

SGU

Acquisition Report

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Kiruna Fjallasen Airborne Geophysical Survey

Contents

1. Project Overview	3
1.1. Introduction.....	4
1.2. Project Location	4
1.3. Scope of Work.....	6
1.4. Key Milestones of the Project.....	6
1.5. Outline of Report	6
2. Survey Information & Design	7
2.1. Coordinate Reference System.....	8
2.2. Data Availability and Sources.....	8
2.3. Survey Design and Specifications	8
2.4. Survey Drape	10
3. Key Personnel & Technical Resources.....	12
3.1. Project Management/Key Personnel Involved.....	13
3.2. Aircraft & Survey Equipment.....	14
3.3. Software & Data Visualisation.....	15
4. Field Operations	16
4.1. Health, Safety & Environment Audits & Incidents	17
4.2. Permits and Visa Applications	17
4.3. Pre-Survey Mobilisation	17
4.4. Survey Acquisition.....	18
5. Data Analysis & Quality Control.....	20
5.1. Calibrations & Verification Results	21
5.2. Air-FTG Data Quality Control.....	21
5.3. iCORUS Data Quality Control	23
5.4. Navigation & Positioning Quality Control	25
Appendix 1 Basler Turbo BT-67 Aircraft and Crew.....	28
Appendix 2 Equipment Location On-board	30
Appendix 3 Air-FTG System and Operating Details	31
Appendix 4 Positioning & Magnetometer System Details.....	36
Appendix 5 Air-FTG Data Quality Control.....	38



1. Project Overview

1.1.Introduction

This report provides information regarding the acquisition and quality control methodology of Air-FTG® and aeromagnetic data, as conducted by Bellgeo Enterprises Ltd (Bell Geospace)

Since 1998 Bell Geospace has specialised in the acquisition, processing and interpretation of 3-D Full Tensor Gravity Gradiometry (Air-FTG®) data, as well as airborne magnetic data as the second applicable geophysical technique applied. For the majority of this time, Bell Geospace was the sole provider of Air-FTG data to the hydrocarbon exploration industry. Marine FTG data has been collected in the Gulf of Mexico, the North Sea and offshore Shetland and Faroe Islands. In 2001 Bell Geospace successfully converted the FTG platform for use on an aircraft; since then Air-FTG and aeromagnetic surveys have since been completed in 47 countries on more than 500 projects across the globe for hydrocarbon and mineral exploration. Bell Geospace prides itself in taking a partner role in every project it embarks on by providing high quality processed data sets with objective-based (customised) interpretation considering technical merits of the data.

The survey equipment used for this project is owned, maintained and operated by Bell Geospace and is permanently installed on Basler Turbo BT-67 aircraft. This aircraft is a modified and modernised Douglas DC-3 airframe, remanufactured in 2008, owned by Bell Geospace and operated by Enterprise Airlines of Oshawa, Canada.

1.2.Project Location

The project is titled Kiruna Fjallasen and is located in the Northern part of Sweden, - the location of the survey area is shown in Figure 1.1. Kiruna Fjallasen was acquired in Q3 2025.

