DEPARTMENT OF
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Record 1974/175

EVALUATION OF RADIO POSITIONING EQUIPMENT FOR HELICOPTER GRAVITY SURVEYS

by

W. Anfiloff

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SUMMARY

Four types of radio positioning systems suitable for use with detailed helicopter gravity surveys have been investigated and evaluated.

The evaluation was based on the performance, cost, size, weight, reliability, and availability of the systems. It was required that the system be able to determine at any instant the absolute co-ordinates or equivalent data of a moving or stationary helicopter with an accuracy of 50 m and with a minimum of systematic error. It should be light and small for easy portability, and not require any extra personnel for its operation.

Of the four systems evaluated, the Decca Trisponder Survey System (Model 202A) was found to be most cost effective and suitable for use with helicopter operations as envisaged in the BMR.

Tender specifications suitable for the hire of a helicopter equipped with a radio positioning system are included in an appendix.

1. INTRODUCTION

The requirement for a helicopter-mounted radio positioning equipment derives from the need to improve the method of determining station locations in Bureau of Mineral Resources (BMR) helicopter gravity work. The photo-identification method used in all past surveys has proved to be inaccurate in some cases. It is suitable only for reconnaissance surveys and not for closely spaced stations or for featureless topography. The anticipation of smaller grid spacings (2 km) for more detailed work, e.g. for the Arltunga Nappe and Central Australia Crustal gravity surveys and surveys in areas with poor base maps such as Papua New Guinea, has led to this search for compact, light, reliable positioning equipment which can be readily carried in a piston-engined helicopter together with a gravity meter, observer, and barometers.

Although systems capable of locating the position of a helicopter with reasonable accuracy have been available for 20 years, only the most recent advances in technology have enabled systems to be made which offer both high resolution and easy portability. Several types of systems are presently available with the potential to fulfil the anticipated BMR detailed helicopter gravity survey requirements of 50 m accuracy and 50 km range, appropriate weight and size, reliability, and simplicity of use. All of the systems studied have a demonstrated capability to locate a helicopter, but their physical characteristics and mode of operation vary considerably. Three of the systems have been used previously in Australia.

2. ELECTROMAGNETIC DISTANCE MEASURING METHODS

Over the past 20 years, numerous types of positioning and distance-measuring systems have been developed which utilize widely differing bands of the electromagnetic spectrum, from VLF to optical frequencies.

The earliest hyperbolic and range radio positioning systems (Bigelow, 1963) operated in the low to medium frequency ranges, and defined distances in terms of phase change or time interval measurable between signals emitted from ground and mobile stations. Characteristics of these systems are the coupling of the emitted wave with the ground, variable ground absorption and hence variable accuracy, large operating range, a large power requirement at the ground station, and a large transmitting antenna. Such systems are not classified as portable.

Subsequent advances in electronics have enabled the same operating principles to be applied in systems using about 3000 MHz radio waves. Since the ground absorption for this frequency is very small, the propagation path from the ground station to the mobile station is line-of-sight, and the power requirements at the ground station are drastically cut. Systems such as Aerodist (Lampbert, 1965) and Hydrodist (Krahmer, 1965) are still in use and give very accurate results, but have been largely superseded by more compact and portable present-day equivalents such as the 3000-MHz Cubic Autotape pulsed phase comparator system.

Recent advances include the development of electro-optical ranging systems, coded pulsed radar ranging systems, and Doppler velocity integration navigation systems.

The electro-optical systems such as the Geodimeter can measure 50-km ranges with an accuracy better than 1 m (Bergstrand, 1965). However, their narrow beam width limits their operations to a source-to-stationary-target, line-of-sight mode. Many new variants are being actively developed.

The coded pulsed radar systems enable line-of-sight ranges up to 160 km to a mobile target to be measured with a 3 m accuracy (Migdal and Hannum, 1970). These newly developed systems operate on radio-ranging principle, utilizing a stable high-frequency clock to measure the propagation time from a ground station to a mobile station. By the use of coded signals, several ground stations can be operated simultaneously to give multiple ranges to the mobile station. Such systems have a very low power requirement and are very amenable to use with helicopters.

The Doppler velocity integrating systems involve a quite different and versatile approach to distance measurement, but do not give highly accurate results. They use radio waves to establish the ground speed of an aircraft from the Doppler frequency shift, and continuously monitor the heading vector to obtain the velocity of the aircraft. This is automatically integrated to give a distance vector from the starting point, independent of any ground stations. Special versions have recently been developed for helicopter use.

In summary: electro-optical systems in their present state of development are inappropriate for rapidly locating a mobile target principally because they operate with a narrow beam width, whereas the latest line-of-sight radio range measuring systems, operating on frequencies between 3000 and 9000 MHz, have a greater reliability, portability, and versatility than their predecessors and are more suitable for the type of helicopter operations envisaged for BMR. Therefore only the latest radio range measuring systems and the Doppler navigation system are evaulated in this study.

3. SYSTEMS EVALUATED

(1) THE CUBIC AUTOTAPE POSITIONING SYSTEM (Model DM-40)

The Cubic Autotape system, operating at a wavelength of about 10 cm (3 GHz), gives line-of-sight ranges up to 100 km between a mobile interrogator and two base transponders. It uses the phase comparison principle, and has an accuracy of one or two metres.

Equipment

The system consists of:

Interrogator - helicopter-borne
(52 cm x 50 cm x 33 cm: 25 kg).

Omnidirectional antenna (10° vertical) - helicopter-borne
(38 cm long: ½ kg).

Transponders (2) - ground component
(30 cm x 20 cm x 15 cm: weight unspecified, estimated 10 kg).

Horn antennas (2) (60° azimuth, 10° vertical) - ground component
(9 kg)

Tripods (2) - ground component
(approx. 7 kg).

12-volt automotive storage batteries
(2 per transponder) (15 kg)

Helicopter-borne components weight:	25 kg
Ground components weight:	105 kg
Total equipment weight:	130 kg

Accuracy and versatility

The system has a high degree of range resolution and accuracy. A helicopter line-crossing trial over a 200-km transponder-transponder baseline gave an error of only 1.4 m in the baseline measurement.

The system can be used to position a stationary or moving helicopter by measuring line-of-sight ranges from two ground transponders. The combination of two 60° horn antennae attached to the transponders, and an omnidirectional antenna on the mobile unit (interrogator), gives a range measuring capability of 100 km. The system has a line-of-sight limitation (discussed later) which can restrict its use in mountainous and forrested terrains.

Availability and cost

The total cost of the system is $75 800* and the rental is $9000 per month for a 3-month rental period. It is available through A.G. Barker and Associates Pty Ltd, Melbourne.

General comments

The system can measure two ranges with 2 m accuracy, even with the mobile unit moving at speeds u p to 200 knots. Optional extras include printers and magnetic tape recorders. The overall size and weight of the system is considerable, since it includes two bulky, heavy horn antennae, and two fairly large transponders of unspecified weight.

