VERTICAL CONTROL FOR AUSTRALIAN TOPOGRAPHIC MAPPING

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ABSTRACT

This paper reviews the historical use of different surveying techniques to provide vertical information for topographic mapping of the Australian Continent.

For over a hundred years, heighting information for early Australian mapping was based on the application of classical surveying techniques of spirit levelling and trigonometric levelling, supplemented by barometric heighting.

In the 1960s, a new wave of technology began to be introduced with the application of accelerometers in ground vehicles to measure elevation change. In the same period, aircraft radar altimeters were adapted to mapping requirements to produce airborne terrain profiles. In the 1970s, these radar altimeters were replaced by analogue laser terrain profilers, to provide extensive vertical control for photogrammetric models over most of Australia. In the last five years, inertial techniques have been occasionally employed to provide vertical control for specific mapping projects and digital laser terrain profilers are now replacing the earlier analogue systems.

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INTRODUCTION

The topographic mapping of the Australia Continent commenced with coastline exploration by seafaring nations well before the first settlement in Sydney Cove, 200 years ago. In this discovery phase, cartographic attention was given to the horizontal positioning of landfall features and little emphasis was placed on the correct heighting of these features or the general nature of the depiction of terrain relief of the new continent.

The early mariners occasionally indicated the heights of coastal mountains visible as landmarks from their ships. They used sextant readings and estimated distances to calculate the tangential elevations, this technique was subject to considerable error but the information produced was only secondary to that of the landfall. Similarly in the inland exploration of the dry Australian continent, terrain relief depiction was only a secondary consideration of the early explorers who were mainly concerned with water features and grasslands for settlement.

The results of the first 100 years of Australian exploration and topographic mapping are probably best depicted on the series of maps of Australia published by James Wyld (Geographer to the Queen) between 1851-1882. (See figure 1.) The topographic data on maps of this time focused on the horizontal positioning of streams and pastoral lands information, mainly in the coastal regions. They show little terrain relief the vast inland areas are blank.

