DRAPE SURFACES FOR AERO-MAGNETIC SURVEYS

1. INTRODUCCION

A drape surface is generated to maintain a constant altitude above ground level when recording aero-geophysical data. The generation of a digital drape surface is one of the most important tasks when planning an airborne geophysical survey. This becomes crucial for aeromagnetic surveys, where tie lines need to intersect traverse lines at the same height above ground. When flying over rugged terrain, maintaining a constant terrain clearance becomes a difficult task.

Security issues also have to be observed. The client wants to fly as close to the ground as safely possible. The surveyor is as responsible for pilot and equipment safety as for the quality of data acquisition.

Regional areas are usually surveyed using a fixed-wing aircraft, covering large areas in a short period of time. The climb/descend capabilities of a fixed-wing aircraft are limited to a small range of angles, usually between 5° to 8°, depending of the type of aircraft. For this reason, there is a need for an accurate software tool to plan a safe flight path, thus avoiding the situation where the pilot is forced to make quick and potentially unsafe decisions while in the air.

The purpose of this paper is 1) to present an algorithm and software interface that generates a drape surface for an airborne geophysical survey employing available DEM data; 2) to describe how a drape surface guides the pilot through a safe flight path; and 3) to satisfy the aero-magnetic survey specifications by employing a well designed drape surface.

2. DIFFERENT APPROACHES WHEN PLANNING AN AIRBORNE GEOPHYSICAL MAGNETIC SURVEY

An airborne geophysical magnetic survey is one of the first phases of a geological exploration project. The airborne system is designed to acquire the magnetic field signature of the earth as well as other geophysical signals, depending on the application. To successfully design and complete the survey, the following factors have to be taken into account.

- Geological targets

  Large areas are usually surveyed to identify geological targets in a short period of time. The selection of the line direction depends on the magnetic inclination in the survey area as well as position of the targets. The survey is designed to perpendicularly intersect geological targets. When acquiring data from a single magnetic sensor, traverse lines are flown at line spacing not exceeding twice the flight height. Tie lines are mostly flown perpendicular to traverse lines at five times traverse lines spacing. Reid (1980) and Coyle et. al (2014) provide details about aeromagnetic survey design including the interaction between flight height, line spacing and other useful information.

The study area presented in this paper was surveyed in 2004 by McPhar Geosurveys Ltd. in the state of Alaska for the United State Geological Survey (Saltus and Milicevic, 2004). The survey area occupies the Taylor Mountains quadrangle and a portion of the adjoining Bethel quadrangle in southwest Alaska. An overview of the survey location is presented in Figure 1.

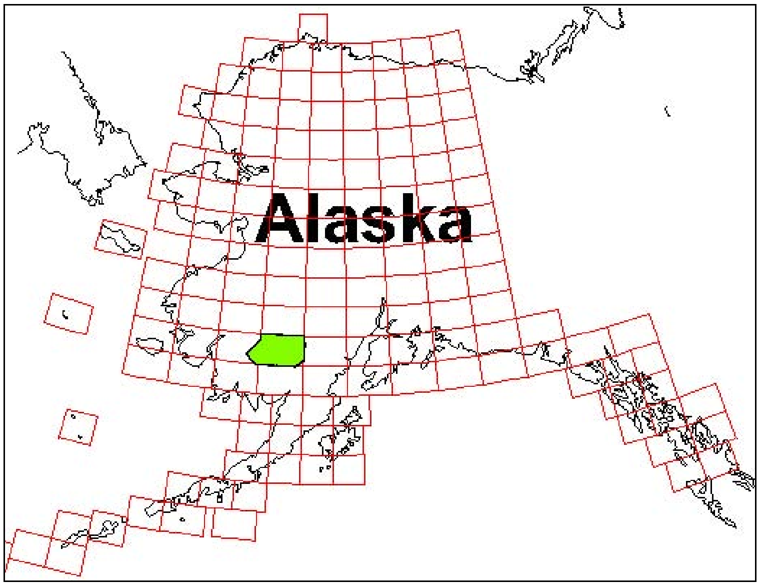

Figure 1 – Overview of the study area (green) with coast lines (black), and Alaska 1:250,000 quadrangle boundaries (red); figure taken from Saltus and Milicevic (2004)

