Presented at Aust Svy Congress / Major Peter Jensen
April 1990

TOTAL CAMERA STATION PROJECT
THE ROYAL AUSTRALIAN SURVEY CORPS EXPERIENCE

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ABSTRACT

This paper outlines progress in the Royal Australian Survey Corps' (RASvy's) attempt to determine the ground coordinates of the aerial survey camera at the instant of exposure of a negative. This may be achieved by making simultaneous GPS measurements in the camera aircraft and at a reference site in the project area. Using techniques developed by DR G. Mader of the US National Geodetic Survey, RASvy has successfully carried out field trials over a small test range at Bandiana, near the School of Military Survey. The aim of the trial was to prove that camera positions can be determined to accuracies commensurate with those required for 1:50 000 scale mapping. It is expected that a significant reduction in the ground control requirements for aerial triangulation will be an immediate benefit from the introduction of this technique.

BACKGROUND TO THE PROJECT

The concept of the Total Camera Station (TCS) was addressed initially by the RASvy Development Coordination Committee (DCC) in 1983. The DCC task involved investigation of the technical requirements for a TCS. In 1984 the Army Survey Regiment investigated the accuracies required of such a system. In addition to the requirement for positional accuracy (Eastings, Northings and Height), it was established that the rotational elements (w, ∅ and k) of the camera must be determined to something better than 1/4 of a dot of parallax at stereomodel scale; i.e., something less than 20 seconds of arc in each axis.

In addition, component items for a trial system were identified. These included a Wild RC-10 camera, a GPS receiver, a recording device and an orientation monitoring device. Little further could be done until GPS equipments were introduced into service in 1986-87.

With the introduction of the TI4100 GPS receivers in March 1987, the concept of the TCS was revived. Whilst undergoing GPS training with the US Defence Mapping Agency (DMA) in Washington in 1987, MAJ Clark liaised with DR Mader of the US National Geodetic Survey, with regard to his kinematic positioning development work and related experiments. As a result DR Mader provided RASvy with technical advice and software developed for his own trials. DR Mader and his colleague DR Lucas had demonstrated achievement of sub-decimetre accuracies for camera position fixation in experiments in Washington and Texas during 1986-87.

DR MADER'S KINEMATIC GPS TRIALS

DR Mader's trials involved flying aerial photography over a densely controlled and targetted test range. The camera aircraft was fitted with a GPS receiver which operated continuously throughout the flight. A ground based reference receiver observed the same satellite constellation simultaneously in order to provide reference site data for post processing the relative kinematic (dynamic) aircraft position.

Post processing of the GPS data provides a string of aircraft 'antenna' positions at one second intervals. By applying the time difference from the nearest whole GPS second until the instant of maximum camera shutter opening, and knowing the GPS antenna to camera front node offset vector, the coordinates of the camera at the instant of exposure were derived.

In order to check the accuracy of the GPS derived camera positions, an independent determination of the camera perspective centres was undertaken by aerial triangulation using a modified bundle adjustment. Comparison of the results demonstrated agreement to within a range of 5-10cm in Eastings, Northings and Height.

DR Mader's research to date has been limited to the determination of camera position, leaving the more complex question of orientation still to be addressed. Nevertheless conservative estimates indicate that savings of 50 to 70% in ground control requirements can be achieved by incorporating GPS derived camera positions in the conventional aerial triangulation process.

In the longer term, it is possible that aerial triangulation could be carried out without any ground control. Provided the orientation problem can be resolved, there is the possibility that aerial triangulation will not always be required.

THE RASVY TOTAL CAMERA STATION TRIAL

TCS Working Group

A RASvy Working Group consisting of personnel from the Directorate of Survey, the Army Survey Regiment and the School of Military Survey was established in January 1988. At its meeting in February it was agreed that RASvy should accept DR Mader's offer of TCS technology transfer and that a trial along similar lines to DR Mader's should be undertaken.

The aim of such a trial would be twofold:

- firstly, to prove a capability; and
- secondly, to quantify its performance.

Provided the demonstrated performance met RASvy's data capture requirements, then suitable justification could be prepared for development of an operational system.

It was acknowledged that there were no commercially available "TCS" systems and that the potential savings offered by employment of an operational system justified further detailed investigation by the Corps.

The working group agreed that the project should be addressed in two phases:

- Phase I - determination of camera position (x,y,z).
- Phase II - determination of camera orientation elements (w,ø,k).

The need to investigate the determination of orientation elements was considered doubtful given the Corps' current practise of block mapping which relies on the aerotriangulation process to produce an homogeneous block of photography suitable for mapping. Orientation parameters are produced as a consequence of this process. As a result, Phase II is considered a longer term goal.

Photogrammetric Test Range

Having identified an aim, the working groups next task was to establish a suitable photogrammetric test range that would enable GPS determined camera positions to be checked. Constraints included:

- site had to be accessible, whilst offering a high degree of ground mark security and stability;
- site had to be located in close proximity to an airfield to permit a complete sortie to be flown in approximately 75 minutes (maximum available time for use of a single four - satellite GPS constellation);
- aerial photography was limited to low altitude/large scale to avoid delays due to aircraft flight time to gain altitude;
- large scale photography was required in order to obtain high accuracy photogrammetric results; and

- the size of the test range was limited to permit optimum control to be positioned for a single strip of photography of approximately seven stereo models.