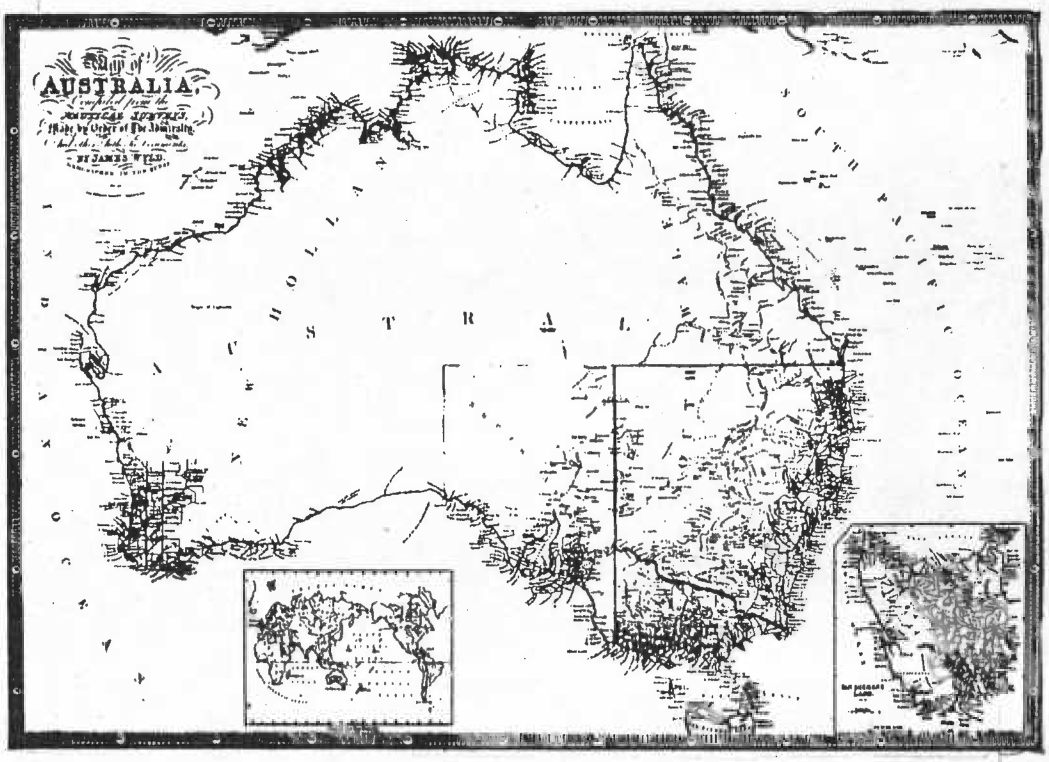

FIGURE 1 JAMES WYLD 1851

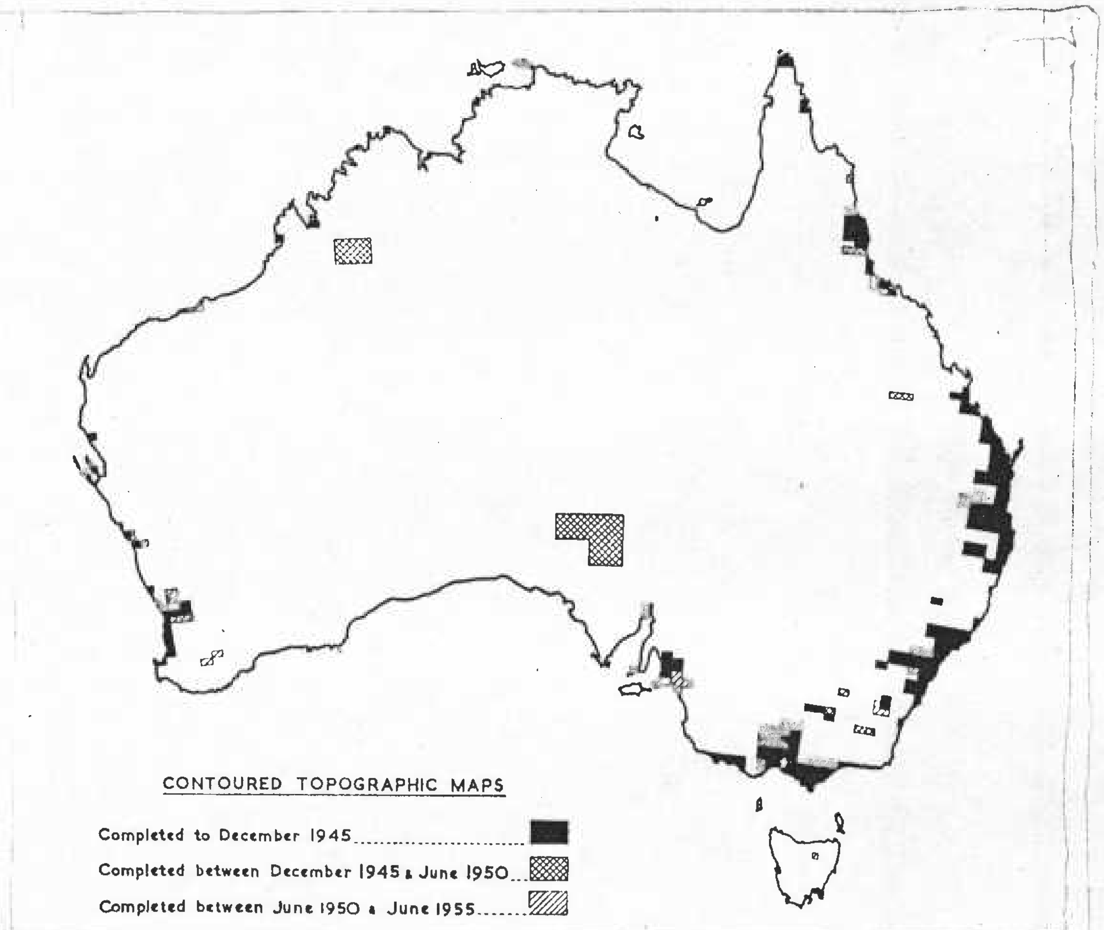

FIGURE 2 TOPOGRAPHIC MAPPING

The first accurate topographic heighting heighting came from the trigonometric surveys, initiated by the various Surveyors-General in the second half of the 19th Century. These identified heights of trig stations, often placed on high and rather inaccessible points. However the physical nature of the flat inland terrain limited station intervisibility and effectively blocked the rapid expansion of an angle based trigonometric network over the continent, despite the immense perseverance of the early surveyors. The exception was Tasmania where hardship by James Sprent, Surveyor General later resulted in a basic trigonometrical framework with heights over the whole of this small but mountainous State in the 1850s. (Surveyors General Conference, 1912.)

From the early 1900s, spirit level traverses began to radiate out from the coastal population centres for infrastructural developments such as railways. In some areas extensive networks were developed on local datums such as the Dajarra datum in Queensland, or the Sydney Water Board datum in New South Wales, but no co-ordinated framework existed.

With the return of the AIF to Australia from World War I in 1919 the Royal Australian Survey Corps commenced the immense task of topographic mapping of Australia by plane table with an establishment strength of fourteen all ranks (Fitzgerald 1965). Twenty years later at the outbreak of World War II only special areas of the country were mapped and emergency activity was hurriedly implemented during hostilities to extend this small coverage of topographic mapping.

By the end of World War II, even with the emergency mapping activity within Australia, the terrain depiction of the whole continent was still very incomplete. (See Figure 2.) In 1948 a start was made on a national planimetric 1:250 000 map series using aerial photography assemblies controlled by astrofixes.

The quality of mapping at that time is best illustrated by the eight mile to the inch map (in four sheets) prepared by the National Mapping Section of the Department of the Interior and published by RASVY Corps in 1951. The depiction of relief again lagged behind even the sketchy horizontal delineation of features.

In 1951 Major General Brown, Director General of the British Ordnance Survey, was invited to undertake a study of the state of surveying and mapping in Australia. He summarised:

> "It is perhaps not generally realised how little of Australia has been mapped. Even maps at so small a scale as 4 miles to the inch, giving only the main features in their true relation to one another and usually without heights, do not exist for more than 12% of the country. More complete mapping, giving heights and contours at 1 mile to the inch and larger scales, do not cover more than 5% of the country" (Brown 1951).

BAROMETRIC HEIGHTING

Although uncontoured the R502 1:250 000 series showed a number of spot height elevations. Barometric heighting was used extensively to obtain spot heights by the classic method of roving a barometer from a base station (Eggeling, 1953). Some barometric heights were however obtained using a long range method of interpolating from three selected meteorological stations often 600 km apart (Squires, 1947). This relied on a smooth pressure gradient condition extending over much of inland Australia during the dry season. Using Kollsman aircraft type altimeters, readings were taken by astro fix parties at creek crossings, homesteads and airstrips. Hocking (1985) one of their original observers noted that the comparison of these heights was often within 15 metres for the same point on different days, or even different years.