Overall assessment

The Cubic Autotape system has been used in helicopter operations to measure large ranges with a high degree of accuracy, and could be used in BMR Helicopter Gravity surveys to give very accurate station locations.

(2) THE MOTOROLA RANGE POSITIONING SYSTEM (RPS)

The system operates in the 3 cm (10 GHz) band, and measures the propagation time for coded pulsed signals to give a line-of-sight range between a mobile station (interrogator) and two or more base stations (transponders). The maximum ranging distance is about 160 km using directional horn antennae.

Equipment

The equipment (Figs. 1, 2) consists of:

Multiplexer/receiver console - helicopter-borne
(48 cm x 12 cm x 43 cm: 16 kg).

Range console (2, 4- or 5-range) - helicopter-borne
(48 cm x 12 cm x 43 cm: 9 kg).

* Throughout this report, system costs and rentals are given as quoted in June 1973.

Antenna, rotating - helicopter-borne
(103 cm diameter: 28 kg).

Transponders (2, 4, or 5) - ground component
(9 cm x 8 cm x 10 cm: 2 kg)

12-volt automotive storage batteries - ground component
(2 per transponder: 15 kg)

Helicopter-borne components weight:	53 kg
Ground components weight:	67 kg
Total equipment weight (2-range system)	120 kg

Accuracy and versatility

The system has a probable range error of about 3 m at 80 km range. The measured range data can be reduced to a more accurate distance measurement by applying signal strength attenuation and atmospheric state corrections. These can be applied subsequently if the signal strength and the temperature and humidity are recorded together with range data during a survey.

The positioning system operates on a line-of-sight basis, and this is its main limitation (discussed later). The maximum operating range of 160 km can be achieved using a rotating directional antenna on the helicopter, and horn antennae radiating directional arcs of 30° vertical and 100° azimuth at 100 dB gain on the base transponders. Small omnidirectional antennae can also be used throughout but the range is then limited to 25 km. Once positioned, a transponder can run unattended. Its operational life is 4-5 days with continuous use, with a 100 ampere-hour storage battery.

Availability and cost

The 2-range system is currently available for hire or purchase from Motorola Aerospace Pty Ltd, Sydney, and the 4- and 5-range systems are currently becoming available. The cost structure is:

2-range: $42 000, or approx. $6 900 per month hire.

4-range: $58 000, or approx. $14 000 per month hire.

5-range: $67 000, or approx. $17 500 per month hire.

General comments

A 2-range Motorola RPS system was evaluated for helicopter use in geodetic type surveying work for the Division of National Mapping. Trials were carried out on 30 August 1972 in the vicinity of Canberra. Distances between trig stations were measured, and the reduced ranges were compared with established survey data. Corrections applied to the raw range data included signal strength corrections up to 7 m, and atmospheric corrections up to 23 m, the latter for 80 km range. It is apparent from the results of this trial (Appendix 1) that the maximum distance error in a single uncorrected range measurement can be as much as 30 m, and is likely to be about 15 m, and that the error can be reduced to between 2 and 7 m if all the necessary corrections are applied.

Overall assessment

Motorola Range Positioning Systems have been successfully used in helicopter operations similar to those envisaged for some BMR gravity surveys. The 2-, 4-, and 5-range systems could all be used effectively to position a network of gravity stations.

(3) THE DECCA TRISPONDER SURVEY SYSTEM (MODEL 202A)

This system operates on the same general principle as the Motorola Range Positioning System, and has the same overall characteristics. The carrier frequency is about 10 GHz. It consists of an interrogating unit and up to four transponders, and measures line-of-sight ranges up to 80 km.

Equipment

The equipment (Figs 3-5) consists of:

Distance measuring unit (interrogator) - helicopter component
(40 cm x 30 cm x 20 cm: 11 kg).

Master transmitter/receiver (mobile) - helicopter component
(10 cm x 15 cm x 18 cm: 4 kg).

Slave stations (transponders) - ground component
(10 cm x 15 cm x 18 cm: 4 kg).

12-volt automotive storage batteries
(2 per transponder) (15 kg).

Helicopter-borne components weight: 15 kg

Ground components weight: 135 kg

Total equipment weight (4-range system); 150 kg

Accuracy and versatility

The Decca Trisponder 202A system has basically the same accuracy and versatility as the Motorola system, and its line-of-sight operational mode is its only limitation.

The equipment currently available in Australia has low gain, 87° azimuth directional horn antennae fitted to its transponders, and an omnidirectional master antenna fitted to the interrogating unit. This combination gives an operating range of 50 km. Newer models have a range of 80 km.

Availability and cost

The system is available from Amalgamated Decca Surveys Pty Ltd, Sydney, for hire or purchase. The cost structure of a 3-transponder (3-range) system is:

Interrogator plus 3 transponders	$25 800
Electronic spares	$ 4 700
Printer	$ 4 300

The quoted rental price for a 3-month rental period given by Amalgamated Decca Surveys Pty Ltd, is $3600 per month, 80% of which can be offset towards purchase.

General comments

A maximum-range and accuracy trial was carried by Decca Amalgamated Pty Ltd for BMR in the vicinity of Canberra on 19 September 1972. The results of the trial (Appendix 2) indicate that the system has a 60-km range capability using an omnidirectional antenna on the mobile unit. The largest range error observed was 8 ± 3 m.

An important feature of the Trisponder system is that neither atmospheric propagation corrections nor signal attenuation corrections need to be applied to the raw range data, as they do for the Motorola system. The system therefore has an on-the-spot distance measuring accuracy of about 11 m.

Overall assessment

The Decca Trisponder 202A system has been used in helicopter and marine work in Australia. An 80-km, four-range system consisting of an interrogator and 4 transponders, all with directional antennae, with a total weight of 150 kg would be ideal for the type of helicopter work envisaged.

(4) THE DECCA DOPPLER (TYPE 71) NAVIGATION SYSTEM (with gyro/magnetic compass)

The Decca Doppler Type 71 apparatus operates on the Doppler velocity integration principle. It uses a 13-GHz signal and gives the forward, sideways, and vertical speeds of V/STOL aircraft. This information is displayed on a ground speed/drift meter and hover meter. The speed data are coupled with heading data from a separate gyro/magnetic compass system by an analogue computer processor which gives X-Y outputs. These can be used to drive an X-Y digital readout instrument or a roller-map track-plotter, which are optional output units supplied by Decca. The gyro/magnetic compass is not part of the Decca system, and must be purchased separately.

Equipment

The equipment necessary to obtain an X-Y digital readout using the Decca Doppler Type 71 system in a helicopter is:

Decca Doppler Type 71 antenna/electronics unit
(40 cm x 40 cm x 13 cm; 16 kg).

Decca ground speed/drift indicator
(Standard ARINC case).

Decca computer Type 1770
(½ ATR (short) size, 6 kg).

Decca digital display unit Type 9478B
(or equivalent).
(11 cm x 14 cm x 12 cm; 2.3 kg).

Gyro-stabilized magnetic compass system
(Several small components; 9 kg)

Total equipment weight = 35 kg.