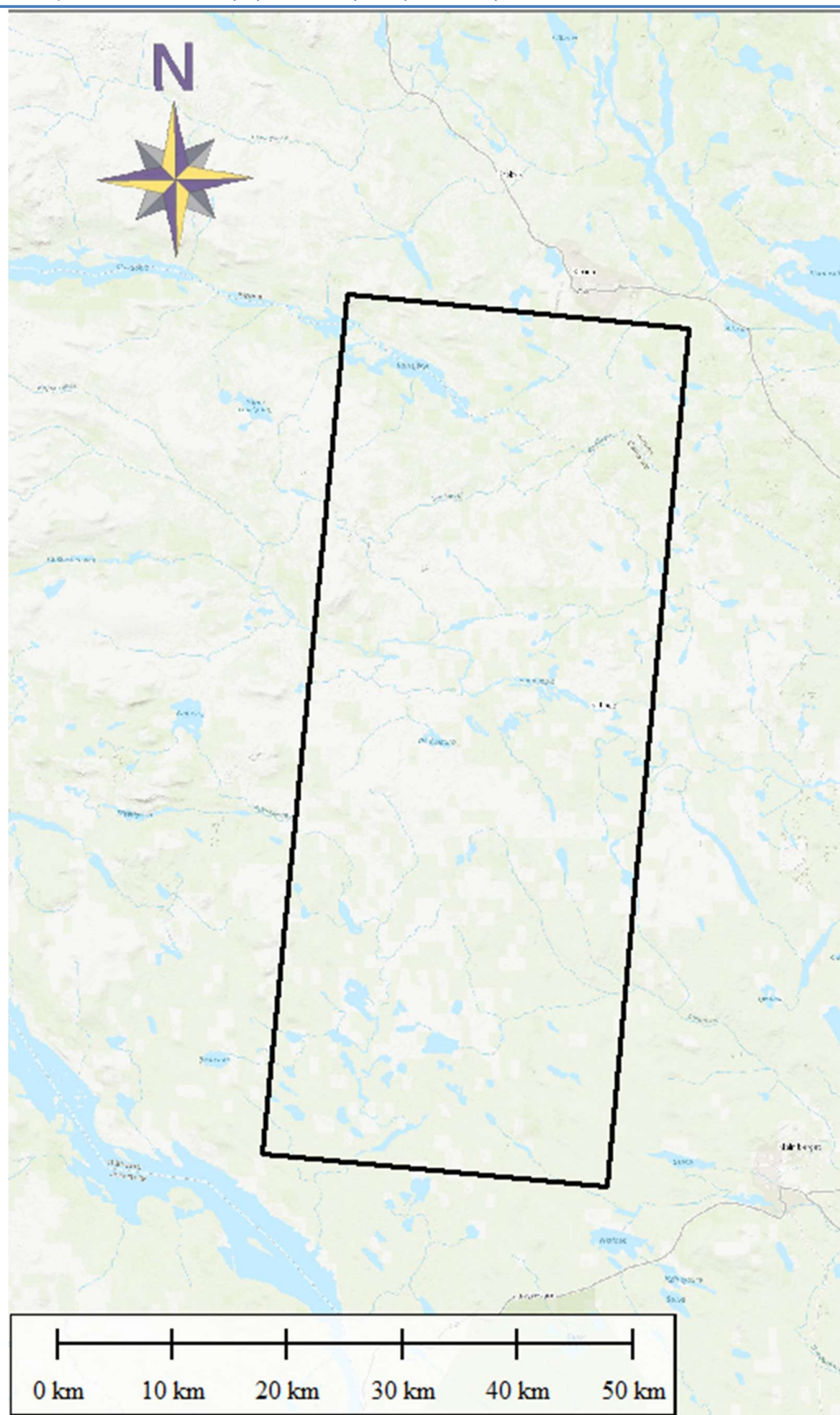


Figure 1.1: Location of the survey area

1.3. Scope of Work

The objective of the survey was:

- › Bedrock mapping together with targeting mineral occurrences related to various rock types
- › To acquire and process Air-FTG® and Gravity data approximately 9,866.85 line km in Kiruna Fjallasen, which will be used to focus the exploration efforts.
- ›

1.4.Key Milestones of the Project

Table 1.1 summarises the summary of events or key milestones of the project. Kiruna Fjallasen was completed in July 2025.

Table 1.1: Key Milestones of events related to the project

Date	Activity
13 July 2025	Aircraft arrival in Gallivare Airport (GEV), Sweden, Base of Operations. FTG Platform Calibration began
16 July 2025	FTG Calibration completed and Acquisition commenced
27 August 2025	All lines includes redos has been acquired on Kiruna Fjallasen. Kiruna Fjallasen survey completed.
29 August 2025	C-GEAJ Aircraft and Crews have been demobilised from base of operation Gallivare Airport (GEV), Sweden.

1.5.Outline of Report

This report outlines the survey parameters, the sequence of acquisition and processing, and to highlight any issues which arose and the solutions which were implemented. The report is divided into seven sections plus appendices:

- › This section presents the overview of the project.
- › Section 2 details the design and specifications of the survey.
- › Section 3 details the key personnel involved, survey equipment deployed and software used.
- › Section 4 details the operations on field, before and during survey.
- › Section 5 details all data evaluation and quality control procedures.

2. Survey Information & Design



2.1. Coordinate Reference System

All coordinates stated throughout the report, as well as all final deliverables, are referenced to the Coordinate Reference System (CRS) shown in the Table 2.1.

