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DEVELOPMENTS IN AIRBORNE PROFILING: LASER TERRAIN PROFILING EQUIPMENT

Paper presented by Australia[1]

Introduction to Australian requirements

Airborne profile recording has proved to be an efficient means of providing vertical control for medium-scale mapping. For a country such as Australia, with its vast remote areas, the method is both economic and practical, producing suitably accurate results.

The unit for area coverage is the 1:250,000 map sheet, and the standard air photography flight pattern used for relatively flat areas is shown in figure I. Other standard flight plans exist for terrain where larger variations in altitude exist.

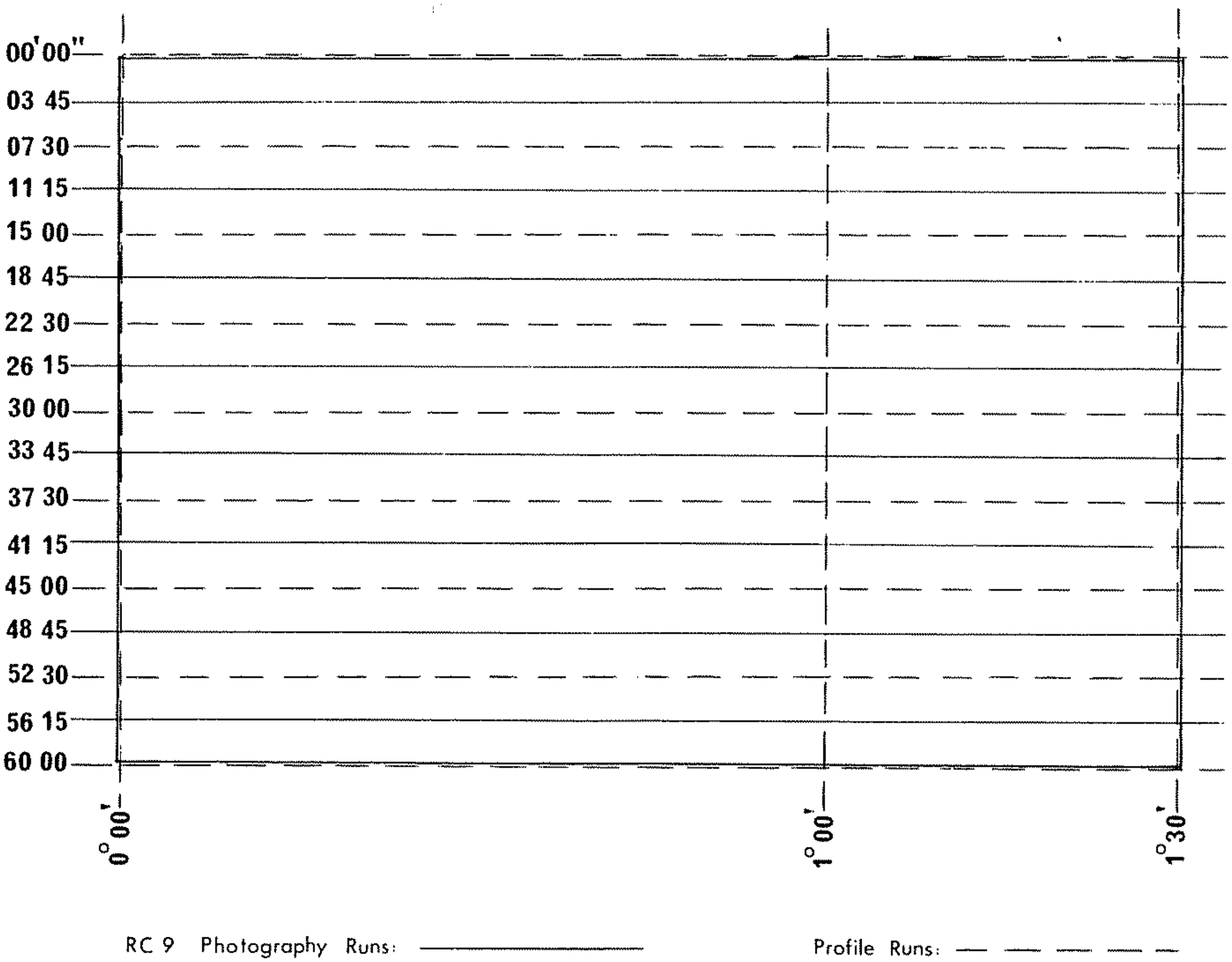


Figure I. 1:250,000 map area: Standard flight line plan

All medium-scale mapping is carried out with a super-wide-angle lens camera and the profiles are flown in the 20 per cent side-lap area. In addition to the east-west profiles, north-south profiles, termed tie lines are flown at intervals of either 60 or 30 minutes of longitude, and it is a requirement of the flight pattern that each east-west flight should be continuous between tie runs. Comparison of the profiles at these intersection points provides a basis for assessment of the profile accuracy, and the results may be used for an adjustment, if required.