Accuracy and versatility

The total system error is mainly a function of the Doppler speed sensor error and the magnetic compass error.

Doppler speed sensor error. The speed measurement error is quoted by the manufacturer to be 0.15% (calibration) and 0.074% (random) for the forwards and sideways speeds. An R.A.F. appraisal (Hammond, 1969), however, indicates a total of 0.3% R.M.S. error for the equivalent Type 72 fixed-wing equipment.

Gyro/magnetic compass heading sensor error (Sakran, 1970). The manufacturer's specifications for the Sperry C-10 system considered to be the best available are:

Random drift rate	= $\pm$ 3° per hour
Dynamic accuracy (in slaved mode)	= within 0.75° of magnetic heading
Slaving rate	= 1° or 2° per minute
Manual synchronizing rate	= 50° per second
Levelling rate	= 2° to 4° per minute.

Hammond (loc. cit.) indicates a total error of 1.66% R.M.S. in heading for fixed-wing application. This error will be somewhat increased in a helicopter application, as follows:

- For a slaved gyro/magnetic compass operation, the slaving rate of 1° or 2° per minute of the gyro by the damped magnetic sensor is likely to be much less than the helicopter turning rate in many manoeuvres.
- For an unslaved gyro/magnetic compass operation, the acceleration cuased by helicopter banking, ascents, and descents will cause increased, possibly excessive, precessional rates for the gyro.

These two factors suggest that it would not be possible to operate the gyro/magnetic compass permanently in either slaved or unslaved mode for the type of operation envisaged, because false headings would be produced. It is possible that the optimum operational procedure would be to unslave the gyro for short durations while manoeuvering the helicopter for takeoff and landing, and to slave it again when the helicopter is in a more steady state on the ground or in flight. However, it is not known whether this method is technically or operationally feasible.

The overall system navigational error for a fixed-wing application of a combined Doppler and slaved gyro/magnetic system is given in the RAF appraisal as 1.7% R.M.S. This is for steady flight, but in a helicopter operation involving repeated landings and takeoffs the error would be greater, and would be cumulative.

The system is versatile in that it functions independently of any ground equipment, which in particular frees it of the line-of-sight limitation. Two limitations that it does have, however, are that the speed sensor does not function over flat water, and the system is prone to error over steeply sloping topography, since the forward and reverse beams subtend different angles with the ground surface.

Availability and cost

The complete system is available from Navitron Pty Ltd, Sydney, and costs between $50 000 and $60 000. No hire or lease/purchase quotations were received.

General comments

No civilian installation of the Decca Doppler Type 71 system in a helicopter has yet been achieved in Australia. It has been suggested that such an installation would introduce several complications not encountered in fixed-wing applications:

- Stronger and more elaborate mountings for components would be required.
- Greater precessional errors in the gyro-compass would occur as a result of high manoeuvring accelerations of the airframe.
- Greater heading errors in the slaved compass output would occur when rapid turns are made.
- Errors in magnetic compass alignment due to magnetic induction by the rotor blades would occur.
- A larger proportion of the available airframe space would be taken up by the system.

The installation would also involve a considerable amount of calibrating and adjusting both initially and periodically to obtain optimum performance from the system.

Overall assessment

A helicopter-borne Decca Doppler (Type 71) navigation system has not been observed in operation. It could be installed in a helicopter but the installation would appear to be fairly costly. A contract for the supply of a suitably equipped helicopter could take up to 9 months to fulfil.

Operationally, the system would be most useful over flat or undulating terrain, or between mountain ranges, and would be particularly effective for surveys in which operational simplicity requirements outweighed the accuracy requirement. Overall errors would be minimized for helicopter gravity surveys since short-duration looping techniques would be used, and errors in position redistributed by the least-squares method. However, there is insufficient information currently available to predict what the actual positioning errors would be.

4. BMR REQUIREMENTS - COMPARISON OF SYSTEMS

The BMR requirement is for a positioning system which can position a helicopter as it lands at a gravity station to make measurements of gravity and barometric pressure. The positioning accuracy should be better than 50 m, and the operating range of the system should be at least 50 km. Because the system would be used to establish a series of secondary bases from primary ones, systematic errors should be minimal. The system should require as few operators as possible, and the mobile component should be transportable by a piston-engined helicopter together with a gravity observer, gravity meter, and barometers, weighing a total of about 130 kg.

A comparison of the characteristics of the four systems evaluated is shown in Table 1. The feasibility of a helicopter-borne Decca Doppler (digital readout) navigation system is decidedly reduced by its complexity, low accuracy, and probable high maintenance requirements. Another disadvantage is that it has never been used commercially in a helicopter in Australia. The advantage of the system over others is that it is independent of ground instrumentation and does not have a line-of-sight limitation.

The three line-of-sight radio ranging systems assessed are highly accurate, dependable, rugged, and simple to operate, and have all been used successfully in helicopter-borne surveys of a variety of types. The most favourable system is the Decca Trisponder 202A, because it has the least weight, size, and cost. The Motorola RPS system is slightly disadvantaged because of its extra size, weight, and cost, but has a greater range. Both of these systems would produce position data accurate to 20 m or better without any systematic errors, and would operate over distances of at least 80 km. The Cubic Autotape DM-40 system, with its restriction to two ranges, and its greater bulk and cost, would be justified only if 1-2 m accuracy were required. All three systems have ground transponders which are powered by 12-volt storage batteries, and can operate unattended for several days. The transponders and batteries can be placed on hilltops and at trig. stations by helicopter.

The line-of-sight mode of operation of the three radio ranging systems would not be a limiting factor over the greater part of the Australian continent, but in hilly and forrested areas, special measures would have to be taken. This would involve clearing vegetation directly in front of transponders, erecting the transponder on masts, and deploying three or more transponders around hills so that shadow zones are minimal. Another important method to achieve line-of-sight communication would be to hover over a station to be occuppied and obtain a range reading. Even when hovering at a height of 200 m to allow for the curvature of the earth over a distance of 50 km, this would introduce an error of less than 5 m into the horizontal distance measured. Use of the three radio ranging systems would be most cost-effective for surveys involving a high density of stations, as this would give a large number of stations per configuration of transponders, and per transponder battery change.

5. CONCLUSIONS

Of the four radio positioning systems evaluated for use with helicopter gravity surveys;

- The Decca Doppler (Type 71) Navigation System (with gyro/magnetic compass) is considered to be unsuitable for use in a helicopter under the conditions envisaged, and unlikely to give the required accuracy.

- The Decca Trisponder (Model 202A), Motorola RPS, and Cubic Autotape DM40 line-of-sight ranging systems have all been used successfully in helicopter surveys similar to those envisaged, and their ranging accuracy exceeds requirements.

The most cost effective system is considered to be the Decca Trisponder Survey System (Model 202A).