Table 2.1: Coordinate Reference System (CRS)

Projection Method	Universal Transverse Mercator (UTM)
Zone	34 N
Horizontal Datum	World Geodetic System 1984 (WGS 84)
Vertical Datum	Earth Gravitational Model 1996 (EGM 96)
Length Units	Metre

2.2. Data Availability and Sources

The following data and information was available prior to the survey commencement:

- › Country borders, cities and smaller settlements, no-fly zones.
- › Onshore topography sourced from the Shuttle Radar Topography Mission (SRTM) Worldwide Elevation Data provided by NASA

2.3. Survey Design and Specifications

Kiruna Fjallasen survey consisted of one block of in-lines and tie lines to be flown. Table 2.2 shows the survey specifications of the project. Figure 2.1 depicts the survey boundary and the regional topography, and Figure 2.2 depicts the final flight plan.

Table 2.2: Survey specifications

Survey Name	Kiruna Fjallasen
Survey type	Full Tensor Gravity Gradiometry
Nominal aircraft altitude	80 m or minimum legally allowable
Approx. sample spacing FTG	60 m
Approx. sample spacing Magnetics	6 m
Nominal across in-line spacing	250 m
Nominal across Tie-line spacing	2 500 m
Nominal in-line orientation	95.55 °
Nominal Tie-line orientation	5.55 °
Final total survey length	9866.85 km