The TCS Test Range was established in the South Bandiana Military Area at Albury-Wodonga. The site provided adequate security and is located approximately seven kilometres from Albury Airport: See Figure 1. The range was also close to the School of Military Survey, from where the trial was coordinated.

TCS Range Control/Configuration. The Test Range was designed at the Army Survey Regiment and comprised 30 targetted points distributed so as to lie in the classical orientation point locations of the proposed photography. This negated the requirement for pugging of pass points during the aerotriangulation phase, hence eliminating a source of error. Target-panel size was designed so as to precisely accommodate the Zeiss Stecometer measuring mark.

The 2nd Field Survey Squadron was tasked with establishing the primary ground control for the TCS Test Range. In May 1988 Operation Shadow Bird, undertaken by a detachment of 2 Field Survey Squadron, established first order horizontal and vertical control for seven points at Bandiana and another two at Albury Airport using TI 4100 GPS receivers. Subsequently a further 23 targets were coordinated to second order standard, using RASvy's Ferranti Inertial Positioning System (IPS). Figure 2 details the TCS test range control configuration.

The GPS survey was adjusted by Directorate of Survey using the GANET 2-D adjustment, demonstrating precisions in the order of 1-2ppm. The relative accuracies of IPS control were better than +/- 5cm at a one sigma level.

SUPPORT FOR THE TRIAL

The TCS trial required specialist support from a number of organizations.

In order to make optimum use of DR Mader's post processing software - NAV 22, he was invited to participate in the trial. He accepted but due to financial difficulties, the visit was postponed until 1990-91.