Survey specifications are as follow,

Traverse line spacing:	1 mile = 1,600 metres
Traverse line direction:	N135°E
Tie line spacing:	8 miles = 12,872 metres
Tie line direction:	N55°E
Terrain clearance:	1,000 ft = 305 m
Total coverage:	8,971 line-miles = 14,353 line-km
Average sampling interval:	20 feet = 6 m

The aircraft employed was a Cessna C207. More details and description of the acquisition equipment and data processing techniques applied during this survey is available in the report provided by Milicevic, 2004. Survey data results can be downloaded from Saltus and Milicevic (2004).

- Digital Elevation Model (DEM)

  During the survey design, the accuracy of the digital elevation model is crucial for the quality of the drape surface to be generated.

  Today's web-mapping-services (WMS) provide accurate DEMs in a short period of time. WMS also allow compiling additional data providing the possibility of overlapping and comparing several layers of information valuable to the survey. For the purpose of planning the survey presented in this paper, the DEM was obtained from the USGS site available for download as December 2003[1], when the survey was designed. Currently, data can be accessed from a variety of sources (SRTM[2], ALOS PALSAR[3], etc), from where DEM images can be processed in the cloud or desktop at user convenience. The software presented in this paper works as a desktop application.

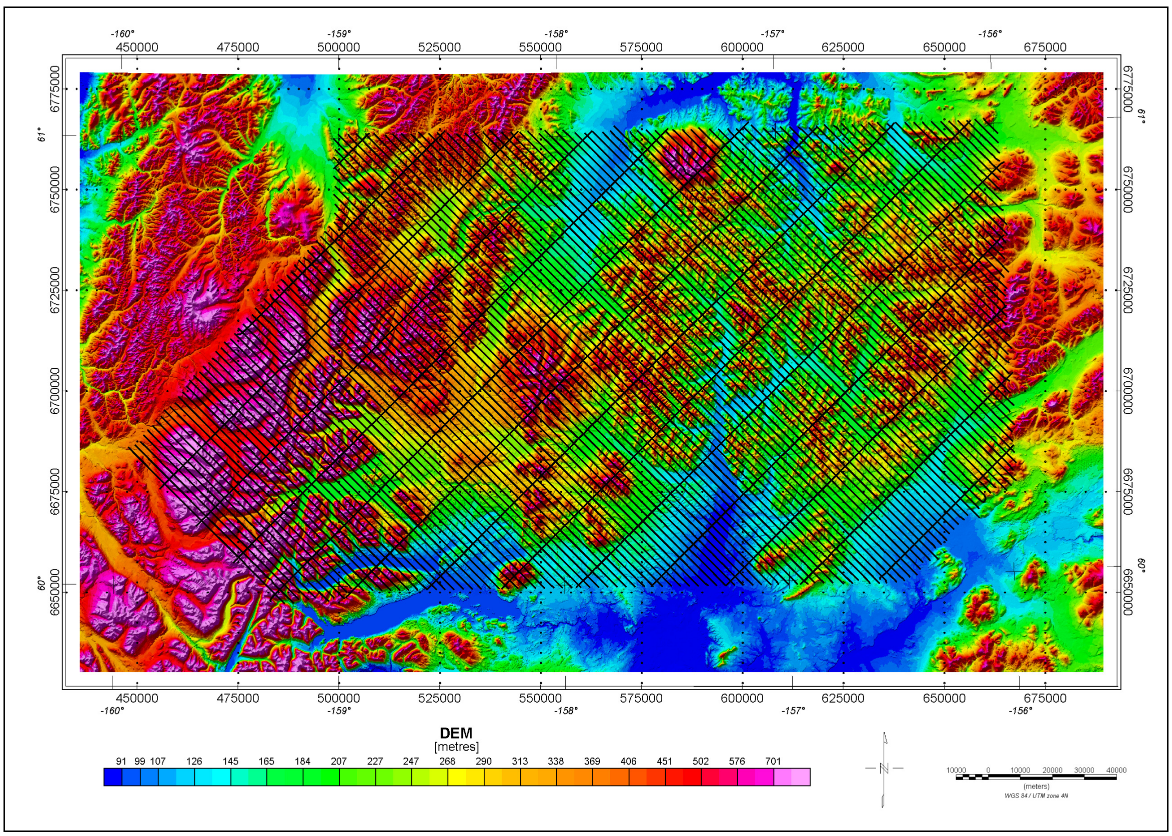

Figure 2 - Flight path plan of the survey area over Digital Elevation Model

[1] http://seamless.usgs.gov/viewer.htm
[2] https://www.earthdata.nasa.gov/sensors/srtm
[3] https://search.asf.alaska.edu/

A window of the DEM is extracted to match the survey area with an extension of about 500 metres to 10 kilometres, depending on the topography. This allows the aircraft to turn around between the end of a flight line and the beginning of the next one, in a safely manner.

For a 1,600 metres traverse line spacing survey, a grid cell size of 400 metres provides an acceptable spatial resolution; representing a quarter of the survey line spacing. Available data for download at 2 arc-sec, approximately 60 meters, satisfies planning requirements. Data is projected above the ellipsoid in the world geodetic system (WGS84).