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APPENDIX 1: RESULTS OF EVALUATION TRIALS AND PHOTOGRAPHS OF THE MOTOROLA RANGE POSITIONING SYSTEM (RPS)

Results of trials at Canberra on 30 August 1972

Trials of a 2-range Motorola system were held in Canberra for the Division of National Mapping. Mr T. Davidson of Motorola Aerospace Pty Ltd operated the system between various trig points in the vicinity of Canberra over ranges up to 80 km. The results of the trial, supplied by the Division of National Mapping, are shown in Table 2 and include atmospheric, signal strength, and geoid reduction corrections.

The results show errors up to 7 m after corrections have been applied. The final errors are not proportional to the magnitude of the range measured, and appear to be linked to the amount of signal strength correction. The maximum error in a single raw slope distance measurement can be estimated from the Tennent-Mundoonen trial to be the sum of:

- 22.8 m - atmospherics correction

- 1.0 m - signal strength correction

± 3.0 m - probable range error

- 2.1 m - final error

i.e., about 29 m.

(a) Multiplexer, range console, and printer installed in a helicopter.

(b) Rotating interrogating antenna (360° x 30°) mounted to helicopter undercarriage.

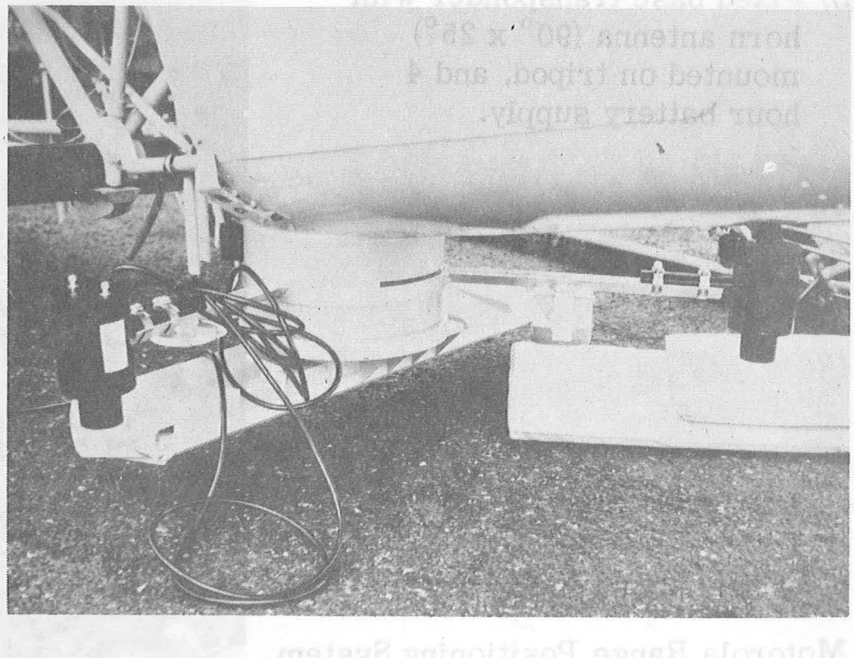


Fig. 1; Motorola Range Positioning System

(a) Rotating antenna interrogating transponders positioned on distant hilltops.

(b) Fixed base transponder with horn antenna (90° x 25°) mounted on tripod, and 4 hour battery supply.

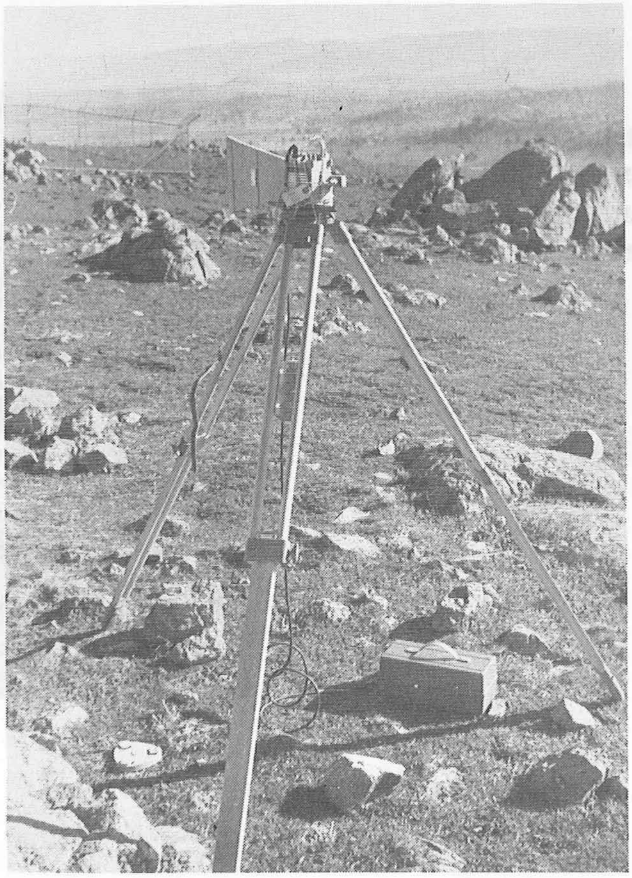


Fig. 2; Motorola Range Positioning System.

APPENDIX 2: RESULTS OF EVALUATION TRIALS AND PHOTOGRAPHS OF THE DECCA TRISPONDER SURVEY SYSTEM (MODEL 202A)

Results of trials at Canberra on 19 September 1972

The Trisponder 202A was tested by Amalgamated Decca Surveys Pty Ltd for BMR in the vicinity of Canberra. A mobile unit and two base transponders were used to measure the line-of-sight slope distances between three trig. stations. The results are tabled below:

Measuring range	Trisponder value(m) (Slope dist.)	Known value (m)* (Slope dist.)	Difference (m)
Tennent-Ainslie	32749 ± 3	32741	8 ± 3
Ainslie-Spring	20683 ± 3	20677	6 ± 3
Tennent-Spring	50742 ± 4	50736	6 ± 4

*Supplied by Division of National Mapping

The mobile unit was transported away from the most distant base transponder, and a distance of over 60 km was measured with both the horn and omnidirectional antennae. Beyond this range, no measurement could be made with either of the antennae. Mr Mollema of Decca Surveys was fairly certain that an internal checking mechanism which had been set at about 65 km was now operating, preventing any larger readouts from appearing.

The Tennent-Spring measurement demonstrates that the actual range capability is over double that officially specified (25 km), and that the maximum error in a single distance measurement is about 11 m.