In this era attempts were also made to make use of barometric heights from low flying light aircraft by estimating the aircraft elevation (10 feet approximately) above a significant feature such as a road intersection or a hill top and calculating the barometric height at that aircraft station from widely spaced meteorological station readings. Frequently, flight paths were down river beds at altitudes below the tree canopy. A rather ambitious technique, and often the aircraft landed at the end of the day with foliage in the undercarriage. However no forced landings were made and much country around Alice Springs was supplemented with spot heights.

The technical problem of how to provide detailed heights for all topographic features on the map was ultimately solved in the 1960s by the photogrammetric plotting of detail from aerial photography, using new generation stereoplotters. However each stereoscopic model still needed to be set up with a minimum of four accurately determined height points which could be identified on the photography. So the solution still presented a technical challenge.

With the Commonwealth Government's decision in 1965 to undertake a new 1:100 000 mapping program with 20 metre contours, rather than attempt to revise the uncontoured interim R502 maps, there was this increased necessity for cost efficient techniques which could provide vertical control across the vast areas of Australia to enable photogrammetric stereoplotting to be carried out.

A number of techniques were tried such as helicopter supported barometric levelling and rapid ground spirit levelling traverses with reversable foot/metric staffs (see Figure 6). But also two new techniques were implemented.

- The vehicle mounted Ground Elevation Meter.
- Airborne profiling.

THE GROUND ELEVATION METER

Two Ground Elevation Meter instruments were utilised in the 1960s, one by Natmap and the other by RASVY. The units were manufactured by Sperry-Sun in the USA and were mounted in GMC four wheel drive/steer vehicles.

The relative elevations along a vehicle traverse route were calculated through an electromechanical system which measured the instantaneous angle of inclination of the road and the velocity of the vehicle along track between known height points. Using this technique it was possible to level 150 km a day on good roads, independent of atmospheric pressure, temperature or visibility.

Accuracy was rated as:

> "Less than 10% of the errors would exceed Vd, or one foot whichever is greater, d being road traverse distance" (Sperry 1964).

Operation of the Ground Meter was sensitive but some good results were achieved and vertical control was supplemented by this method in Queensland map sheets for subsequent analytical photogrammetric densification.

The application of the Ground Elevation Meter was limited to well made roads and its determinations were at times unreliable. A faster more versatile technique was needed to provide vertical control for stereoplotting in remote areas without roads particularly where the available photogrammetric control was only horizontal, as with slotted template assemblies. An airborne technique was developed from military radar altimetric equipment.

AIRBORNE RADAR PROFILING

The Airborne Profiling Recorder (APR) basically consisted of two sensing devices; a radar system to measure terrain clearance; and a height deviation indicator (hysometer) to record aircraft flight deviation from a predetermined isobaric surface. The hypsometer measured the deviation from the isobaric surface and the recorder applied this correction to the radar distance to produce a terrain profile chart.

The technique was originally developed in Canada for small scale mapping (Blachut, 1954) and applied in Australia in the mid 1960s. The aircraft, after reaching altitude of 7,000-8,000 ft usually overflew an airstrip to obtain a datum then flew the required profiles, while measuring deviations from a constant isobaric surface "closing" on an airstrip as the final datum.

Radar profiling proved a fast method of obtaining height control in flat terrain but it encountered accuracy problems in hilly areas due to the one degree sampling cone of the radar beam, producing a footprint of about the size of a football ground.

Radar profiling was flown extensively by the Adastra Aerial Survey Company under contract to Natmap and provided vertical control for 20 metre contouring for a large area of Australia. See figure 3.

The potential of the airborne technique was obvious but the system accuracy was marginal with a theoretical mean square error of about 3 metres. In practice other problems were encountered with lack of resolution of signal and inaccuracies due to the wide beam. These shortcomings led to Australian investigations in the late