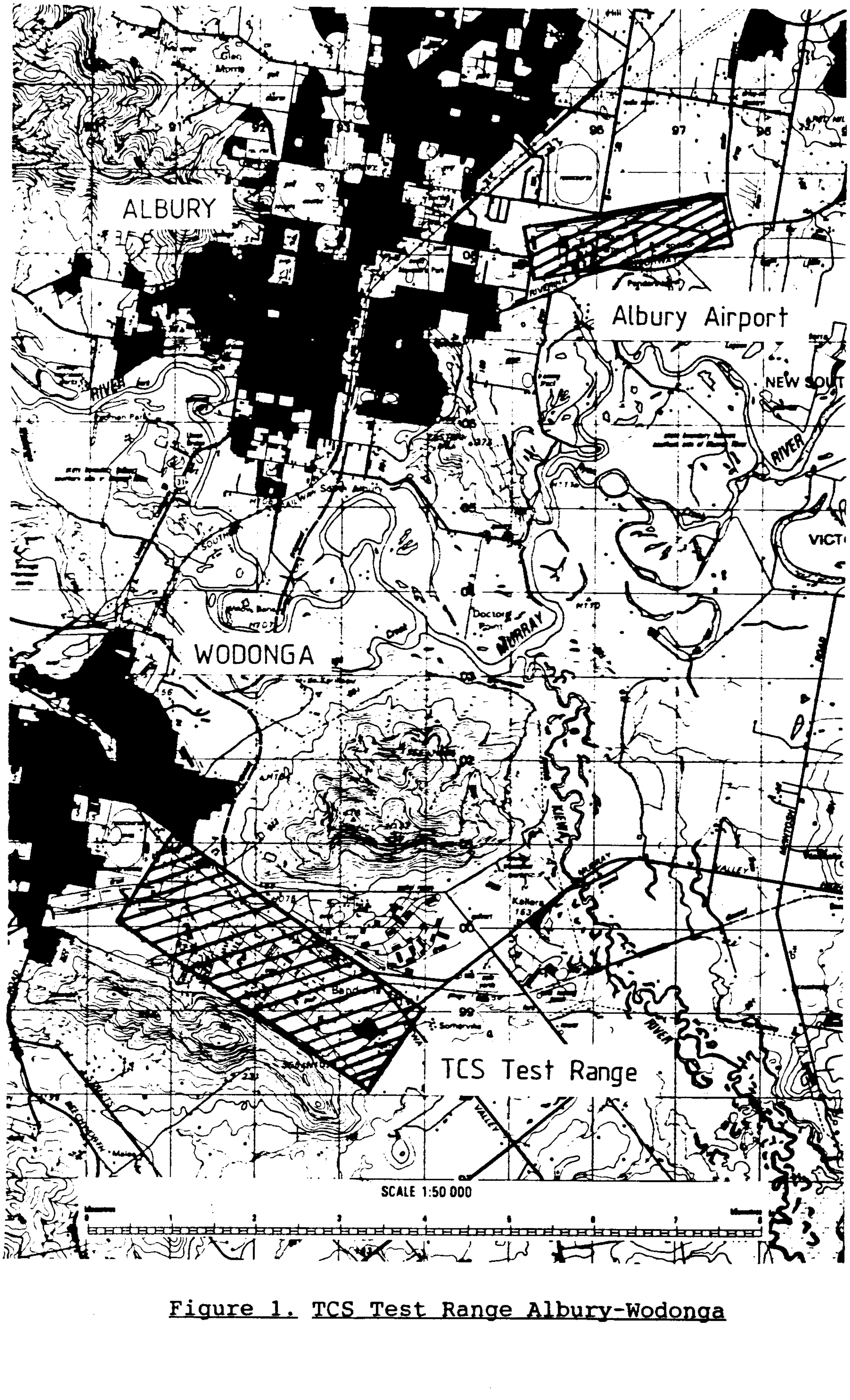


Figure 1. TCS Test Range Albury-Wodonga

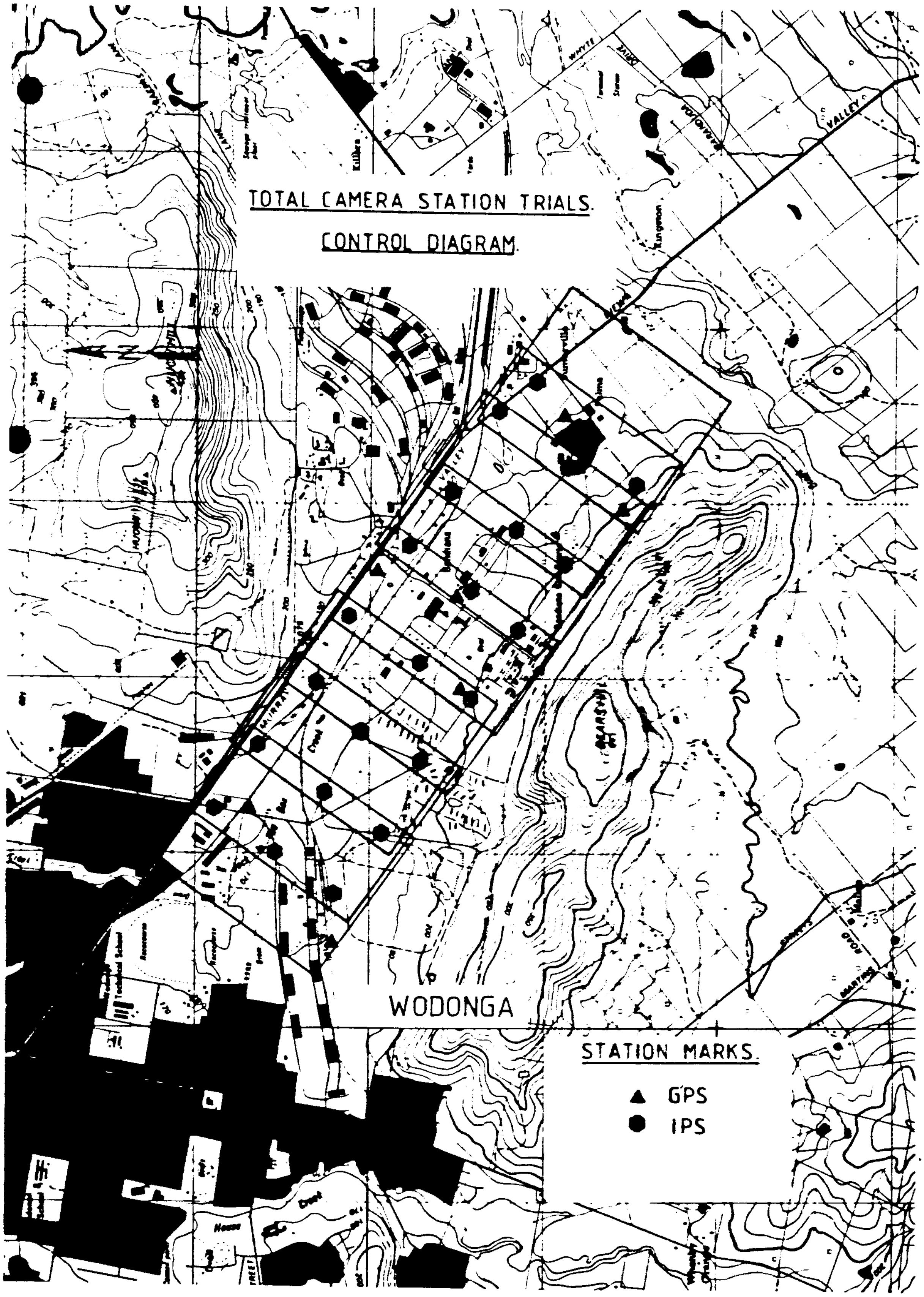


Figure 2.   TCS Test Range Control Configuration

Assistance was also sought from the Defence Scientific and Technology Organization (DSTO), Salisbury, South Australia. DSTO agreed to:

- provide advice on design and positioning of a suitable antenna;
- provide a digital data recorder (floppy disk drive) for the TI 4100 receiver; and
- assist with the determination of the camera orientation parameters (this is a longer term project).

Technical support was provided by the Survey Support Section, Sydney Workshop Company, RAEME. This included servicing, installation and interfacing the camera and GPS receiver in the aircraft.