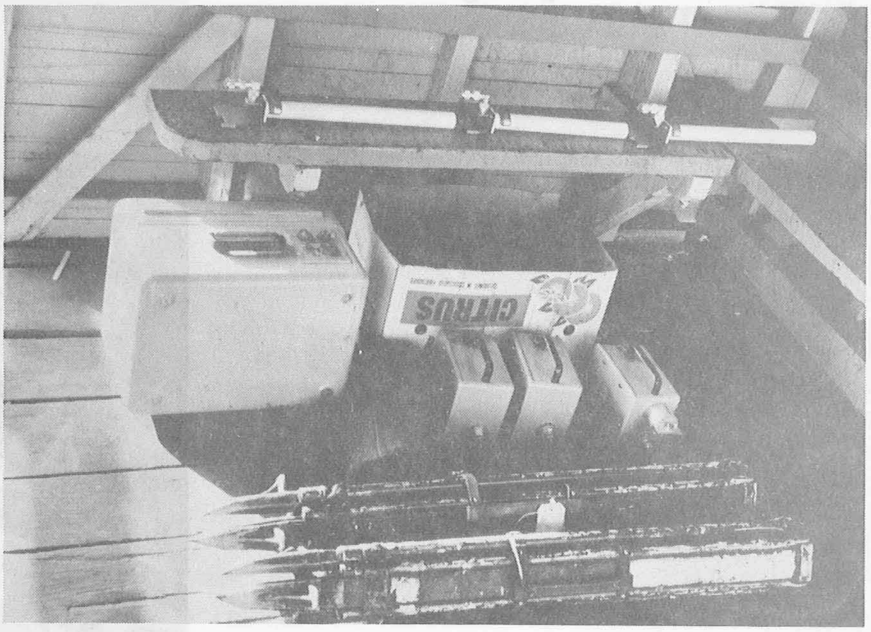
The results of the trial can be summarized as follows:

- The drift in readings is up to 4 m either side of the mean.
- The absolute slope distance accuracy for any single reading for ranges up to 50 km is about 11 m.

- The range capability of the system is at least 60 km with an omnidirectional antenna, and probably up to 80 km with a directional antenna on the master (interrogating) unit.

- A reduced atmospheric propagation error was incurred because the main oscillator frequency of the system is set to give a minimum error over water and this condition applied when measuring between hill tops (well removed from ground effect).

(a) Complete system
(2 ranges)



(b) Mobile (interrogating) unit
showing two ranges displayed simultaneously
(marine application)

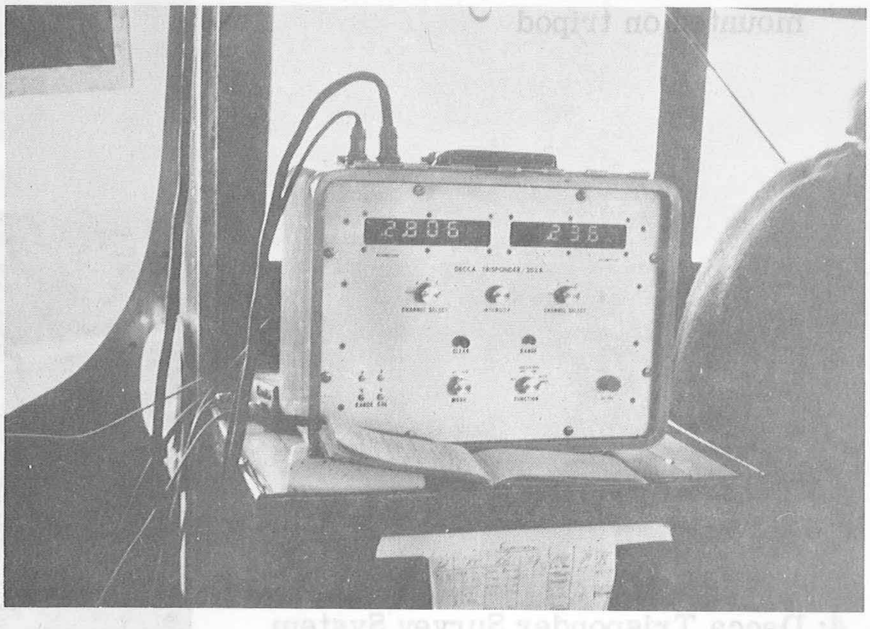
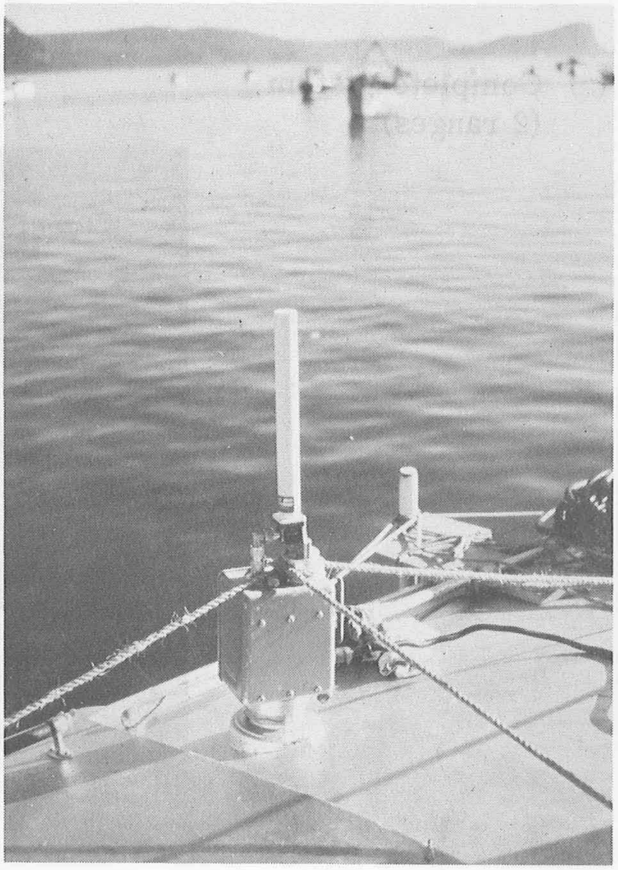


Fig. 3: Decca Trisponder Survey System (Model 202A)

(a) Transponder and omnidirectional antenna (360° x 5°) for the master mobile (interrogating) unit.



(b) Fixed base transponder and directional antenna (87° x 5°) mounted on tripod

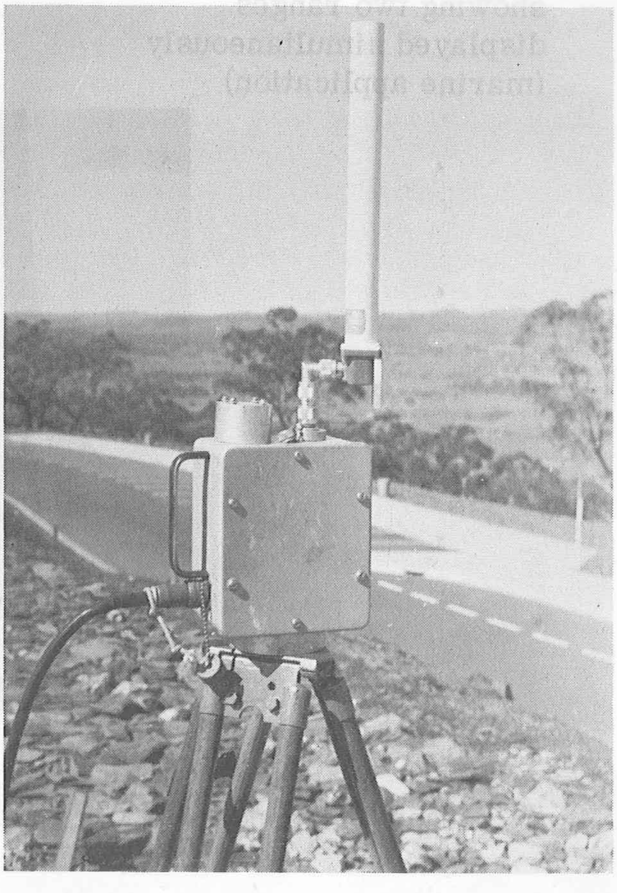


Fig. 4: Decca Trisponder Survey System (Model 202A)