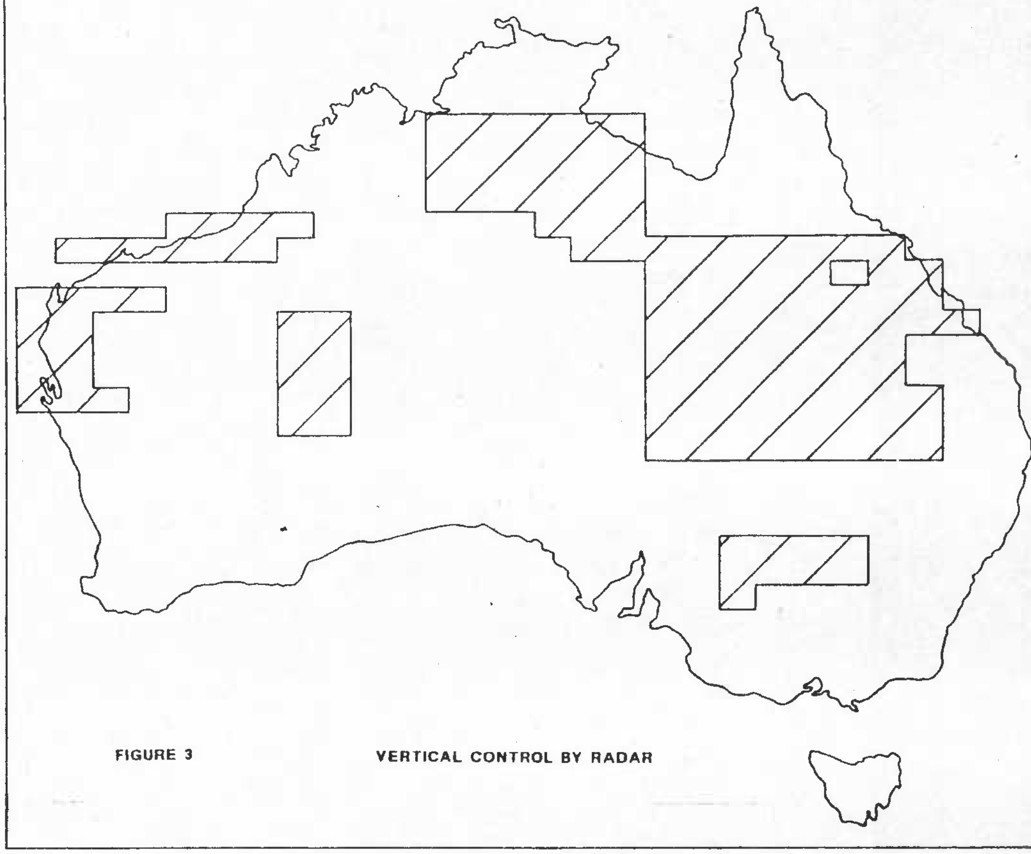

FIGURE 3 VERTICAL CONTROL BY RADAR

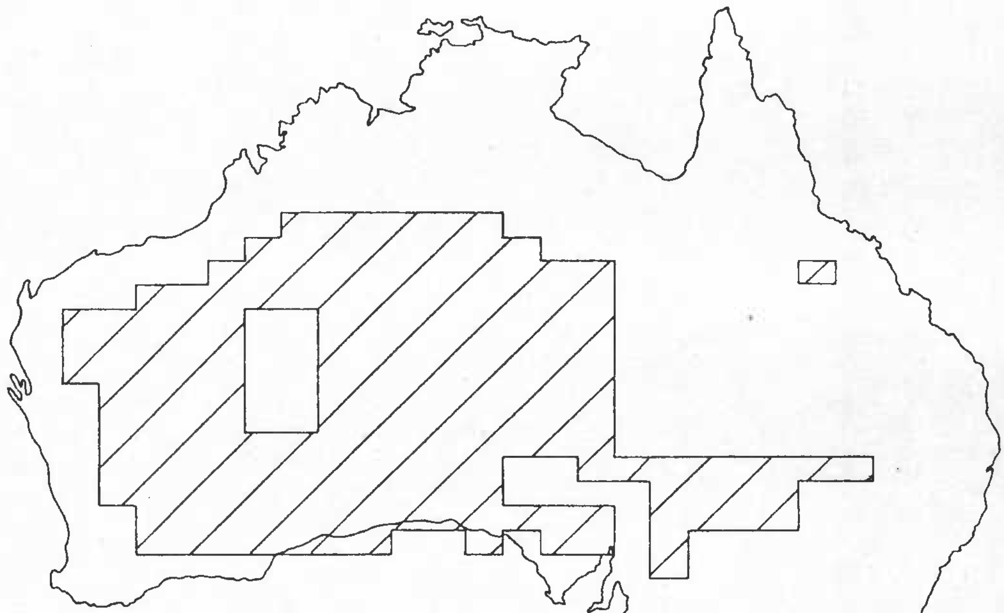

FIGURE 4 VERTICAL CONTROL BY LASER (WREMAPS 1)