The camera aircraft was provided by the Australian Surveying and Land Information Group (AUSLIG) under contract to RASvy. This aircraft (CESSNA 421c) currently flies RASvy Wild RC.10 mapping photography. AUSLIG personnel provided advice on equipment installation and trial procedures.

THE STATIC TRIAL

In early March 1989, a static trial was conducted at Sydney Workshop Company, Mascot, NSW. This bench test provided the opportunity to address equipment interfacing and installation aspects. Mounting racks were fabricated, the GPS antenna installation was resolved, and software was written to compute and record the time of the maximum camera shutter opening.

<u>TCS Components.</u> The equipment used for this project comprised the following:

- Wild RC-10 Camera;
- TI 4100 GPS Receiver and Antenna;
- HP 9825 Desk Top Computer;
- HP 5341 Frequency Counter;
- HP Serial and Parallel Interfaces; and
- 28 - 240 Volt Power Inverter.

The TI 4100 (RAM) receiver was upgraded with the Texas Instruments NAV plus software option to provide an improved dynamic tracking capability.

<u>TCS Operation.</u> The TCS components were essentially the same as those employed by DR Mader in his trials. Figure 3 details TCS configuration. In essence, the frequency counter measures the precise time between the maximum shutter opening and the next GPS whole second. The computer then derives the

precise time for the exposure and records both the GPS time and exposure number.

Antenna Location

Antenna positioning was ultimately a compromise between a number of competing factors:

- an optimum signal reception location (free from obstruction);
- a position to minimise antenna - to - camera separation; and
- a position which would minimise structural modification of the aircraft and hence eliminate the need for DCA approval.

For the purpose of this trial an antenna position on the nose of the camera aircraft was chosen. This site was clear of obstructions such as the tail/rudder assembly, but because of the immediate surface area, lent itself to the possibility of multipath interference. Refer to Figure 4.

The optimum antenna position, directly above the camera, was ruled out due to the major modification required to fit the antenna to the pressurised cabin area, as well as the consequent requirement for DCA approval. Had a more suitable flight-qualified antenna been available to replace the TI 4100 antenna, less stringent strain-relief measures would have been required and a more favourable location could have been achieved.