Principles of profiling and reason for development of specialized equipment

The principle of this method of heighting requires the aircraft to fly along an isobaric surface, at a pre-selected altitude, while the profiler records the distance to the ground. Deviations above or below the selected isobaric surface are recorded and either automatically corrected for on the profile record or recorded and applied as corrections at each profile point used for control.

The development of airborne profile recording equipment began in the mid 1940s when the National Research Council of Canada experimented with radio altimeters and then radar instruments. These initial experiments proved that specialized equipment was necessary, both for measur-

[1] The original text of this paper appeared as document E/CONF. 47/L.64.

ing and the positioning photography. Research proceeded with various systems, and, at the same time, the possible applications of profiling expanded. Commercially available profilers may be divided into two groups on the basis of their measuring systems—either radar or laser.

The accuracy limitations of the radar instruments stem largely from the 1° cone of the transmitted beam. At the operating altitude of 3,000 m, the beam is sampling terrain heights over an area approximately 70 m in diameter. Thus, in areas with steeply sloping terrain, timber coverage, buildings, etc. an accurate height determination is not possible. This limitation cannot practically be overcome, because it would entail an inordinately large increase in diameter of the reflector.

The problem encountered with early laser units was somewhat different. With the frequency and intensity of light used, the aperture diameter was decreased to a few centimetres, but the flying height had to be reduced to approximately 700 m. Thus, the system was capable of measuring to a few parts per million of the height, but the reduced operating height decreases the system accuracy owing to adverse meteorological conditions at low altitudes. This limitation is acceptable for relatively short profiles, but not for extensive mapping control. For Australian conditions, it is generally necessary to operate at a minimum of 2,000 m altitude to avoid thermal turbulence.

With the limitations of existing instruments in mind, the Division of National Mapping of the Department of National Development undertook the sponsorship of the development of a laser terrain profiler specifically for mapping purposes, through the scientific research facilities of the Weapons Research Establishment of the Department of Supply.

The Laser Terrain Profiler and Principles of Operation

By a judicious selection of flight lines the laser terrain profiler will establish a grid of reference levels within the National Levelling Survey of Australia. The profile levels obtained supplement the existing vertical control and provide the height control necessary for setting up photogrammetric models for contouring. The contour interval for the Australian 1:100,000 mapping programme is 20 m.

The system is currently installed in a Grand Commander aircraft and consists of two main units:

(*a*) *The Profiler Unit* (figure II):

- A. Laser and modulator;
- B. Receiving telescope;
- C. Photomultiplier assembly;
- D. Modulator driver;
- E. Strip camera and camera control unit.

(*b*) *Equipment Rack* (figure III):

- A. Water module;
- B. Vacuum module;
- C. DC converter;
- D. Current regulator;
- E. Height computer;
- F. Photomultiplier EHT supply;
- G. Timing unit;
- H. Ultra-violet chart recorder;
- I. Cathode ray oscilloscope.

Other units used in the system are the laser cathode heater supply (figure II F), the barometric reference unit (BRU) and a 35 mm frame camera. The latter are not illustrated.

The profiler is an airborne continuous wave argon ion laser unit which transmits to the ground a very narrow, amplitude modulated, laser beam. A small amount of the laser light reflected from the ground is collected through the receiving Cassegrain telescope, and after amplification, it is phase-compared in the height computer with the transmitted signal. The modulation frequency selected is such that a full 360° phase change equates to a distance change of 100 m. Allowing for the transmitted and return paths, this represents an aircraft to ground distance change of 50 m. Resolution of the phase difference is made to an accuracy of one metre.

With the single modulation frequency employed in the present system it is not possible to directly determine the number of multiples of 50 m of aircraft to ground distance, but while the system is in operation each 50 m change of distance is recorded as a phase step on the profile chart. This means that if the height of at least one point on each profile line is known to within 25 m, there is no ambiguity in the profile heights. In practice, these points of known height can be conveniently located vertical control stations near the start or finish of profile lines or anywhere along it.

Power for the laser is obtained from a 28 volt DC supply to a 250 volt DC converter and an adjustable current regulator to allow for deterioration of the laser power efficiency conversion which should be a nominal 100 milliwatts.