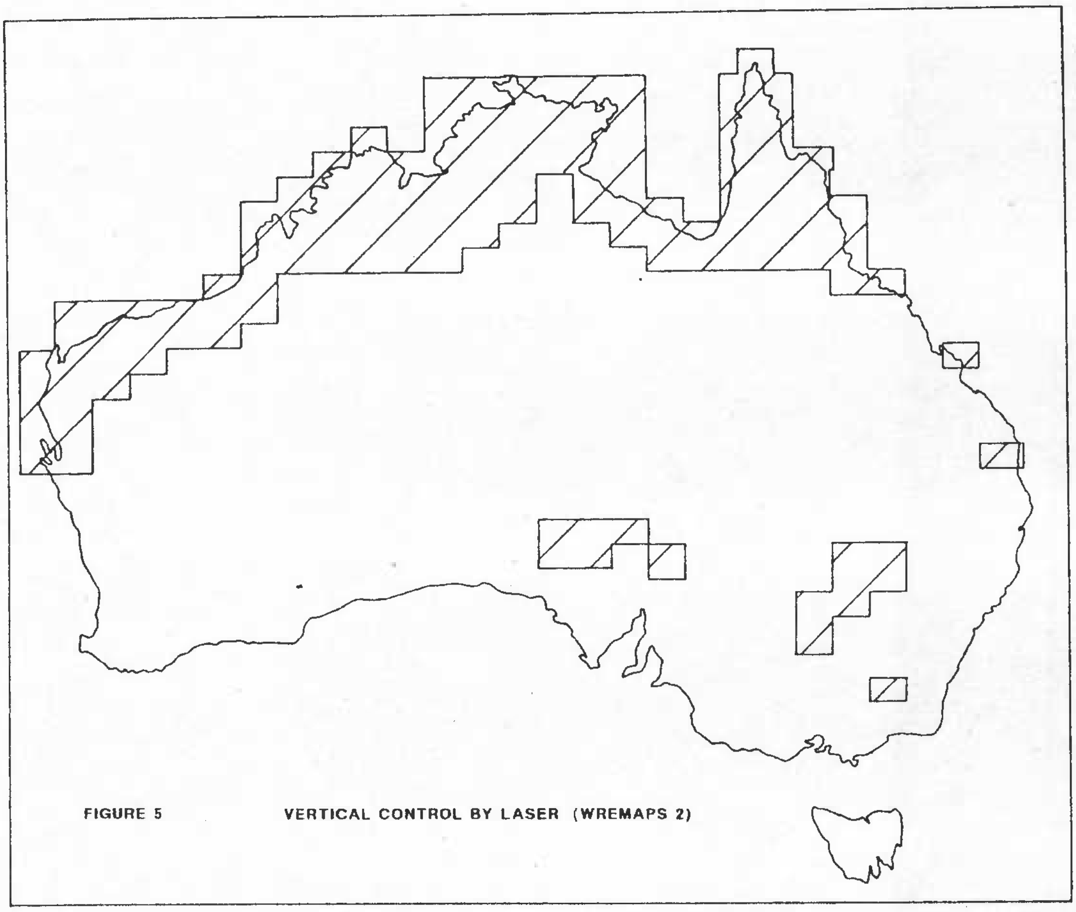

FIGURE 5 VERTICAL CONTROL BY LASER (WREMAPS 2)

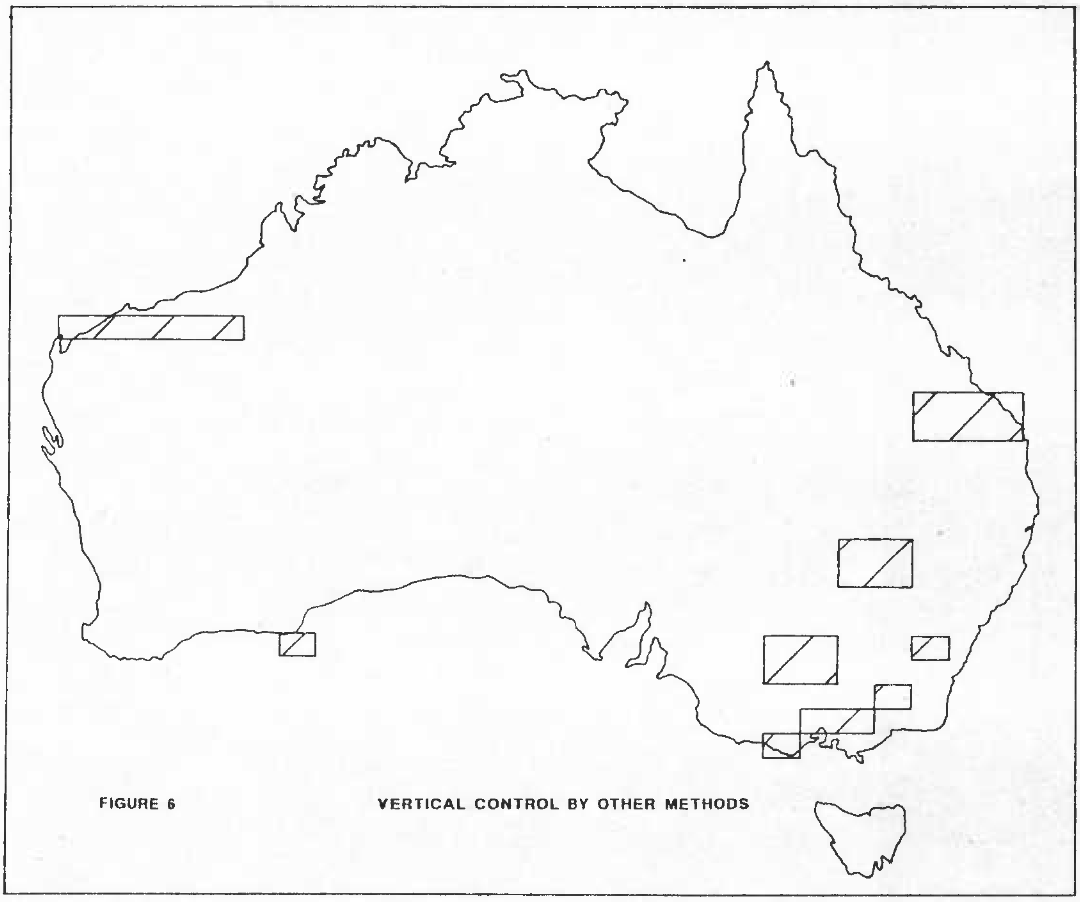

FIGURE 6 VERTICAL CONTROL BY OTHER METHODS

1960s for a laser beam to replace the radar beam in an airborne profiler.

WREMAPS 1

The Laser Terrain Profiler, WREMAPS 1, was then developed for the former Division of National Mapping, by the Weapons Research Establishment, WRE, (now the Defence Research Centre) Salisbury, South Australia. It was a world first and has been described in detail by Penny (1971) and Wise (1979).

From its introduction in 1970 to its decommissioning on completion of operations in 1979, 250,000 kilometres of laser terrain profiles were flown with the WREMAPS I prototype. These profiles in turn provided vertical control for the contoured photogrammetric 1:100 000 plotting of 2.7 million square kilometres; about 36% of the total area of Australia.

This new laser profiler comprised a continuous wave Argon ion laser, transmitter and receiver; a barometric reference unit to establish the isobaric surface deviations; and a continuous strip 70mm camera to record the laser profile path. Output was analogue in the form of an ultra-violet light sensitive paper chart. Reduction was manual and very labour intensive.