(a) Fixed base transponder and horn antenna ($45^\circ \times 5^\circ$) mounted on tripod

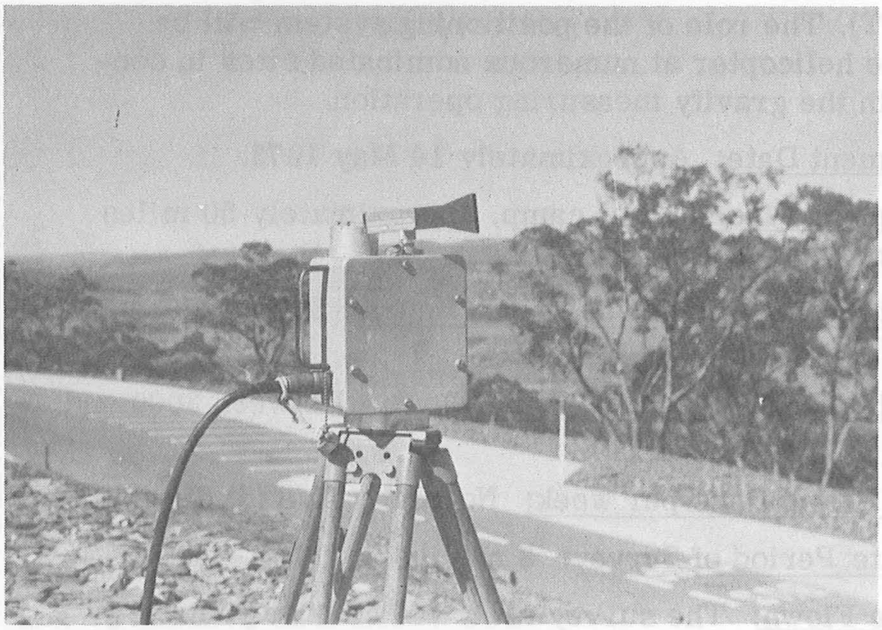


Fig. 5: Decca Trisponder Survey System (Model 202A)

APPENDIX 3: CONTRACT SPECIFICATIONS

HIRE OF HELICOPTER WITH RADIO POSITIONING EQUIPMENT, CENTRAL AUSTRALIA 1973

1. Price Basis: Firm for the duration of the contract.

2. Scope of Requirements: Hire of one helicopter equipped with a suitable radio positioning system for a gravity survey by the Bureau of Mineral Resources (BMR) in the vicinity of Alice Springs, (NT). The role of the positioning system will be to locate the helicopter at numerous nominated sites in conjunction with the gravity measuring operation.

(a) Commencement Date: Approximately 14 May 1973.

(b) Commencement Place: BMR camp, approximately 50 miles east of Alice Springs.

(c) Approximate Total Number of Flying Hours: 500 hours (max.) at a rate of about 40 hours per week.

(d) Approximate Number of Miles to be Flown: Between 3000 and 4000.

(e) Number of Flying Days per week: Normally five (5) days.

(f) Approximate Period of Survey: 3 months.

(g) Areas to be Flown: The survey area will consist primarily of two separate strips, one extending northwards across the Alice Springs sheet, and one extending from the Woodroffe sheet to the Napperby sheet. The survey may include parts of the published 1:250 000 map sheets listed hereunder:

Mount Peake, Barrow Creek, Napperby, Alcoota,

Hermannsburg, Alice Springs, Illogwa Creek,

Lake Amadeus, Henbury, Rodinga, Ayres Rock,

Kulgera, and Woodroffe.

(h) Completion Date: See (f) above.

(i) Completion Place: Such place within the survey areas (see (g)) as is mutually agreed by the party leader and pilot to completion of the survey.

(j) Bases: The survey will be conducted from bases determined by BMR.

(k) BMR Personnel: The proposed survey party shall comprise about 7 BMR personnel (party leader, geophysicist, 3 technical assistants, and 2 field hands).

(l) Accommodation and Camping Equipment: During the helicopter survey BMR personnel will camp at successive operating bases and accommodation will be available in the BMR camps for helicopter crew personnel. All messing and camping equipment shall be provided by BMR.

(m) Engineer: A fully qualified engineer with at least 2 years experience maintaining helicopters of a type equivalent to that proposed in the tender shall be provided by the contractor at the BMR camp.

(n) Pilot: The pilot shall be experienced in bush helicopter flying and shall have completed not less than 500 hours of commercial flying in helicopters.

3. Type of Operation: The objective of the gravity survey will be to cover two continuous strips of ground about 20 kilometres wide with an array of stations on a 2 kilometre grid. The operation will consist mainly of short, low-level flights between stations, and 5-minute landings at stations to permit geophysical instrument readings. The expected rate of progress is between 30 and 40 stations per day for 3-5 days continuously.

Longer flights with few landings shall be required occasionally for reconnaissance or ferrying purposes. When a landing period will exceed ten minutes, the engine will normally be shut off. Flying time for payment purposes shall be calculated on the basis of "engine on" to "engine off".

4. The Radio Positioning System: A radio positioning system is required which is wholly or partly carried by the helicopter, and which can locate the helicopter within an accuracy of 0.05% of the distance to ground control being used. Positional fixes will be required either on the ground or with the helicopter hovering above ground stations, and the positional data should be in the form of digital X-Y co-ordinates or 2 or more channels of digital range values. In the case of ranging type positioning systems, more than 2 ranges are preferred, and a minimum guaranteed range capability of 50 km per channel is essential. The ground stations for such a system should be light and portable, and have a capacity to operate unattended for several days.

4.cont/..

The system should not unduly reduce the remaining payload capacity of the helicopter, nor the free space available within the cockpit. In particular, the overall weight and size should not prohibit the transportation of two BMR personnel, a gravity meter, and three barometers, having a combined weight of 200 kg. The system shall be operated by either the pilot or a BMR officer who shall be instructed in its operation by the Contractor, but the overall responsibility for the proper use of the system and its maintenance will rest with the Contractor.

Evidence should be given of any previous experience by the contractor in the use of the proposed positioning system in similar helicopter applications to that described in Section 3.

Unserviceability of the system will be deemed unserviceability under clauses 14 and 15 at the party leader's discretion.

5. Navigation and Seating Arrangements:

(a) The pilot shall co-operate with the BMR officer on board in navigating by means of the radio positioning system and air photographs. At times the pilot may be required to fly and navigate alone.