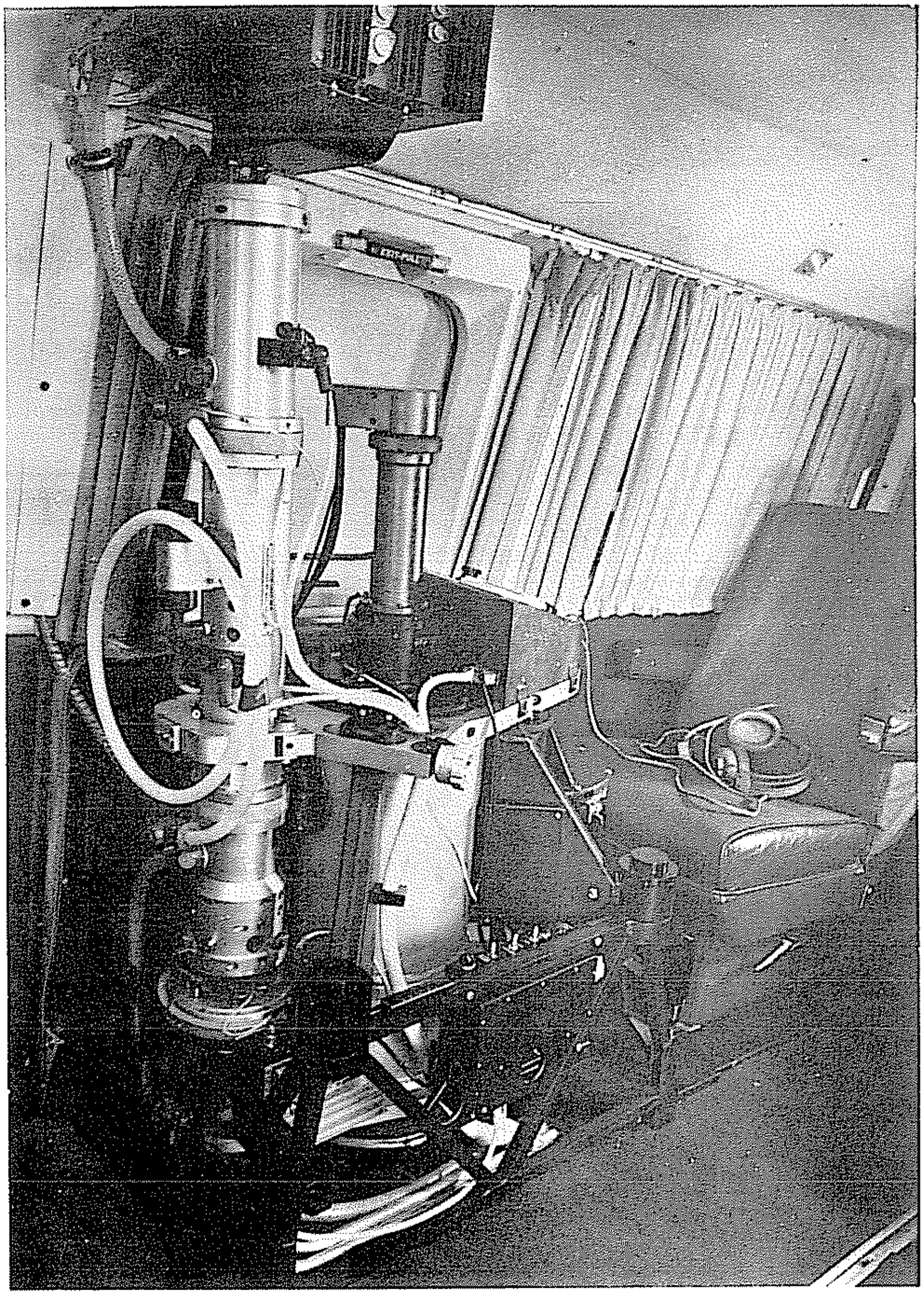
The chart recorder is a six-channel, three-speed, ultra-violet recorder with channels used for the laser trace indicating terrain clearance, BRU, frame camera event, height computer half-scale shift and two channels for a timing code.

The timing unit generates coded lapsed time pulses for the recorder and strip camera. This simultaneous event recording is one of the good features of the system. Loss of correlation of data is to be avoided at all times in a surveying operation.

The strip camera, a cassette-loading 70 mm unit, provides photographic imagery of the track traced out by the laser spot on the ground. The camera incorporates a 7 inch focal length Kodak Aero Ektar lens with a fixed aperture of 2.5 giving a scale of photography of approximately 1:15,000 from an altitude of 2,000 m. An internal window set at 45° to the lens axis reflects the incoming rays to the film which is situated at the focal plane behind a slit. Since the window is partially transparent, the ground is imaged on the screen and is viewed by the operator through a rotating disc engraved with a spiral. This disc is driven by the film transport motor which can be regulated to remove relative motion between the ground and the spiral thus ensuring equal longitudinal and transverse film scales.

The camera and navigation sight body can be rotated relative to the axis of the aircraft as with a conventional aerial survey camera to align the film with the track covered on the ground when drift necessitates crabbing to maintain a selected track. This alignment of the camera with the track provides a measure of the drift angle, which is one of the factors used in the computation of the inclination of the pressure plane along which the aircraft is flying.