Visual navigation techniques were used with a gyroscopic B3 driftsight and flight strips of 1:80 000 aerial photography. The laser/receiver measuring accuracy was about half a metre and the whole system capable of an accuracy of better than 3 metres.

WREMAPS II

This was a compact, pulsed laser profiler built by WRE as a second generation system development on WREMAPS I. It has been flown by RASVY, in a single engined Palatus

Porter aircraft and in a Queen Air aircraft, in conjunction with a supplementary RC10 camera. It utilises a UV chart together with a computerised paper tape output rather than only the laborious analogue output from WREMAPS I. The new generation unit has been used extensively overseas by RASVY for foreign aid mapping. Navigation again was by visual driftsight methods. It is still operational and areas so far profiled in Australia are shown in figure 5.

<u>WRELADS</u>

Following the success of WREMAPS equipment, WRE commenced to develop WRELADS as an offshore profiler for the Navy Hydrographer. WRELADS incorporates two lasers, one to bounce off the water and the other to penetrate the water and profile the seabed in shallow water. A prototype has been extensively tested and tenders are being called for the construction of an operational unit. The final unit scans 200 metres either side of track and will incorporate GPS equipment for offshore position fixing.

<u>LAPS</u>

The current airborne laser profiling system used in the Surveying and Land Information Group is the Laser Airborne Profiling System (LAPS). It is essentially a refinement of the concept of the earlier WREMAPS profilers. It was designed principally to upgrade radar profiled areas of marginal accuracy for 20 metre contouring and to meet 1:50 000 map specifications for 10 metre contouring, where required.

Although the potential accuracy of both WREMAPS system and LAPS is similar, LAPS has considerable advantages over WREMAPS 1 in operation:

- A significant reduction in the physical bulk and weight of the operational equipment.

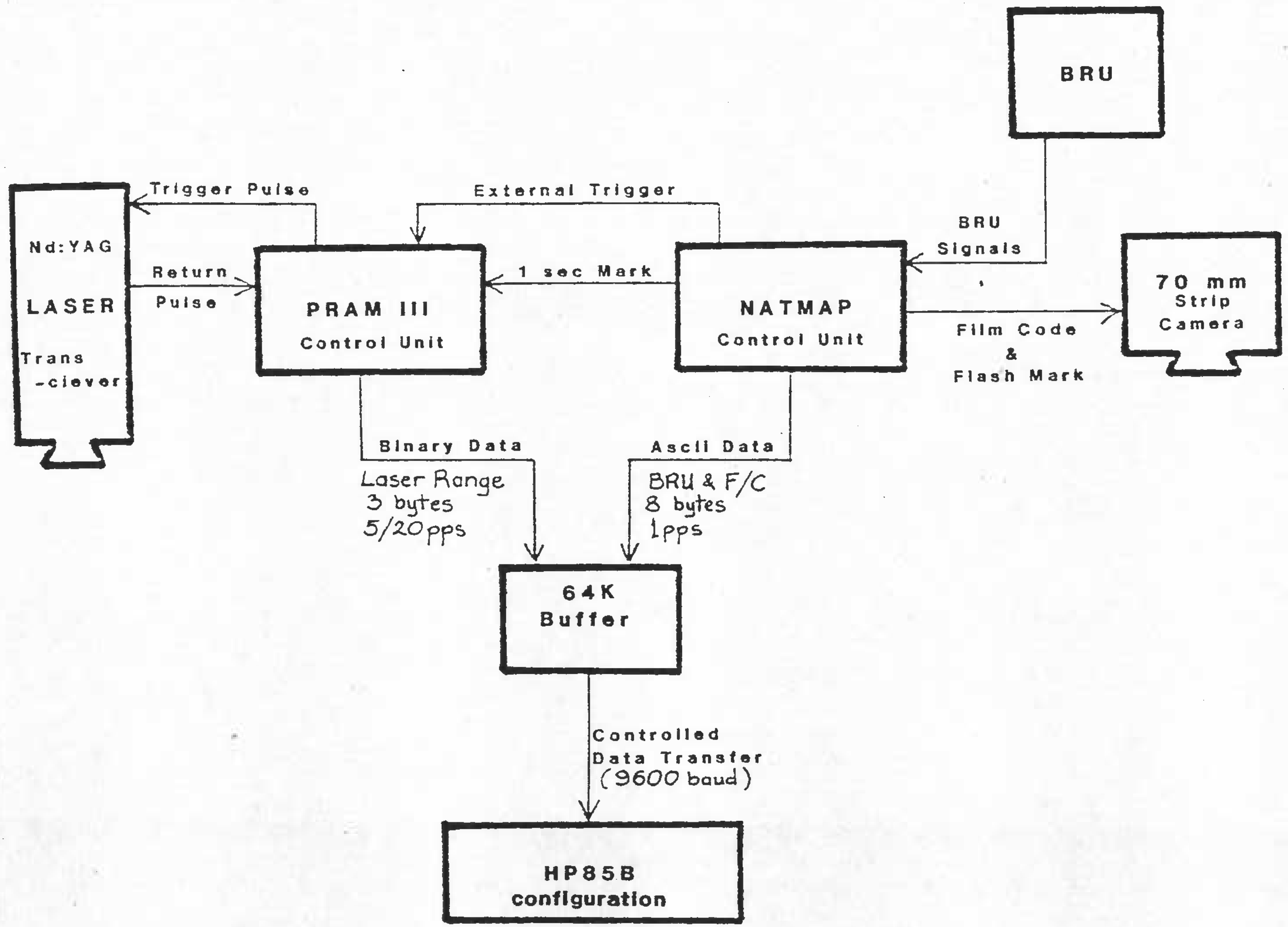

FIGURE 7 LAPS EQUIPMENT CONFIGURATION

- Improved reliability.