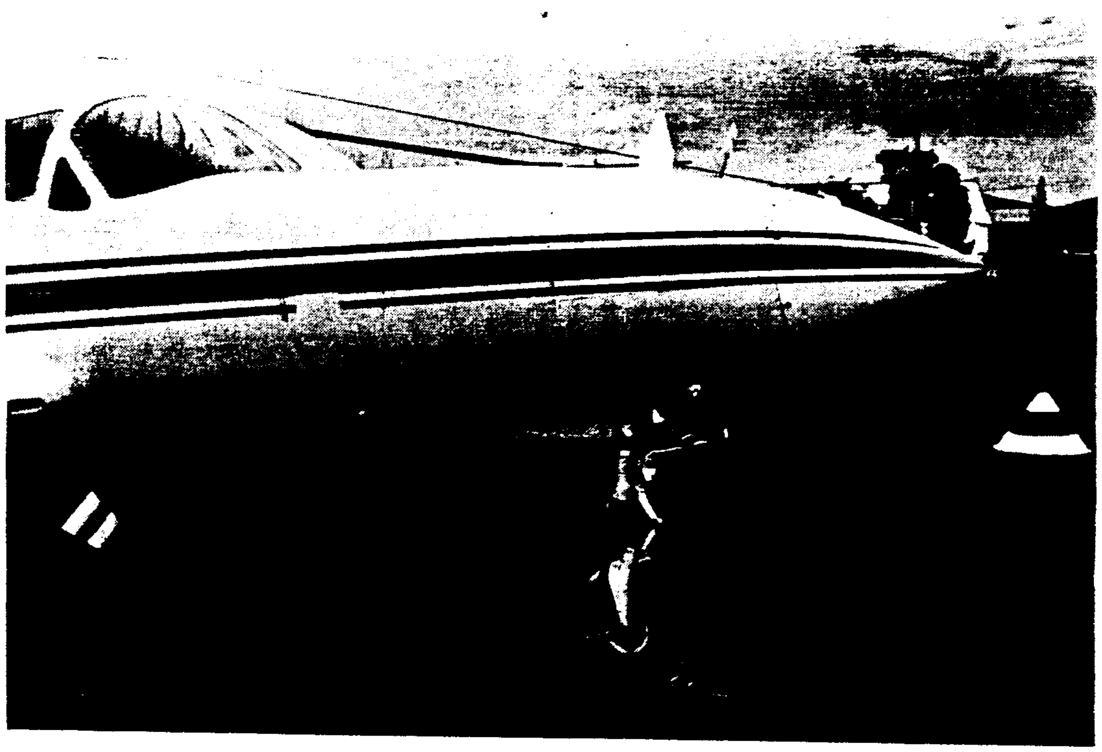
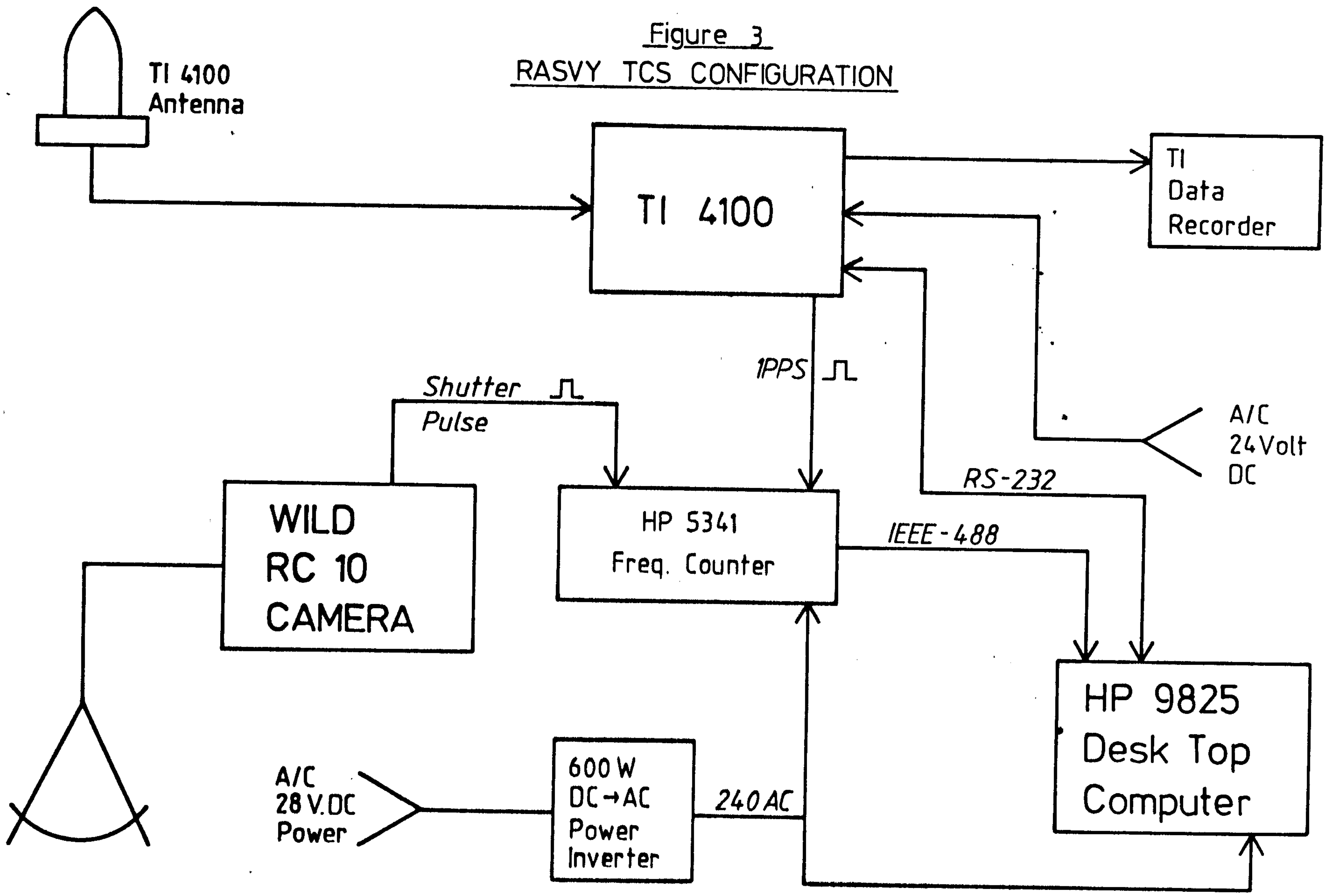


Figure 4. Antenna Location

Figure 3

RASVY TCS CONFIGURATION



In spite of the less than ideal positioning of the TI 4100 antenna and its apparent unsuitability for dynamic tasks, post processing of trial data revealed the complete absence of cycle slips, which would normally have resulted from multipath effects or loss of satellite signal caused by obstruction. Experimentation appears to be the most appropriate method of suitably positioning the GPS antenna.

Camera Modification

The standard WILD RC.10 aerial camera provides a pulse corresponding to each exposure to permit the interfacing of certain hardware. The mechanical method used to determine the maximum shutter opening lacks the precision required for the TCS project. At an airspeed of 100 knots the camera aircraft travels approximately 50 meters per second. The camera pulse should therefore be reliable to a millisecond to preserve the sub-decimetre level accuracy attainable from Dr Mader's kinematic positioning software.

AUSLIG technicians had modified the RC.10 camera pulse trigger mechanism to facilitate the interface requirements of RASvy's Digital Elevation Height Logger (DEHLS) or Statoscope. This modification involved replacement of the WILD trigger device with a Hall Effect switch. The switch is controlled by a small magnet in the camera shutter which is activated when the slot in the shutter is centred over the lens.

Antenna-Camera Offset

The camera front-node to antenna phase centre vector was measured by conventional traverse using theodolite and steel tape. Two sides of the triangle and the included angle were measured to determine the horizontal antenna offsets. A check measurement was obtained by plumbing the camera and antenna centres to the ground. The vertical offset was determined by measuring vertical components from a level line. Care was taken to ensure that the aircraft fuselage was levelled to the same attitude as it adopts during flight. The camera level bubble was used to reset the aircraft's attitude while parked over the reference mark. Figure 5 details antenna location and its relationship to the aerial camera.