To facilitate easier identification of terrain on the superwide-angle photography used for map compilation,



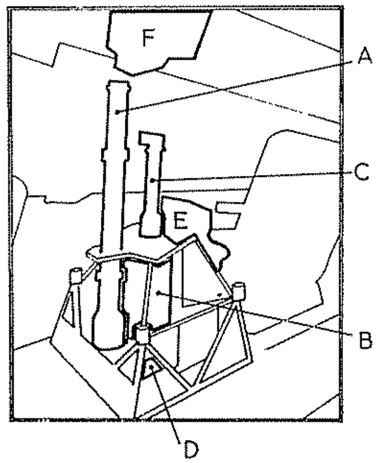
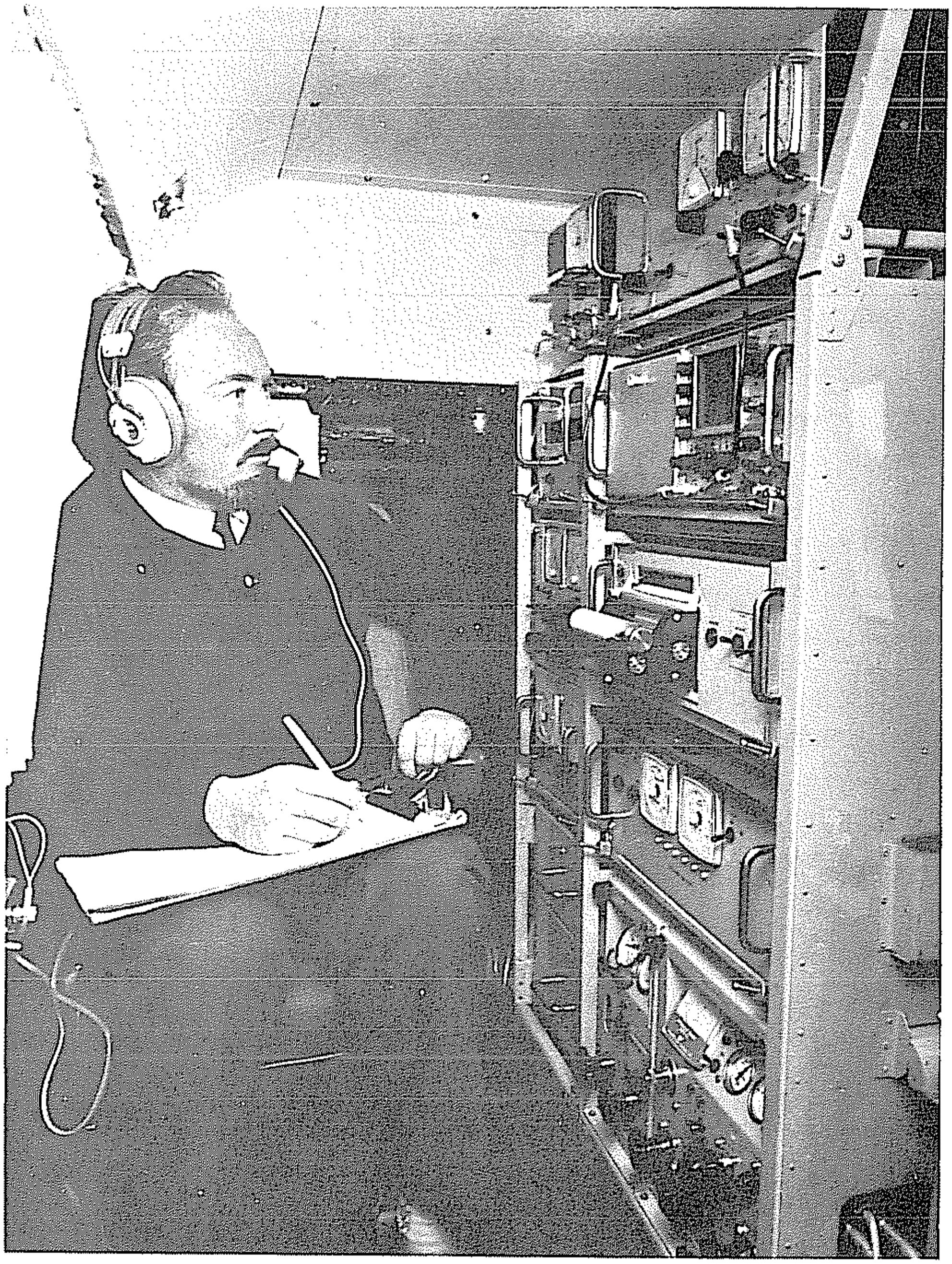


