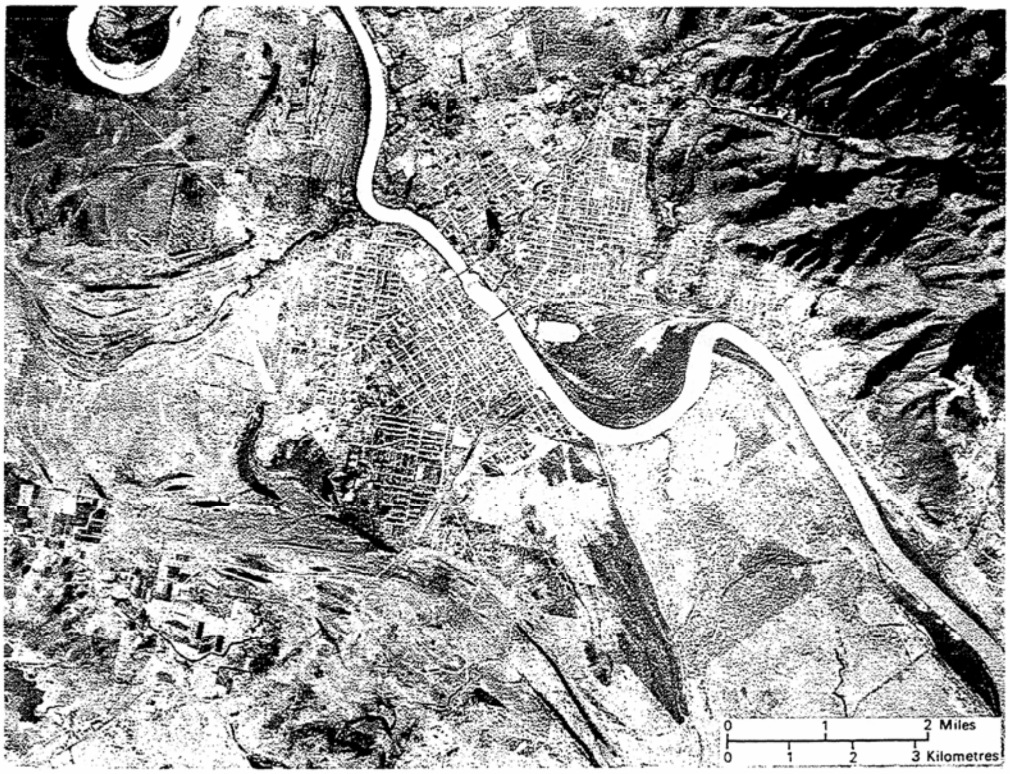


Fig 16 A. Source data consists of overlapping pairs of aerial photos forming two models in this case.

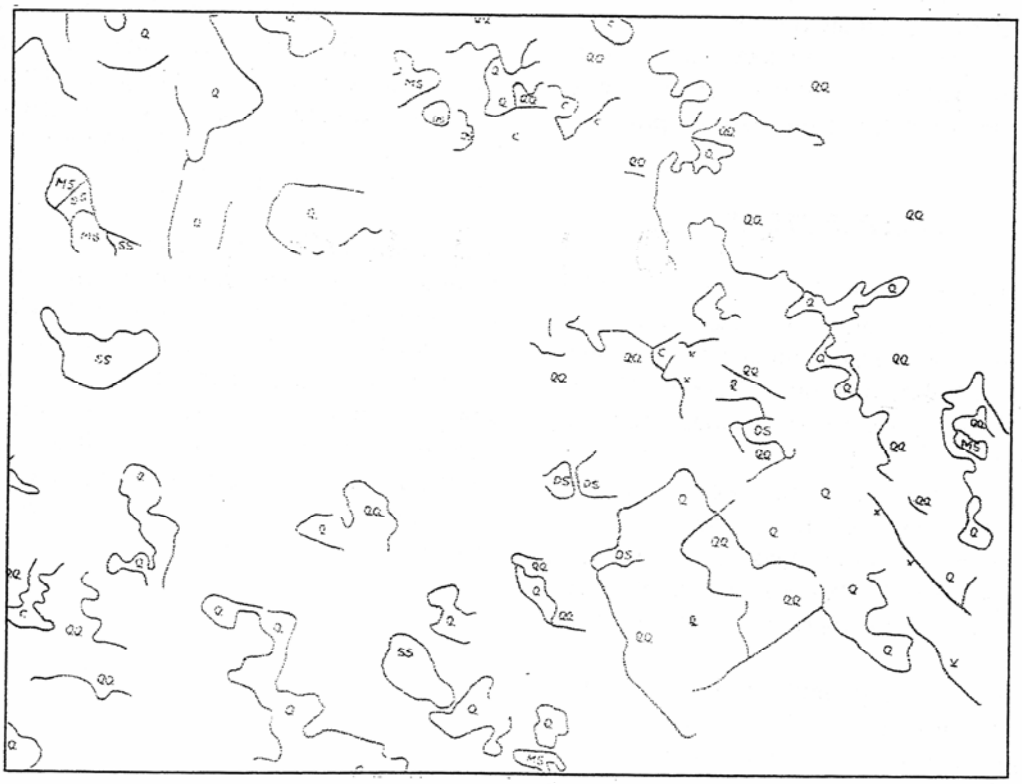


Fig. 16 B. Vegetation Detail, interpreted from aerial photos (16 A) and plotted in green.

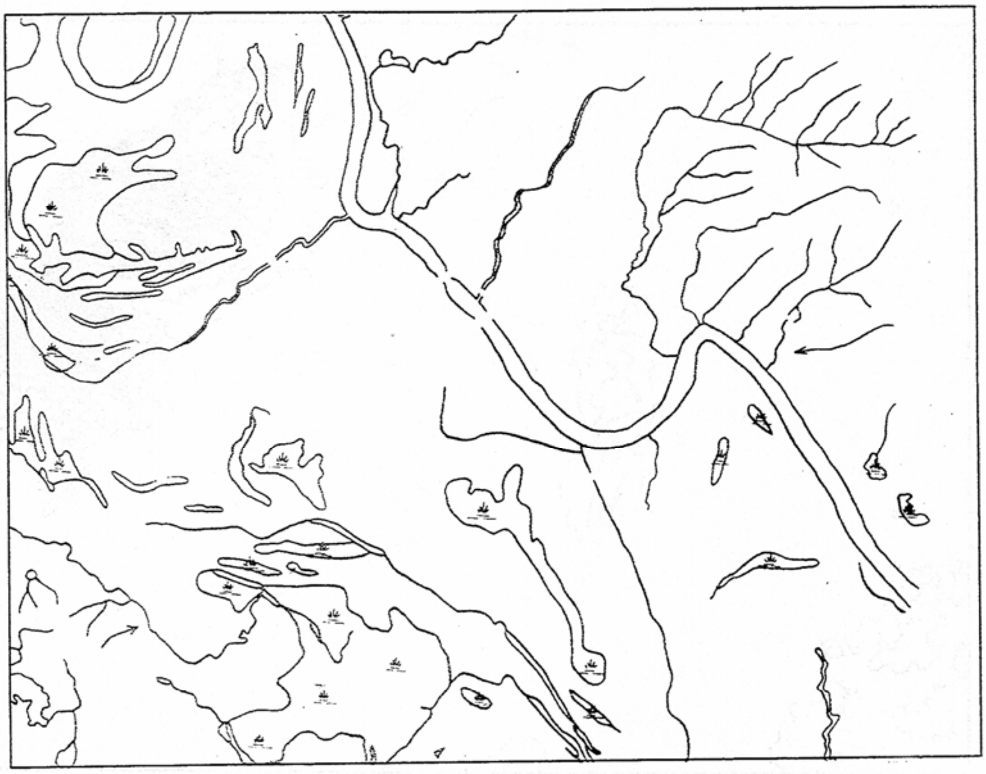


Fig. 16 C. Hydrographic Pattern, interpreted from aerial photos (16 A) and plotted in blue.

Fig. 16 D. Cultural Features, interpreted from aerial photos (16 A) and plotted in black.

Fig. 16 E. Relief (contours), interpreted from aerial photos (16 A) and plotted in brown.

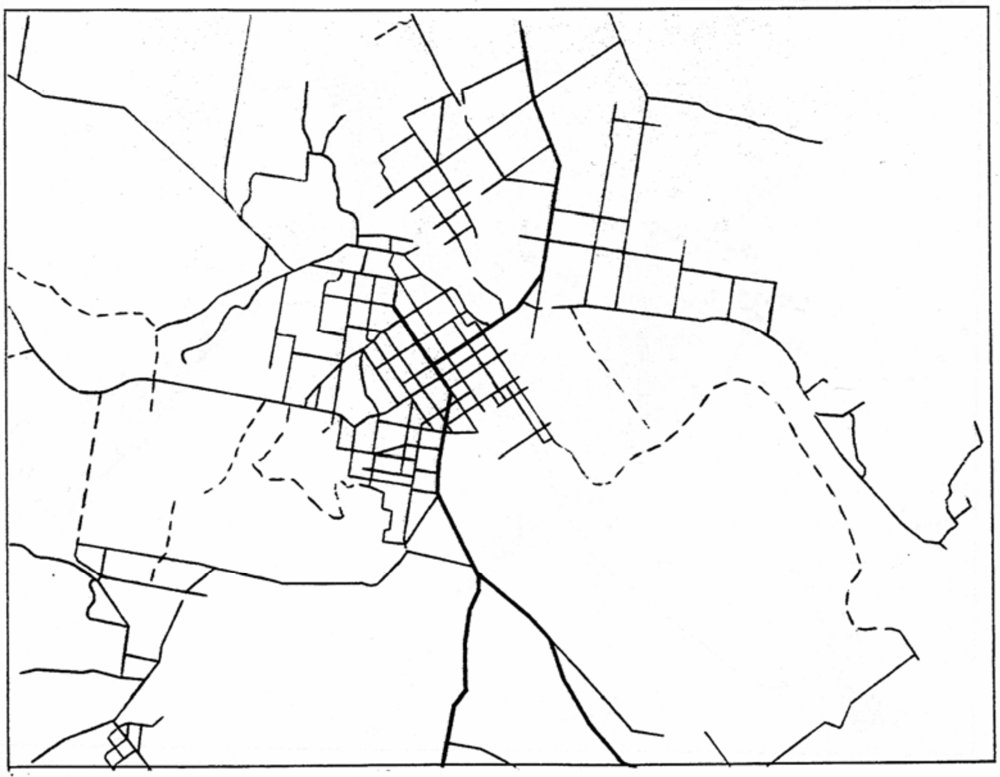


Fig. 16 F. Roads, interpreted from aerial photos (16 A) and plotted in red.

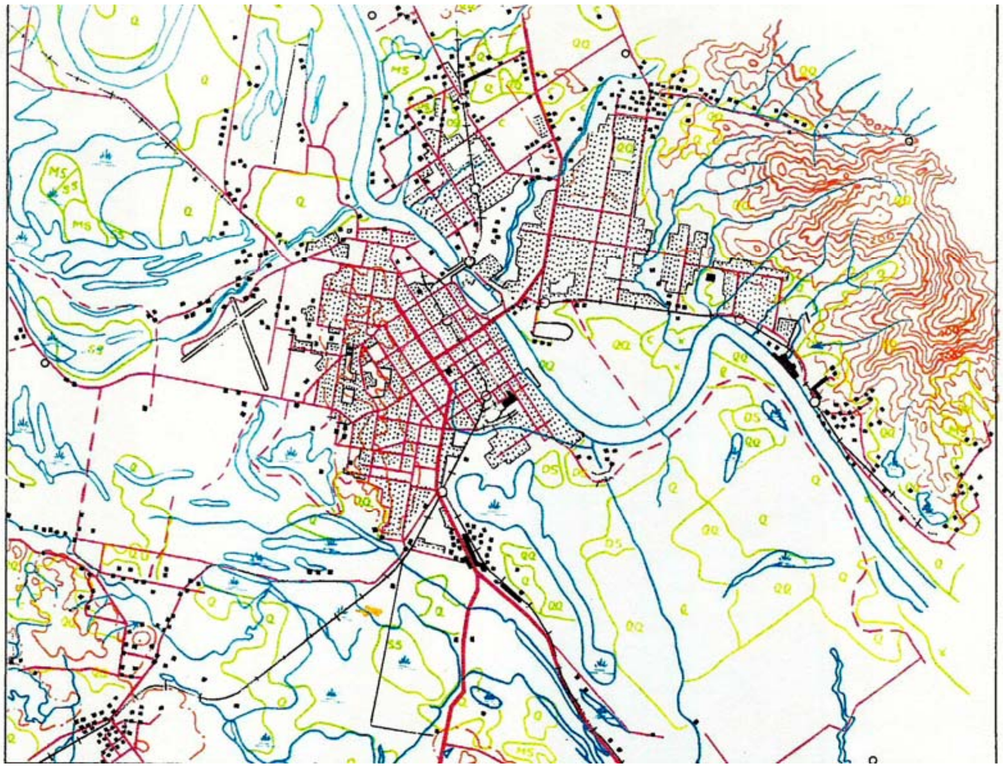


Fig 16 G. Map compilation resulting from the combination of stereo-plotted detail from B, C, D, E, and F.

ACKNOWLEDGEMENTS

I wish to thank the people who helped me remember. However, memory fades and any errors are mine. Clive Freegard worked wonders with the old photos. Keith Barrie, Kevin Crane and Alan Thomson kindly read the paper and suggested improvements. My wife, Iris, an ex-Natmapper, sorted out the diagrams and so forth. Finally, sincere thanks are due to all the people who worked in the National Mapping Melbourne and Canberra offices during those years, helping to put Australia on the map.

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ANNEXURE B

NATMAP

DEPARTMENT OF NATIONAL DEVELOPMENT AND ENERGY

TECHNICAL REPORT 27

NATIONAL MAPPING AERODIST PROGRAM

by

C. G. McMaster

CANBERRA AUSTRALIA
1980

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NATIONAL MAPPING'S AERODIST PROGRAM

ABSTRACT

The Division of National Mapping's Aerodist surveys between 1963 and 1974 provided horizontal control for 1:100 000 scale mapping over slightly more than half Australia and extended the survey network to various reefs and islands.

This report describes the Aerodist program, both the surveys in the field and the computations in the office.

1. INTRODUCTION

Prior to the Aerodist survey, the Division of National Mapping used third order astronomical observations to supplement triangulation and traverse stations of the geodetic survey as control for mapping.

From 1957 the geodetic survey was rapidly extended with the Tellurometer electromagnetic distance measuring equipment (Ford 1979). Aerodist, the airborne version of the Tellurometer, became a rapid and economical method of providing additional control points for mapping, particularly in the flat areas of inland Australia, where lines of sight between stations were short (Lambert 1967). However, field parties with traditional survey skills had to develop the ability to operate electronic equipment; electronic technicians were required to maintain the equipment in the field; and field parties increased in size.

Processing the data benefited from electronic computers. In Canada the Department of Mines and Technical Surveys favoured computation in the field (McLellan and Yaskowich 1966), but in Australia National Mapping preferred merely to verify in the field that adequate data had been obtained, and to compute in the office.

The Royal Australian Survey Corps also used Aerodist in its areas of responsibility, particularly in northern Australia and Papua New Guinea.

2. DEVELOPMENT

The Aerodist system was essentially an airborne development of the Tellurometer system of microwave measurement of distance. It was developed by the South African firm of Tellurometer Pty Ltd under a contract awarded by the United States Army Engineers Research and Development Laboratories in 1958.

Prototype equipment was static tested in South Africa and tested in the air in the USA and the UK in 1959 and 1960. The maximum range achieved, ground station to ground station, exceeded 300 km. The maximum instrumental error was claimed to be 1 metre, with a consistency of repeated measurements over any one line of 2 metres ±10 parts per million. The range and accuracy of any particular measurement was dependent on ground reflection and atmospheric conditions (US Army ERDL 1961).

National Mapping's subsequent experience found these to be optimum results only achievable in ideal conditions, and only after the equipment had been modified.

3. PURCHASE

In October 1960 National Mapping received approval to purchase a set of Aerodist equipment.

The first set to arrive in 1961 did not pass its acceptance tests and was rejected. A two-channel system of two master and four remote units was delivered and accepted in 1963. A channel consists of an airborne master unit and a remote unit on the ground. Each remote is referred to by a colour code. Frequencies are separated to prevent interference between channels when they are operating simultaneously. Two channels are needed to measure a line.

In the following years more equipment was bought, much of it was modified, and it was installed in a succession of aircraft - see Annex A.

4. SURVEY METHODS

National Mapping used the Aerodist system to measure distances normally between non-intervisible ground survey stations, building up a regular trilateration pattern of 1°, sometimes 30', squares. The Aerodist master units in the aircraft were flown across the line between remote units at the ground stations - see Figure 1. The changing distances between the master and remote units were recorded on a chart recorder in the aircraft.