The DEM presented in this paper illustrates a common situation for surveying a rugged terrain, as shown in Figure 2. Highest elevations (warm colour) are observed in the western part of the area, with maximum values of 1,574 metres above sea level (ASL). Minimum values (cold colour) are observed in rivers and creeks at 150-180 meters ASL which intersect the area in several directions.

- Navigation system

Positioning errors arise from the inability to navigate and record the sensor position with absolute precision. Today's global positioning system (GPS) navigation module can provide a differentially corrected position accurate to within about 3 meters in horizontal position and 15 metres in vertical position (Denham and Gunn, 1997). Differential GPS navigation has decreased location related errors to less than 2 nanoTesla (Grauch and Millegan 1998).

- Terrain clearance

To successfully level magnetic data, traverse lines and tie lines must be flown at the same altitude at point of intersection. This condition defines a constant terrain clearance, with a minimum range of variation. When this requirement is not fulfill, the surveyor must re-fly lines or portion of lines, increasing the survey cost.

Special considerations are required in rugged terrain, where drastic variations in elevation may exceed the climb/descend capability of the aircraft.

For the survey presented in this paper, the specified terrain clearance is 300 metres with a tolerance of ± 60 metres from an ideal drape surface over a 1000 metres distance, with the usual exceptions made for rugged terrain, regulatory compliance from the Federal Aviation Administration (FAA) and/or aircraft safety considerations.

A zoomed view in the south-west part of the survey area is shown in Figure 3 highlighting rugged topography in one of the survey lines. For about ten kilometres (white arrow), the aircraft suppose to manoeuvre a terrain change of 1,008 metres when flying over high and low topographic features.

