J. D. LINES

INERTIAL PLATFORM AND ATTITUDE INDICATOR FOR AN AIRBOURNE PHOTOGRAMMETRIC CAMERA

INERTIAL PLATFORM AND ATTITUDE INDICATOR FOR AN AIRBORNE PHOTOGRAMMETRIC CAMERA

In mapping on land, air photography is taken in convenient blocks of several strips of photographs overlapping both longitudinally within each flight strip and laterally from one strip to another. From this flight pattern, a neat geometric array of photogrammetric models can be obtained. With minimum camera distortion and dislevellment of the camera at the instant of exposure, the very orderliness of the array of models provides the basis of a strong mathematically based adjustment of the photogrammetric observations taken to join the models together, and in turn to relate the block of models to datums for position and height by including coordinates and/or elevations of specific ground points, which are known in terms of the Australian Map Grid (AMG) and the Australian Height Datum (AHD).

2. As the principal virtue of photogrammetric block adjustment techniques is to provide a means of obtaining a maximum number of derived model control points from a minimum number of ground control points, the degree of ground control extension achieved by photogrammetry must rely on close attention to the precision of the various phases of the total technique from camera calibration, through to the degree of relaxation which can be tolerated in the mathematics of the photogrammetric adjustment

3. While considerable progress has been achieved in the overall precision of photogrammetric block adjustments for mapping purposes in recent years, the basic requirement of a perimeter "fence" of horizontal control points established by a homogeneous survey to second order standards will remain, even though it has been shown that internal ground control points in the block add little, if anything, to the quality of the photogrammetric adjustment. For height control, it is generally considered that known ground elevations are required at about every fifth model in a strip. These specifications apply to most forms of topographic mapping, but where very large scale work is required, more stringent specifications may well be necessary, even to fully controlling each individual model by ground survey.

4. Essentially, the results of a block adjustment provide the necessary elements to enable each individual model to be set up in a stereoplotting machine to permit detail and contours to be plotted correctly for position, scale, orientation and contour interval. If these elements can be obtained by direct measurement to a precision adequate for the scale of mapping required, then the mapping of terrain which is difficult in terms of access, large water surfaces, logistic support and perhaps adverse weather conditions for regular block photography, becomes a much more attractive proposition.

5. The attraction of direct measurement providing auxiliary data for aerial triangulation has long been recognised. With the increasing advances in technology over the last thirty years or so, many new forms of hardware have been developed, but have not achieved wide acceptance in regular topographic mapping operations. This has been due to two main limitations, firstly the high cost of matching theory with practice in properly controlled practical tests, and secondly, the doubts which have been entertained about the relationship of the obtainable precision of conventional aerial triangulation coordinates on the one hand, and the precision of auxiliary data and the number of models which can be bridged on the other. This philosophy has generally been viewed against the background of land mapping operations, but needs reviewing when considering difficult mapping targets such as offshore features.

6. Auxiliary data has been mostly used in two identifiable groups; those controlling data of the absolute orientation of single models, and those providing a more general control of the resulting coordinates directly. In both instances, the primary aim is to minimise the double summation effects of errors in the transfer elements in the normal procedures of aerial triangulation. Effective auxiliary data must introduce economies in ground control in standard mapping operations and be much more effective in difficult terrain. A theoretical analysis of the increased benefits to be obtained have been discussed by Dr. Jerie.[1]

7. Equipment in the first group mentioned includes the horizon camera, gyroscopes, solar periscope and radar (APR) to measure aircraft clearance. The second group includes electronic distance measuring/positioning equipment such as Shoran, Aerodist, statoscope, doppler navigation and APR. Two systems which incorporate elements of each group have been described by Dr. Zarzycki[2] relating to a project in Nigeria and Messrs. Di Carlo and Eakin[3] in a paper on the American AN/USQ-28 mapping and surveying system.

8. Dr Zarzycki used the horizon camera, doppler navigation and statoscope to provide auxiliary data, whilst the AN/USQ-28 system was reported as incorporating:—

- "a new advanced design mapping camera with a recorded thirty arc second verticality.
- an extremely precise inertial navigation system.
- distance measuring equipment with increased range and accuracy.
- a terrain profile measuring sensor with increased range.
- advanced design navigation and photographic optical viewfinders.
- a light source with variable intensity light for long line azimuth measurements."

---

1. H. G. Jerie, "Theoretical Precision of Aerial Triangulation with the Use of Auxiliary Data", Photogrammetria XIX No. 7.

2. J. M. Zarzycki, "The Use of Horizon Camera, Doppler Navigator and Statoscope in Aerial Triangulation", Photogrammetria XIX No. 7.