The static trails concluded with a flight test to confirm the operation of all components.

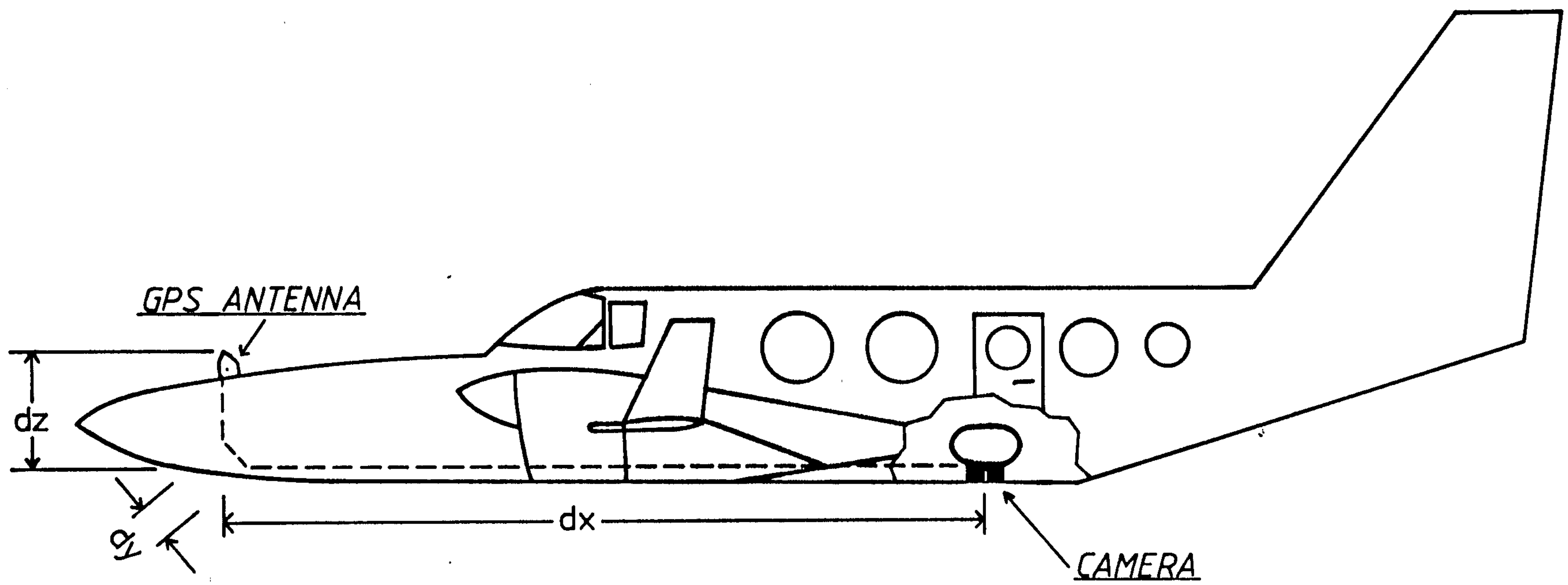


Figure 5 : TCS Antenna Location

TOTAL CAMERA STATION TRIAL

The trial was conducted over Bandiana during 6-13 April 1989. In spite of almost continuous rain, four successful sorties were flown.

Typically, a sortie began with the aircraft positioned over a reference ground survey mark from which offsets to the aircraft antenna were carefully measured. The GPS receiver in the aircraft was powered up one hour before take off using auxiliary power.

A reference receiver was set up over another reference mark at the airfield in order to simultaneously track the same satellite constellation. The TI 4100 can only track four satellites and cannot change constellation without losing phase lock. This limited each sortie to the use of a single four - satellite constellation of one hour 20 minutes duration. An elevation mask of 15 degrees was employed to predict the constellation.

Ten minutes before taxiing, both aircraft and ground reference GPS receivers began recording data at one second intervals. Immediately prior to taxiing, the aircraft TI 4100 dynamics state was changed to medium dynamics.

After a normal take off procedure the aircraft was able to spend approximately 45 minutes over the test range. A total of six photography runs per sortie were made before returning to the airfield and taxiing back to the reference mark. A further ten minutes of static GPS data were gathered prior to system shut down. Recording of static data prior to and after each mission, permits any drifts in the NAV 22 kinematic solution to be monitored.

The camera was levelled in flight before each sortie and locked in position so as to maintain a fixed orientation with respect to the aircraft antenna during flight. The antenna offsets and meteorological data were logged before each flight. Camera drift was set for each run and recorded, so that the antenna-camera offset could be determined.

Each run over the test range took approximately one minute at 95-100 knots and comprised about 20 exposures at 80% forward overlap or seven adjoining photographs. Flying at 2,500 feet above ground level and using a 150mm wide-angle lens provided photography at 1:5 000 scale. This large scale single strip of photography provides adequate opportunity for comparison of accuracies between GPS and photogrammetrically determined camera positions. Further, a comparison of ground control determined using the bundle adjustment (PAT-B) and GPS camera positions, with ground control established by GPS/IPS will highlight the potential of the TCS to determine ground coordinates.