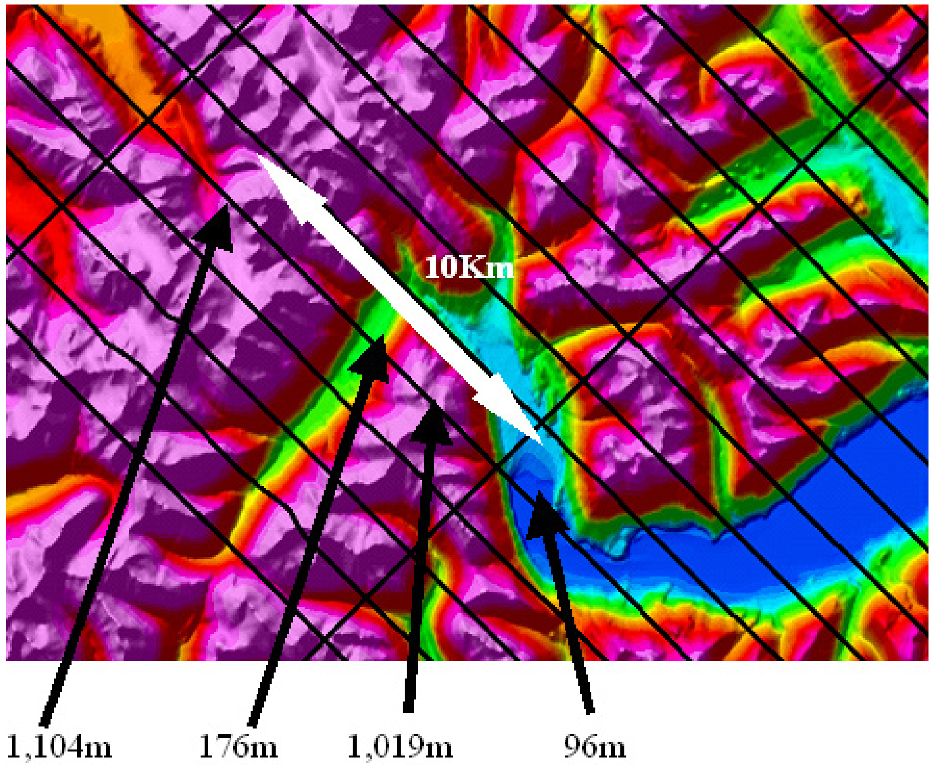

Figure 3 - Flight path plan over DEM, showing drastic terrain variations which force to modify the survey terrain clearance

- Flight schedule

  Areas are scheduled to be covered as fast as possible, with flight lines in sequential order. When some of the technical specifications of the project are not performed as expected, the surveyor must re-fly lines or portion of lines.

  Without a drape surface to guide the pilot, it could be a difficult task to maintain the same altitude when acquiring data from planned adjacent lines, which are flown in opposite direction and perhaps on different days.

3. SOFTWARE OVERVIEW

The software was written as a Geosoft[4] eXecutable function (GX) to run under Oasis Montaj geophysical data processing system. It generates a drape surface taking into account the input/output parameters shown on Figure 4.

[4] https://www.seequent.com/products-solutions/geosoft-oasis-montaj/

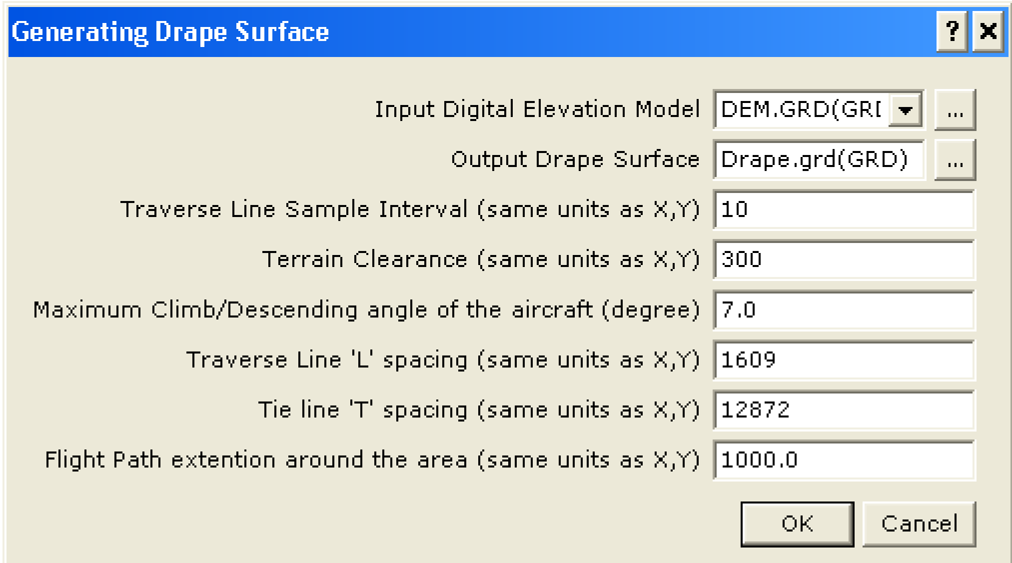

Figure 4 - Input/output interface for generating a drape surface

The input DEM data should be previously converted from the original format into the readable Geosoft Oasis montaj format. Projection should be in rectangular coordinates. Conversion from a variety of formats and projections is available from this geophysical data processing system.