3. C. Di Carlo and G. J. Eakin, "Mapping and Survey System Geodetic AN/ASQ-28", presented to Congress of International Society of Photogrammetry, Madrid 1964.

9. This latter system was mounted in a modified version of a Boeing 707 aircraft and is obviously beyond the resources of the vast majority of mapping organisations.

10. The intention of all methods is basically to record data to readily identify the nadir point on each photograph. If the ground position of the nadir point relative to the geodetic network, and accurate height data can be concurrently obtained, so much the better.

11. It is interesting to recall that gyroscopes have not been seriously used until the advent of the AN/USQ-28 system. Some years ago, the Nistri Co. in Italy developed a prototype system which did not attempt to control the attitude of the camera. as does the American system, but rather to record the pitch and roll components. This was achieved by passing a light spot through the lens which represented the nadir location. As far as is known, the Italian development was never marketed.

12. With the advent of much improved inertial navigation systems incorporating very precise gyroscopes, the prospect of achieving acceptable accuracies in the measurement of pitch and roll at the instant of exposure of an aerial camera was explored by the Division of National Mapping, with the Australian Defence Scientific Service at Salisbury, South Australia. This approach was preferred to the rather complex and extensive equipment required to physically control the mass of a modern photogrammetric camera.

13. The prompting reasons for the initiation of this project were the impending requirements to map the coastal and offshore areas of Australia. The prospect of combining an inertial system with a camera attitude indicator and an airborne position fixing system in a medium size twin-engine aircraft was envisaged as a feasible operation, providing the weight of the various components could be kept to reasonable limits. From present indications the combined Aerodist/inertial system/camera attitude indicator can be accommodated in an aircraft of 8,500 lb. all-up-weight and with a disposable load of 1,800 lb. available for the survey crew and equipment, beside a five hour endurance with necessary reserves.

14 The initial feasibility discussions for the Australian production took place in 1970. The original task description was quite brief and called for a two-axis reference system with 10 arc minute capability for periods of one hour with strong emphasis being placed on size and weight, as this system together with a superwide angle camera and a position fixing system together with their peripherals was intended for operation in a light twin-engine aircraft. Naturally it evolved that specifications became more definitive as better equipment performance figures became available.

15. As high precision integrating gyro systems were not freely available at the time, initial investigations took in infra-red detection of the horizon ahead, behind and to both sides of the aircraft. The success of such a system to provide the required angular definition depended on finding a suitable atmospheric window, and although 10 micrometre section of the spectrum showed some promise, the undulations of the horizon at relatively low altitudes, the frequency of cloud formations and associated

meteorological problems finally caused this line of investigation to be discontinued. Work on this investigation has been described by R. H. Abbot.[4]

16. Some years previously, the Division had experimented with a Wild HCl horizon camera which used spectroscopic emulsion film to provide better response to atmospheric penetration. This was largely unsuccessful for much the same reasons as infra-red scanning, although problems were also experienced in calibration and maintenance of calibration of the horizon camera.

17. In all techniques for determining a vertical reference, there is the underlying factor in the system design of balancing aircraft altitude with expected precision of the determination of the local vertical. As a general rule, it should be expected that the measuring environment would be more favourable at relatively high altitudes, but of course, any error in the determination of the local vertical is magnified in terms of ground position. Until actual operations dictate otherwise, planned operating altitudes are 2,000-3,000 m, primarily due to the necessity to operate above the average levels of air turbulence.

18. In mid-1971, attention was turned to gyro-inertial solutions. The required accuracy of 10 arc minutes being maintained over a period of one hour effectively ruled out conventional gravity monitored gyros, and Schuler-tuned vertical reference systems came under scrutiny.

19. After some lengthy investigation, arrangements were concluded with the Royal Aircraft Establishment, Farnborough, U.K., and Ferranti Ltd., U.K., for the supply and fabrication of a modified inertial platform, with Ferranti also to design and manufacture certain portions of the interface and recording components. Ferranti at this time had quite extensive experience in the design and manufacture of miniature inertial platforms, and their systems had been well tried and proved. Concurrently with this activity, the Australian Defence Scientific Service commenced the design and construction of the basic concept of rigidly attaching the platform to the camera, converting and transmitting the coded pitch and roll data for recording on the edge of the film in the taking camera, and the general assembly of all the equipment into a convenient, practical surveying system.

