HeliGrav^{TM} helicopter long-line transported ground gravity versus traditional ground gravity acquisition – survey efficiency and results from an Australian regional survey

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SUMMARY

A combination of HeliGrav^{tm}, helicopter and vehicle supported land gravity was utilised on a large regional gravity survey in Western Australia. The survey was conducted during the summer with 4 by 4 km stations, in-filled in places with 2 by 2 km points under difficult environmental and logistical conditions. Access to the survey area was varied, but mostly difficult. The most inaccessible area was surveyed via the use of the HeliGrav^{tm} system. All of the methods performed well as evidenced by the repeatability of the data, which exceeded the survey specifications. It was the combination of all of the different techniques which allowed for the high success in obtaining the planned stations, and which improved on operational efficiencies. Operational efficiencies were further improved by using the ground crews to cache fuel and move the GPS base stations for the aircrew.

This was the first time that HeliGrav^{tm} has been used in the hot and arid conditions of Australia. With the use of a suitable helicopter and starting survey operations at dawn, the effects of the high temperatures were mostly mitigated.

INTRODUCTION

Scintrex Pty. Ltd. was contracted to undertake a large regional gravity survey in late 1998, early 1999 for the Australian Geological Survey Organisation (AGSO). The survey of 5,700 gravity stations was located over the area known as the Southern Eastern Goldfields. Surveying involved the measurement of gravity and positioning data on a grid of 4 kilometres and infilled at 2 kilometres within selected areas, and the establishment of a network of permanently monumented gravity stations referenced to the Australian Fundamental Network datum.

A combination of Scintrex's newly developed HeliGrav^{tm} helicopter long-line transported land gravity system, and conventional helicopter, vehicle and 4-wheeler supported ground gravity readings were used to collect the data. All conventional methods utilised the Scintrex CG-3 or CG-3M gravity meters and NovAtel GPS system, while the HeliGrav^{tm} system is based on the Scintrex CG-3 sensor and Ashtech Z-Surveyor GPS systems. HeliGrav^{tm} surveying was conducted over most of the Boorabbin sheet due to very poor access using conventional ground and helicopter techniques. With the combination of all of these methods, all of the planned HeliGrav^{tm} points and more than 99% of the planned stations were successfully surveyed.

SURVEY AREA AND CONDITIONS

The survey covers the Norseman, Widgiemooltha and Boorabbin 1:250,000 scale map sheets, over which AGSO had previously established gravity stations at approximately 11 x 11 km. Access to the survey area is limited with paved access to the north via the Great Eastern Highway and in the centre via the highway between Kalgoorlie and Gibson. A limited number of unpaved roads and dirt tracks transect the survey area.

The area of most difficult access was the Boorabbin sheet. Ground survey crews were able to obtain less than five stations per day in this region due to limited access and thicker vegetation. The HeliGrav^{tm} system was used as the primary data acquisition tool on this sheet as the system has been designed for difficult access areas.

The technical specifications included an accuracy of 0.05 mGals, and 0.1 metres for the gravity and vertical positioning. The survey was conducted during the Australian summer and daytime temperatures often exceeded 40^{o} C. This caused difficulties for the crew and for helicopter operations due to the degradation of the lifting capacity of the helicopters. The large distances between survey points also imposed logistical restrictions in terms of data collection and survey efficiency. Frequent GPS base station moves and changes in the base of operations were the norm.

THE HELIGRAV^{TM} HELICOPTER LONG-LINE LAND GRAVITY SYSTEM

The HeliGrav^{tm} system consists of a gravimeter sensor suspended in a dual gimbal system. The gravimeter and gimbals are leveled by servomotors operated by signals from internal electronic levels and can accommodate tilts of up to 30° from the horizontal. The gravimeter is the Scintrex CG-3 land gravimeter, which utilises an extremely rugged quartz element sensor capable of withstanding shocks of up to 25**g** without damage, and without offsets greater than 0.02 mGals. It also has no need for clamping between readings, and is compatible with helicopter vibrations in transport. A GPS antenna is mounted on the gravimeter package termed the HeliGrav^{tm} pod, which is attached to the helicopter via a 50 metre cable, for towing and communication.