The DEM data (originally in 2D, matrix-like) is extracted into a 1D vector format according to the input sample interval along the planned survey line. The input traverse ‘L’ and tie ‘T’ line spacing define the distance between lines. The drape surface is primary calculated by adding the nominal terrain clearance (TC) to the digital elevation model.

$$\text{Drape} = \text{DEM} + \text{TC} \qquad \text{Equation 1}$$

The software verifies that the climb / descend angle that aircraft is able to handle stays in the accepted range. By inspecting the points along each line, forward and backward to simulate the flight in both directions, a correction to the drape surface is applied where the terrain variation indicates an angle greater than the maximum limit. The algorithm inspects every point location (x,y,z) and finds the best solution based on the law of cosines.

Figure 5 illustrates a case where a correction is applied. It shows one of the most critical survey line with length of ~46 km and terrain variation between 100 to 1200 meters. The first iteration identifies angles in the range between -16° to 22° (greater than 7° accepted limit) as shown in the topography, in red color. After several corrections, mostly on top peaks and valleys, the resulting drape surface is as shown on top in green color.

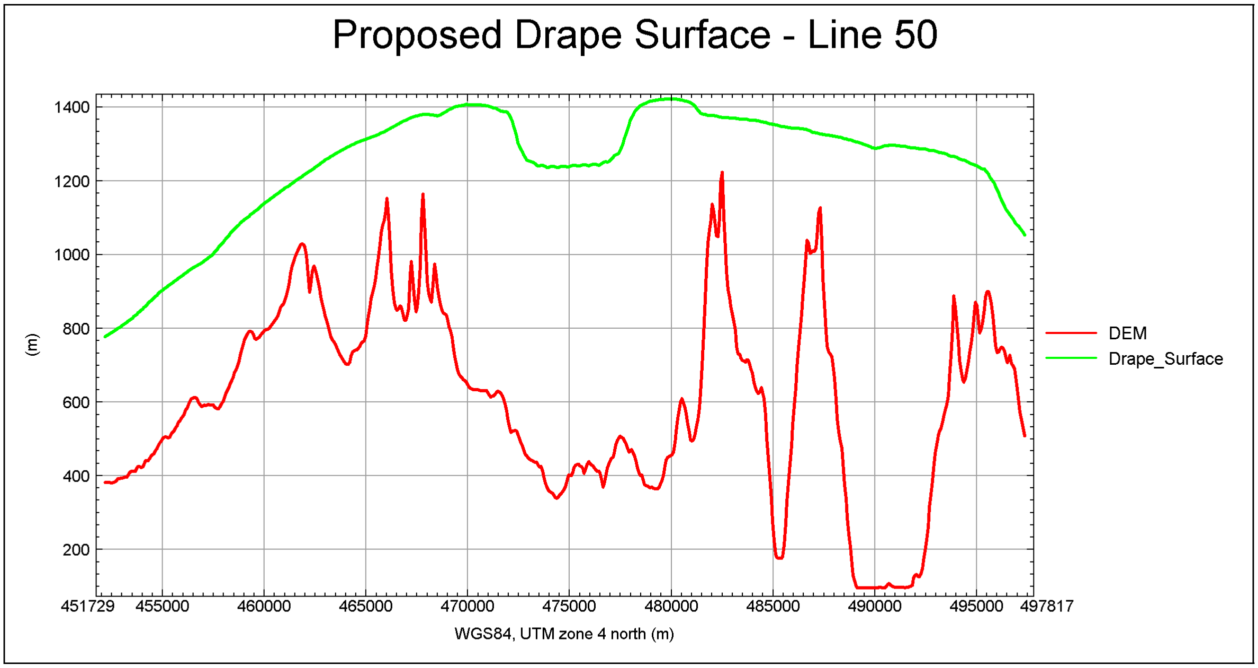

Figure 5 - Graphical representation of DEM (red) in one of the most critical survey lines, corrected (green) to allow the aircraft to efficiently handle climb/descend angles over rugged terrain