20. It is interesting to record that some of the instrumentation from a Black Arrow launch vehicle used in the launching of Britain's first technology satellite will be incorporated in this new equipment. Some details of the control system used are discussed in a paper by Messrs. Hamilton and Dewis.[5]

---

4. R. H. Abbot, "An Investigation of the Infra-Red Horizon", Technical Memorandum 474 (AP), Australian Defence Scientific Service, 1972.

5. G. B. Hamilton and D. K. Dewis, "Black Arrow Attitude Reference System", Journal of the British Interplanetary Society, Vol. 25, 1972.

Reference System – General Description

21. Figure 1 is a block diagram of the two axis reference system which consists of the inertial platform at the central core and includes the present position computer, navigator control, navigator display, power supply, B.C.D. converter, cooling unit and a static converter to complete the reference system. The inertial platform itself will be fitted to the camera and attitude measurements of pitch and roll will be derived from the total system output via the B.C.D. converter and digitized for the camera display.

22. The prime sensor, which provides the basic information to the rest of the equipment, is a Ferranti miniature inertial platform illustrated in Figure 2. At the heart of the inertial platform, the sensors are contained in a very compact instrument cluster which is supported within an array of four gimbals to allow fully aerobatic performance. Within the cluster are three viscous-damped force feedback accelerometers and three single-axis floated rate-integrating gyros. The accelerometers are aligned and gyro-stabilised to measure aircraft accelerations along north, east and vertical axes.

23. The horizontal accelerations are integrated in the present position computer into velocity components. These components are further integrated in the present position computer to give displacements, which are added to the initial position to define the present position for navigation. The present position computer also computes the torquing rates necessary to keep the platform aligned as the aircraft moves and as the Earth rotates.

24. Since the instrument cluster containing the sensors is initially aligned, and subsequently gyrostabilised and torqued in flight to maintain its orientation, it provides an excellent datum from which to measure aircraft attitude in pitch, roll and heading.

25. When the system is switched on at the navigator control, a built-in test (BIT), lasting for a few seconds, is applied to all the units. The equipment is then switched through an alignment sequence, achieved by switching elements within the present position computer. When this sequence is complete the system is switched into navigation, and the above data is supplied continuously without further action on the part of the pilot.

26. The navigation display presents a continuous visual readout of present position latitude and longitude and provides the operator with an indication of system failure.

27. The output from the pitch and roll synchros will be digitized and an output prepared in B.C.D. form covering the range ± 9.99 degrees.

28. The final output, apart from a monitor display on a console in the aircraft, will be a photographic record of the pitch and roll, (X and Y tilts) on one edge of the film in each successive camera exposure. This data will be introduced into the camera in two 6 digit neon displays. This neat approach will obviate the need for an extensive event related recording system, which is frequently a matter for concern in many other forms of data acquisition.