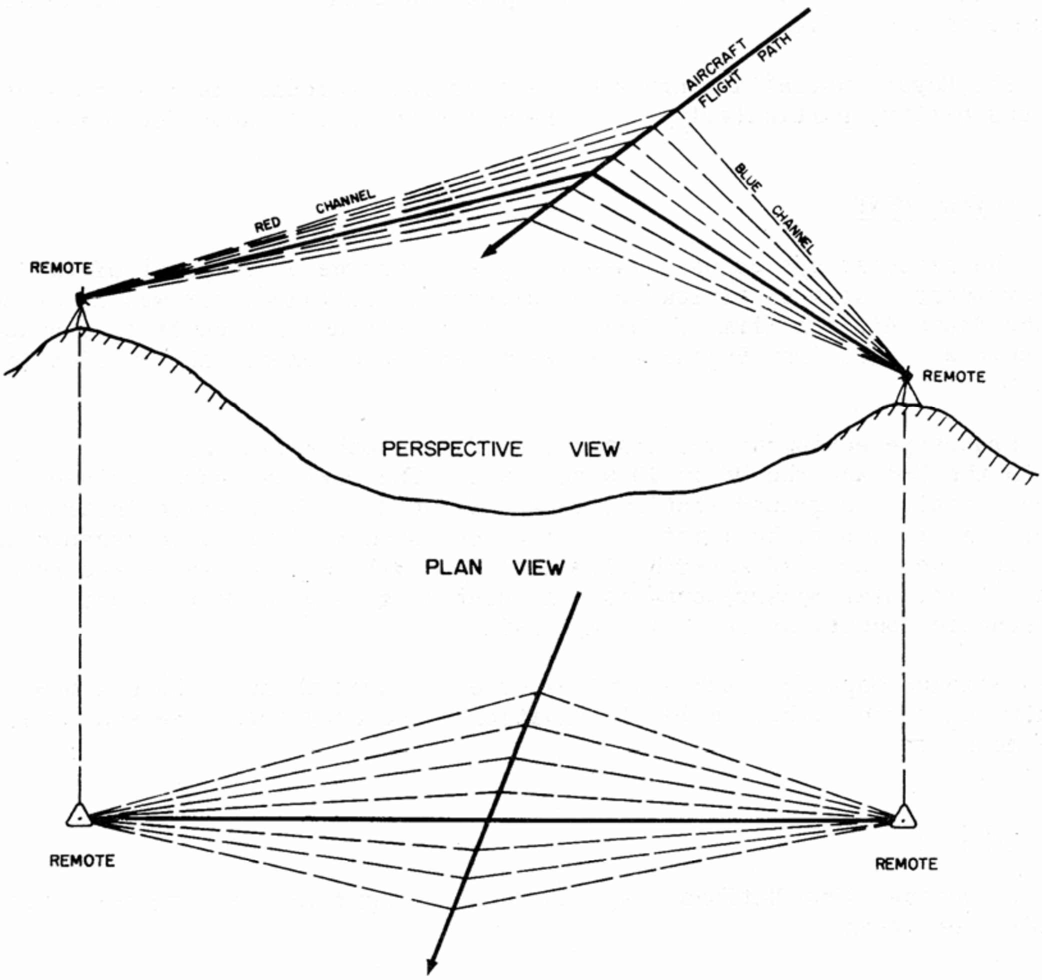

FIGURE 1 AERODIST LINE CROSSING

The Aerodist survey configuration was basically a series of braced quadrilaterals of measured lines, linked to and contained within the existing geodetic network, forming discrete blocks of trilateration - see Figure 2.

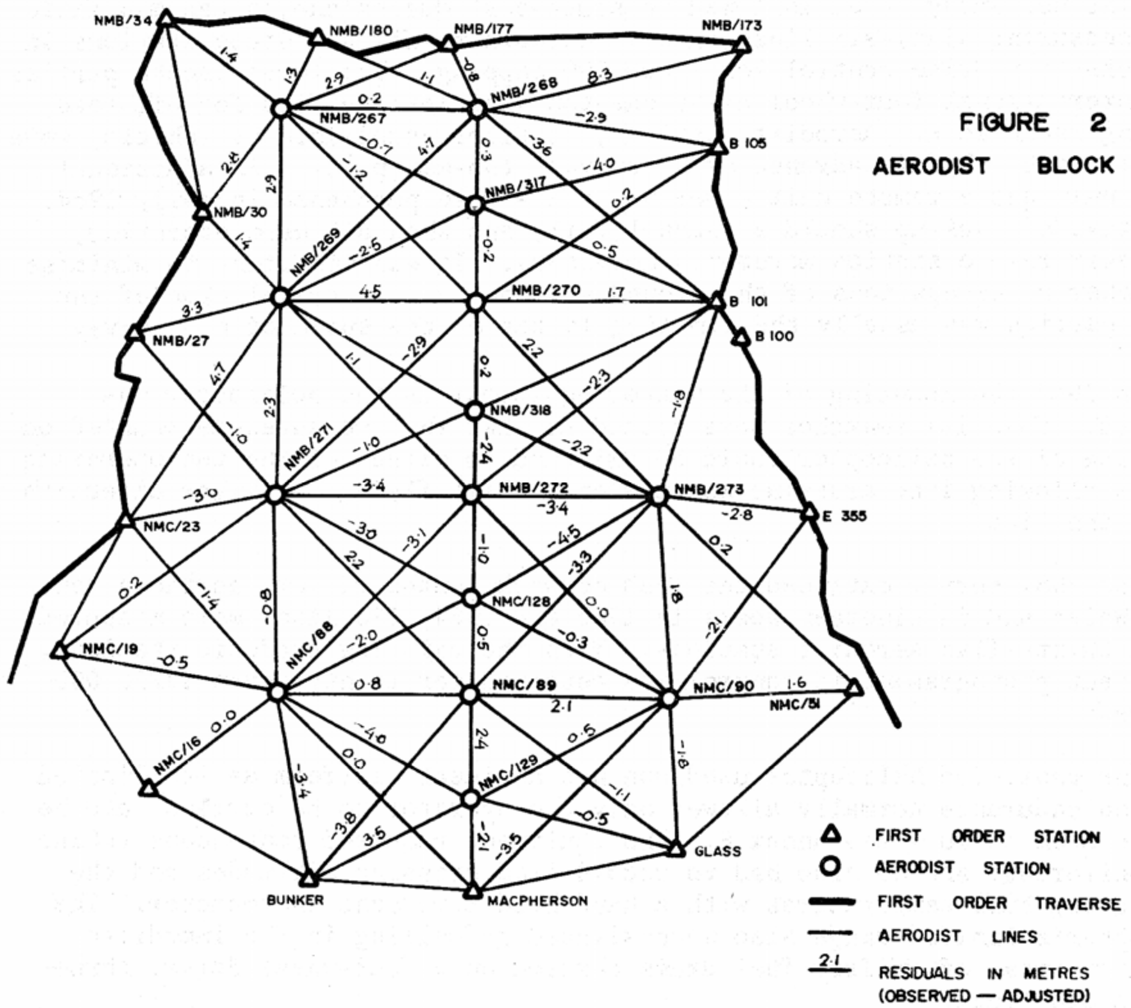

FIGURE 2
AERODIST BLOCK 15

Aerodist distances were measured between geodetic stations at regular intervals during each survey to calibrate the equipment. Corrections were computed and applied to all Aerodist distances.

Subsequent reductions using Aerodist charts, meteorological observations and height information enabled the spheroidal distance between the ground stations to be calculated.

Finally each Aerodist block was adjusted by least squares to the surrounding geodetic control, using program Varycord (Bomford 1967) to obtain coordinates on the Australian Geodetic Datum.

5. FIELD PROGRAM

The Aerodist survey began in eastern Australia and moved west into the more remote areas.

5.1 The Evaluation Phase 1963-64

After static testing in mid 1963 the two-channel system was mounted in a Bell 47J-2 helicopter on charter from Ansett-ANA, and airborne trials and personnel training started using trigonometric stations in western Victoria. The first new survey then followed in south-east Queensland, a ten-man field party measuring sixty-six lines in a 10 network to fix seventeen stations in six weeks to provide control for 1:250 000 mapping. The three remote parties used International four-wheel drive one-ton vehicles modified for off-road and long range work. Aerodist stations, at sites accessible by vehicle, were usually established in advance by a separate two-man party. An additional master unit and a remote unit - see plate 1 - were purchased in early 1964. They provided back-up should a channel fail, and when all were operating, made fewer remote station movements necessary. It was important to minimise the number of occupations of the ground stations as the travel time of the remote parties was usually the limiting factor on the speed of the survey.
In 1964 the mounting of the master equipment in the helicopter was improved. Co-axial switches were fitted so that the two antennae mounted on each side of the helicopter could be switched to either of the two operating masters allowing line crossing measurements while flying in either direction across the line.

The 1964 survey extended the 1963 network southward into northern New South Wales and in nineteen weeks in 1963 and 1964, 176 lines were measured to fix thirty-five Aerodist stations. With the existing geodetic stations sufficient photogrammetric control was obtained for twenty-seven 1:250 000 map areas.

The chartered helicopter used was not an ideal platform as its limited load and endurance normally allowed only one operator to be carried, and he had too much to do - see Annex B. The equipment required continuous tuning and monitoring, and he also had to record line crossing altitudes and the wet and dry bulb temperatures with a hand-held Lambrecht thermometer. The helicopter's limited range also necessitated refuelling in the immediate operation area, often from fuel drums carried on a four-wheel drive, three ton Bedford truck.

5.2 The Development Phase 1965-66

For the 1965 field program the master equipment was installed in an Aero Commander 680E high-wing aircraft chartered on a two-year contract from Executive Air Services, Melbourne. This firm remained the master aircraft contractor for the remainder of National Mapping's Aerodist program.

Installing the equipment in this aircraft was a tight fit, and required the master operator to face aft; but a second operator was carried to record and book the data.

A psychrometer was installed with a thermocouple sensing head mounted outside the aircraft to record master temperatures.

The 1965 survey extended the 1963-64 networks and, remeasured fifty lines to improve their precision. Late in 1965 measurements were made in a separate block in the Broken Hill area of New South Wales.

In 1966 Aerodist control was intensified in central Queensland and south-western New South Wales. A chain of quadrilaterals was measured westwards from Charters Towers to Mount Isa and the first offshore work was undertaken off central Queensland. A total of 310 Aerodist lines were measured and forty-nine new stations were coordinated.

The aim now was to provide control to the density and accuracy required for the 1:100 000 mapping program, which had been approved late in 1965.

Aerodist control in one degree squares with stations at thirty minute intervals around the perimeter of the photogrammetric blocks - see Annex C - was adopted to help control slotted template assemblies. Vertical control was provided by the airborne radar or laser terrain profile recorders (Wise 1979).

The servicing of the Aerodist equipment in the field had so far been done in primitive conditions by one or two technical officers. In 1966 a custom-built workshop caravan, equipped with electronic test equipment, and with space for office work and Aerodist chart and field book examination, was brought into use. Comprehensive overhauls of the equipment and field testing prior to each year's surveys also became standard practice.

From 1966 an Aero Commander 680FL (Grand Commander) was used as the master platform - see Figure 3 and Plates 2 and 3. The larger cabin allowed the equipment to be installed in shock-mounted racks and the two master operators to sit side by side facing forwards. A wild HC1 horizon camera was also installed, linked to a Vinten 70 mm camera, enabling simultaneous horizon and vertical photography during photo-trilateration measurements - see Plate 4. The Vinten camera was also used for spot photography of the Aerodist survey control points so that they could be precisely identified on the mapping photographs. This spot photography became standard procedure on all Aerodist surveys.

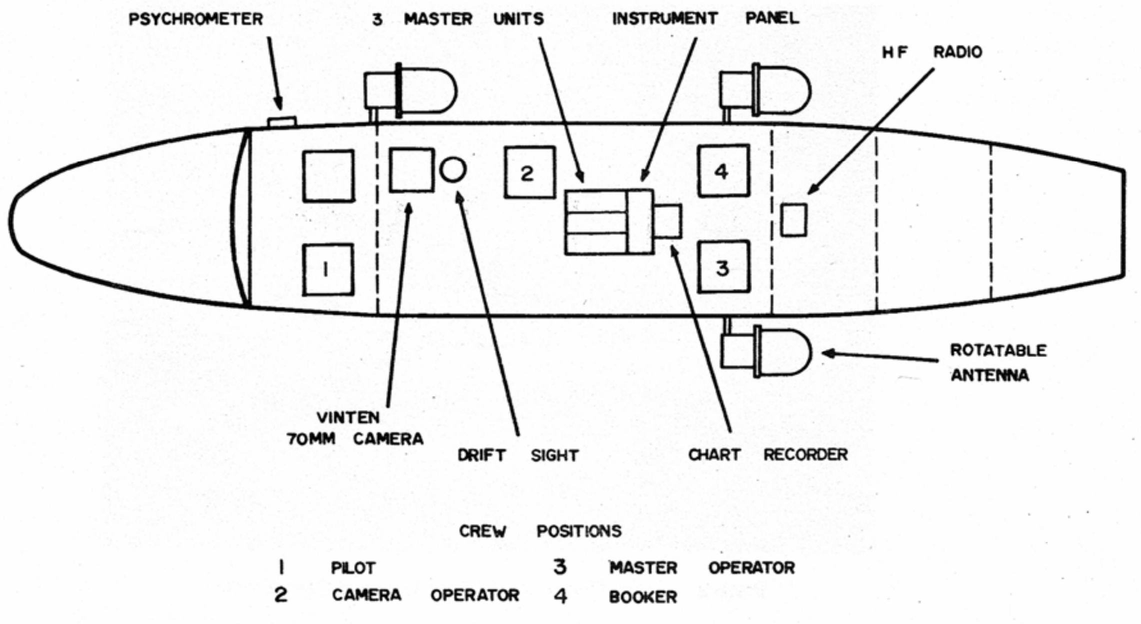

FIGURE 3 EQUIPMENT CONFIGURATION IN AERO "GRAND COMMANDER"

Plate 1 Remote equipment in use

Plate 2 Aero Commander 680 FL Grand Commander

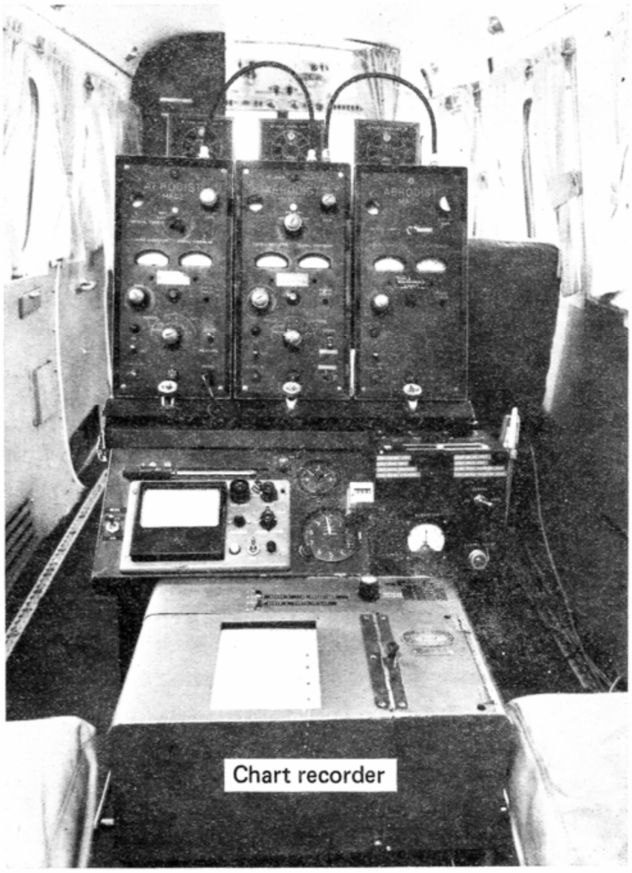

Plate 3 Master equipment

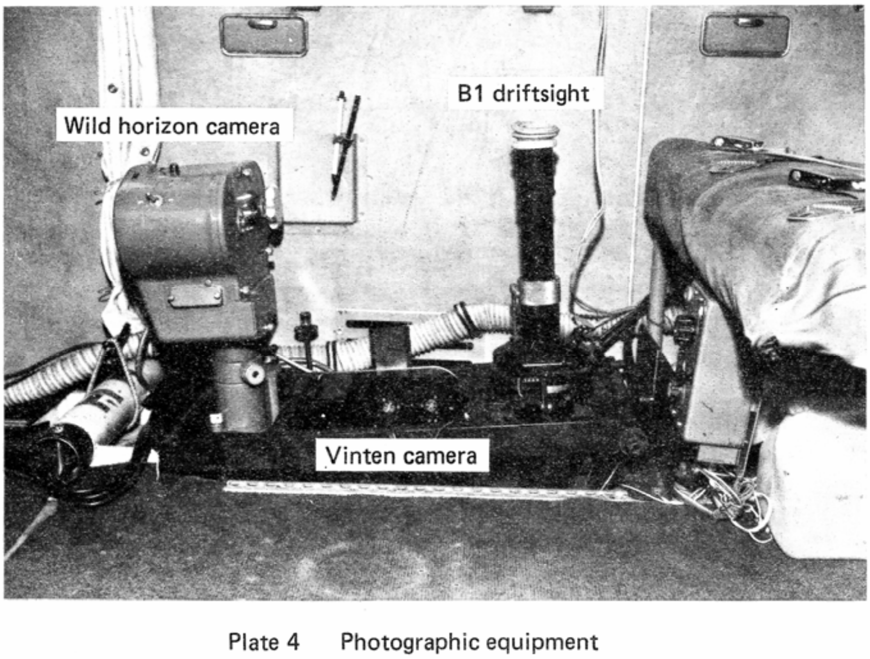

Plate 4 Photographic equipment

5.3 The Production Phase: 1967-74

By 1967 National Mapping had established satisfactory Aerodist working procedures which continued for the rest of the program.