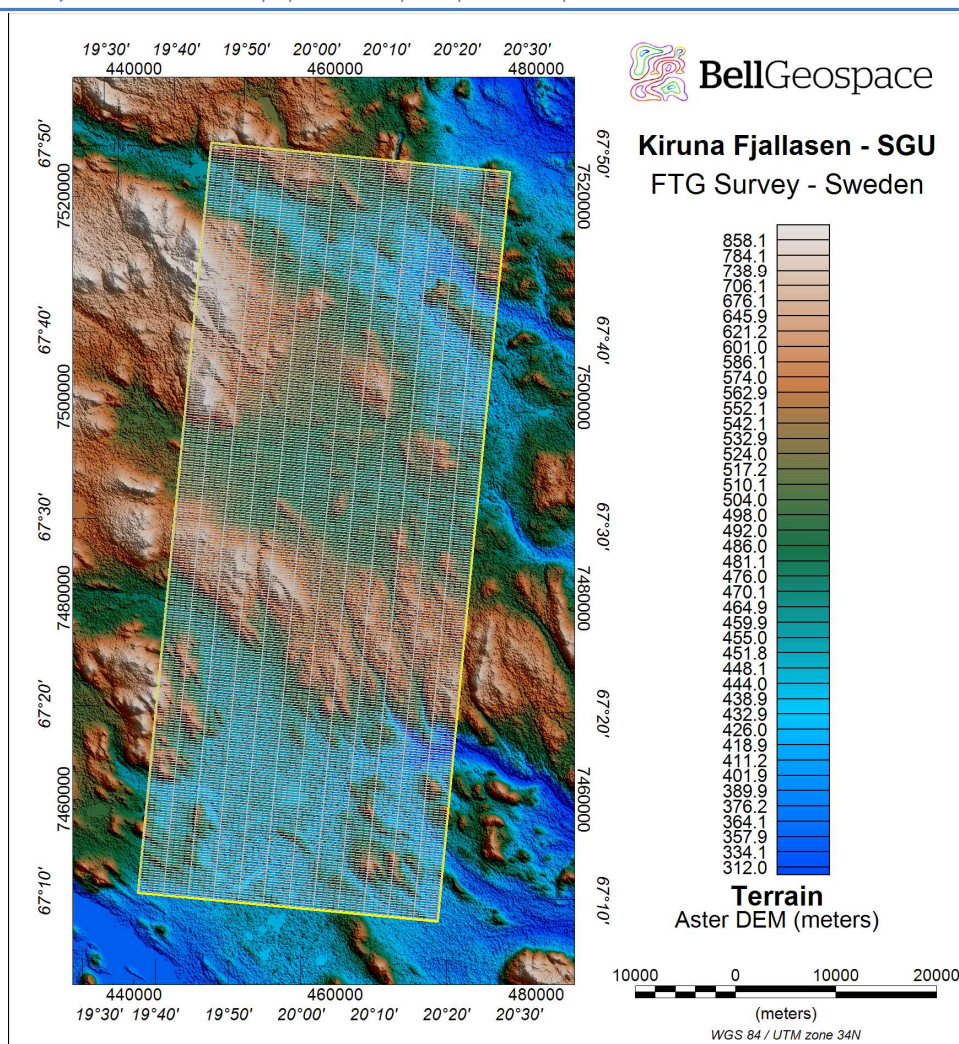


Figure 2.1: Topography over Kiruna Fjallasen survey area

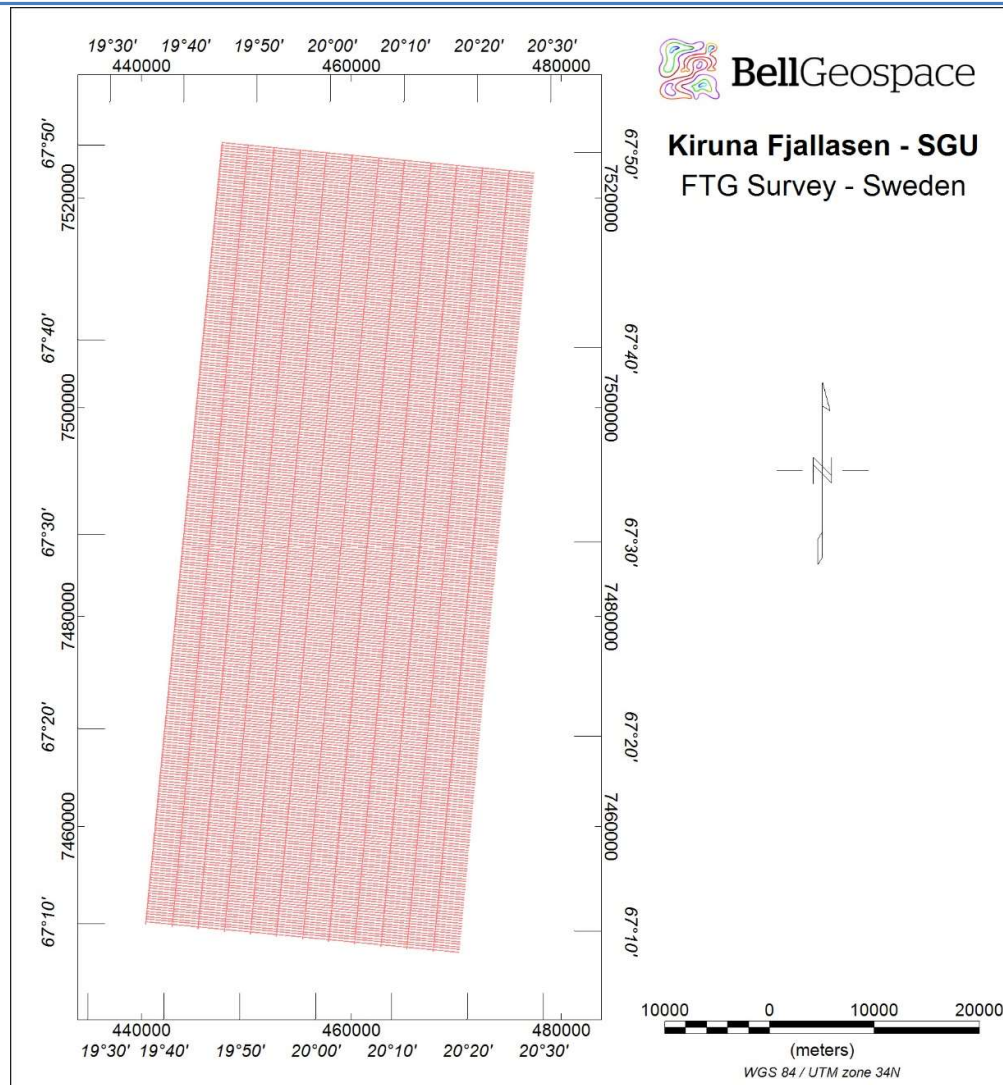


Figure 2.2: Kiruna Fjallasen Final survey design.