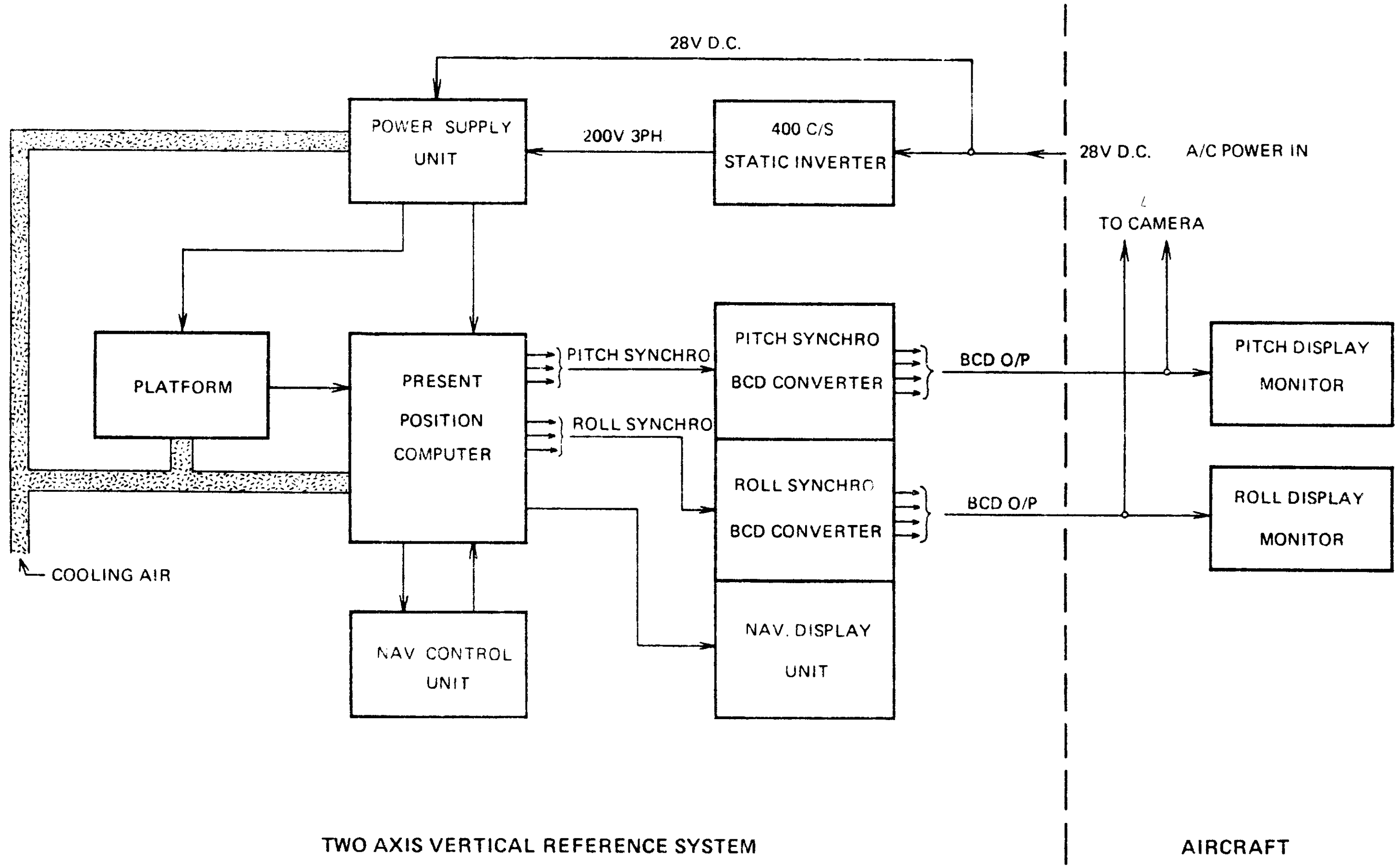

Figure 1. Two Axis Vertical Reference System

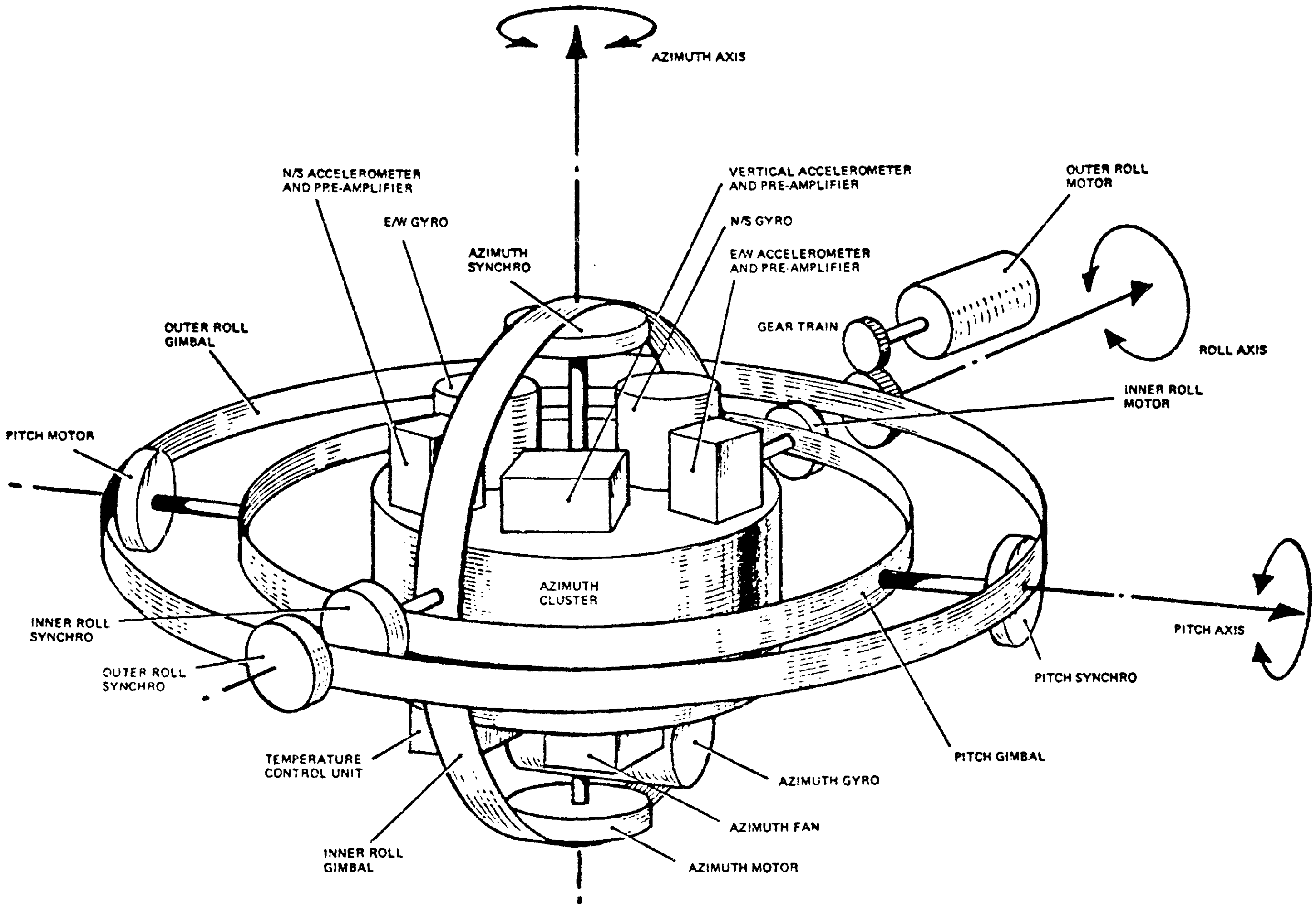

Figure 2. Schematic Diagram of Platform

29. The weight of all the various components and interfaces in the reference system is expected to be about 140 lb., and all very compact in size. The inertial platform weighs 26 lb. and overall maximum dimensions are 8.4 x 12.4 x 8.5 inches which is the scale of miniaturisation hoped for in a development of this kind.

30. The attitude accuracy of the reference system over a period of 6 hours from ground alignment will provide a maximum error (1 sigma) not exceeding 10 arc minutes for the recorded camera pitch and roll. This is not a matter of speculation but has been guaranteed by the supplier. It will be appreciated that this offers great flexibility in aircraft range over water features.

31. For photogrammetric plotting, further information to determine the scale, position and orientation of each model is required in the form of geographical coordinates of each camera air station, and aircraft altitude at the instant of exposure. In fact, altitude is not theoretically necessary to establish the perspective centre of each photograph if the nadir and the true coordinates of the nadir of each photograph in a normal overlapping flight strip is known. However, in the course of obtaining position with the Aerodist MRC 2 airborne distance measuring equipment, which will be used in the integrated system with the camera attitude indicator, an exact knowledge of the aircraft altitude adds to the precision of the fix, and in practice will always be obtained.

32. When using Aerodist in the 3-channel mode, i.e. taking measurements to three ground stations of known position and height, it is theoretically possible from this geometry to compute three-dimensional coordinates of the air station at the instant of measurement. In practice, because of the accuracy limitations of the slant range measurements, the spatial coordinates of a fix computed from the three component rays will be distorted. This can be alleviated if the computation is controlled by a height measurement accompanying each required set of 3 simultaneous slant range measurements. In operations, it is planned that the equipment will be used in conjunction with a transducer activated statoscope, and the flying assisted by a sensitive height-lock on the auto-pilot.