The centre party with aircraft and workshop caravan was based at the nearest suitable landing ground. Each week an operational plan was drawn up showing remote parties, their vehicles, radio call signs, lines to be measured and the movement of parties. Subsequent changes to the program, made either by the Aerodist master operator or by the party leader, were relayed to all the field parties by radio.

From 1967 chartered helicopters were used for remote party transport in areas where ground access to control stations was difficult. Helicopter camps, with fuel supplies, were sited central to the work area.

Forward-control Landrovers were used by the field parties in 1967 but proved to be unreliable and were replaced by long-wheel-base Landrovers. International trucks continued to be used for the heavier work of towing the caravan or carrying fuel, but the lighter Landrover was the normal remote party vehicle.

An Aerodist field party typically consisted of:

Centre party:	1 surveyor, party leader
	2 technical officers (Survey)
	2 technical officers (Engineering)
	Pilot of the Aerodist aircraft
Helicopter camp:	1 surveyor
	1 field assistant, fuel truck drivers
	Helicopter pilots and engineer
Remote parties:	4 technical assistants
	4 field assistants

Aerodist field operations continued each year until 1972 when 517 lines were measured in thirty-four weeks ranging over 950 000 square kilometres in the Great Sandy, Gibson, Great Victoria Deserts and the Nullarbor Plain. This completed the main Aerodist surveys, but work continued in 1973 and 1974 to strengthen the existing network and establish control on groups of islands off Western Australia.

The table at Annex D summarises the total Aerodist field program, with more than 3000 lines measured to fix 480 stations.

Over 100 surveyors, technical officers and assistants in the Topographic Branch - later the Control Survey Branch - from National Mapping's Melbourne office worked on the field program from 1963 to 1974.

Some thought was given to the acquisition of a new system, of airborne position fixing equipment, but with the completion of the 1:100 000 mapping control and the arrival of Doppler satellite positioning equipment, the need for airborne work diminished.

Like the preceding Tellurometer traverses, the Aerodist program was a once-only task.

5.4 <u>Phototrilateration Surveys</u>

During the 1966 survey, an attempt was made to use the, phototrilateration method to intensify the control in the previous Aerodist areas of Queensland. This method did not require ground occupation of the new control thus enabling the survey to proceed at a faster rate.

Distances to three remotes set up at coordinated stations we simultaneously to provide a continuous fix of the aircraft's position- see Figure 4. Vertical and horizon photographs were taken throughout measurement and an event-mark was automatically recorded on the Aerodist chart at the instant of each exposure, allowing the three slant distances to each remote to be calculated. In practice, it was difficult to position the aircraft over the area of the proposed control station while record measuring traces to the three remotes, particularly as the forward antenna was mounted on one side of the aircraft fuselage.

The air coordinates at each exposure were subsequently computed by program TRILAT (Annex E) with good results, but because the horizon could not be satisfactorily located on the HC1 photography and the metric quality of the Vinten photography was poor, ground coordinates could not be accurately derived.

The technique was used again without the HC1 camera in 1973, to establish lower order control on offshore features off the north-west c of Western Australia.

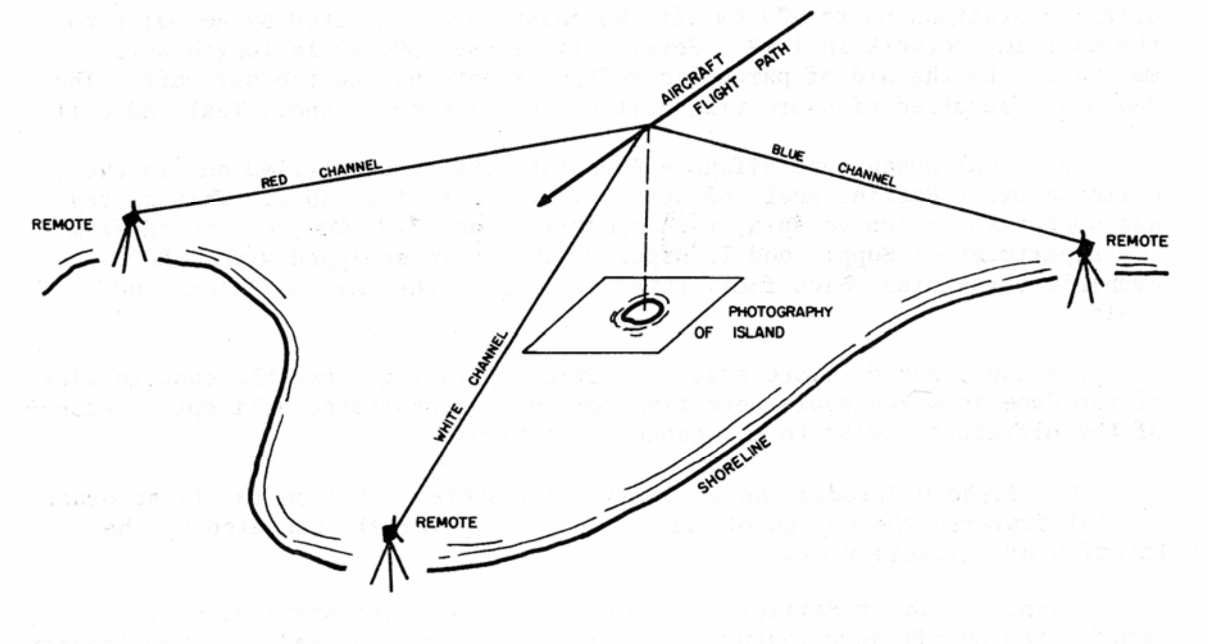

FIGURE 4 AERODIST PHOTO TRILATERATION

5.5 Offshore Surveys

A number of Aerodist surveys were undertaken between 1966 and 1971 over the Great Barrier Reef from Fraser Island to Papua New Guinea. Other surveys were made to islands off On slow and Port Headland in the Recherché Archipelago in Western Australia in 1973. These surveys presented special problems of transport, station establishment and network design.

The initial offshore survey using the normal line crossing technique was conducted in a two-week period in September-October 1966. Forty lines varying in length from 35 to 180 km were measured, connecting PAN triangulation stations on islands off the Queensland coast between Bundaberg and Proserpine to the mainland first-order traverse. The RAN survey vessel HMAS Paluma, supplemented by locally hired boats, was used to transport the remote parties between the islands.

Ground reflections due to the steep topography at many of the stations caused problems, and on many lines usable measurements were only obtained by flying at very low line-crossing altitudes.

In 1968, HMAS Teal, a coastal mine-sweeper, transported a National Mapping reconnaissance and station-marking party around the central Barrier Reef. This party also established local survey control by running Tellurometer traverses from the Aerodist stations and fixing stations on various features including shipwrecks and shifting sand cays.

To help recover marks on shifting sand cays, permanent marks were established in nearby live coral.

Following the computation and adjustment of the coordinates of the 1966 survey, the Aerodist network was extended seawards in 1969 and 1971. Ten offshore stations up to 500 km off the coast were connected by Aerodist to the existing network in 1969. Several lines over 300 km in length were measured with the aid of parabolic reflector antennae on the aircraft. The RAN again supplied offshore transport using the mine-sweepers, Teal and Gull.

The final Queensland offshore Aerodist survey was carried out in the northern Great Barrier Reef and across Torres Strait in 1971. This survey was supported by two vessels, the Cape Pillar and Cape Don, chartered from the Department of Supply and Transport. They were equipped with LARC amphibious vehicles which facilitated landing at the various islets and reefs.

The shore-based remote station parties operating along the eastern side of the Cape York Peninsula were transported by a chartered helicopter because of the difficult access to the geodetic stations.

The offshore Aerodist network was cantilevered out from the first order coastal traverse, the design of the network being largely dictated by the location of suitable reefs.

During the Great Barrier Reef surveys, 38 Aerodist stations were coordinated on offshore features and 160 lines were measured, the two longest exceeding 373 km.

A number of the offshore stations were reoccupied from 1978 by National Mapping survey parties using JMR Doppler positioning equipment. The resulting computations showed that one of the Aerodist station coordinates was in error by fifty metres but the remaining differences were less than ten metres, with an average of about 6 m. The gross error was due to misinterpretation of poor Aerodist charts.

5.6 Station Marking

Aerodist stations were normally established as a separate operation in advance of the measuring surveys, and involved the reconnaissance, selection and marking of the stations. Where feasible, Tellurometer connections were measured between the Aerodist stations and stations on the geodetic network to strengthen the Aerodist configuration.

Marking surveys were generally undertaken by National Mapping parties, with the exception of thirty-eight stations established in western Queensland in 1967 and twenty-one in the eastern Northern Territory in 1968-69 by survey firms on contract.

The working party usually consisted of a surveyor and up to ten technical staff, often with the aid of a helicopter in remote areas.

The main site selection criteria were:

> The station was to be located within five kilometres of the normal point for 30' quadrilaterals, and within eight kilometres for 1º quadrilaterals; and preferably within the lateral overlap of the mapping photographs.
>
> The site was to be selected with a view to permanency and ease of future location and access.
>
> Rays to adjacent stations were not to be obscured by natural or man-made features located within 5º either side of a ray or within an elevation of 1º.

Stations were heighted by spirit levelling if a bench mark on a known datum was within eight kilometres; otherwise a barometer height traverse was run to provide provisional heights for Aerodist line reductions. Station heights on the Australian Height Datum were subsequently provided by a separate program of third-order levelling.

Topographic Instruction 1/7/1 (Natmap 1965) sets out the Aerodist station marking procedures.

6. COMPUTATIONS

6.1 General Procedure

The Aerodist charts were examined in the field to confirm that at least seven usable crossings had been obtained for each line, by checking that the line had been crossed and that the summed distances either side of the crossing were at least 80 m greater than the minimum sum.

Coarse distances were computed on at least two runs, checking that B, C, D patterns were present on all runs. The field book information was checked particularly any eccentric mark details - see Annex F.

Charts and field books were sent by air to the office where three or four officers were continuously engaged on reductions, supplemented by field party members between field trips.

Height differences between the remotes and the air station were determined from differential air pressures recorded at the instant of each line crossing. The digital "Mechanism" remote barometers were calibrated regularly and correction graphs drawn. Aircraft altimeter height were checked regularly by flying the aircraft directly over an Aerodist remote station at various altitudes and comparing the measured distance to the distance calculated from the pressure differences. Aircraft altimeter corrections were derived, and if significant, applied prior to the distance reductions.

Corrections to Aerodist distances were applied by comparing calculated distances between geodetic stations with the measured Aerodist distances during discrete operational periods.

The transmitted A frequency used for measuring was subject to minor phase defects resulting in inaccurate measurements. To overcome this a so-called negative A trace was recorded and the arithmetic mean value of positive and negative A gave a correct A reading.

It became a standard procedure to record a short section of A+ and A- traces from the remote instruments at the start and finish of each line measurement.

Each run was broken out and the chart values at twenty-one spaced regularly points along the chart were read off and transcribed to data sheets with the relevant field book and station information.

The data was punched on to cards by a service bureau and batch jobs were run through the CSIRO computing network, initially on a Control Data 3200 computer, later on Control Data 3600 and 7600 computers.

Ambiguities due to poor Aerodist chart traces and incorrect station data could be resolved by computing each quadrilateral. Preliminary coordinates of the new stations were computed by intersection (program Intsect - see Annex G) using a minimum, of three Aerodist distances radiating from previously coordinated stations.

Preliminary coordinates and the proven distances resulting from the Intsect run were used as initial data in program Varycord, weighting distances and azimuths inversely to the 1ength of the lines. Several iterations of Varycord were necessary.

6.2 Aerodist Line Reductions

Line crossing data, in the form of a continuous strip-chart recording the changing ranges from the aircraft to the two remote stations, had to be reduced to the spheroidal distance between the stations.

A minimum of seven good line crossings were measured and the mean of the separate reductions adopted.

A range to a remote station was transformed by the recorder from a phase difference between the emitted and received signals of the primary ‘A’ frequency.

A zero or 360º phase difference deflected the pen to the top of the chart, while a 180º phase difference deflected the pen to the bottom of the chart. The maximum pen deflection was set equal to the width of chart, enabling the distance to be read at any instant.

As the changing deflection of the pen was similar when the distance was increasing or decreasing, an ambiguity resulted that was resolved by a second pen trace, which had two positions. A downward deflection of this pen indicated a phase difference in the range 0º to 180º (0-50 metres) while an upward deflection indicated 180º to 360º (50-100 metres).
To determine the whole number of wave lengths ("the coarse figure") of which the A frequency gave the final fraction, three additional frequencies (B, C, D) were automatically transmitted and recorded for short periods at regular intervals. These frequencies were such that the values read from the chart, when subtracted from the A frequency, gave the tens of thousands of metres, thousands and hundreds respectively.

The sum of the two distances between the aircraft and each end station reached a minimum as the line was crossed. Summed distances at ten points equally spaced in time either side of the minimum were used in each reduction. These sums were plotted against time, producing a parabola, whose minimum value was the sum of the two distances at the instant of line crossing - see Figure 5. The minimum sum was determined by fitting a parabola to the 21 points by least squares. Each minimum sum was reduced to a spheroidal distance.

Using the atmospheric pressures and wet and dry bulb temperatures recorded at the ground and air stations the refractive index of the air between the stations was calculated for each run.

The refractive index was calculated from:

$$n = 1 + 77.601 * 10^{-6} (P + E) / (273 + t)$$

where $E = 4744e / (273 + t)$
and P is the mean barometric pressure in millibars
t is the mean dry bulb temperature in degrees centigrade
e is the vapour pressure.

As the A frequency gave a direct chart readout in metres using a mean refractive index of 1.000330, the corrected path length L was given by:

$$L = 1.00033 * d/n$$

where n is the calculated refractive index of the air between the stations, and d is the minimum distance extracted from the chart.

For an aircraft height (master station) h_2, and ground height (remote station) h_l, the chord length C at sea level is given by:

$$C = [\ R / (R + h_1)\ ] * [L^2 - (h_2 - h_l)^2]^{½} * [\ (1 - h_2 - h_l) / 2R]$$

where R is the radius of the earth, for which a mean value of 6 365 000 m was adopted.

The spheroidal distances were calculated by adding the chord-to-arc correction:

$$S = C + C^3 / 43R^2$$

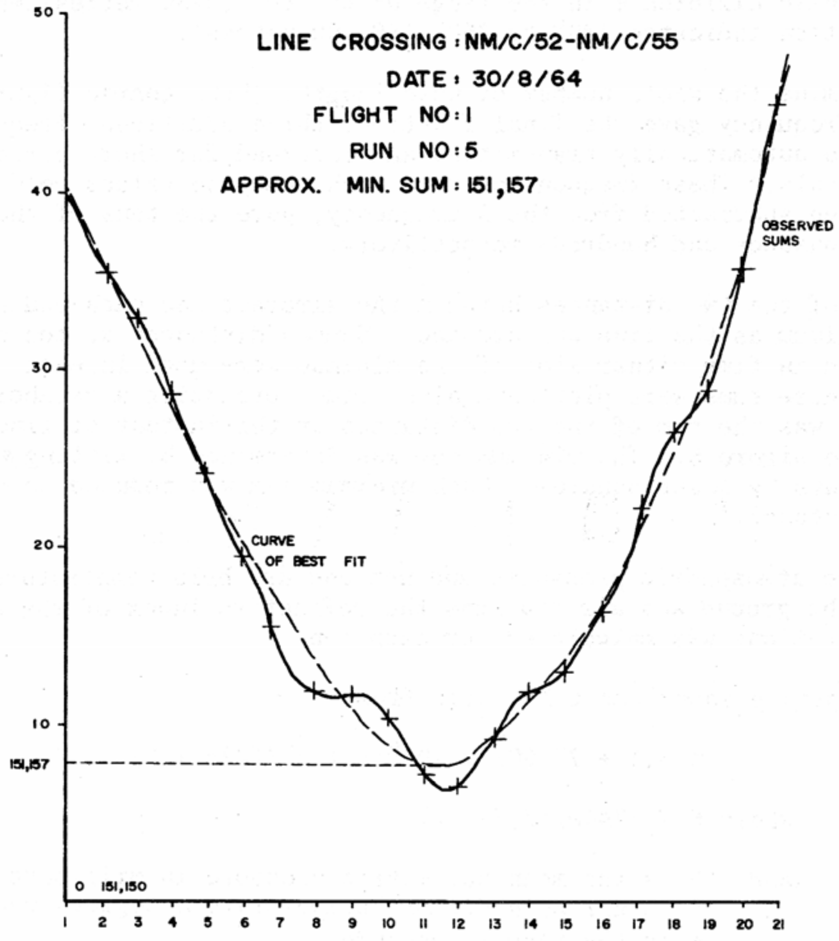

FIGURE 5 LINE CROSSING GRAPH

Eccentric corrections to the ground mark were added where necessary, and a correction was added for the separation of aircraft antenna.