2.4. Survey Drape

In order to optimise the survey pilots' flight path, a "drape surface" was calculated, with the clearance set at a minimum of 120 metres height above terrain (ground or water surface). The drape forms a safely flyable surface that accommodates all of the survey lines, improves the data fit at line intersections and reduces spurious variations in signal strength between lines. The drape calculation limits the climb and descent rates to 450ft/min in order to prevent rapid air pressure changes that can affect the GGI performance. Maintaining moderate climb and descent rates help the pilots maintain control of the aircraft in the event of an engine failure. Drape surfaces were designed to be as low as safely possible, in order to maximise the data resolution. Figure 2.3 shows the pre-planned drape surface.

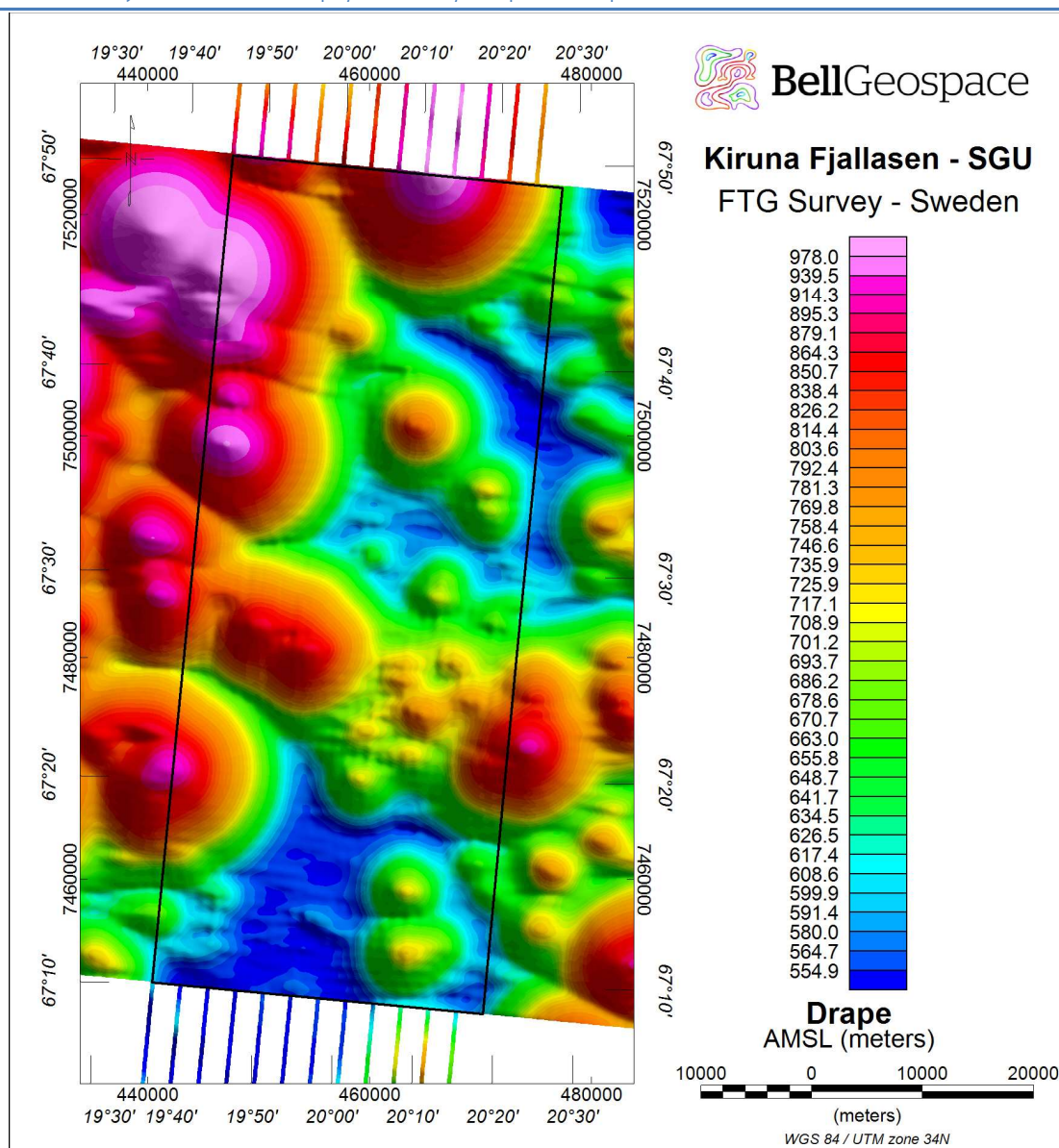


Figure 2.3: Kiruna Fjallasen Drape surface measured at height above geoid

3. Key Personnel & Technical Resources



3.1. Project Management/Key Personnel Involved

Bell Geospace formed a survey acquisition team to undertake the field operations. This field crew comprised of, at minimum, two pilots – a captain and a first officer – subcontracted from Enterprise Airlines and two Bell Geospace system operators. One of the operators was also designated as the Field Operations Supervisor, who had overall responsibility for the field operation, reported to Bell Geospace management, and ensured that the survey was conducted efficiently, safely, and in accordance to the contract specifications. Exchanges of survey field crew happen every few weeks, particularly on extensive projects.

The Bell Geospace Service Support Department provided technical advice and support to the field crew and its technicians were regularly sent to the field to perform routine or essential maintenance to the survey equipment.

All data acquired and processed on field was sent to Bell Geospace's QC Geoscientist that was assigned to be analysed and processed further.

Details of the personnel involved in the acquisition and processing phase are listed in Table 3.1.

Table 3.1: Key personnel involved in the project

Name	Organisation	Position
John Marshall	Enterprise Airlines	Captain
Greg Noonan	Enterprise Airlines	Captain
Wes Van Mierlo	Enterprise Airlines	Captain
Michael Hudson	Enterprise Airlines	First Officer
Jesse Patchett	Enterprise Airlines	First Officer
James Milson	Enterprise Airlines	First Officer