(b) Seating arrangements in the helicopter shall be such as to permit a BMR officer to sit close to the pilot to enable them to navigate from the same air photograph, and must be such as to accommodate two persons in addition to the pilot and the radio positioning equipment. The arrangements of the positioning equipment within the helicopter would preferably be such that the pilot and BMR officer are able to observe the positional readout simultaneously.

6. Radio Communication: The helicopter shall be equipped with radio transceivers fitted for communication with all the Department of Civil Aviation Stations appropriate to the area. The transceiver shall be maintained in first class order and be able to maintain constant communication with Department of Civil Aviation bases. The BMR reserves the right to declare the helicopter "unserviceable" if this condition is not maintained. It is desirable in addition that either the helicopter radio be fitted to transmit on a BMR frequency or a BMR radio be able to transmit on a helicopter frequency.

7. Fuel and Oil: BMR shall undertake to purchase and distribute the helicopter fuel and oil free of charge to all points at which it will be subsequently required during the survey. The contractor shall supply the fuel pump and filters

8. Helicopter Maintenance: The contractor shall be responsible for the maintenance of the helicopter in such a way as to cause a minimum of disruption to the survey operation.

9. Messing Arrangements: BMR personnel receive fixed camping allowances and each contributes a certain amount (about $3.00) per day to a party mess account. Bulk purchases of food for the party are made from this account.

The helicopter crew shall contribute to this mess account at the same rate per person as BMR personnel.

Should the helicopter crew personnel require any special foods in addition to that provided they may be pruchased and transported at their own cost, unless sufficient notice is given of such special requirements as to enable the items to be incorporated in the party supplies.

All messing and camping equipment shall be provided by BMR. Crew members shall live under the same conditions as the BMR personnel.

Preparation of Personal Effects and Movement Procedure:

Subject to operation commitments the helicopter crew personnel shall prepare all personal effects, bed rolls, stretchers and tents, ready to load on to trucks when camp is to be moved, and set up their own bed, etc., at the new camp site.

To permit full utilization of the helicopter during the operation helicopter personnel other than the pilot shall travel by BMR or other vehicles between operating bases, if so requested by the party leader.

10. Commencement of Hire: The hiring period shall be deemed to have commenced upon the helicopter being declared "available for flying". If, on the day, a helicopter is not available before 8 am. the BMR reserves the right to refuse to declare the helicopter "available for flying" provided that, in the opinion of the party leader, the late start does not allow efficient utilization of the aircraft on that day.

10.cont/..

The helicopter must be available to commence work on an agreed date within 6 weeks from receipt of order at the nominated commencement place.

11. Certification: The contractor shall be required to provide the aircraft at commencement of the hire airworthy and so certified, properly manned and equipped in accordance with the standard configuration for the type of aircraft as required by the Department of Civil Aviation, and shall so maintain the aircraft for the period of the hire.

12. Orders and Directions: The pilot and engineer operating and maintaining the aircraft shall be and remain at all times the servants of the contractor but shall carry out the orders and directions of the hirer, for the purpose of the hire, which shall not require the contravention of any law or any order or regulation made under the law of the Commonwealth of Australia provided that the pilot shall have the right at all times, having regard to the safety of the aircraft and the passengers, to decide the composition, weights and storage of any cargo to be carried in the aircraft, the suitability of weather conditions for flying and the altitude and speeds of flight, and the locality of any landing.

13. BMR Representative: The BMR shall be represented by the party leader who will give the orders and directions and act as liason officer in all matters concerning the conduct of the survey.

14. Time Out: In each period of fourteen (14) days there shall be a total allowable unserviceability of four (4) days, without penalty calculated in periods of half (½) days, except that if in the party leader's opinion a half (½) days work cannot be fruitfully performed following unserviceability, the period shall be calculated as one (1) day.

The allowable period of four (4) days for unserviceability is to include time required for normal service maintenance and routine component changes.

Except in unusual circumstances there will be no flying on Saturday or Sunday of each week (i.e., 4 days in each 14 day period), and the contractor is required to undertake maintenance on those days. The contractor must agree that when an "unusual

14.cont/...

circumstance" is declared by the party leader other days in each week will be taken for maintenance purposes, and the start of such days shall coincide (as far as deemed practicable by the helicopter personnel) with the cessation of flying from any one base.

15. Penalty: When the aircraft is unserviceable because of unavailability of aircrew, repairable mechanical failure of the aircraft, or repairable damage due to accident, the contractor shall use his best endeavours to rectify the situation in order to meet the hirer's requirements, supplying replacement aircraft if necessary.

If the replacement or repair period exceeds ten days (including the four days allowed unserviceability), the contractor, subject to the discretion of the hirer, shall be liable to a penalty of $200 per day for each additional day's unserviceability.

16. Daily Inspection: Daily inspection of the helicopter shall be carried out before the first and after the last flight of the day.

17. Aircraft Logs: The contractor shall maintain a log, a copy of which shall be available to the hirer.

18. Insurance and Indemnity: The contractor shall keep the aircraft insured at all times during the period of charter under all insurance policies in force at the commencing date of the charter and shall furnish particulars of all such policies and upon request produce them to the Commonwealth for examination.

The Commonwealth, its officers, employees and agents shall be entitled to all protection afforded by such policies and the contractor shall not do, or permit or suffer to be done, anything, whereby the policy or policies of insurance may become void or voidable, and shall ensure that any necessary endorsements are made on the policies to cover the operations under this contract.

The contractor shall indemnify the Commonwealth, its officers, employees and agents against any claims by any person in respect of:

a. loss or damage to the aircraft

b. loss or damage to property caused by the aircraft during the period of the charter, and

c. personal injury or death arising out of the operation

18.cont/...

of the aircraft during the period of the charter of any persons other than officers, employees and agents of the Commonwealth.

The contractor shall take out a policy of insurance to cover his obligations as above and shall ensure that all rights of subrogations against the Commonwealth are waived.

19. Assignment: During the period of the contract the helicopter shall be used only by the BMR. The benefit of the hire shall not be assigned to any other person by either the BMR or the contractor, nor any sub-contract entered into by the contractor during the period of the contract.

20. Right to Refuse Passengers or Cargo: The pilot shall have the right to refuse to carry any passengers or cargo which might endanger the safety of the aircraft.

21. Curtailment of Sortie: If during the course of any sortie it becomes apparent that insufficient daylight remains to complete it the pilot shall consult with the senior BMR officer present of any alternative method of completing as much work as is practicable. If the pilot insists on reducing the time by other than the method preferred by that officer he shall submit a written explanation on his return to base.

22. Search and Rescue: The contractor shall initiate action for search and rescue should such be necessary. Costs incurred shall be shared as follows:

Search and Rescue of Personnel: Pro rata to the number of the hirer's and contractor's personnel.

Salvage and Recovery of Helicopter: To be the contractor's responsibility.

The aircraft must carry survival rations. All persons on board must be equipped with a water bottle, and footwear and headgear appropriate for use in desert conditions.