The final accepted distance was the arithmetic mean value of at least seven runs. The range between the maximum and minimum values on any line was usually about five metres.

Computer programs (AERO, AERONU, -see Annex H) were written to compute the corrected spheroidal distance from the manually derived chart data and the field book information.

6.3 Chart Reader

A strip chart conversion unit developed by the CSIRO Division of Land Research and Regional Survey was purchased in 1966 to automate the time consuming manual extraction and reduction of Aerodist data.

The Aerodist chart trace was converted to a digital record on punched paper tape allowing direct input to the computer. The field book and station data was punched on cards and software written for the complete reduction from the breakout of the chart through to the final spheroidal distance.

The system was run with moderate success in parallel with the manual reduction for several years but because of increasing mechanical and electronic problems with the reader it was eventually discarded in favour of manual reduction.

6.4 Accuracy

Aerodist measurements of known geodetic distances were made as the surveys progressed. The difference seldom exceeded five metres. When they did, the reasons were usually apparent:

> Poor quality A traces, due to marginal equipment performance, long lines, or steep outlooks at remote stations causing large ground swings.
>
> Blunders in eccentric station connections.
>
> Inaccurate meteorological observations.
>
> Misreading the aircraft altitude at the line crossing, subsequently overcome by reading two altimeters, one imperial and the other metric.

From all the Aerodist Varycord adjustments, the average difference between the observed and the adjusted distances is 1.49 metres, for an average line length of around 100 km. On the twenty-nine adjustments, the average maximum residual was 6.3 metres.

Subsequent Tellurometer traverses or JMR fixes at a number of Aerodist stations verify that the Aerodist coordinates are accurate to better than 5 metres, with the exception of the one offshore station mentioned above.

ACKNOWLEDGEMENT

The author wishes to thank his colleagues in the Division of National Mapping who assisted with the preparation and editing of this report.

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AERODIST EQUIPMENT - MAJOR PURCHASES AND MODIFICATIONS

1963	Purchase of Aerodist model MRC2: 2 master, 4 remote units, chart recorder, rotatable master antennas, ancillary equipment.
1964	Modification of aircraft antenna switching by manually changing cables.
1964	Purchase of 1 master, 1 remote unit.
1965	Purchase of 1 remote unit.
1966	Modifications of 1 remote unit to two frequencies.
1966	Purchase of 3 master units.
1967	Modification of 2 remote units to two frequencies.
1968	Purchase of spare chart recorder.
1969	Purchase of 2 remote dipole assemblies and bases for new fixed master antenna.
1971	Modifications to remote units to enable front panel control of A+ A- switching and Klystron coarse tuning. Crystal calibration was also made more accessible to the operator.

Annex B

GUIDANCE NOTES FOR AERODIST MASTER OPERATORS

Preliminary

1. Check psychrometer bottle for water and check evaporation sock for wetness before take-off.

2. Switch on Aerodist master, chart recorder, intercom, radio and psychrometer as soon as aircraft is airborne. Master equipment requires 20 minutes to warm up.

3. Check for crystal current after a few minutes - tweak triode if necessary for maximum reading. Klystron tune should be at the centre of its run, about 7 turns from either end.

4. Check master modulation (mod) after warm up time - A75, B75, C75, D65.

5. Switch the remotes to H.T. 15 minutes before they are required. Tune in and check for performance whilst ferrying into the measuring position, if possible.

6. Cheek the A, B, C and D crystal visual displays on both units.

7. Adjust the topping and bottoming of the chart recorder channels.

8. Check chart for quality trace and correctness of aircraft headings.

Tones and Mod Checks to Remotes

a) Tones (instruments in measure mode)

Master switches to D.

Remote switches to D tone position and adjusts switching level until D goes negative.

Master stays on D.

Remote switches to A and remote adjusts switching level so that A reads 15 - 25 on meter.

The same procedure can be used to clean up B and C if one is in doubt.

b) Mods

Remote goes to MOD.

Master switches to A.

Remote adjusts A mod to read 75 then asks master for B.

Master switches to B.

Remote adjusts B to read 75 then asks master for C.

Master switches to C.

Remote adjusts to read 75 then asks master for D.
Master switches to D.

Remote adjusts D to read 65 and informs master.

To Adjust Switching Levels and Mods in Master

If it is suspected that the master is not switching a pattern in, i.e. not switching on either channel, then adjust the tone levels.

Go to measure and turn function switch to mod.

Select A on pattern switch and adjust the mod with a screwdriver to read 75.

Select B on pattern switch and adjust B mod to minimum.

Adjust B tone gain control to 15-20.

Readjust B mod to 75.

The signal now comprises 15-20 tone and mod 75.

Repeat this for C - 15-20 tone and mod 75.

Repeat for D - 15-20 tone and mod 65.

Aircraft Headings

As soon as the aircraft is lined up to come into the crossing position and sufficient signal strength is obtained, briefly check the chart to determine aircraft position in the sky. If equipment adjustment is necessary, determine where the crossing is and ask the pilot to fly backwards and forwards on long runs until the units are set up. This is quite important as the aircraft may fly out of the effective heading range of remotes whilst equipment is being set up.

Heading Changes

To facilitate heading changes it is helpful to have previously determined the bearing of the perpendicular to the line to be measured. Apart from consideration of aircraft drift due to wind, the heading of the aircraft should be within plus or minus 7 degrees of the perpendicular bearing.

To flatten a steep increasing trace the aircraft must be turned towards the station providing that trace. Similarly, to steepen a flat increasing trace, the aircraft heading must be turned away from that station.

If both traces are too flat the heading is too square and must be altered constantly in either direction until one trace is flat and one trace is steep.

If both traces are too steep head more square to the line.

If both traces are decreasing evenly the heading must be changed to force one trace to "turn-over" and start increasing.

An alternate foolproof procedure to correct headings without prior consideration is to always ask for MINUS 5º first and watch for the immediate effect on the trace. If adverse, immediately follow with a PLUS 10º correction and add further 2 or 5 degree increments where appropriate.

If the initial minus 5º heading change has a beneficial effect, continue to take off degrees until the correct heading is obtained.

Low Signal Strength

The usual procedure is to go closer to the station yielding low signal strength and gain altitude. However the problem is sometimes best overcome by decreasing altitude.

Aircraft Altitude

As a general rule about 1000 feet of altitude for every 10 miles of line length produces good charts e.g. 60 mile line - 6000 feet altitude. However 1000 feet less is sometimes better, depending on terrain. To lessen the effect of height errors, the aircraft altitude should, as a general principle, be kept as low as possible.

Interference

If the trace repeatedly breaks or is poor with a sudden loss of signal strength at a particular point on the run this indicates that there may be interference on line, such as a tree, cairn or high ground. Generally the aircraft will need to gain a higher angle on the ray path from that station by going closer or higher. The remote setup may also be shifted in the case of local interference.

Trouble Shooting

Master:

1. If no signal is picked up from a remote, confirm that the remote is switched on and pointed at the right line.

2. Cheek that correct antenna connections to required Masters are being used, and check that the antenna switch is in the appropriate position for the present aircraft heading.

3. If contact is made with a remote, but signal strength is low, the remote should DF (Direction Find) slowly.

4. If contact continues to be poor, but speech communication exists, check triode tune on remote and transmission on remote. Have remote operator check reflector tune and maximum deviation position on his unit.

5. If signal strength is good, but there is no speech to one remote either way, and no FM is received, it is most likely that the lead to the remote IF is disconnected, or faulty.

6. If the signal strength is adequate, but the A trace very noisy or wide, whereas B, C and D are clean, check that A pattern is not over-modulating by first checking the master, and then having the remote operator reduce his switching level to zero. If this gives a clean trace, the problem is then reduced to setting up mods and tones. If only one pattern is clean, it suggests that this pattern is not switching out and is overlaying each of the other patterns. Generally, if there is no technician in the plane, take adequate notes and keep the chart for reference so that

the fault can be diagnosed on the ground. Try to determine whether the malfunction is the Master or Remote by trying other remotes of the same colour if available.

Length of Line

A difference of 200 metres should be aimed for, between the MINSUM from the crossing sum and the sums at the ends of each run.

Less than 100 metres difference is unacceptable.

A cross should be made on the chart at the crossing point and 200 metres counted from there, allowing more for head wind where necessary to avoid a short run-in in the other direction.

Booking

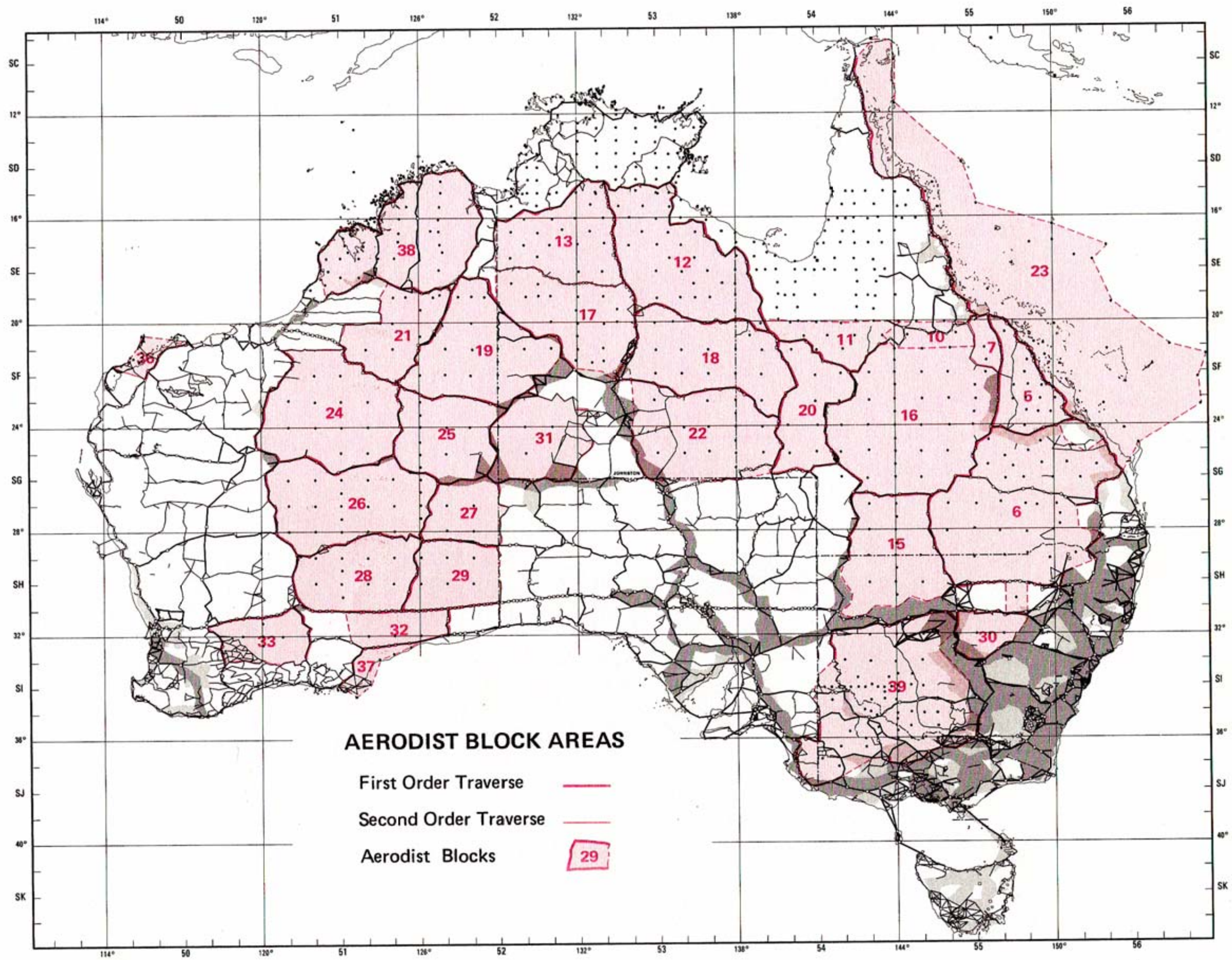
All marginal lines should be booked unless obviously hopeless, and a short annotation made if the line is considered unusable. Seven acceptable lines is the minimum requirement, and an extra one should always be taken where the aircraft has to head back through the line at the finish.

The foot and metric altimeters should ideally be read simultaneously at the crossing point, and at least one set of readings should be compared by the feet to metres conversion graph as a gross error check.

The readout on the psychrometer thermocouple is in volts, where 0.4 volts equals 10 degrees. Care must be taken to ensure that values are read on the correct scale. If in doubt about the wet bulb reading, the sock should be checked in flight.

Navigation

A visual check on the pilot's navigation during ferry flight and approaches to crossing lines is well worthwhile, and sometimes explains perplexing problems of poor signal strength and strange charts.


AERODIST BLOCK AREAS
First Order Traverse
Second Order Traverse
Aerodist Blocks
29
6 7 10 11 12 13 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 36 37 38 39

NMP/80/054

Annex D

WORK COMPLETED

YEAR	AERODIST BLOCK ADJUSTMENT NUMBER AND GEOGRAPHIC AREA	CONTROL STATIONS FIXED	LINES MEASURED
1963	ADS BA 6 – Queensland	17	66
1964	ADS BA 6 - extended into northern New South Wales	18	110
	ADS BA 5 – Queensland		
1965	ADS BA 5/BA 6 - existing net intensified	11	150
	ADS BA14 (part BA39) - New South Wales		(50 re-measured)
1966	ADS BA 5/AB 6 - intensification & phototrilateration	49	310
	ADS BA 7, BA10 – Queensland		
	ADS BA 8 (part BA23) - offshore central Queensland		
	ADS BA39 (includes BA14, BA34, BA35) - New South Wales and Victoria		
1967	ADS BA11 - Queensland	60	315
	ADS BA12 - Northern Territory		
	ADS BA13 (part) Northern Territory		
	ADS BA39 - extended & intensified		
1968	ADS BA13 - completed	40	223
	ADS BA15 - Queensland, New South Wales		
	ADS BA17 - Northern Territory		
	ADS BA23 - Southern Great Barrier Reef		
1969	ADS BA12 - new stations on Qld-NT Border	50	259
	ADS BA15 - completed		
	ADS BA16 - Queensland		
	ADS BA20 - Queensland		
	ADS BA23 - Great Barrier Reef		

1970	ADS BA17 - completed	50	390
	ADS BA18 - Northern Territory		
	ADS BA22 - Northern Territory		
	ADS BA31 - Northern Territory		
1971	ADS BA18 - completed	40	254
	ADS BA19 - Northern Territory & Western Australia		
	ADS BA21 - Western Australia		
	ADS BA23 - northern Great Barrier Reef		
	ADS BA30 - New South Wales		
1972	ADS BA21 - completed	80	517
	ADS BA24 - Western Australia		
	ADS BA25 - “		
	ADS BA26 -- “		
	ADS BA27 -- “		
	ADS BA28 -- “		
	ADS BA29 -- “		
	ADS BA33 -- “		
1973	ADS BA32 - Western Australia	50	327
	ADS BA39 - control intensification		
	ADS BA36 - Onslow - Monte Bello offshore, WA		
	ADS BA37 - Recherché Archipelago, WA		
1974	ADS BA38 - Western Australia	15	100

Topographic Survey Branch. | *Division of National Mapping* | *Program* TRILAT

AERODIST TRILATERATION

Fortran Computation Data

1	8	42	47	56	63	65	69
SURVEY	BA 36 TRYAL ROCKS EAST TRITESTS	DATE	09/09/73	FLIGHT	1	RUN	03

	Stations (1)	Latitude Deg. (15)	Latitude Min. (18)	Latitude Sec. (21)	Longitude Deg. (28)	Longitude Min (32)	Longitude Sec (35)	Temp. °F Dry (42)	Temp. °F Wet (47)	Press. (mb) (53)	Height (ft) (61)	Ecce. Corr. (m) (67)	Ant. Corr. (m) (73)	Index Corr. (m) (77)
A	TSC	20	24	59·499	115	34	25·299	74·8	65·10	1011·84	89	0·0	·	−1·5
B	TSH	20	51	07·340	115	20	23·338	77·9	65·10	1010·71	121	0·0	·	+1·3
C	NMF653	20	39	23·409	115	34	33·954	75·6	64·40	1012·26	72	0·0	·	+3·0
	AIRCRAFT	20	16	30·000	115	23	00·000	17·0	0·00	0·08	2235	No. of Fixes =	2·0	

		Stations				Stations				Stations	
1	5 A	12 B	19 C	28	32 A	39 B	46 C	55	59 A	66 B	73 C
011	25100	64914	47103	012	24991	64832	46994				
Unit	RED 1	WHITE 3	BLUE 3	Field Book	NM12537	NM12530	NM 12544	A/C Field Bk	NM 12617	Photo Field BK.	NM —

Notes: (1) *Temperatures for ground stations are to be entered in degrees farenheit.*

(2) *For aircraft readings:* *enter Reference temperature in degrees centigrade under column "Dry".*
enter Diff. Dry in meter's units under column "Wet".
enter Depress. in meter's units under column "Press. (mb)".
enter Ind. Alt. corrected for index error of altimeter under column "Height (feet)".