The first version of the software was implemented to work along a survey line in both directions according to the planned flight path. The line-based drape correction performs better than a grid-based technique in reducing height-related artifacts (Cowan and Cooper, 2003). However, the grid-based technique allows the pilot to perform the flight in any direction in a safe manner (Sander, 1998). A decorrugation filter based on the Fast Fourier Transformation (FFT) algorithm (Geosoft technical note) was then applied to the grid-format drape for smoothing purpose, with further iterations to correct the new drape if necessary.

The resulting drape surface is then converted into the format readable by the aircraft navigation system. Figure 6 shows a 3D view looking south-east of the generated drape surface (top) over DEM (bottom) for the survey area presented in this paper. For better visualization, the drape surface is being exaggerated on elevation to properly show how it smooths the surface when flying over rugged terrain. Highest elevations are seen in the western part of the survey area, where the drape surface is more affected by corrections.

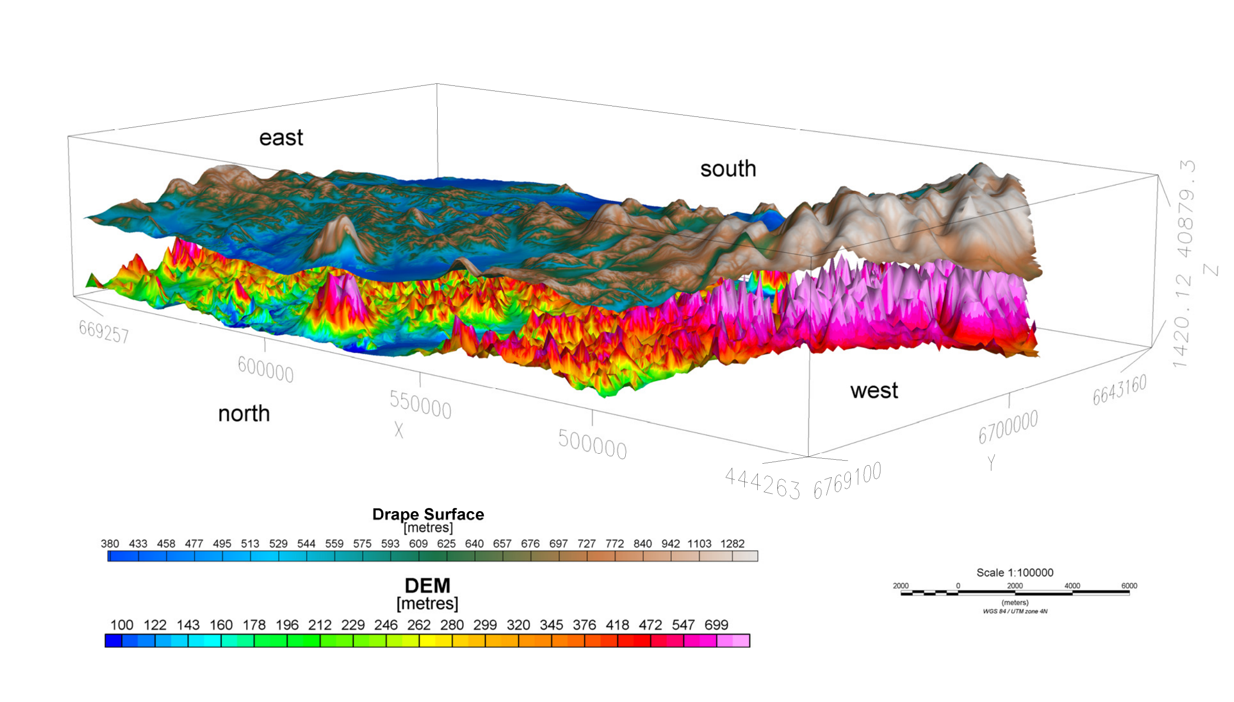

Figure 6 - view locking south-east of DEM (bottom) and Drape Surface (top)

4. ASSESSING THE DRAPE SURFACE EFFECTS OVER MAGNETIC DATA

In order to maintain the appropriate spatial resolution of magnetic data, the drape surface should guarantee that tie lines intersect traverse lines at the same height above ground, in a small range of variation. This requirement reduces the levelling corrections to apply over aeromagnetic data. Two lines intersected by two tie lines were selected to demonstrate this, as shown in Table 1.