In or on the helicopter are the system control and data acquisition electronic package, a second GPS antenna and a radar altimeter. Real time differential GPS is used to provide the accuracy required to navigate to the survey points, and particularly, to navigate back to repeat points. Post flight differential GPS is used to obtain the positional accuracy of ±0.1 metre in elevation.

Figure 1: The gravity system in Australia showing the pod, tow cable and helicopter.

Under guidance from the navigation system, the helicopter arrives at the location of the gravity station and seeks out the nearest suitable site for the station, i.e., an opening in the trees, as free of local topographic irregularities as possible. The pilot then gently lowers the gravimeter package to the ground. Once the gravimeter is on the ground, the pilot drops another 10 m or so in elevation and moves slightly to one side, so that about 8 m of cable lies on the ground, thus effectively decoupling the gravimeter from the vibrations and down-wash of the helicopter. While the leveling and reading process is underway, the helicopter hovers.

A secondary positioning method is used in areas of thicker vegetation, which may interfere with the GPS on the HeliGrav^{tm} pod. At the moments of landing and take-off, the pod and helicopter are separated by a taut, vertical cable of known length, so that the relative coordinates of the helicopter and the gravimeter are accurately known.

THE PHYSICAL SURVEY

Surveying of the primary base station network initially began on September 4th, 1998 utilising one vehicle and two personnel. This was then increased to two vehicles and four personnel due to slow production caused by difficult access. Land gravity surveying then began from Coolgardie on September 26th utilising two field vehicles. Approximately one month later, a Kawasaki KH-4 helicopter was added the survey crew, replacing one of the field vehicle crew. Later, a Bell 206B helicopter was added to the survey crew for about one month as the high temperatures degraded the performance of the KH-4 to the point where its hours of operation were curtailed.

After the Christmas break, surveying resumed based in Kambalda using two vehicles and the 4-wheel motorcycle, until January 12th. Helicopter surveying then began utilising two pilots and a 10 hour day, with up to two vehicles making field observations.

The predominant mode of surveying utilised helicopters due to the remoteness and lack of access of parts of the survey area. In all, less than 1% of intended helicopter (excluding HeliGrav^{tm}) reading locations were abandoned due to lack of access, which was a tribute to both the skill and experience of all pilots used on the survey. Surveying on the Norseman and southern half of Widgiemooltha 1:250,000 sheets involved landing at sites, which were situated amongst tall trees, providing additional risk and difficulty for helicopter survey crews. A total of 2976 (52%) stations were observed using both helicopters.

The utilisation of 2 pilots over a 10 hour day increased the utilisation of the helicopter and crew. In order to avoid the heat of the day, the 10 hours was separated into a 6 hour session starting at dawn and a shorter afternoon session ending before sunset. This technique produced production rates of anywhere between 50 and 70 stations per field day, dependent upon the difficulty of landing and location of refueling sites.

Surveying with vehicles provided a lower cost alternative to the use of helicopters. In areas where roads and tracks existed, or where vegetation was sparse, vehicles provided an easier and more effective method of transportation, although acquisition rates of single vehicles did not exceed that of the helicopter. Using a combination of 2 vehicles was very productive and gave variable station acquisition rates of between 30 and 45 readings per day. The vehicle survey crews were also responsible for the fuel caching and base GPS movements of the helicopter crews, decreasing the helicopter hours. Vehicle stations were generally limited to those located on or within 1 km of tracks, as marked on the AUSLIG 1:100 000 map sheets. A total of 1594 (28%) stations were observed. This represents a significant number considering the lack of access in most of the survey area.

Surveying on the 4-wheel motorcycle was used for the salt lakes and proved almost as productive as using the helicopters. Unfortunately, the number of stations situated on the salt lakes was limited and one, Lake Cowan, was too soft to work on. A total of 142 (2%) stations were observed on salt lakes using the motorcycle.