(3) *Enter camera exposure distances in sequence across the page, as enumerated, before commencing a new line.*

Compiled: R W Gold	*Checked:* E Zang
Date: 10/4/74	*Date:* 10/4/74

PROGRAM TRILAT - DATA SHEET

ANNEX E

PROGRAM TRILAT - OUTPUT

SURVEY BA 36 TRYAL ROCKS WEST TRITESTS DATE 09/09/73 FLIGHT 1 RUN 03

STATION	LATITUDE	LONGITUDE	DRY	WET	PRESS	ELEV ECCE ANT IND	A/C ELEV
TSC	20. 24. 59.499	115. 34. 25.299	74.7	65.30	1011.98	89. 0.0 -0.0-1.5	764.6
TSH	20. 51. 7.340	115. 20. 23.338	77.7	64.40	1010.70	121. 0.0 -0.0 1.3	765.2
NMF653	20. 39. 23.409	115. 34. 33.954	77.0	65.30	1012.10	72. 0.0 -0.0 3.0	762.0
AIRCRAFT	20. 16. 30.000	115. 23. 0.000	18.0	0.00	.19	2370. -0.0 2.0-0.0	763.9 MEAN

EXP	OBSERVED DISTANCES			REDUCED DISTANCES			ADJUSTED DISTANCES			LATITUDE	LONGITUDE	EXP
20	25082.0	64012.0	46618.0	25069.9	64004.9	46609.8	25067.7	64003.0	46613.4	20 16 32.017	115 23 8.959	20
21	25018.0	63958.0	46547.0	25005.9	63950.9	46538.8	25002.3	63947.7	46544.9	20 16 33.911	115 23 10.244	21

Date: 23/4/66	Flt.: 1	Line: NM/C/39 TO ULALU (TRIG)
A/C: EXZ	Pilot: I. BELL	NOTES: R.A. VASSIL Operator: L/C. McMASTER
Take off: E.S.T. 0850	Land: 1145	Base: HAY, N.S.W.

Remote Positions	
Red 1 : ULALU (TRIG)	(G.J.)
White 2 : NM/C/39	(P.W.)
Blue – : –	

Run	Time E.S.T.	Head	Signal Strength 1 Red	White 2	~~Blue~~	Atmospherics 1 Dry	2 Dep.	Alt. FEET	
1	1032	135	17	22	–	REF. TEMP. 19.7°C 0.47	0.135	5850	
2	1038	310	25	25	–	0.52	20.6 0.135	5820	✓
3	1041	135	33	19	–	0.525	20.8 0.13	5830	✓
4	1044	315	27	22	–	0.52	20.7 0.125	5830	✓
5	1046	130	30	19	–	0.51	20.4 0.125	5820	✓
6	1050	315	27	22	–	0.48	20.3 0.125	5810	✓
7	1053	135	33	20	–	0.49	20.3 0.127	5810	✓
8	1056	315	27	22	–	0.49	20.4 0.118	5810	✓
9	1059	140	32	21	–	0.48	20.2 0.12	5830	✓
10	1103	315	25	22	–	0.47	20.4 0.12	5850	✓
11	1106	135	31	18	–	0.49	20.7 0.117	5830	

Height Checks END. RAV

Time	Altitude	Position

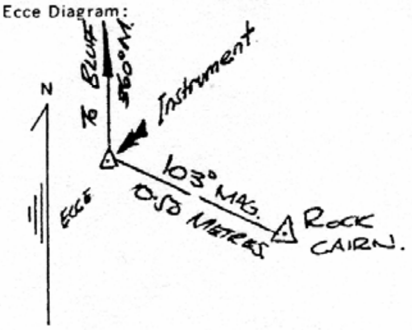
Met Conditions 1/16 CIRRO ~~AND~~ ALTO STRATUS
WINDS SSE. 10 TO 15 KNOTS
A LITTLE CUMULUS ALTO STRATUS
FAIRLY CLEAR HORIZON

Topo. Conditions
SANDY, LEVEL PLAINS.
SCATTERED CLUMPS OF TREES

Equipment Performance
REF. TEMP. HAD SOME SUN ON RUN 2 ~ Cabin Temp is fluctuating
✓ Denotes Good Run.
On Easterly side of Line Crossings - Terrain Difficulty
1054 hrs: MODS: A 70, B 70, C 70, D 65

Remarks
NOISE ON RED 1, TREES 50 YARDS AWAY ON LINE, AT ULALU ~ FOR RUN 1.
Co-AX. POSITION 2 FOR RUN 2
RUN 1 IS VERY POOR.

AERODIST REMOTE FIELDBOOK

Barometer No.: 33	Eccentric Station Data.
Psychrometer No: 29574	Ecce Mark: IS A 3/8" COPPER TUBE SET IN CONCRETE
Met. Conditions: 5/8 CLOUD COVERAGE 10-15 KNOT S-E WIND.	Ecce to Station Mag. Brg.: 103° MAG.
	Distance: 10.50 METRES.
Topo. Conditions: FROM HIGH CLEARED HILL ACROSS HIGH HEAVLY TIMBERED UNDULATING COUNTRY	Ecce Diagram: 
Equipment Performance:	
Remarks.	Instrument stand point to be clearly indicated on Ecce. Diagram. Distences to be in METRES

Date: 28TH JUNE 65		Inst.: BLUE 1			Location: FAIRHILL						
Operator: B. YARLLEY		Inst. Brg.: 360° M.			To Station: THE BLUFF						

Run	Time	Temp.		Pressure				Meter Readings.					
		Dry	Wet	1	2	3	Mean	Dev.	Trans.	+300 v	+ 6 v.	Batt.	S.S.
1	1600	59.5	51.2	2150	2140	2160	2150	√	.59	67	58	76	40
2	1603	59.6	51.3	2150	2140	2160	2150	√	.59	67	58	76	34
3	1606	59.0	51.1	2155	2145	2160	2153	√	.59	67	58	76	36
4	1616	59.0	51.2	2155	2145	2160	2153	√	.55	67	58	76	35
5	1618	58.9	51.1	2155	2145	2160	2153	√	.55	67	58	76	34
6	1620	58.7	50.9	2155	2145	2160	2153	√	.55	67	58	76	36
7	1622	58.9	51.0	2155	2145	2160	2153	√	.55	67	58	76	34
8	1626	58.0	50.5	2155	2145	2160	2153	√	.55	67	58	76	33
9	1628	58.0	50.6	2155	2145	2160	2153	√	.55	67	58	76	33
10	1630	58.1	50.7	2155	2145	2160	2153	√	.55	67	58	76	32
11	1633	57.8	50.0	2155	2145	2160	2153	√	.55	67	58	76	30

PROGRAM INTSECT

VARIABLE HEADING FOR OUTPUT

NO. OF STATIONS	7	AERODIST BLOCK ADJUSTMENT 29 1972

STATION NAME	LATITUDE Degs.	LATITUDE Mins.	LATITUDE Secs.	LONGITUDE Degs.	LONGITUDE Mins.	LONGITUDE Secs.	DISTANCE Metres
NM F 224 R.M.	30	51	31·896	128	01	58·145	138119·84
NM F 84 R.M.	30	57	07·287	127	02	45·278	105742·07
NM F 74 R.M.	31	00	50·780	125	55	43·136	151906·34
NM F 646	30	30	17·982	126	00	32·678	109966·43
NM F 643	30	00	24·436	125	59	55·866	95830·53
R 199	29	24	51·317	125	54	15·644	123630·89
NM F 639	28	59	27·312	125	59	45·960	147724·93
NM F 644 INTERSECTED POINT	30	00	10·0	127	00	9·0	

Compiled – B.W. 13.8.74
Checked – P.L. 14.8.74

PROGRAM INTSECT – DATA SHEET

ANNEX G

PROGRAM INTSECT - OUTPUT

TITLE
NO OF STATIONS 7 AERODIST BLOCK ADJUSTMENT 29 1972

NEW COORDINATES		LATITUDE	LONGITUDE
NM F 644	INTERSECTED POINT	29 59 57,606	126 59 31,412

STATION	LATITUDE	LONGITUDE	OBS DIST	ADJ DIST	DIFF
NM F 224 R,M,	30,51, 31,896	128, 1, 58,145	138119,84	138116,59	3,25
NM F 84 R,M,	30,57, 7,287	127, 2, 45,278	105742,07	105742,49	-,82
NM F 74 R,M,	31, 0, 50,780	125,55, 43,136	151906,34	151907,07	-,73
NM F 646	30,30, 17,982	126, 0, 32,678	109966,43	109963,89	2,54
NM F 643	30, 0, 24,436	125,59, 55,866	95830,53	95831,54	-1,01
R 199	29,24, 51,317	125,54, 15,644	123630,89	123632,48	-1,59
NM F 639	28,59, 27,312	125,59, 45,960	147724,93	147720,40	4,53

AERODIST LINE REDUCTION

COMPILED: P. LANGHORNE
CHECKED: C. McMASTER

PROGRAM AERONU

AERODIST PROJECT	DATE	STATION	HEIGHT (MS)	CORRN.	STATION	HEIGHT (MS)	CORRN.	ANT SEP
SURVEY BA 19	21/ 6/71	NMF 597 E	420·3	4·0	NMG 252 E	492·9	0·0	1·5

RUN	SUB.CONSTANT	PROP. PARTS		DRY °C	WET °C	PRESS. (MBS)	TERMS 1 TO 11										
REF. TEMP	DIFF.DRY	DEP	A/C ALT.(MS)	DRY °C	WET °C	PRESS. (MBS)	TERMS 12 TO 21										
1	102200	499	523	19·3	8·6	971·2	178	147	118	97	75	54	42	33	20	14	12
20·9	0·44	·48	2067	19·2	10·4	963·8	155	127	100	79	62	48	32	21	14	10	
2	102200	468	554	19·3	8·7	971·0	96	74	61	50	38	31	21	18	14	13	11
21·0	0·46	·48	2073	19·8	9·2	963·8	109	91	77	65	42	36	32	22	18	14	
3	102200	478	544	19·5	8·7	971·0	159	131	104	84	63	48	32	22	17	12	11
21·0	0·46	·48	2067	19·4	10·2	963·7	173	142	105	90	70	51	38	28	21	10	
4	102200	482	540	19·6	8·8	971·0	100	80	63	49	43	35	22	16	14	13	12
21·0	0·46	·48	2070	19·2	9·2	963·7	105	86	73	59	49	37	24	19	14	12	
5	102200	499	523	19·6	8·8	971·0	102	100	86	72	53	42	30	21	20	15	12
21·0	0·46	·46	2067	19·3	9·4	963·5	76	62	55	45	33	24	14	12	8	9	
6	102200	466	556	19·7	8·8	970·8	110	93	76	58	47	37	31	24	15	13	13
21·1	0·47	·49	2070	19·1	8·6	963·5	101	80	67	62	39	29	22	19	17	14	
7	102200	478	544	19·7	8·8	970·8	163	130	108	86	64	50	37	26	18	15	14
21·1	0·47	·48	2070	19·6	9·0	963·4	176	147	109	96	72	50	36	27	20	16	
8	102200	501	521	19·9	8·9	970·6	166	139	106	88	66	50	27	26	18	12	16
21·0	0·46	·46	2067	19·9	11·0	963·2	168	137	111	89	69	51	33	29	17	12	END

117/ APR 71

PROGRAM AERONU - DATA SHEET

ANNEX H

PROGRAM AERONU - OUTPUT

SURVEY BA 19	DATE	STATION	HT.MS.	CORR.	STATION	HT.MS.	CORR.	A/C ECCE
	21 6 71	NMF 597 E	420.3	4.0	NMG 252 E	492.9	0.0	1.5

RUN	REFT	DDRY	DEPR	ALT	DRY	WET	PRES	DRY	WET	PRES	REF INDS	A/C ALTS	SLOPE DISTANCES		CORR	HNR	MINSUM	DIST
1	20.9	.44	.48	2067.	19.3	8.6	971.2	19.2	10.4	963.8	276,286,212,	2180,2189,	49922.0	52323.1	53.5	51.3	102211.4	102145.87
2	21.0	.46	.48	2073.	19.3	8.7	971.0	19.8	9.2	963.8	276,276,211,	2183,2195,	46821.0	55424.8	54.4	51.0	102212.1	102145.94
3	21.0	.46	.48	2067.	19.5	8.7	971.0	19.4	10.2	963.7	276,284,211,	2177,2187,	47821.1	54424.0	53.8	51.0	102211.4	102145.83
4	21.0	.46	.48	2070.	19.6	8.8	971.0	19.2	9.2	963.7	276,278,211,	2181,2189,	48221.0	54023.5	53.8	51.0	102210.8	102145.22
5	21.0	.46	.46	2067.	19.6	8.8	971.0	19.3	9.4	963.5	276,279,213,	2178,2185,	49920.2	52321.1	53.4	51.0	102207.6	102142.36
6	21.1	.47	.49	2070.	19.7	8.8	970.8	19.1	8.6	963.5	276,275,210,	2179,2186,	46621.0	55625.1	54.1	50.7	102212.4	102146.79
7	21.1	.47	.48	2070.	19.7	8.8	970.8	19.6	9.0	963.4	276,275,211,	2179,2187,	47822.0	54425.1	53.8	50.8	102213.4	102147.98
8	21.0	.46	.46	2067.	19.9	8.9	970.6	19.9	11.0	963.2	275,287,213,	2175,2184,	50122.2	52123.1	53.3	51.2	102211.6	102146.30

RUN	DISTANCE	DEVIATION	SUM RESIDUALS SQD
1	102145.87	.08	50.83
2	102145.94	.16	96.17
3	102145.83	.05	107.08
4	102145.22	-.56	79.22
5	102142.36	-3.43	174.43
6	102146.79	1.00	137.66
7	102147.98	2.20	110.55
8	102146.30	.51	142.72
MEAN	102145.79	RANGE	5.63

ANNEXURE C

NATMAP
DEPARTMENT OF NATIONAL DEVELOPMENT

TECHNICAL REPORT 26

LASER TERRAIN PROFILER

by

P J. Wise

CANBERRA AUSTRALIA
1979

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LASER TERRAIN PROFILER

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A Profiler Assembly

B Equipment Rack and Profiler Assembly

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E Explanation of Time Code

F Half-Scale Example of Film and Chart

G Survey Flight Record

H Laser Terrain Profiling 1971 – 1979

LASER TERRAIN PROFILER

ABSTRACT

The Laser Terrain Profiler, WREMAPS I, was developed by the Weapons Research Establishment (WRE) Salisbury SA at the instigation of the Division of National Mapping to meet defined operational requirements.

Since its operational introduction in 1970 over 250 000 kilometres of laser terrain profiles have been flown. These profiles have provided vertical control for the photogrammetric plotting of 2.7 million square kilometres (the area of Australia is 7.7 million square kilometres) at a scale of 1:100 000 with a contour interval of 20 metres.

This paper describes the technical aspects of WREMAPS I, its operational use and subsequent reductions to provide height control for photogrammetric map compilation by the Division of National Mapping.

LASER TERRAIN PROFILER

1. INTRODUCTION

National Mapping is currently engaged on the compilation of contoured maps throughout Australia at scales of 1:100 000 and 1:250 000 and has used the Laser Terrain Profiler to establish closely spaced network of elevations within the primary network of the Australian Levelling Survey. The elevations determined are used for vertical control to level stereoscopic pairs of aerial photographs in photogrammetric plotters.

The profiler is airborne and comprises a laser distance measuring system, a barometric reference unit to establish the height datum, a special continuous-strip 70 mm camera to record the track, gyroscopes to sense the attitude of the aircraft, and associated support equipment, including paper roll recorder for displaying all relevant data.

2. OPERATIONAL CONFIGURATION

The equipment was originally used operationally in an Aero Commander aircraft and is currently installed in a Nomad 22B. The flight operation requires a crew of four: pilot, navigator, electronics technician and camera operator/booker. The typical configuration is shown in Figure 1.