33. With this equipment, and accumulated experience with the Aerodist system, it is expected that a "single shot" fix will have a standard error of position of approximately 3 metres. Up to date, it has not been possible to test the actual precision of an Aerodist fix, as there has been no means of accurately transferring the aircraft position at any instant to the ground coordinate system. With operation of the camera attitude indicator/position fixing system, a practical figure can be determined by testing procedures. The system is presently predicted as being sufficiently accurate for 1:100 000 scale mapping.

34. It should be noted that the present position computer in the vertical reference system is not accurate enough for mapping purposes. As a navigation aid, it has position errors of about 0.5 nautical miles after 30 minutes and 1.25 nautical miles after 1 hour, which is excellent for navigation.

Summary

35. The total concept is being designed and assembled to provide an integrated airborne surveying system, with the accent on well tried and proven components to keep operational reliability at a high level. It will provide a relatively fast and economical method of mapping reefs and other offshore features which would be extremely tedious and expensive in terms of ground control, when using currently available techniques.

36. Apart from the immediate purposes of the Division of National Mapping, the potential of the system also has great attraction in terrain where access is difficult, logistics are complicated and mapping control is scarce. If used in conjunction with geodetic quality satellite receivers for positioning of ground stations for aircraft position fixing, the employment of such a total system would have a wide variety of applications, particularly in areas lacking sound survey control.

37. Operational testing is expected to be completed during 1975.