Figure II. The profiler unit



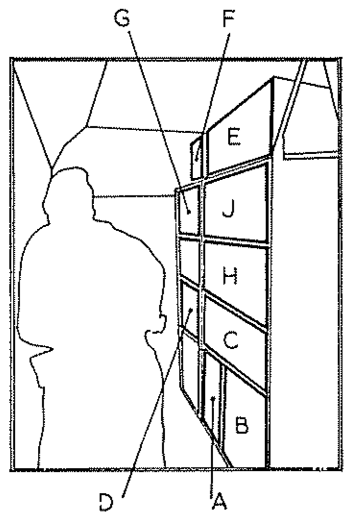


Figure III. Equipment rack

a motorized frame camera with a 50 mm focal length has been installed and can be activated by the profiler operator at any required instant. When this is done the paper chart of the data recorder is event-marked. It should be noted that in some areas of Australia, the area of terrain exposed on the strip camera does not include sufficient terrain patterns to enable cross-identification of the profile positions to the mapping photography to be made with certainty. In these circumstances, the frame-positioning camera, which photographs at a much smaller scale than bandwidths, both electrically and optically, to reduce this noise content. The received 3 mHz signal is amplified by a head amplifier on the photomultiplier and fed into the signal channel of the computer. A reference signal, which is a small sample of the transmitted signal, is taken from the modulator driver and applied to the reference channel of the computer. Both these signals are then amplified, limited and compared in phase, the phase difference appearing as a DC output suitable for driving a galvanometer head in the U/V recorder.

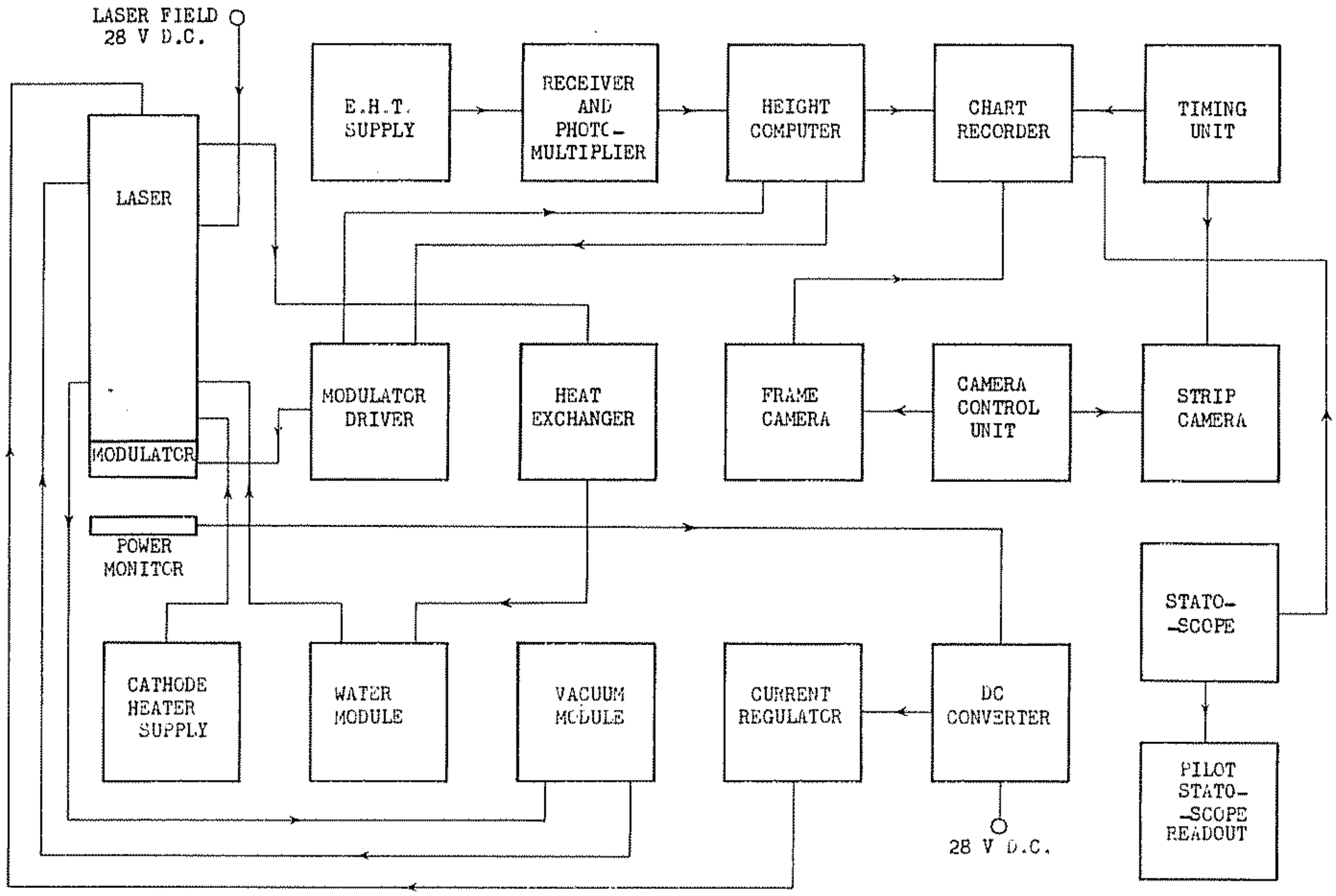


Figure IV. Laser terrain profiler

the strip camera, is used to obtain supplementary photo coverage.

