NOTES ON AIRBORNE CONTROL SURVEYS, 1970–1973*

Paper presented by Australia

This paper deals with the development and application of three airborne methods used by the Division of National Mapping of the Department of Minerals and Energy, to extend horizontal and vertical control from the national geodetic survey and the national levelling survey, respectively. The objective is to provide a closer framework of survey control, suited for topographic mapping at 1:100,000 scale.

SUPPLEMENTARY DEVELOPMENTS IN AIRBORNE PROFILING

Laser terrain profiling equipment

Since the Sixth United Nations Regional Cartographic Conference for Asia and the Far East was held at Teheran, Iran, the airborne laser terrain profiler has been operating successfully throughout Australia on 1:100,000 scale mapping projects.[1]

*The original text of this paper, prepared by the Division of National Mapping of the Department of Minerals and Energy, Australia, appeared as document E/CONF.62/L.38.

[1] "Developments in airborne profiling: laser terrain profiling equipment", *Sixth United Nations Regional Cartographic Conference for Asia and the Far East*, vol. II, *Technical Papers* (United Nations publication, Sales No. E.72.I.20), pp. 275–282.

Commencing in early 1971, several modifications have been made to the measuring and operational techniques of the profiling system, the more important of which are:

(*a*) A second modulation frequency in the laser profiler;

(*b*) Installation of a Bendix B3 gyroscopically controlled drift-sight;

(*c*) Installation of a second barometric reference unit;

(*d*) A gyroscope to measure lateral roll;

(*e*) Aircraft operation under a Bendix M4C type of auto-pilot.

The second modulation frequency in the laser profiler is 500 kHz, which provides a full-scale deflection of 300 m, to be switched in as required. This feature overcomes any loss of ground reference after passing over an isolated cloud patch or terrain with almost vertical cliffs. It also allows profiles to be independent of any requirement to carry ground heights as chart output from datum points to sections of profiles.

The Bendix B3 drift-sight permits full ahead sighting of the proposed flight line under gyroscopic control which means that profiles can be navigated much more accurately, usually within 200 m along the required flight line. Drifts can also be more confidently determined, as they can be read without interference by minor rolling or pitching of the aircraft.

The provision of two different barometric reference units makes possible a double monitoring of the aircraft height in relation to the selected isobaric surface. Since this height is not as rigidly measured as the laser distance, it was decided that two different measurements of the pressure height were warranted. The units are a Wild RST2 recording statoscope and a barometric reference unit, especially designed by the Scientific Services of the Department of Supply.

The lateral roll of the aircraft is measured by a pick-off modification of the gyroscope in the B3 drift-sight, which permits small corrections to be made to the height of the profile as recorded on the chart output.

Lastly, a Bendix M4C auto-pilot was installed to control the aircraft movements while on profiling operations This auto-pilot has provided a vast improvement to the profile data, as under normal flying conditions, the aircraft excursions from the required attitudes are kept to a minimum.

Operational techniques

The techniques of profiling have improved to the extent that the north-south laser tie-lines in a survey area are flown almost directly over vertical ground control. The datum differences are transferred photogrametrically to these tie-lines from the ground control, which, in urn, are used to control the datum values of the ntersecting series of east-west laser profiles in the survey area

Operational results

The laser terrain-profiling output since March 1971 for vertical control, for 20-m contouring, of 1:100,000 scale mapping is as follows (see also figure 57):

(a) *1971*. In a nine-month field-season, 29 map areas at 1:250,000 scale (equivalent to 174 at 1:100,000 scale) were profiled, covering an area of 480,000 km². A total of 55,000 km was measured on all laser profiling projects;

(b) *1972*. In an eight-month field-season, 37 map areas at 1:250,000 scale (equivalent to 222 at 1:100,000 scale) were profiled, covering an area of 615,000 km². A total of 58,000 km was measured on all laser profiling projects.

In eight 1:250,000 scale map areas, representing a wide variety of terrain from flat to mountainous country, photogrammetric checks were applied to 451 laser points. These checks were obtained by levelling photogrammetric models, containing published Australian height datum ground control, solely on laser points, then reading the differences to the ground control within the models.