The Nomad installation comprises:

> a driftsight, Bendix Model B3: a gyro stabilised optical instrument powered from the aircraft's 28 volt DC supply through an inverter and located on the starboard side of the aircraft directly behind the co-pilot seat;
>
> an electronic equipment rack, specially designed for the aircraft and holding a number of electronic equipment modules, mounted on the port side of the cabin under the wing;
>
> the profiler assembly, holding the laser tube, receiving telescope and a 70 mm tracking camera, located aft over a central hatch;

See Annexes A, B and C.

3. SYSTEMS DESCRIPTION

Electrical Supply Unit

Power Supply Distribution Unit:

Receives two regulated 28 volt DC supplies (A and B) from the aircraft generators. Supply A is distributed to all units except the converter module which is fed directly from supply B for laser beam generation.

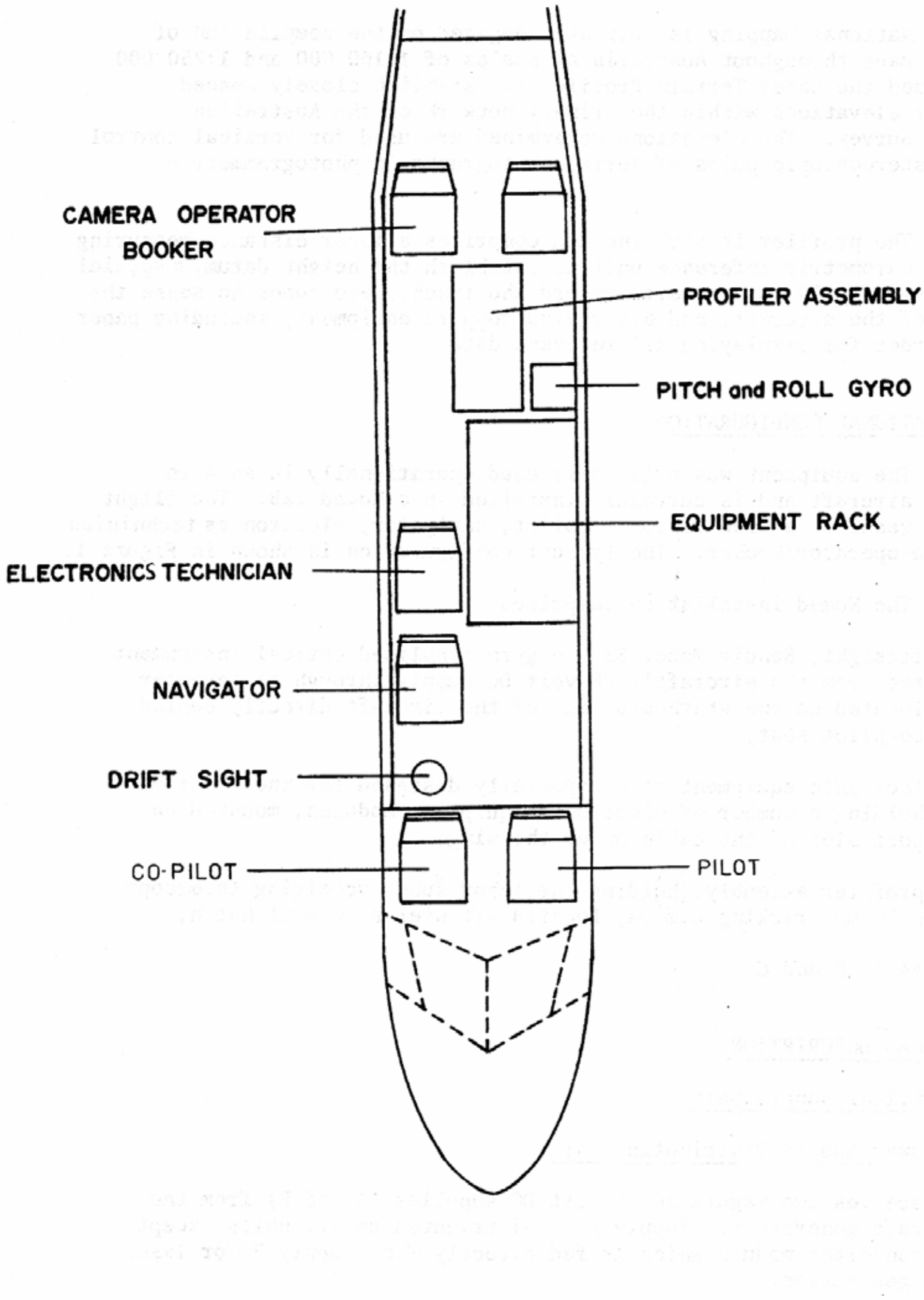

Figure 1: Flight Crew Positions and Laser Terrain Profiler Installation in Nomad

Laser Support Units

Converter Module:

Converts 28V DC from the aircraft to 250V DC for use by the laser.

Current Regulator:

Controls the laser current which can be varied from 11 amps to 18 amps, and provides starting circuits for the laser.

Water Module:

Circulates demineralised cooling water at a regulated flow and pressure to the laser and then via an air cooled head exchange on the top of the fuselage back to the holding tank. In addition, the return circuit contains a water head exchanger coupled to an external raw water supply for ground testing.

Vacuum Module:

Maintains laser vacuum and supplies argon gas for the laser discharge.

Receiver Support Unit

E.H.T. Supply:

Extra High Tension supply to the photo multiplier. It basically consists of a converter which provides a high voltage output for the photo multiplier tube.

Profiling Units

Laser:

The transmitter section contains a continuous-wave argon ion laser and an electro-optical modulator. The laser is energised by a DC are discharge maintained between anode and cathode and the light output is enhanced by an axial magnetic field. The laser provides a low divergent beam of light, concentrating most of the optical energy into a single spectral line of 4880 nm (blue-green).

Receiver:

The photomultiplier detects the returning laser signal through a 2.54 metre focal length Cassegrain telescope. After filtering, it is amplified in the tuned-head amplifier and fed to the height computer.

Height Computer:

Compares the phase of the reflected signal with the phase of the transmitted signal. The aircraft to ground distance can be measured on either a coarse scale or a fine scale using one of two modulated frequencies, 500 kHz or 3 MHz.

Calibrating the Height Computer establishes the relationship between chart movements and terrain clearance.

The profile trace automatically moves from one extremity to the other when the calibration setting is selected and thus defines the upper and lower limits of the trace.

In fine scale (3 MHz) this span is equivalent to 50 metres, and measuring between these extremes on the chart in millimetres, the exact ratio of terrain movement to chart movement is calculated; nominally 1 mm on the chart is equivalent to 0.5 m in terrain height.

In coarse scale (500 kHz) the span is equivalent to 300 metres and nominally 1 mm on the chart is equal to 3 m in terrain height.

The distance from the bottom of the chart to the lower extremity of this trace defines the zero of the profile trace. (see Annex D).

Barometric Reference Unit (BRU):

Records small changes in pressure by "capturing" a reference sample of air and continuously comparing the subsequent static air pressures while profiling. The variations are recorded as a continuous trace on the chart. The calibration facility is in the reference pressure capsule and appears as a pulse on the chart. The depth of this pulse is related via a graph of pressure tables at each altitude to give a nominal ratio: 1 mm is equivalent to about 0.6 m in aircraft height.

The distance from the bottom on the chart to the BRU trace just before calibration defines the BRU zero.

The Chart Breakout Sheet is used to compute the actual relationship - see Annex D.

Pitch and Roll Gyroscopes:

The amount of aircraft movement from straight and level flight is indicated on the chart via the pitch and roll gyros. The variation in traces from the gyros on the profiling chart indicate places where heights may be suspect, i.e. laser beam not vertical and indicating false height.

Recording Units

Timing Generator:

A modified WRE TIM code generator comprising a timing unit which provides a coded sequence of pulses for continuous time reference. The digital display shows elapsed time in hours, minutes and seconds. An oscillator drives a chain of dividers to produce a binary coded decimal time code. The code is fed directly to the recorder and the tracking camera. See Annex E.

UV Recorder:

The function of the recorder is to record on ultra-violet light-sensitive paper, using U/V light and galvanometers, the output of the height computer, barometric reference unit, gyros and timing unit. See Annex F.

Tracking Camera:

Photographs the ground track of the laser in strip form, on 70 mm film. The camera incorporates an 88.9 mm focal length Kodak "Aero Ektar" lens with a fixed aperture of f2.5. A partially transmitting mirror set at 45º to the lens axis reflects approximately half of the incoming light to the film set at the focal plane, just beyond a narrow slit. The remainder of the light is transmitted by the mirror to a ground glass screen where an image of the ground is formed. To ensure equal longitudinal and transverse film scales, the film transport speed must exactly match the ground image speed. A rotating glass disc with an engraved spiral is mounted directly above the screen in such a manner that when it rotates, the spiral appears as a set of parallel lines moving in the same direction as the image of the ground. The mechanical gearing between the film transport motor and the spiral disc is such that whenever these lines appear to move at the same speed as the image of the ground, the film transport speed is equal to that of the ground image on the slit. Drift angle can be measured, and compensated for, by rotating the camera until the ground image motion aligns with straight lines engraved on the viewing screen. This ensures that the slit is normal to the ground track thus producing an undistorted picture. Manual exposure control is achieved by a neutral density wedge positioned in front of the slit to compensate for film speed changes and varying light conditions.

Monitor and Testing Unit

Oscilloscope:

Used to monitor wave forms and provide visual display of the height computer outputs. Also used for general testing.

Automatic Pilot

Collins 3-axis Model AP107:

A three-axis auto pilot unit with height holding capability is essential to ensure the aircraft is maintained within a 50 metre vertical envelope at all times during profiling. It is not practical to fly the aircraft manually within this ±25 metres criteria throughout the usual 4 to 5 hour operational flight.

4. PRINCIPLE OF AIRBORNE PROFILING

The distance between ground and aircraft is determined by comparing the phase of the transmitted and reflected laser light, which is continuously recorded on the ultra-violet sensitive chart.

By flying over points of known elevation at the start and finish of each flight line and applying an accurate correction provided by the Barometric Reference Unit which continuously senses small changes in the flying height of the aircraft, the height datum is established and misclosure calculated and proportioned along the line. The height of any intermediate point can then be derived. - see Figure 2.

In practice, heights are obtained from profiles flown in a rectilinear pattern over the area to be mapped - see Figure 3. As the levelling control net is marked on the ground only at intervals of some kilometres and is relatively sparse, it is difficult to select points of known elevation at the beginning and end of every line.

However each north-south or tie line is planned to have a bench mark at the beginning and end, and the east-west lines intersect the tie lines.

The bench marks then provide the datum for the tie lines and enable heights of the intersection points to be calculated. These intersection points in turn provide the datum for each E-W line.

From the existing aerial photography of the block, photographs covering the path of each proposed line are selected and joined together to make a strip mosaic for each line. Bench marks are plotted and the proposed flight lines drawn in. These strips of photographs are called 'Navigation Rolls'.

5. WEATHER LIMITATIONS

To obtain optimum profiles, cloud cover and atmospheric thermal turbulence should be minimal. Cloud below the aircraft should be less than 20% on the line, but more importantly, the crossing of one profile with another must be completely clear. Cloud above the aircraft is not a problem unless it is causing turbulence or excessive shadow. When flying over cloud the laser beam is totally absorbed, and consequently there is no return signal and the trace is lost. Furthermore, the cloud obscures detail on the strip film. If cloud is encountered, switching to the coarse ranging phase in short bursts before and after enables the datum to be held. In Australia turbulence can often be avoided by flying about 2000 metres above sea level, but it may be necessary to fly at 3000 metres to keep the aircraft straight and level. Early morning flights are normally best with profiling continuing until the turbulence rises to 3000 metres, which is the limit for the aircraft flying without oxygen. The sun angle is not critical, but long and merging shadows in heavily vegetated areas may make it difficult to see detail on the strip film.

6. PRE-SURVEY OFFICE PROCEDURES

For planning purposes a scheme diagram at 1:1 million scale is drawn to show all existing differential levelling on the Australian Height Datum. Trigonometrical heights on hill tops are disregarded at this stage as they are generally unsatisfactory for photogrammetric heighting points.