- The use of computer technology to capture and reduce the data in digital form.

- Improved office processing and streamlining of results.

- Greater range of the laser beam.

Whereas previously all data was manually reduced, this can now be undertaken by computer after the flight network has been adjusted by least square methods. This represents considerable savings in manpower costs and reduces possible errors introduced by human factors.

LAPS consists of the following hardware modules:

- A Continental 50 millijoule Nd:YAG Laser Transceiver
- ACCI PRAM IIIA Control Unit
- Barometric Reference Unit
- Control Unit (Internal Design)
- 70mm Strip Camera
- 64K Buffer
- HP85B Personal Computer with 9121D Dual Floppy Disc Drive

Figure 7 shows the equipment configuration together with the signal and data paths which occur during inflight data capture operations.

The basic system was purchased from Associated Controls and Communications Incorporated (ACCI) in 1985 and interfacing with camera and computer were developed in the Dandenong Office. The laser operates at a wavelength of 1.06 megahertz and has a selectable pulse rate either at 5 or 20pps. As the ground speed of the aircraft is

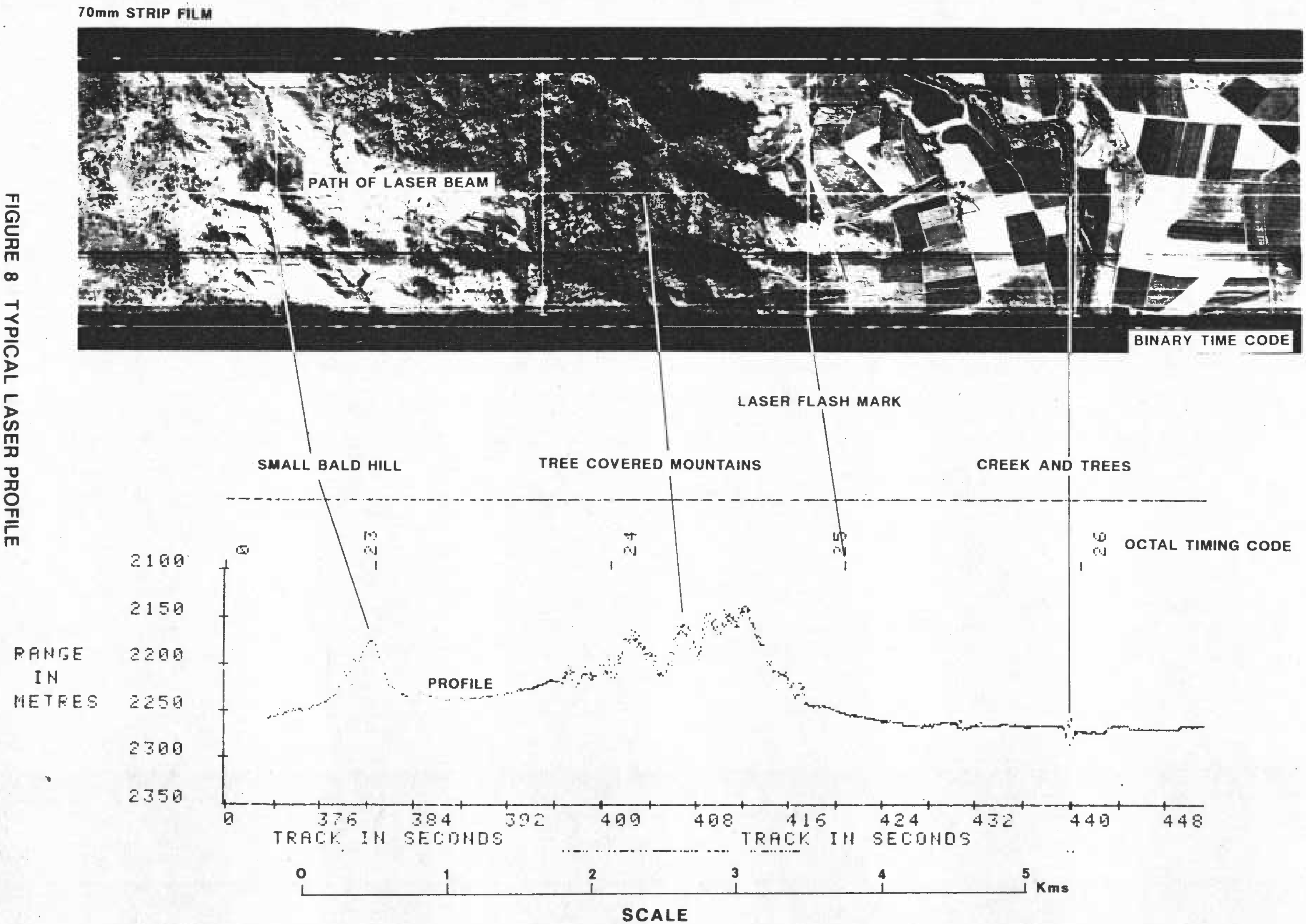

FIGURE 8 TYPICAL LASER PROFILE

about 200 knots, or 100m/second, this represents a pulse separation on the ground of either 5 metres or 20 metres depending on the pulse rate. Operationally the aircraft is usually flown at around 3,200M above ground, and with beam divergence the footprint on the ground is approximately 1 metre.