The results of these checks are as follows: 63 per cent are within 1 m; 86 per cent are within 2 m; 95 per cent are within 3 m; 99 per cent are within 4 m; 100 per cent are within 5 m.

In assessing these results, it should be noted that pointing accuracy in restitution instruments for 1:80,000 scale aerial photography is of the order 1.5–2.0 m.

Uses other than topographic mapping

In addition to profiling for mapping at 1:100,000 scale, several special project surveys were profiled by the laser terrain profiler. One such project was to check 1:100,000 scale (20-cm contour interval) orthophoto maps which had been compiled using radar terrain profiling for height control; that check examined 24 contour crossings on the orthophoto maps, over a flight length of 36 km; the standard deviation between the orthophoto and laser profile heights was 2.6 m, with a maximum deviation of 4.4 m, which indicated compatibility between radar and laser derived heights for mapping projects at 1:100,000 scale.

Another project was a tree-height study of forests in a mountainous area; and a comparison of the ground profile of the same area, as determined by the laser profiler, with 1:9,600 mapping. A comparison of 16 ground profile points between the laser profiler and the map over a length of 8 km of part of the flight line indicated a standard deviation of 2.8 m and a maximum deviation of 6 m. The laser profile, when plotted against the profile derived from the map contours, illustrated a very close agreement between the respective profiles, even where the terrain was very steep and covered with timber.

Further modifications

Recently, two further modifications were completed and both were scheduled to be used for the first time in profiling operations during 1973. One of these modifications is the development of a sealed laser unit, which does not require a continuous replenishment of gas. Consequently, the vacuum and argon flow supply units have been removed from the system, as they are no longer required; while another advantage is that one sealed laser unit will last between 700 and 1,000 hours of "on time", which is sufficient for one whole field-season.

The other modification is that the 70-mm film strip camera lens now has a focal length of 88.9 mm instead of 177.8 mm. This focal length will provide a photograph scale of approximately 1:25,000 from an altitude of 2,500 m, which will facilitate the transfer of laser profile points from the strip photograph to the mapping photograph of approximately 1:80,000 scale. Another advantage is that a wider strip of terrain will be photographed by the modified camera, which will assist in terrain interpretation and transfer of profile points.

A proposed modification is the provision of a gyroscope two-directional tilt read-out, which will record the simultaneous longitudinal and lateral tilts of the aircraft, while profiling is in progress. This facility will permit the determination of more precise profile heights for special profiling requirements

Further development of profiling systems

In addition to the laser terrain profiler, described above, a second generation system has been recently developed, again by the Scientific Services of the Department of Supply. This system employs a pulse laser capable of operation in a Porter Pilatus type aircraft up to 5,000 m above terrain and 8,000 m above sea level. Some of the system details of this laser are as follows:

(*a*) The laser is a Q-switched Neodynium frequency doubled YAG type with an output pulse of 20 nanoseconds duration at 530 nanoseconds wave-length. The