At the beginning of the HeliGrav^{tm} survey, with the availability of a less expensive KH-4 helicopter, the GPS base station locations were surveyed in advance. The HeliGrav^{tm} crew mobilised to the survey site in November 1998 using Coolgardie as the base of operations. A 50 metre cable was used to tow the HeliGrav^{tm} module and to communicate with it. During the first production flight, the pilot damaged the HeliGrav^{tm} unit on the third station. Review of the video record mounted on the helicopter showed that the pilot could not control the pod during landings and the damage arose from the pod hitting a tree and then tumbling to the ground.

After the Christmas break an experienced Canadian helicopter pilot was sent to Australia to conduct survey operations using a Bell 206B from a different helicopter charter company. The second and much more experienced pilot had no problems in controlling the pod and in landing and take-off of the pod.

During the operations, the high ambient temperatures were not of a significant factor as the helicopter had the lifting power available for the survey. Also, the crew's practice of commencing daily operations at day break when the temperature was cooler helped to minimise the periods when operations had to be suspended due to high temperatures.

The HeliGrav^{tm} crew was supported by ground crews who cached helicopter fuel and wherever possible, moved the GPS base stations. During the course of the survey, as the stations close to the survey base, Coolgardie, were surveyed, the helicopter was left in the field to minimise the ferry time. The aircrew drove back and forth every day.

HeliGrav^{tm} operations, being relative expensive, was limited to the areas of the Boorabbin sheet where access by conventional ground and helicopter supported methods was difficult. Due to the system's unique design of being able to take measurements from a helicopter without landing, no planned station was abandoned. In addition, the ability of the pilot to place the pod into very small spaces meant that the deviation from the planned survey positions could be much less than the same deviations recorded with the other systems.

However, as demonstrated by previous experience, a highly skilled pilot is required for this operation. The lack of trained pilots meant that it was difficult to use a two pilot operation. Consequently, due primarily to flight time restrictions, the overall production rate of the system was lower than expected, in the 25 to 30 readings per day range. Under production conditions, approximately 8 to 9 readings per hour could be achieved. However, this rate could not be sustained for long due to flight hour. A total of 995 stations were obtained by HeliGrav^{tm} operations.

REPEAT STATIONS

In order to demonstrate the repeatability and reliability of data, it was part of the contract to repeat selected stations placed strategically in both time and location within and between survey loops. For the conventional methods, each repeat station was clearly marked with survey flagging, along with the location of the GPS antenna and gravity reading point to ensure that repeatable data was obtained.

In HeliGrav^{tm} operations, landing the helicopter to tie flagging or place pickets to mark the repeat stations is not feasible at most station locations due to the tall vegetation. Instead, 2 kg bags of wheat flour in their original paper bags were dropped from the helicopter at a height of about 70 metres above ground onto the repeat survey sites. The white flour was easily seen by the pilot who also must have the piloting skills to land the HeliGrav^{tm} pod onto the spot marked by the flour. The process is captured on video tape for verification.

Statistic	***Latitude***	***Longitude***	***height (m)***
Standard deviation	0.000005	0.000009	0.042
Median	0.000000	0.000000	0.001
mode	0.000000	0.000000	0.000
Minimum	-0.000019	-0.000138	-0.096
Maximum	0.000052	0.000051	0.098
Coordinates - WGS84			

Table 1: Statistics of GPS and gravity data observed at repeat stations for conventional surveys.

Table 1 gives the statistical results of tests for the differences measured at repeat stations for conventional surveys. These values are based on the difference as measured between each successive occupation of a station. Some stations have been repeated several times, while others only once. The statistics show that the standard deviation of errors measured in ellipsoidal height is 4cm with maximum and minimum values less than the 0.10m precision required. Height is the most critical value for GPS surveying, and is also of the lowest accuracy. In general, all such heights showed errors at repeat stations of less than 0.10m with only several just outside this range .

Similar to the GPS data, a table of statistics was compiled for the differences measured in observed gravity at repeat points. This table shows that precision throughout the survey was high and exceeded the specifications of the contract.