A brief description of the measuring process is as follows. The laser beam emerges from the bottom mirror of the laser with a diameter of approximately 3 mm and passes through the modulator unit, where it is intensity-modulated with a 3 mHz sine wave. The modulated beam is then passed through a diverging telescope and produces a 30 cm diameter spot on the ground when the aircraft is at 2,000 m. The receiving telescope, which has a field of view of about 60 cm diameter at 2,000 m, is aligned to the laser-illuminated spot on the ground and receives reflected laser light from this area. The received signal is passed through a field stop and an adjustable interference filter set to 4880 A, on to the photomultiplier cathode. The output from the photomultiplier consists of a small amount of 3 mHz signal and random noise, the result of reflected sunlight. The equipment has been designed with narrow

Operational techniques

When a 1:250,000 map area has been selected for laser profiling, the superwide-angle mapping photographs at a scale of approximately 1:84,000 are obtained and prepared for field use. This preparation consists of marking the lateral overlap on each photo run, and plotting the proposed flight path along the centre of this overlap. The photographs are then used in conjunction with similarly prepared 1:250,000 map sheets for in-flight navigation. The standard flight plan for superwide-angle photography is always used for profiling operations, irrespective of whether superwide-angle photography is immediately available. If this photography is not available, the existing 153 mm photography is premarked and used for navigation. To provide suitable profiles the flight track should not deviate by more than 700 m from its planned position.

The normal field operation for laser profiling employs a party of four men under the control of a surveyor. This group is based, of necessity, at an air strip which is suitably located in relation to the area to be profiled. On days when the weather is suitable, two missions are normally flown, each yielding a measurement of two profile lines.

In accordance with previously accepted APR procedures, each mission is flown between initial and terminal datum surfaces which form part of the National Levelling Survey. This procedure enables evaluation of a misclosure correction and relatively frequent controls on the profiling operation.

measured drift, indicated air speed and outside air temperature are recorded against time by the profiler operator between successive datums. Along the lines to be profiled, the navigator is responsible for keeping the aircraft above the planned flight path, and he maintains voice contact with the pilot and other crew members by means of an aircraft intercommunication system. The laser equipment is fired, maintained and shut down by the operator in the rear seat.

It is expected that all maintenance and repairs, except those involving specialized equipment, such as for some of the optics, will be carried out in the field. The repairs