Line \ intersection point	1	2	3	4
L2140	222.52	236.12		
L950			673.42	260.40
T10120	223.58			260.27
T10300		239.35	670.24	

Table 1 - Variation in elevation (Z in metres, ASL) between traverse and tie lines

As presented in Table 1, traverse line 2140 is intersected by tie line 10120 in point 1, with variation of 1.06 meters. On point 2, it intersects with tie line 10300, with variations of 3.23

meters. Line 950 is intersected by tie line 10300 in point 3, with variations of 3.18 meters. On point 4, intersects with tie line 10120, with variations of 0.13 meters.

Another purpose of the software is to maintain the flight path as close as possible to the planed terrain clearance without intersecting topographic features. The average planned terrain clearance for the survey presented in this paper is 305 meters (USGS open-file 2004-1293). Because of the high topographic activity in the survey area, the need for getting both traverse lines and tie lines intersecting at the same height above ground, and the climb/descend angle the aircraft is able to handle, there are places where the elevation is much higher than planned. This represents a compromise between flight safety and data quality.

An example of this situation is shown on Table 2, containing data from the zoomed area shown on Figure 3. The line was flown in south-north direction. The aircraft is climbing to the top of the mountain with original slope of 29.1°, forcing to reduce the terrain clearance to 78 meters for better maneuvers. At the very top of 766 meters, terrain clearance is reduced to 39 meters to handle the topography. Descending the mountain, the slope drastically increases, forcing to fly higher than the nominal terrain clearance. For safety reasons, due to the river width and the next group of coming mountains, this line is planned to be flown at higher altitude.

DEM (meters)	Climb / Descend angle (degree)	Drape Surface (meters)	Terrain Clearance (meters)
713	29.1	791	78
766	8.8	805	39
627	62.9	825	198
380	45.8	834	454
172	17.8	839	667
96	0.7	842	746

Table 2 - Data from the zoomed area on Figure 3 showing how terrain clearance increases or decreases from the nominal terrain clearance, to satisfy safety requirements.

In aeromagnetic data, when the source is located at shallow depths there is a clear difference in anomaly shape between a vertical pipe-like body (such as kimberlite) and a thin sheet, to mention some geological models. As depth-to-source increase, these differences become less obvious (Cowan and Cooper, 2003); hence the importance of flying a constant drape surface.

Numerous companies employ proprietary algorithms (Sander, 1998) for calculating a drape surface. The Geological Survey of Canada (GSC) released a Geosoft's GX application in 2014 for this purpose (Dumont and Bardossy, 2014).

5. CONCLUSIONS

A drape surface generated by the software presented in this paper satisfies the following requirements when flying an airborne geophysical magnetic survey:

- A drape surface guides the pilot in order to fly as close as possible to the planned terrain clearance according to the climb/descend angle which a fixed-wing aircraft is able to handle
- Having an accurate digital terrain model and a pre-planned drape surface, avoid the fact of forcing the pilot to make in-flight decisions in a short time-manner; satisfying safety requirements
- Traverse lines are intersected by tie lines at approximately the same height above ground, in a small range of variation; reducing the levelling correction that must be applied to aeromagnetic data.

The software was implemented by McPhar Geosurveys Ltd. to enable their flight crews to maintain an optimal flight altitude during surveying while at the same time ensuring that traverse and tie lines intersect at the same altitude. The result is a considerable improvement in resolution and quality of the magnetic data acquired, particularly in rugged terrain.

ACKNOWLEDGMENTS

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