23. Payments: If desired, claims for payment may be submitted at the conclusion of each 14 day period.

24. Conclusion: When the survey is nearing completion the party leader shall keep the pilot informed and shall notify him, as an agent of the contractor, at least two (2) days in advance the data on which the contract will conclude.

Should the contract not be completed within 3 months the hirer and the contractor, by mutual consent, may agree to extend the contract under the same conditions to enable the project to be completed.

ATTACHMENT "A"

Particulars concerning the helicopter, crew, and radio positioning system are to be supplied.

A. HELICOPTER PERSONNEL: State the composition and experience of crew for the helicopter offered.

B. HELICOPTER PERFORMANCE AND REQUIREMENTS: Particulars of the performance of the helicopter. A minimum performance at 32°C air temp. and 600 m pressure altitude in still air is to be guaranteed.

1. Type of helicopter offered
2. Number of passenger seats and arrangement with respect to pilot:
3. Rated engine horsepower:
4. Horsepower available for take-off under conditions outlined in introductory paragraph:
5. Cruising speed:
6. Average effective fuel consumption:
7. Set weight (empty helicopter plus pilot, emergency rations, radio, oil, and misc. fittings):
8. All-up weight of helicopter:
9. Gross pay load:
10. Fuel capacity carrying 1 passenger (80 kg), + 50 kg of equipment:
    a. Main tank;
    b. Jerry cans carried by helicopter;
    c. Auxillary tanks attached to helicopter:
11. Fuel capacity carrying 2 passengers (80 kg ea.) + 50 kg of equipment:
    a. Main tank;
    b. Jerry cans carried by helicopter;
    c. Auxillary tanks attached to helicopter:

ATTACHMENT "A" cont/..

12. Total endurance of helicopter making landings under:
    a. Conditions 10 (Maximum requirement 5 hrs approx);
    b. Conditions 11 (Maximum requirement 4 hrs approx):

13. Endurance to be kept in reserve for operations in areas where ground access is:
    a. relatively easy;
    b. difficult or impossible:

14. Minimum area for landing and take-off under full load, assuming limits of area determined by large trees (6 m high):

15. Flying hours between any serviceing:

16. Flying hours between serviceing requiring attention of engineer:

17. Maximum days between inspection or serviceing by engineer, assuming flying hours less than specified in 16:

18. What time allowance must be made in day's planning for:
    a. each refuelling;
    b. maintenance of helicopter including cleaning of spark plugs;
    c. pilot's meals:

19. Total aviation fuel and oil requirements for the survey:

20. Equipment other than camping to be supplied by Bureau at main camp:

21. Equipment to be supplied by BMR at refuelling points other than main camp (contractor to supply fuel pump and filters):

22. Weight of equipment that must be transported between camps by helicopter and not BMR trucks:

23. Weight of equipment to be transported between camp sites by ground vehicle:

24. Life saving equipment to be carried by the helicopter:

C. HELICOPTER CREW:

1. Will it be necessary for BMR to provide accommodation and food for helicopter personnel:

2. For how many:

ATTACHMENT "A" cont/..

C. HELICOPTER CREW (cont/..)

3. Are the helicopter personnel prepared to live under conditions identical to all members of the BMR party:

4. Will the helicopter engineer, and on non-flying days the pilot, be prepared to assist in breaking, moving, and setting up camp the same as BMR staff, including, if necessary, the driving of a vehicle from one site to the next:

5. Whether the contractor's personnel will give every possible assistance to the BMR survey party in order that the continuity of the survey party may be maintained should sickness or resignation cause a temporary reduction in BMR staff:

6. What truck loading would be required by the contractor's personnel:

Additional Data

1. Any conditions regarding "Time out" which the owner would like to improve (see Attachment "A" para. 11):

2. What is the maximum number of hours a pilot is permitted to fly:

   a. per day;
   b. per week;
   c. per month:

3. Number of consecutive days on which pilot is permitted to fly:

4. Charges applicable to substitute helicopters:

D. RADIO POSITIONING SYSTEM PARTICULARS:

1. Type of system offered:

2. Range capability:

3. Accuracy achievable under the conditions specified in section 3:

4. Number of major components in the system and the size and weight of each:

5. Manner of deployment of the components of the system when operating, and the operating method:

ATTACHMENT "A" cont/..

D. RADIO POSITIONING SYSTEM PARTICULARS (cont/..)

6. Power requirements of the system and power consumption rates:
7. Performance rating of the system (hours before failure):
8. Serviceability of the system and availability of spares and service:
9. Limitations of the system in general likely to affect its performance under the survey conditions specified:
10. Approximate time necessary to effect the installation of the helicopter-borne components of the system into the helicopter in the first instance:
11. Approximate time to transfer the installation into another helicopter at the survey locations stated in section 2:
12. Availability of replacement parts of the system at the survey location stated in section 2:
13. Method of assessing the accuracy and performance ratings stated in 2 and 7 above, and examples (if any) of previous use in helicopters:
14. Availability of experienced technical service staff to visit the survey party if necessary to effect repairs.

TABLE 1. COMPARISON OF RADIO POSITIONING SYSTEMS

System	Operational characteristics	Maximum range (km)	Instrumental positioning accuracy	Equipment weight	Estimated cost ($Aust)
Cubic Autotape DM-40	Microwave frequency line-of-sight range measurement, two ranges only	100	.001% error	130 kg	$75 800 $9000 per month rent
Motorola RPS	Radar frequency line-of-sight range measurement, up to 5 ranges	160	3 m or .003% error	120 kg (2-range system)	$50 000 - $80 000 $6900 per month rent (2-range)
Decca Trisponder 202A	Radar frequency line-of-sight range measurement, up to 4 ranges	80	3 m or .003% error	150 kg (4-range system)	$40 000 $3600 per month rent (3-range)
Decca Doppler Type 71 (with gyro/magnetic compass)	Doppler principle Velocity integrator		2% error (estimated)	35 kg	$50 000 - $60 000

TABLE 2. RESULTS FROM TRIALS OF THE MOTOROLA RANGE POSITIONING SYSTEM (RPS)

Mean range reading	Slope corrn	Sea level reduction	Atmospherics corrn	Signal Strength corrn	Observed distance	True distance	Error (metres)
STROMLO to YARROW							
31688.0	-1.41	-1.41	- 9.14	-3.82	31669.0	31672.6	-3.2
31682.7	-1.41	-4.63	- 9.14	+3.6	31671.1	31672.6	-1.1
STROMLO to AINSLIE							
14383.7	-0.13	-1.84	- 4.34	+3.0	14387.4	14387.3	-6.8
14395.2	-0.13	-1.84	- 4.34	-6.2	14382.7	14382.7	-4.5
TENNENT to MUNDOONEN							
80129.3	-2.0	-13.8	- 22.8	-1.0	80089.7	80092.4	-2.1
TENNENT to SPRING							
50746.7	-2.43	-9.0	- 14.4	+4.7	50725.6	50725.2	+ .08