Statistic	*Observed Gravity (mgal)*
Standard deviation	0.018
Median	0.000
Mode	-0.008
Minimum	-0.072
Maximum	0.054

Table 2: Statistics of differences in observed gravity at repeat stations for conventional surveys.

SURVEY METHOD PRECISION

An analysis of the relative precision and accuracy of each individual survey technique shows general consistency between methods and gives results very similar to those outlined above for all repeat readings. The following table lists the standard deviation in the differences measured in ellipsoidal height (m) and observed gravity (mGal) for the individual survey methods and the total number of repeat readings made for each method.

Method	*Elevation (m)*	*Observed Grav. (mgal)*	*Number*
Helicopter	0.044	0.017	180
Vehicle	0.041	0.020	260
Motorcycle	0.045	0.012	21
All (incl. b/s)	0.042	0.018	502
HeliGrav^{tm}	0.238	0.044	36

Table 3: Standard deviation of individual traditional survey techniques

It should be pointed out that the method for marking and obtaining HeliGrav^{tm} stations causes the repeatability of the method to decrease. The repeat stations are inevitably in a slightly different spot. Repeat points were sometimes as much as four metres form the original point, although most were with two metres. The repeatability between HeliGrav^{tm} and conventional surveys is a better indication of the reliability of the system.

INTEGRATION OF HELIGRAV^{TM} & CONVENTIONAL SURVEY DATA

In order to demonstrate consistency and compatibility between data acquired using the HeliGrav^{tm} system and conventional helicopter techniques, several stations were observed with each system.

The stations were initially occupied using the HeliGrav^{tm} system, with the approximate position of the HeliGrav^{tm} pod being marked on the ground with flour. Each station was then re-observed using the KH-4 helicopter, with the GPS sensor positioned as close as possible to the flour mark and the gravity reading taken immediately adjacent. For this to occur, it was necessary for the KH-4 pilot to lift off so that the gravity reading could be taken safely on the flour mark.

STATION	LAT. (decimal degrees)	LONG. (decimal degrees)	ELEV. (metres)	BOUGUER (mgal)
1537	-	-	-	0.027
1539	-0.000020	0.000006	-0.127	0.027
1540	-0.000003	0.000009	-0.009	0.038
1542	-0.000006	0.000009	-0.099	0.001
1543	0.000003	0.000010	-0.040	0.014

Table 4: Comparison of data measured by the HeliGrav^{tm} and conventional survey techniques

Table 4 presents the differences measured at the repeat stations for each system, in WGS84 latitude and longitude, ellipsoidal elevation, and Bouguer Gravity value. A total of 9 stations were marked by the HeliGrav^{tm} crew for repeating, but of these, only 5 could be landed at safely with the KH-4. The GPS sensor could not be positioned within 20m of the flour mark at Station 1537 and was off by several metres at Station 1539. At both stations, the gravity reading was taken right over the mark left by the HeliGrav^{tm} pod. All other stations taken at the correct location show repeatability within contract specifications, without the need for any type of network correction between the two systems. This result is particularly significant given the difference in field procedures and data processing techniques.

CONCLUSIONS:

Under difficult conditions, a large regional gravity survey was successfully conducted in Western Australia using a combination of HeliGrav^{tm}, and traditional helicopter, and multiple vehicle supported land gravity.

The HeliGrav^{tm} system proved to be capable of conducting a regional survey under desert or arid conditions. Using a larger helicopter (a Bell 206 versus the traditional R-44), commencing operations at dawn and having good ground support were factors in the success of the operation.

A combination of helicopter or HeliGrav^{tm} operations along with a ground support crew capable of obtaining gravity readings when ever possible seems to be the most efficient method of utilising helicopters.

The method of dropping bags of flour appears to be a satisfactory method of marking repeat stations with very low environmental impact. The repeatability between HeliGrav^{tm} and traditional ground methods is confirmation that the system can collect gravity data to the accuracy of traditional ground methods without having to land. The fact that several of the stations marked for repeats between the two techniques could not be accessed by the helicopter crew attests to the ability of HeliGrav^{tm} to obtain land gravity readings where other methods can not access.

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