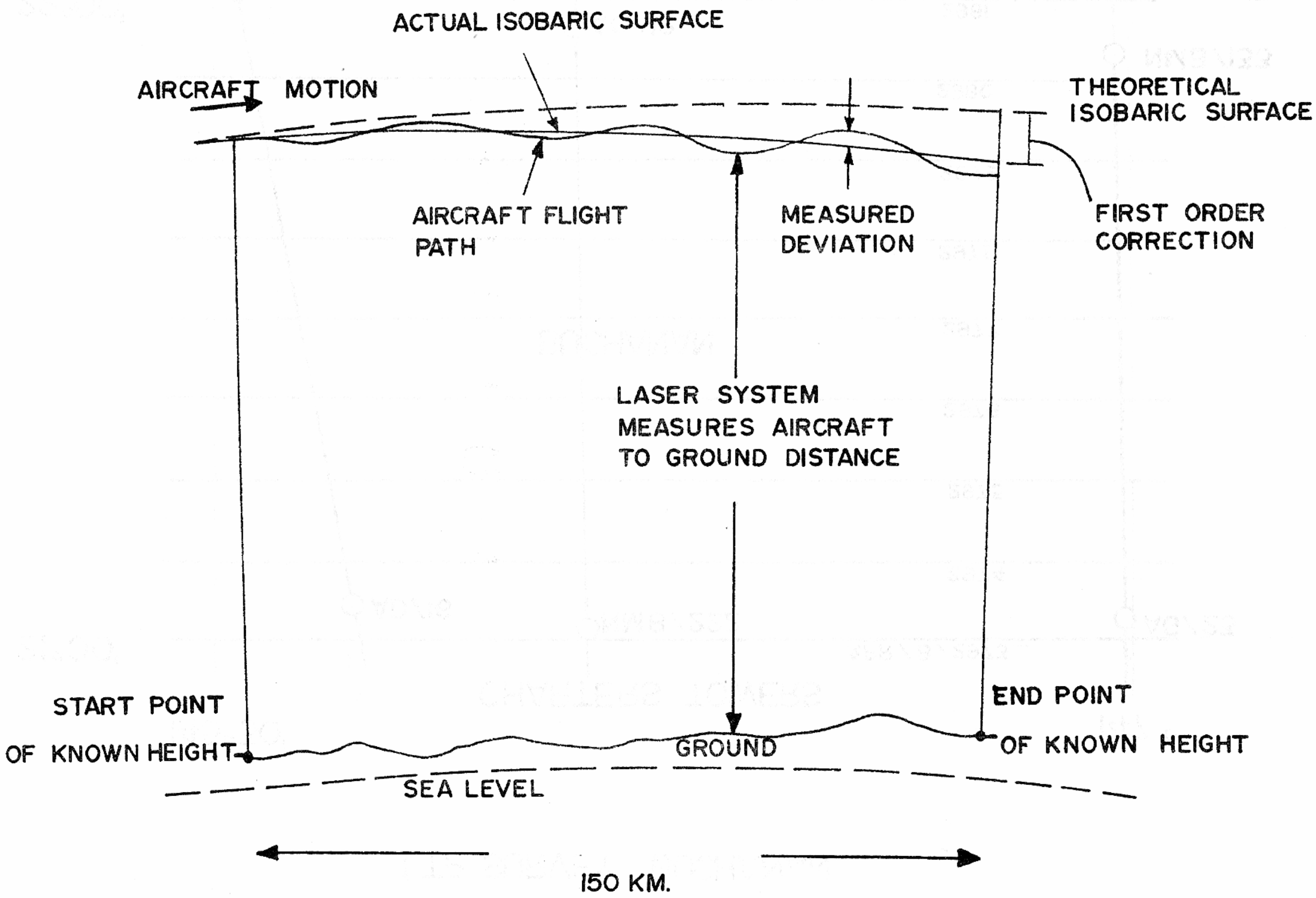

Figure 2: Principle of Airborne Profiling

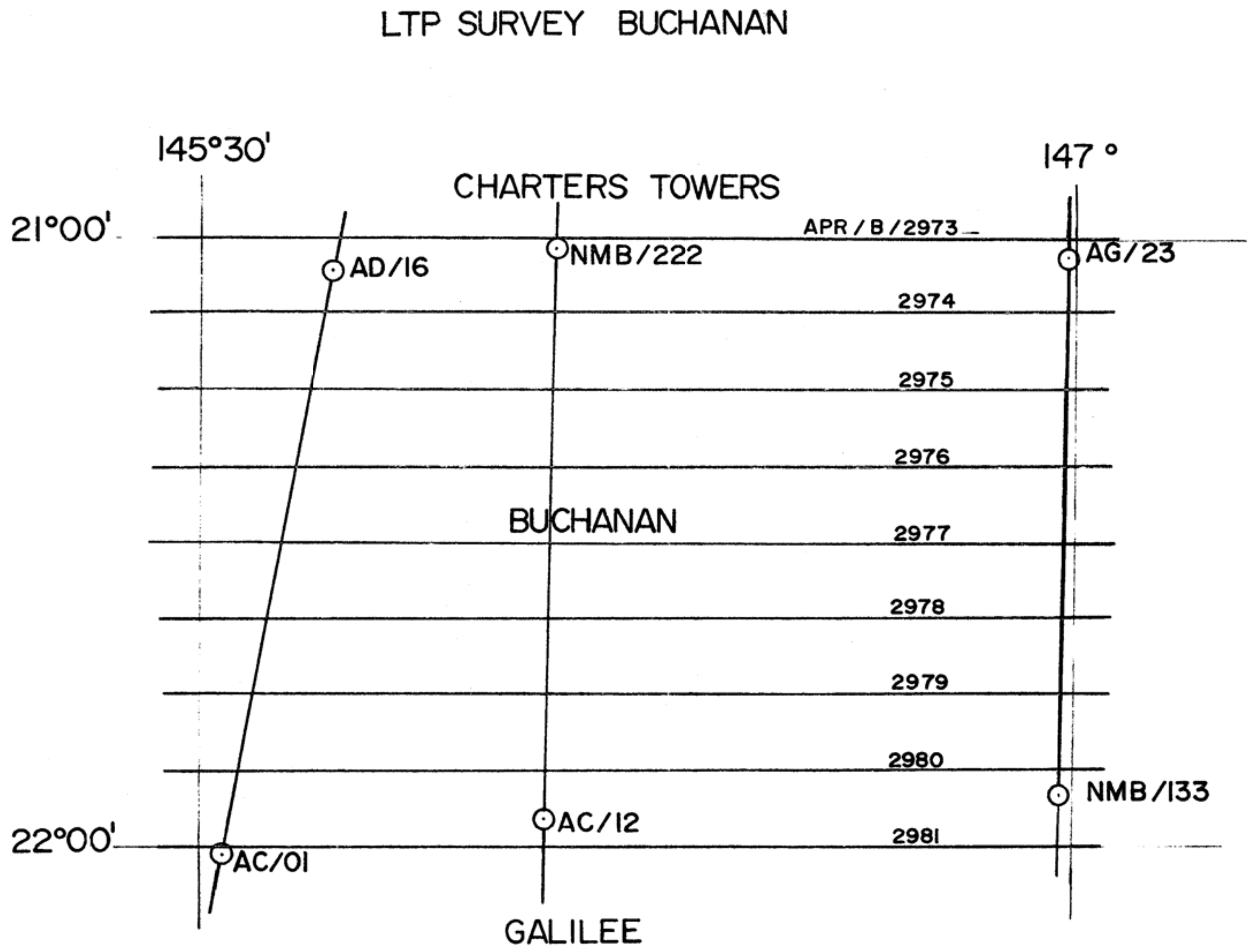

Figure 3: Profiler Flight Diagram

Each area where vertical model control is required for photogrammetric compilation is broken down into sub-groups of 1:250 000 map sheets areas.

The profiling flight lines vary according to the method to be used to intensify the horizontal control. Where the graphical slotted template method is to be employed, the terrain profiles are flown in the side lap of successive east-west runs of photographs and N-S tie lines are flown every degree and a half of longitude. Where semi-analytical methods are to be used with the MODBLOC program, N-S and E-W profiles are flown to produce a grid pattern of more widely distributed control points, requiring about 30% less flying.

Each profile line is given a unique registration number to systemise later data collection.

7. PROFILING OPERATIONS

The laser profiler takes twenty minutes to warm up and become operational.

As the aircraft climbs to altitude the navigator prepares his navigation rolls, the booker prepares the flight report - see Annex G, removes the blanking slide, loads a suitable cassette into the camera after scribing the line details on the film and ascertains the correct wedge position for the best exposure. Immediately before starting the line, calibrations are done by the electronics technician.

To obtain the most accurate profile, the fine scale 3 MHz frequency is employed giving a span representing 50 metres across the chart. In order to retain all height information a stepping arrangement steps the profile up or down when it reaches the bottom or top of the chart in exact steps of 50 metres.

Provided the terrain is not too steep these scale shifts can be deciphered, but over rapidly changing steep terrain this is not always possible. To overcome this situation a 500 kHz frequency is employed representing a span of 300 metres. This frequency, although not giving as accurate a profile, is switched in for 1-2 seconds, especially before and after possible difficult terrain so that scale shifts can be correctly designated.

When all operators are ready, the pilot lines up the aircraft and the navigator establishes precise drift, calling any corrections to the pilot who alters the aircraft's heading accordingly. The booker also notes the drift and adjusts the alignment of the camera.

When recording, heading corrections are kept small to avoid large bank angles and consequential incorrect heighting as the aircraft changes attitude along the line.

Some three minutes prior to crossing the first tie line or ground control point, the chart and camera are switched on in the fine range and shortly afterwards the coarse range is switched in for 1-2 seconds to establish coarse datum.

Throughout the run the navigator is required to keep the aircraft within 2 km of the planned path using the photographic navigation roll. The timing of the overflight of significant topographic features is noted by the booker who must also call for changes to coarse range phase if there is danger of losing the fine scale. The booker must be constantly aware of any problems occurring that could cause the line to be aborted.

The electronics technician is responsible for keeping the Laser Profiler running well, switching in the coarse phase, changing charts as required, and periodically noting the condition of the equipment to enable faults to be diagnosed and rectified.

On line, the booker is responsible for monitoring the camera operation, setting the film transport speed and drift, checking exposure and film transportation. Periodically he notes the aircraft's speed, altitude and heading. He is required to note the times of these and other events as indicated by the navigator and the technician to enable selected features to be found quickly during subsequent reductions.

Some 200 kilometres of flight line information is gathered on a single profile chart and, provided that a coarse phase switch is done before and after, chart changes on line are quite acceptable. By mutual agreement, the technician and navigator may change charts so as to avoid running out of chart over important areas. The loss of profile during a chart change averages about five seconds, about 500 m of flight line.

A strip film contains 500 kilometres of profile record, so it is seldom necessary to change cassettes on line.

Three minutes after passing the last tie line crossing or ground reference point, the chart and camera are switched off. The technician records another set of calibrations, and the booker scribes on the film details for the line completed and details for the next line. If time permits another set of calibrations is recorded, but the end set of calibrations for one line are acceptable as start calibrations for the next.

During the return to base the Laser Profiler is shut down, for 10-15 minutes as the laser unit must cool before being turned off. A test piece of film is exposed by the booker at the camera settings used during the operations. This is developed on landing to check the camera operation. Flight reports are completed and all data is taken to the field office.

8. POST-SURVEY - IN THE FIELD

The charts need to be edited so that the whole of one line or line segment can be found on a particular chart. Each chart is stamped with the line details at each end and examined for quality.

Exposed film is removed in total darkness and placed in labelled tins. The film test is removed and developed in a small tank to check camera operation and empty cassettes are reloaded with film.

Once the lines have been examined and accepted the line summary is updated.
From the calibration information at the beginning and end of the line the Chart Breakout Sheets are completed and chart scale established. The scale shifts are interpreted and enumerated in increments of fifty metres.

Charts and films, together with their flight reports and breakout sheets, are periodically airfreighted to the office.

9. POST-SURVEY - IN THE OFFICE

On arrival the 70 mm strip films are sent for processing and a mirror image print obtained. The print is edited and stored with its chart in an individual box. A register cross -references the line numbers and box numbers.

10. CONTROLLING THE PROFILES

The ground control already based on the Australian Height Datum (AHD) provides the datum for each tie line.

As the profile rarely passes exactly over the particular ground control, the absolute height of the profile is found by selecting a point on the profile near the ground control and reading the height difference between the two at 1:80 000 photo scale in a photogrammetric plotter. All control points are related to the adjacent profile in this manner. Adopting the elevation of the first point, the elevations of other points are calculated through the profile and compared with the machine values. The difference between the two values is the misclose, which is linearly proportioned along the profile.

Profiles not crossing sufficient ground control points are reduced to the datum using the tie lines. The intersections with the tie lines are determined using the 70 mm film. From the tie line the heights of these intersection points are computed and held fixed. Miscloses of the intersecting lines can be calculated from these values.

11. PHOTOGRAMMETRIC VERTICAL MODEL CONTROL

While each line is being reduced to the AHD, points are selected from the 70 mm strip films to enable each photogrammetric model of the mapping photography to be levelled. Each point is given a number and its position marked on the strip print, paper print and diapositive of the mapping photography. The points are selected for best photogrammetric position, depending on the location, terrain, and profile clarity at that point.

Selected points of detail are aligned with the chart, by the time code along the edges of the film and chart, and their position and number marked. The distance of the laser and BRU trace above their respective chart datums is measured in millimetres and entered on a computation form besides the point number, time code and scale shift.

12. HEIGHT COMPUTATIONS

To convert the chart distances into metres of height, the laser and BRU readings (in millimetres) are multiplied by their respective scale factors calculated from the Chart Breakout Sheet - see Annex E, and then the two values are added together. This sum, plus the scale shift gives the raw chart height. True height is obtained by adding the previously obtained misclose information to the raw chart height.

All heights are calculated to 0.1 m and rounded up to the next metre. Rounding up has been adopted as any undetected aircraft roll will indicate a height that is lower than true on the laser trace.

A programmable hand calculator is used for data reduction.

13. FINAL VALUES

Due to the large amount of computation involved, a sample check of each area is carried out against vertical control not used for controlling the tie lines. Photogrammetric models containing laser heights and existing control are photogrammetrically levelled and residuals read out for the laser height points. Residuals larger than 5 m are investigated and in most cases are resolved.

The final height lists, aerial photographs and diapositives are forwarded for plotting and contouring.

14. ACCURACY

The laser measures the distances to an accuracy of ±0.3 m at all. times; however, cumulative errors due to the dependence on a barometric reference to measure aircraft displacement from an isobaric surface, which is not always stable, and the tilts of the aircraft, can sometimes decrease the accuracy of the system, to ±3 m.

The accuracy figure actually obtained depends on the atmospheric conditions at the time of profiling. In practice, ±2m can be expected. This is about the pointing accuracy of the photogrammetric plotters used on 1:80 000 scale photography, so the two systems are compatible.

This accuracy has been achieved for 1:100 000 mapping of large areas of Australia where no continuous forest cover exists and slopes are gentle. Accuracy deteriorates over timbered mountainous country.

15. RESULTS

The Laser Terrain Profiler has proved to be of great use for mapping the Australian continent at a scale of 1:100 000 with 20 metre contours - see Annex H. It has been utilised to obtain profiles across published maps as independent map accuracy tests, to measure tree heights, and to provide profile data for microwave link route design. In the last nine years further advances in laser technology has seen a further development of WREMAPS I by W.R.E. to develop and produce a solid state pulsed laser unit, WREMAPS II, for the Royal Australian Survey Corps which has been successfully operated in a Pilatus Porter single engine aircraft. Currently developments are continuing in the application of the Laser Terrain Profiler to bathymetric surveys to provide seabed profiles to a depth of 30 metres.

The field program to provide basic vertical model control is planned for completion by the end of 1979 with consequent office reductions finalised by mid-1981. Without the Laser Terrain Profiler the provision of model control over the same area would not have been possible in the same time by any other means.

16. ACKNOWLEDGEMENTS

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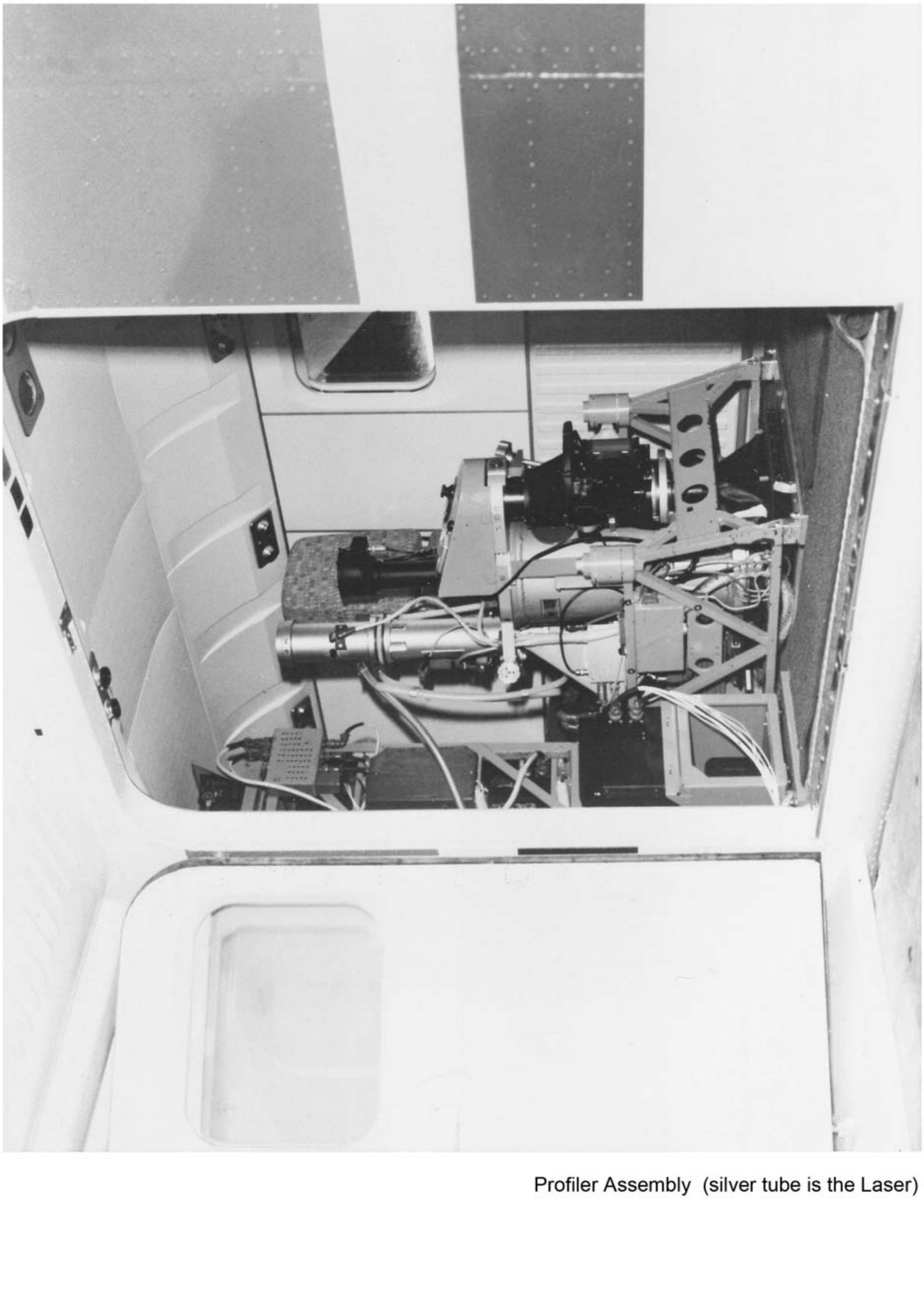
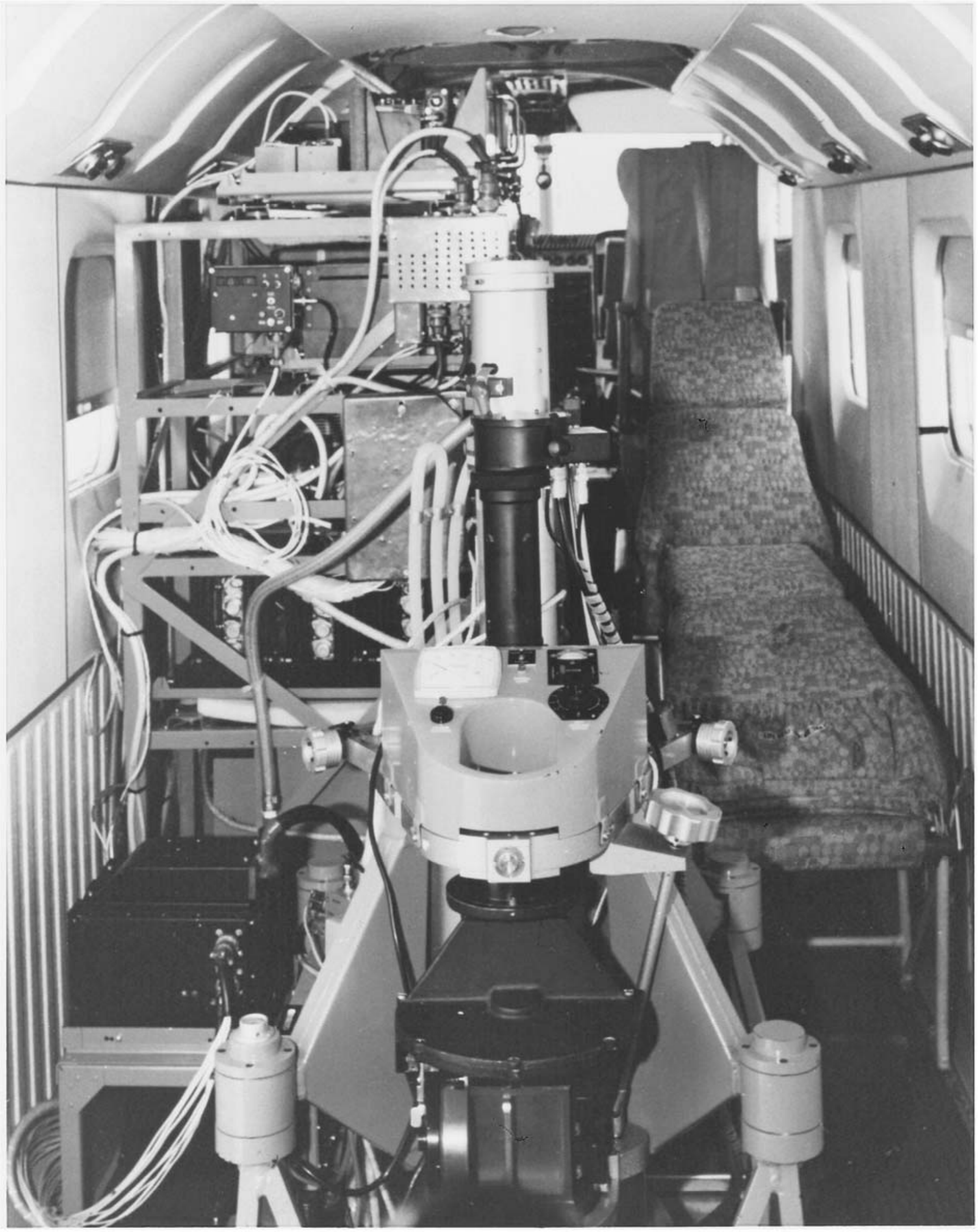
Messrs R.A. Vassil,
J. Manning
A.G. Turk
R.W. Menzies

and his colleagues in the Division of National Mapping, in editing this report.