The LAPS is mounted modularly in a Cessna 421C aircraft and is operated through an aerial camera optical flat glass port otherwise used for a Wild RC10 camera. Recently, 7,500 Kms of line were profiled in Queensland over a five week period. On one day alone, 1,500 Kms were flown. This is equivalent to around 300,000 pulse measurements. Obviously much depends on the weather conditions but it indicates the potential productivity of the system. A typical laser profile is shown in Figure 8. The digital data is related to the continuous strip film by timing marks which correlate the film and the digital data.

After field operations the data, which has been stored on floppy disks is loaded to a VAX 11/750 minicomputer. Office processing then consists of running a least squares adjustment of the network of profiles to solve for the datumising parameters for each line while simultaneously tieing all intersections together and fitting to known bench marks along the profiles. Photo identifiable points are then selected from the adjusted profile lines to provide vertical control for aerotriangulation.

Point selection is achieved by using a small digitising tablet connected to NEC APC IV Personal Computer on line to a VAX 11/750. Any particular section of a profile can be displayed on the PC screen. As the hand cursor is moved along the film from the strip camera the screen indicates the point along the section of the profile. To mark points on the film a pricker is used through a small hole through the centre cross on the hand cursor. To optimise accuracies, points are selected in flat cleared areas.

Current LAPS Developments

The HP85 system is currently being replaced by a NEC APC IV Personal Computer as a data logger. During inflight data acquisition, the HP85 is limited to just collecting data and storing on the disk as it is not fast enough for further processing at the required capture rate. Each range measurement is made up of 3 bytes which must be decoded to give a value to the nearest 0.1 metre. Similarly data must be logged for the BRU readings which are obtained every second with more computing power in the aircraft. Real-time processing of data is however possible using the NEC Powermate IV computer and software development of this potential has been commenced.

Navigation is at present undertaken by visual driftsight procedures and positioning of the profile values can only be done using the strip camera and transferring the position onto mapping photography. The utilisation of dynamic positioning GPS techniques will enable a three dimensional route profile to be produced. This will increase its potential for use on linear route investigations in rugged or remote areas as has been reported for high technology route profiling in Queensland with an integrated inertial laser profiling system (Blair and McLellan, 1984).

CONCLUSION

The surveying of topographic relief across Australia posed an immense problem for map makers until the technique of stereoplotting from aerial photography was introduced after World War II. At that time the problem changed to one of how to provide vertical control for the individual stereoscopic model set ups. Although the basic network of geodetic heights and land traverses were brought into a homogeneous network on the Australian Height Datum the rapid densification infill of vertical control only began to be achieved with the application of airborne profiling techniques. Firstly the Canadian radar APR and then the Australian innovation of laser profilers provided vertical control for stereoplotting of detail from aerial photography with 20 metre contours.

Using the mass of vertical control information from airborne profilers greatly accelerated the relief mapping of Australia and in June 1988 the last contoured sheet in the 1:100 000 coverage of the continent will be compiled. This will virtually provide 20 metre contours to a standard accuracy of one half a contour interval over the complete topography of the country. Mostly this is still graphical in form but it is planned to convert this to digital form during ongoing map revision. Gradually this digital data will be converted into a digital elevation model providing the user with computer compatible terrain relief.

Other auxilary data techniques are now available for the densification of control during aerotriangulation and this will reduce the need for separate vertical control surveys. The use of statoscope has long been advocated by Ackermann (1977) to bridge up to 50 models with very limited acceptance. However the use of Kinematic GPS equipment in the aerial photography aircraft (Manning, 1987) promises to reduce or completely eliminate the need for horizontal and even vertical control for aerotriangulation in the future.

REFERENCES

Ackermann, F. (1977) Progress in Aerial Triangulation for Medium Scale and Small Scale Topographic Mapping *Eighth United Nations Regional Cartographic Conference* Bangkok 159-168.

Blachut, T.J. (1954) The radar profile and its application to photogrammetric mapping *International Archives of Photogrammetry* Volume XI.

Blair, J.D. and McLellan, J.F. (1984) Route Profiling in Queensland Using Satellite Control and an Integrated Inertial and Laser Profiling System *The Australian Surveyor* Vol 32 No. 4 257-273.

Brown, R.M. (1951) Report to the Minister for the Department of The Army Commonwealth of Australia (unpublished report) Appendix C.

Eggeling H.F. (1953) Barometric levelling *The Australian Surveyor* March.

Fitzgerald, L. (1962) The Story of the Royal Australian Survey Corps *Sixth Australian Survey Congress*, Adelaide.

Hocking, D.R.H. (1985) Star Tracking for Mapping - An Account of Astrofix Surveys by the Division of National Mapping during 1948-1952 Proceedings 27th Australian Survey Congress Alice Springs p 13-28.

Manning J. and Derkacz, L. (1987) Aerotriangulation Applications of Satellite Positioning Techniques *Proceedings of RMIT Centenary GPS Conference*, Melbourne 21.2-21.21

Penny, M. (1971) Laser Terrain Profiler may be world first. SCODOS September, Department of Supply, Canberra.

Sperry Surveying Company (1964) Ground Elevation Meter - Instruction manual, Texas.

Squires, P. (1947) Survey Heights by Barometer, DPR71 Commonwealth Scientific and Industrial Research Organisation Sydney.

Wise, P.J. (1979) Laser Terrain Profiler Technical Report 26 Division of National Mapping, Canberra.

Presented at the 30th Australian Survey Conference, Sydney, 9-15 April 1988