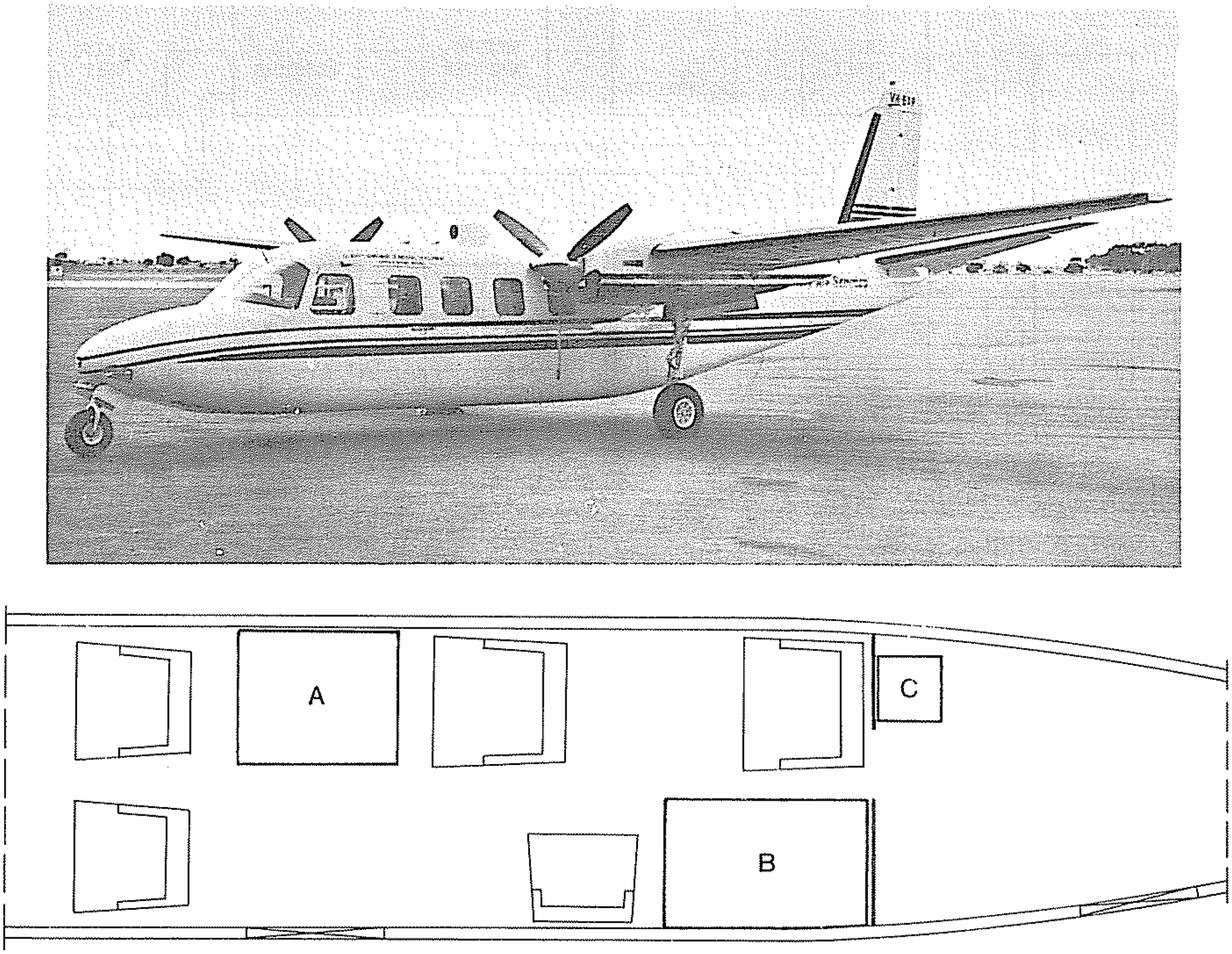


Figure V. Grand Commander aircraft and equipment layout

The basic air crew for a profiling mission comprises the aircraft pilot and the survey crew of navigator, profiler operator and equipment technician. (Figure V shows the Grand Commander aircraft employed and a layout of the equipment in the aircraft. The laser profiler, equipment rack and barometric reference unit are designated *A*, *B* and *C* on the diagram.) The pilot maintains a constant pressure altitude at the selected altitude throughout the flight, with the aid of a remote read-out from the barometric reference unit indicator mounted on his control panel. Regular readings of aircraft heading,

will be carried out in a specially fitted-out workshop, with electric power generator and pump for ground testing of the laser equipment and dark-room facilities, built onto the tray of a four-wheel-drive vehicle. A comprehensive range of spares will be carried in the workshop and space has been provided for field office work. Four lasers have been manufactured for this project; two are held by headquarters and one is carried in the field as a spare.

At the conclusion of each mission all collected data is assessed for acceptability of the traces on the recorder