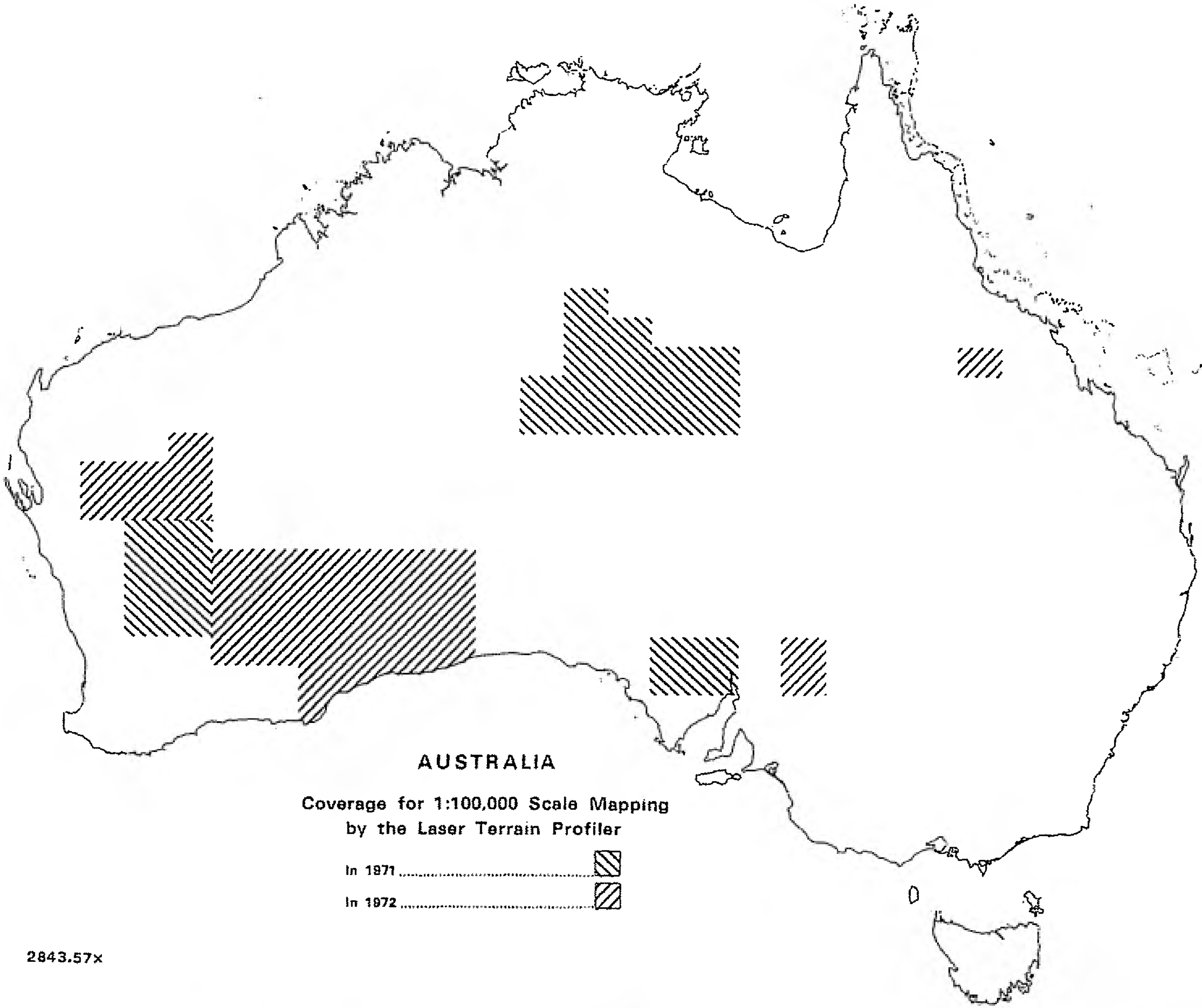

Figure 57. Australia: coverage for 1:100,000 scale mapping by laser terrain profiler

er diameter at the aircraft is 9 cm with a beam ergence of 5×10^{-4} radians;

b) The optical receiver has a focal length of 1.27 m, aperture of 0.1 m and an angular field of 1×10^{-3} dians;

(*c*) The camera has a focal length of 0.1 m providing a otograph scale of 1:30,000 at 3,000 m above terrain, a 70-mm continuous-strip film.

(*d*) The barometric reference unit is a stage II version the Scientific Services of the Department of Supply of e specially developed barometric unit, with an in-eased stability factor;

(*e*) The data are recorded on magnetic tape and as a sual display on chart paper, to include profile height ither in 0–100 m or 0–600 m mode), barometric ference, lateral roll angle and timing code;

(*f*) The profiling equipment is mounted so that it can manually levelled in pitch attitude, while the rack and atform are separately anti-vibration mounted. The tal weight of the equipment is 137 kg.[2]

AERIAL SPOT PHOTOGRAPHY OF CONTROL STATIONS

Control station identification

As survey control stations are invariably established s a basis for photogrammetric mapping operations, it is ssential that their positions are accurately identified on erial photographs. For photogrammetric purposes, an ncorrect identification can nullify the value of the most recisely established ground control station.