DATA REDUCTION

Data Verification. At the conclusion of each sortie, the GPS data was reviewed using a routine provided by DR Mader as part of his OMNI suite of programs. The OMNI software provides the facility to:

- reformat different GPS data sets into a standard ASCII format;-ARGO;
- analyze data quality with the aid of graphical representation;
- merge data sets obtained from different receivers;
- compute static relative positions; and
- compute dynamic relative (kinematic) positions.

The ARGO (automated reformating of GPS observations) routine converts binary GPS data recorded on data cassette, to ASCII format for further processing. ARGO also detects 'cycle slips' or receiver measurement discrepancies. The occurrence of numerous cycle slips would indicate problems with GPS tracking for that sortie and possibly the need to re-fly.

Initial inspection of the data collected during the RASvy trial indicated that three of the four sorties obtained good quality receiver measurements. The fourth sortie exhibited numerous cycle slip occurrences for the aircraft receiver. Upon investigation it appeared that the receiver dynamics had not been altered properly prior to the aircraft taxiing.

DR Mader's Visit. Further processing of data was not possible until early February 1990, when DR Mader was invited to Bonegilla to train RASvy personnel in the use of his latest version of OMNI software. During the one week visit, data from two missions was processed and preliminary results were obtained.

Kinematic Processing. In order to determine the camera position at the instant of exposure, the GPS antenna position for each receiver measurement epoch (in the case of the TI 4100 - each second) is first computed. NAV22, the kinematic positioning software provided by DR Mader, determines the string of one second aircraft antenna positions for each mission.

The traverse is corrected for the antenna-to-reference mark offsets measured prior to the flight and then the antenna position at the instant of exposure is interpolated. Timing data recorded during each photographic mission correlates each photograph with GPS time. The interpolation is then achieved by matching a third order polynomial to the four consecutive GPS measurements surrounding the exposure time. It is then possible to compare the GPS derived camera perspective centre coordinates with those determined by conventional photogrammetric means.

Photogtrammetic Reduction

The Aerotriangulation Troop of Air Survey Squadron (Army Survey Regiment, Bendigo) was tasked with photogrammetrically determining the perspective centres of photography flown during the trial.

The trial photography was assessed and the most suitable missions were selected for processing using the Program Aerotriangulation Bundle adjustment (PAT-B).

Control Identification/Mensuration. AGD 84 coordinates of 29 horizontal control points along with their AHD heights were used as control for the range. Each control point was panelled prior to photography to eliminate point marking and point transfer errors. During mensuration monoscopic observations were carried out on the original negatives using the Zeiss Stecometer which has a least count of one micrometre.

Image points observed on the seven photographs for each of the four runs observed (28 photos) averaged a Root Mean Square Error (RMSE) of 3 to 4 microns or 2cm at photograph scale.

Adjustment. Each strip of photography was adjusted using PAT-B and perspective centres for each of the 28 photos were derived. The ground control was assigned a standard deviation of 5cm; accommodating both positioning and targeting errors. Since control points were used as pass points, they were classified as image points during the adjustment. The standard deviation set assigned to pass points averaged five microns for each run, with the final RMSE shown above. Following adjustment, the control averaged a RMSE over the four runs of between 4 and 6 microns in planimetry and four microns in height. At photo scale this represents 2 to 3cm in X and Y and 2cm in height.

Finally, the perspective centre positions were derived at the 90% confidence level to within:

- X +/- 5cm;
- Y +/- 6cm; and
- Z +/- 3cm.

The results of the photogrammetric adjustment confirm the strength of both the ground control survey and the photogrammetric measurements. Further, the resultant perspective centre coordinates provide sound control values against which kimematic GPS camera positions can be compared.

Kinematic GPS Camera Positions

Results to Date. Results obtained during DR Mader's visit are encouraging. Unfortunately the lack of a suitably optioned '386 PC has prevented more than one mission being processed for the present time. A '386 processor similar to that hired for DR Mader's visit is currently in procurement and should permit further processing and analysis of results before the next suitable photography window.

Initial comparison of GPS versus photogrammetrically determined positions, revealed the presence of both systematic and random errors in the GPS derived camera positions.

The cause of the systematic errors is yet to be determined, but coordinate transformation algorithms and timing biases are possible sources.

The random errors indicate an uncertainty in position in the in-flight direction of approximately +/- 1m. A random height error of approximately +/- 0.7m has also been identified. The size and nature of the biases is consistent with a camera timing problem similar to that experienced by DR Mader in his early trials. Investigation has revealed that the camera lens (wide angle) employed in the trial, had not been modified with a Hall Effect mechanism. The pulse used to trigger the counter and hence tag each photograph, was the standard WILD RC.10 pulse. It has been shown to be unsuitable for kinematic work, since it does not truly represent the exact time at which the shutter is fully open.

While the sensitivity of the camera pulse mechanism used in the trial will prevent the achievement of sub-metre camera positioning from this data, it is worth noting that camera positions at the +/- 1m level, satisfy accuracy requirements for RASvy's current 1:50 000 scale mapping program.