Profiler Assembly (silver tube is the Laser)

Equipment Rack and Profiler Assembly



Profiler Assembly Showing 70mm Camera

LTP REDUCTIONS
1. CHART BREAKOUT SHEET

ANNEX D

N/S LINE APR/ C/ 3281 Complete

BLOCK 32

AREA

DATE 1/5/78 BOX NO: L 807

INDICATED ALTITUDE 7020

LASER TRACE

ZERO

(fine and coarse)

Distance of zero above lowest cm line:

at initial cals 23.1 mm

at final cals 24.3 mm

Mean 23.7 mm

SCALE FACTOR

Phase change: at initial cals 112.1 mm

at final cals 107.9 mm

Mean 110.0 mm

FINE SCALE FACTOR

ie 110.0 mm represents 50 m

∴ 1mm represents 0.455 m

COARSE SCALE FACTOR

ie 110.0 mm represents 300m

∴ 1mm represents 2.727 m

STATOSCOPE TRACE

ZERO

Distance of zero above lowest cm line:

at initial cals mm

at final cals mm

Mean mm

SCALE FACTOR

See B.R.U.

	at initial cals	at final cals
1		
2		
3		
4		
5		
Sum		

Pulse depth (from graph)

⟹ Mean mm

Pulse Depth / Mean ⟹ 1mm equivalent to m

BAROMETRIC REFERENCE UNIT TRACE

ZERO

Distance of zero above lowest cm line:

at initial cals 85.9 mm

SCALE FACTOR

	at initial cals	at final cals
1	22.2	22.1
2		
3	22.2	21.9
4		
5	22.2	22.1
Sum		

Pulse depth (from graph) 12.00

⟹ Mean 22.2 mm

Pulse depth / Mean ⟹ 1mm equivalent to 0.541 m

VERTICAL ROLL GYROSCOPE TRACE

ZERO

Distance of zero above lowest cm line:

after initial cals mm

before final cals mm

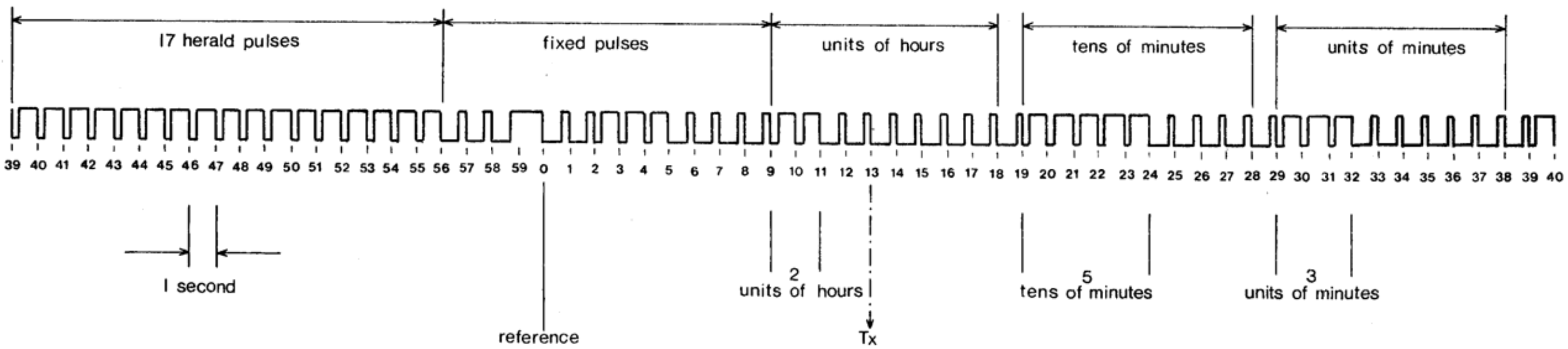
Mean mm

Take local Zero

Computed [signature] 3/5/78 Checked [signature]

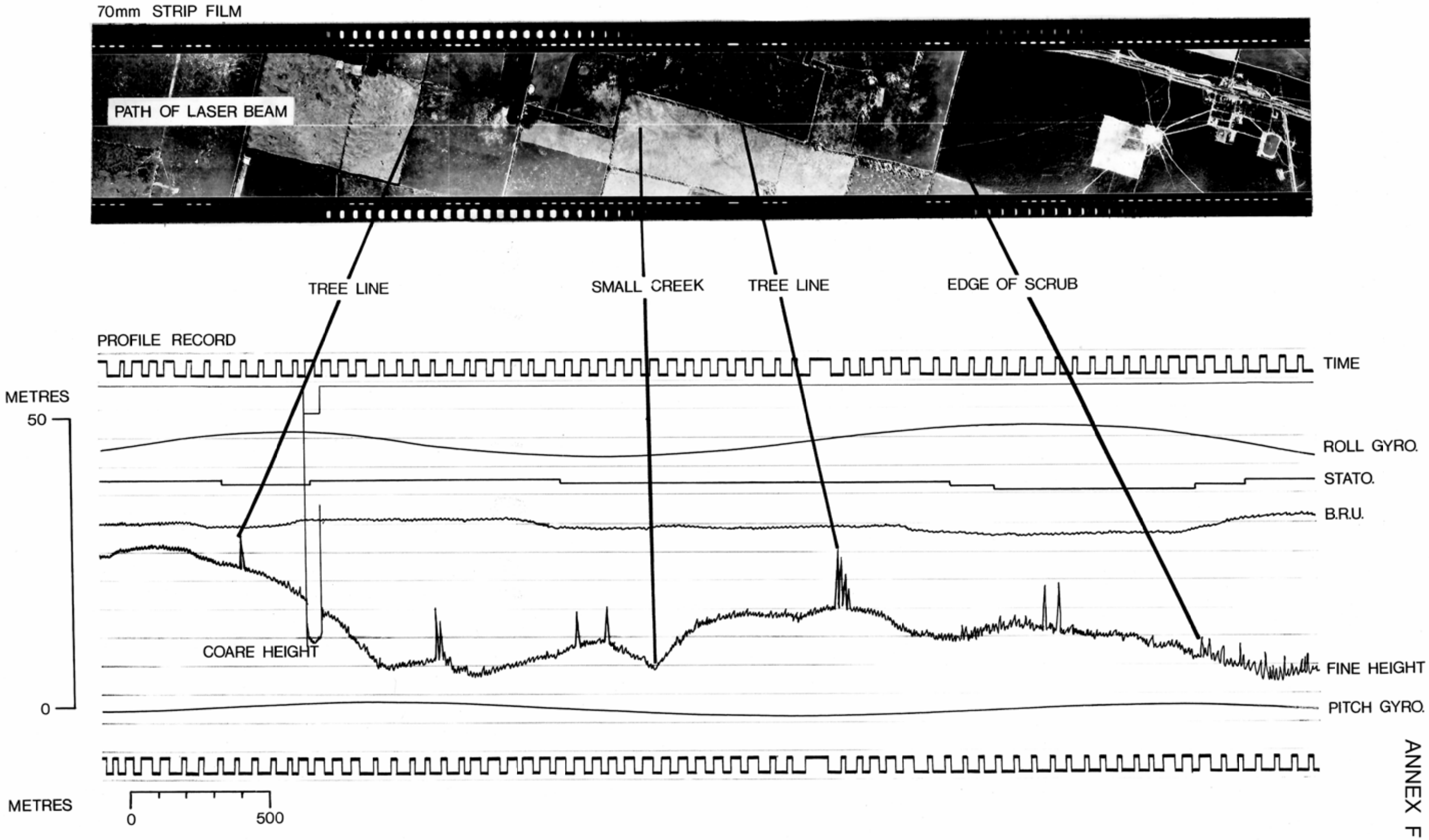
LTP 7/4

Chart Breakout Sheet



Time at Tx = 2 hours 53 minutes 13 seconds

Explanation of Time Code



Half-Scale Example of Film and Chart

ANNEX F

ANNEX G

LTP 8/73

LASER TERRAIN PROFILING – SURVEY FLIGHT RECORD

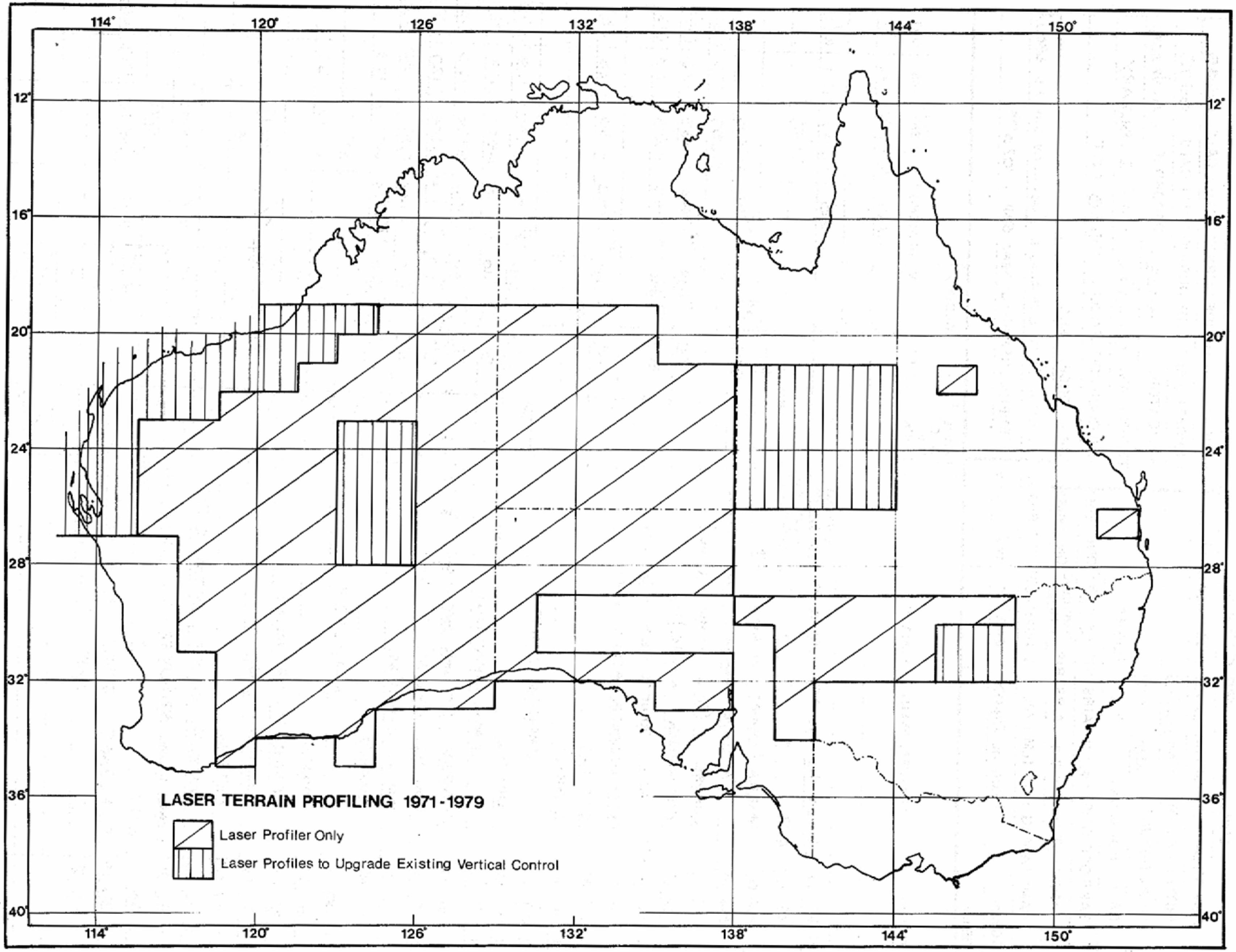
LINE: APR/C/3281

MAP AREA: COBHAM LAKE, BROKEN HILL	INDICATED ALTITUDE DURING INITIAL CALS: 6545
INITIAL DATUM: NM/C/15	INDICATED ALTITUDE DURING FINAL CALS: 6575
FINAL DATUM: NM/C/29	NAVIGATOR: P.J. WOZE RECORDER: R.A. VESSEL
DATE: TUESDAY 7.5.'74 FLIGHT: 1	TECHNICIAN: O. ERTAK PILOT: D. BLEARY
TAKE OFF TIME: 0837 AIRSTRIP: BROKEN HILL QNH: 1025.9	TIMECODE COMMENCED: 0838 CST
LANDING TIME: 1034 AIRSTRIP: BROKEN HILL QNH: 1025.8	TURBULENCE: NIL

CAMERA	MAG. NO.	FILM TYPE	LOADED	LENGTH	READS	
						CLOUD: 7/8 TO OVERHEAD (DOWN AS LOW AS 6800')
70 mm	1	KODAK 2402	6.5.'74	100'	56	GENERAL REMARKS: AREA QNH : 1023 mb
35 mm						

TIMECODE	FEATURE, EVENT OR REMARK	FRAME NO. OR FILM CHECK	DRIFT	WEDGE / V/H	HEADING MAG	ALTITUDE QNH SET: 1025.9	IAS K	OAT °C
0 47 10	START INITIAL BRU/LASER CAL CHART ON GYROS ON				020	6545	128	10(13)
48 11	END " " " . CHART OFF GYROS OFF					6545		
54 05	CAMERA / CHART / GYROS ON		4°S					
54 10	7/8 CLOUD OVERHEAD · DRIFT CHANGE		5°S	039/100	170/164	6555		
54 58	COARSE (PITCH BUBBLE LEVEL)			100		6555	125	(13)
56 37	CROSSING NM/C/15		5°S	100/039	169/162	6555	126	(13)
1 00 00 ±1s	LASER POWER READING 54		5°S	100/040	167/153	6565	129	(13)
1 04 30	AUTO WEDGE ADJUSTMENT							
1 05 32	COARSE		5°S	50/040	172/152	6550	128	(13)
1 06 40	COARSE			68				
1 07 00	CHANGE CHARTS							
1 07 20	COARSE		5°S	75/040	172 C/152A	6555	129	10(13)
1 12 10	DARK SHADOWS		5°S	100/040	168/142	6555	128	(13)
1 16 18	COARSE (EASING BACK ON THROTTLE)		5°S	45/040	172/140	6560	129	(13)
1 22 00	ROUTINE CHECK		5°S	40-100/040	171/130	6555	127	(13)
1 26 30	DRIFT CHANGE		4°S	100/040	174/128	6565	130	(13)
1 27 56	COARSE		4°S	100/040	174/128	6565	129	
1 30 03	NM/C/29					6570		
1 30 24	COARSE					6575	132	
1 31 00	LASER POWER READ							
1 31 56	RAILWAY LINE		4°S	100/040	178/	6575		
1 32 03	COARSE					6570		
1 32 20	CAMERA / CHART / GYROS OFF							
1 32 28	START FINAL BRU/LASER CALS CHART ON				180/	6575	131	10(13)
1 33 41	END " " " " " OFF					6575		
1 36 18	FILM TEST START MAG No 1			100/38	225	6570	132	10(13)
1 40 29	" " END (Dam near end)							

Laser Terrain Profiling - Survey Flight Record



114°
120°
126°
132°
138°
144°
150°
12°
16°
20°
24°
28°
32°
36°
40°
LASER TERRAIN PROFILING 1971-1979
Laser Profiler Only
Laser Profiles to Upgrade Existing Vertical Control

ANNEX H