Theoretically, the ideal way to achieve accurate identi-ication is to premark the control with a signal of a uitable size prior to the taking of the systematic mapping photography.

However, this idea presupposes that this mapping photography can be organized to follow immediately the establishment of the ground control points—a situation which has very wide variation in practice, particularly in the more distant regions of the country. Unless it does follow almost immediately, a considerable problem arises in that the stations must be revisited on the ground and the markers checked. Another frequent situation is that the mapping photography is completed prior to the control survey work.

In the latter case, a visual ground identification can be made. This procedure cannot guarantee 100 per cent accuracy due to human errors and, except for a revisit to the station, cannot be checked.

Spot photography identification technique

In view of these problems, it is currently standard practice to use aerial spot photography for the identification of control stations for mapping work.

The technique involves the photography of the station, usually with a small format camera, first from a low altitude where the station itself is clearly visible; and then from successively higher altitudes so that the identification can be transferred from one photograph to the other; and, lastly, to the mapping photography.

[2] Australia, Department of Supply. Weapons Research Establishment, Defence Scientific Service, "An airborne laser terrain profiler", Technical note OSD 116. June 1970

Aircraft type requirements

It is normal to charter local aircraft in the area of operation, which means that various types are used, though whenever possible, a high-winged single-engine aircraft is used. The ideal situation is where an aircraft, suitably modified to accept a vertical camera, is available. An increasing number of such aircraft are available around Australia. Where a modified aircraft is not available, it is necessary to use an aircraft with a window which can be opened in flight, so that photographs as nearly vertical as possible are obtained by the use of a camera held out of the window of the banked aircraft.

Station marking

Where a station is monumented with a standard survey cairn or beacon, no further marking is necessary, although it is usual to supplement the spot photography with low-level oblique colour photos to assist in the initial identification of the station. A zoom lens is used for this purpose to eliminate unnecessary low flying.

The situation frequently occurs where the station is established by another survey organization; but where it is established by the Division, e.g., an Aerodist station, the actual point is premarked with circular trenches or crosses made from white painted stone, panels of plastic sheeting, etc., depending upon the nature of the background terrain.

Aerial cameras and film types

For a number of years, 35-mm cameras were used for spot photography, but the recent development in motorized 70-mm cameras has meant that better quality, larger format spot photos can now be achieved.

The camera most commonly used is the Hasselblad 500 EL fitted with a 40-mm wide-angle lens. This camera can be fitted in a simple mount or used hand-held with ease and comfort. Its built-in power-supply is an important feature. Kodak XX aerographic film in preloaded cassettes is normally used. The 70-shot magazines are easily changed and reloaded in the air. A good-quality reflex 35-mm camera fitted with a zoom lens (43–86 mm) and loaded with colour transparency film is used for any colour oblique photography required.

Aerial photography techniques

The Division requires that spot photographs be obtained at three heights above the terrain so that an initial positive identification and suitable scale relationships for transfer to the mapping photographs are obtained. These heights are approximately 250, 500 and 1,000 m. At least two photographs at each level are obtained so that a stereo-image is produced. Oblique 35-mm photos are taken at the low altitude where two pictures are exposed, one with the minimum (43 mm) focal length and the other at the maximum (86 mm) focal length setting.

Photo runs are made in an east or west direction so that the photos are from the same aspect as the mapping photography. It is an added advantage to take photographs away from the sun so that the target is in full sun with the shadows falling away. This factor is especially important with colour obliques. A careful flight plan is necessary for locating control stations, and it is found easier if the aircraft arrives at a station at the lowest photograph level and then climbs to the next level before departing for the next station on a descending path. By this manoeuvre, the station can often be located as a silhouette against the skyline. The initial visual sighting of a ground station is often difficult at flying heights about 1,000 m above ground level. Exposure settings for the camera are calculated using the Kodak aerial computer and an aerial exposure index for the film, chosen to give a gamma of 1.0.

Station identification transfer

After the film is developed, each frame is annotated before prints are ordered. The largest scale pictures and the colour obliques are used to identify the target which is normally visible on the smallest scale print. By means of a differential stereoscope, Bausch and Lomb zoom 95, with an accommodation ratio of 4:1, the control point is positively transferred to the RC9 mapping photo. Apart from the accuracy of the transfer, there is recorded evidence of the original identification which is always available for further reference and independent checking.