Further Processing

A number of additional photogrammetric assessments are planned, to further analyze the kinematic GPS results.

Kinematic versus Photogrammetric Camera Positions. Current results are based only on 28 points of comparison (four runs each of seven photographs). Significantly more perspective centres could be derived, if each photo having ground control in greater than 50% of the format area was measured and input to PAT-B. A comparison of GPS versus photogrammetrically derived perspective centres for these additional photos will permit a statistically stronger determination of the accuracy of the kinematic GPS solution.

Antenna-Camera Offsets. A further test will involve using kinematic GPS "antenna" positions as control in PAT B, to determine ground control coordinates for comparison with the GPS/IPS surveyed control points. A comparison of "ground" positions should reveal constant biases which represent the vector separating the camera and antenna. Differences from the measured offset length will hopefully be explainable in terms of systematic and random influences.

Results of the above analyses will provide a sound basis on which to conduct further testing. The value of accuracy assessments from such a small data sample are limited only to 'proving a concept'. Factors such as overlapping block geometry, optimum antenna positioning and improved camera timing, will serve to significantly improve positioning accuracy.

Further System Developments

In conjunction with current processing and analysis of trial data, a number of developments of the RASvy TCS are being investigated.

During the next suitable GPS/photography window (Dec 90-Apr 91) a second TCS trial will be conducted, in which it is hoped to obtain photography and kinematic GPS data at operational altitudes. This trial will involve photography at 1:80 000 scale over the RASvy Lake Hume photogrammetric test range. This test range, centred on Albury-Wodonga, is densly controlled and covers an area corresponding to a standard 1:250 000 scale map area. Such a trial will permit assessment of the effectiveness of the TCS at an operational level.

In order to undertake such a task it is planned to employ two dual TI 4100 receivers at both reference and aircraft locations, thus simulating an eight channel capability at each site. This configuration will permit sorties of up to four hours duration and hence allow high altitude overlapping strips of photography to be flown.

DSTO are currently investigating the interfacing of a "Lap-Top" PC with the TI 4100. It is anticipated that the PC will perform data recording, time tagging and TI 4100 control functions when operational. This will significantly reduce the power consumption, weight and space aspects of the previous TCS configuration. Most importantly however, GPS data recording will be more efficient, being recorded direct to hard disc.

DSTO engineers are also investigating a small flight qualified GPS antenna. It is hoped that this antenna can be positioned directly above the aerial camera. In addition to addressing the interfacing requirements of the antenna, the technicians will accurately measure the camera-antenna offset.

The engineers are also designing a series of tests which will calibrate the camera shutter trigger mechanism. This should permit a more accurate assessment of systematic errors from subsequent flying trials.

It is expected that the developments being undertaken during 1990 will significantly improve the performance of the RASvy TCS. Data resulting from the proposed 1991 operational trial is expected to confirm the encouraging results obtained to date, and will provide suitable justification for development of an operational system.

CONCLUSION

While results of the initial RASvy TCS trial are incomplete, those obtained to date are encouraging. Agreement between GPS determined camera coordinates and those derived photogrammetrically at approximately the +/- 1m level indicate clearly the potential of GPS controlled photogrammetry. Ongoing analyses of trial data will assist further refinement of the TCS configuration in preparation for a planned operational trial during 1991.

Potential savings offered by GPS controlled photogrammetry are enormous, not only in terms of the dollar-cost but also manpower and time savings. Conventional control surveys required to establish photogrammetric ground control are a significant cost in the map production process. By way of example, RASvy undertook a mapping control survey in PNG during 1989, establishing 73 control points along the border region with Irian Jaya. Operation Kumul took 40 personnel just under two months to complete, at a cost of $3.1 million. With possible savings in survey control requirements of between 50-70% using GPS controlled photogrammetry, a significant reduction in operation costs could clearly be achieved.

Within Australia the potential to reduce control requirements from about 20 points per 1:250 000 map area to around five points, will offer similar savings in control aquisition costs.

In the case of conventional block photography, there is little requirement for direct measurement of camera orientation data. The geometric strength of overlapping photography should be used in conjunction with the aerotriangulation process to provide homogeneous blocks of photography suitable for mapping. The accuracy with which orientation elements must be determined appears to be a limiting factor and may ultimately mean that the concept of a Total Camera Station is restricted in reality to a partial or Position only Camera Station.

Current operational constraints, such as the limited day time constellation window (December to April in Australia), the inability to track more than four satellites simultaneously and the generally poor health (reliability) of existing satellites, had considerable impact on conduct of the initial trial. Fortunately these constraints are temporary ones.

Assuming the GPS constellation is completed in 1992 and provided developments being undertaken by DSTO engineers are successful, the prospect of an operational GPS - controlled photogrammetric capability for RASvy seems assured.

ACKNOWLEDGEMENT

The authors wish to acknowledge the invaluable technical and software support provided by Dr Gerry Mader and Dr Jim Lucas of the US National Oceanic and Atmospheric Administration (NOAA), National Ocean Service, Rockville, Maryland, USA.