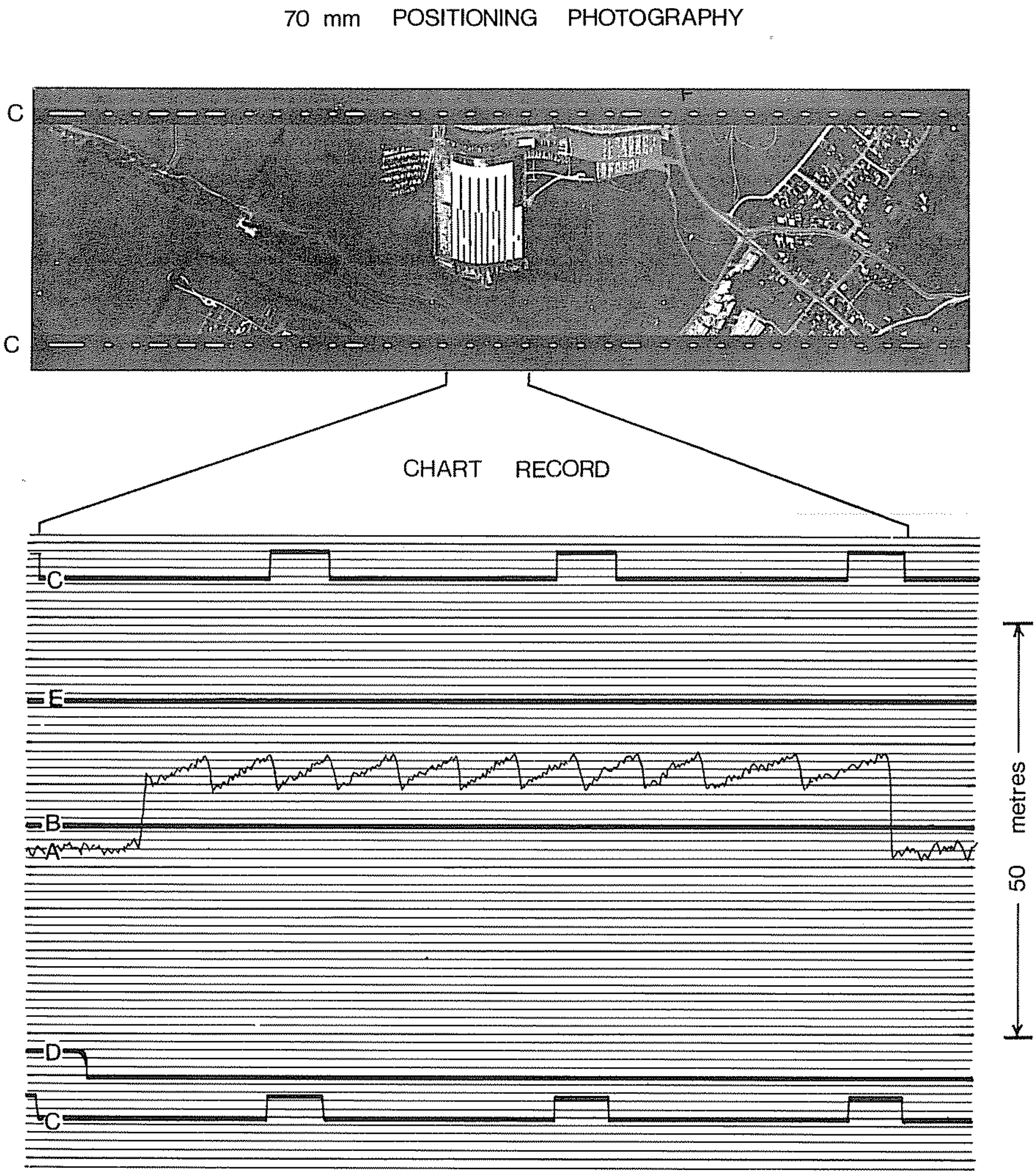

70 mm POSITIONING PHOTOGRAPHY
C
C
CHART RECORD
C
E
B
A
D
C
50 metres

Figure VI

chart to ensure that trace density has been maintained and the signal-to-noise ratio is acceptable. When an area has been completed, the chart rolls, films and flight records are annotated and sent to headquarters for processing, reduction and evaluation.

Here the extraction of height values for control points, while not simply a matter of reading values off the chart, does not require any lengthy computations. The timing code for the point selected is read off the film and the same point is located on the chart. The readings on both the laser height and the barometric reference unit traces are measured and converted to metres by applying previously determined scale factors. The scales of both traces are determined by calibration procedures carried out prior to the initial datum crossing. An orientation constant, determined by obtaining the difference between the chart height and known height of the initial datum surfaçe, plus the misclosure correction are applied, giving the reduced level of the selected point.

Further modifications

Prior to operations, it was recognized that a sealed laser unit which does not require a continuous replenishment of gas would be advantageous. This innovation would not require the vacuum and argon supply module at present in the system, and this, together with work on a field replaceable cathode heater, are now being developed.

With the present single modulation frequency a circumstance could arise where laser reflection from an isolated cloud patch below the aircraft could lead to loss of resolution of the 50 m ambiguity for a short period. In most terrain this would not be a serious problem, but in an area of rapid ground height changes parts of the profile trace could be difficult to use because of uncertainty of ground height to within 25 m.

A modification of the system to include a second modulation frequency coinciding with a full-scale deflection of 300 m, to be switched in if required, is being designed. This modification will overcome any possible problems of loss of ground reference and also make the profiles independent of any necessity to carry ground heights forward from datum points to the beginning of each profile.

Further modifications in hand include a vertical gyro to give read-out of aircraft tilt, and an improved barometric reference unit built around a transducer. This latter will obviate the rather long warm-up time of the present unit and will provide greater sensitivity.

Uses other than topographic mapping

Although the present laser system has been specifically developed for topographic mapping, it is sufficiently versatile in its altitude operating range, which can vary from a few hundred metres to 3,000 m, to be a very useful tool for other purposes.

Already projects have been outlined where this equipment can effect very large savings over the cost of ground surveys, particularly where contour information is non-existent or existing contours are at very large vertical intervals. These include profiles to serve as a trial survey for the examination of gradients for a new railway, checking line-of-sight problems connected with the cross-country transmission of television frequencies and some of the mensuration problems associated with forestry activity.

These are but a few of the potential applications of laser profiling, which although developed for the provision of height control for the compilation of maps, also has a use in testing the accuracy of the end-product map compiled by photogrammetric methods. This is a quick and reliable solution to an otherwise tedious and expensive problem.

Technical description

A detailed description of the equipment is given in *Technical Note OSD 116* published by the Australian Defence Scientific Service, Weapons Research Establishment, Department of Supply.