This procedure is commendable for speed of field operation, particularly where adequate signals exist, and for accuracy of control point transfer.

Aerodist operations in Western Australia in 1972

During 1972, the Division carried out field surveys to establish horizontal control for topographic mapping at 1:100,000 scale throughout the Great Sandy, Great Victoria, Gibson and Nullarbor desert areas of Western Australia.

Having an average elevation of 400 m and comprising lightly vegetated sand ridges, gravel rises and mulga plains, the country was suited to survey by airborne electronic distance-measuring techniques. However, the remoteness and undeveloped nature of the area usually restricted vehicular traffic to the few existing tracks, movement across country being slow and thus uneconomical.

To cope with these conditions, operations were programmed around a Grand Commander 680 FL fixed-wing aircraft carrying the three-channel master Aerodist system, with two Hughes 500 helicopters to move the four "remote" mobile ground transponders. These, in turn, were supported by 10 four-wheel-drive motor vehicles, ranging from Landrovers to 3-ton Bedfords.

A total of 20 men were involved, including three pilots and a helicopter maintenance engineer from the contractors supplying the aircraft.

Eight airstrips, located throughout the area, were used as fixed-wing aircraft bases during the measuring programme. As the endurance of the aircraft was limited to 7 hours and the ferry time from the nearest base to the measuring zone often exceeded 1½ hours, it was important to have as many line combinations as possible available for measurement while the aircraft was in the area.

The use of two helicopters permitted the movement of two ground parties simultaneously, reducing the time between control station occupation and increasing the number of lines available for measurement within a given period. Furthermore, in the event of a helicopter breakdown, it permitted the immediate recovery of personnel occupying ground transponder stations, which reduced the necessity to carry excess emergency water and rations, allowing more economical utilization of the helicopters.

Operations commenced on 1 April 1972 and concluded on 30 November 1972. During that eight-month period, sufficient field data were gathered to permit the co-ordinates of 80 new control stations to be determined. Control was established at 1° latitude and 1° longitude intervals over an area of 950,000 km^2; 530 lines were measured, varying in length from 25 km to 155 km. Each line was measured using the Aerodist "line-crossing" technique, and a minimum of seven crossings constituted one "line measurement". For identification and point transfer purposes, 120 previously established and new control stations were photographed vertically in 70 mm from heights of 200, 450 and 900 m above terrain. In the course of the survey, 790 fixed-wing and 670 helicopter hours were flown; the ratio of lines measured to aircraft hours to helicopter hours was 1:1.5:1.3. Figure 58 shows a representation of the Australian Aerodist network and delineates the area surveyed during 1972.

Much of the field data obtained during 1972 are yet to be reduced and computed; however, three areas, comprising 123 lines, contained within geodetic loops, have been adjusted by the least-squares method and the results indicate an average modulus residual value of 1.4 m.

Methods of improving the performance of the Aerodist equipment are continually being tested; and the standard Aerodist measuring system has been modified in a number of ways to improve ease of field servicing, quality of output and operating range. The major modifications incorporated in the system are:

(*a*) Relay and co-axial switching to permit utilization of any two combinations of the three master channels on two antennae;

(*b*) Two fixed 30-cm diameter flat-plate antennae with standard dipoles mounted on each side of the aircraft fuselage and connected to the master unit by minimal length low-loss cable. This type of antenna reduces drag in flight, increasing manoeuvrability, speed and range. The flat plates are suited for lines up to approximately 160 km in length, when the line-crossing technique is used;

(*c*) Three single-frequency remote transponder units, modified to incorporate interchangeable "backs" which permit operation on any of the three master frequencies;

(*d*) The introduction of standard fibre glass printed circuit-boards for the master units and modifications to master and remote units to allow the utilization of 95 per cent locally available parts.

Static tests have been undertaken using a 30-cm diameter parabolic dish in place of the flat-plate reflectors currently mounted in the rotatable "pods", the intention being to increase the measuring range for simultaneous three channel operation. Tests are also being carried out to gauge the effect of increasing the remote parabolic reflector diameter from 0.6 m to 1 m.

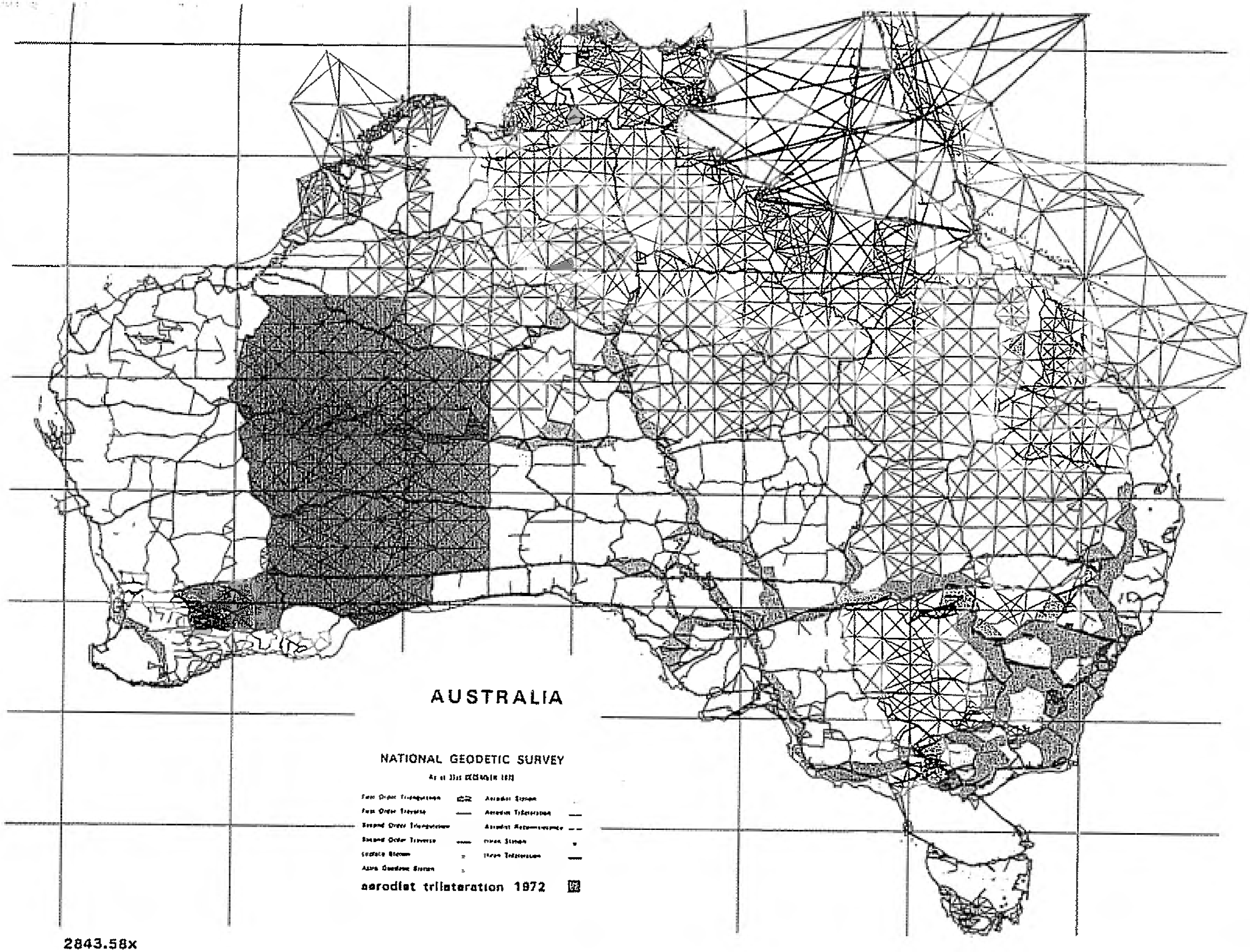

Figure 58. Australia: national geodetic survey, Aerodist trilateration, 1972