Andrew Hughes	Enterprise Airlines	Mechanic
Xavier Jacques	Enterprise Airlines	Mechanic
Malcolm Mordue	Bell Geospace	Supervisor
Richard McKie	Bell Geospace	Supervisor
John Watkins	Bell Geospace	Service Support Manager
Ikhsan Zikrurramadhan	Bell Geospace	Project and QC Manager
Arne Kreiensiek	Bell Geospace	QA Geoscientist

Chris Bellamy	Bell Geospace	Senior Geophysicist
Malcolm Destro	Bell Geospace	Processing Geophysicist
Scotty Morrison Smith	Bell Geospace	HSE & Logistics Manager
Gaud Pouliquen	Bell Geospace	Director of Sales
Colm Murphy	Bell Geospace	Chief Geoscientist

3.2.Aircraft & Survey Equipment

The following aircraft and survey equipment were deployed for this survey:

Table3.2: Aircraft Summary

Aircraft Type	Manufacturer	Model
Fixed Wing Aircraft – Basler Turbo BT 67	Douglas	C-GEAJ

Table 3.3: Survey Equipment Summary

Survey Equipment	Manufacturer	Model
Airborne Gravity Gradiometer	Lockheed Martin	FTG 3
Airborne Gravity	iMAR	iCORUS-02
Airborne Magnetometer	Geometrics	G-822 Mobile Cesium Magnetometer
Aeromagnetic Compensation	RMS Instruments	DAARC500
Base Magnetic Station	GEM Systems	GSM-19 Overhauser Magnetometer
Global Positioning System	Novatel	ProPak LB
Radar Altimeter	Honeywell Aerospace	KRA 405B
Laser Altimeter	Renishaw	ILM 1200 R

Additional details of the aircraft and survey equipment are in the following appendices:

- › Appendix 1 provides technical details on the survey aircraft.
- › Appendix 2 specifies the locations of survey systems installed on the aircraft.
- › Appendix 3 provides technical details on the Air-FTG system.
- › Appendix 4 provides technical details on the other survey systems.

3.3. Software & Data Visualisation

ODIN is a company-wide central database, developed internally, that stores and shares operational and analytical information gathered from the field and office operations. It facilitated tracking of survey progress, monitored system health and collaborated on survey designs and data evaluation.

Much of the Air-FTG software used in the field is proprietary and by Lockheed Martin, the Air-FTG system manufacturer. This software displayed the FTG response as well as key parameters that were crucial to the correct operation and provided warnings when components were not operating within technical specifications. Lockheed Martin software was also used to perform FTG calibrations and on-field processing.

Geosoft's Oasis montaj is a geoscience software package used primarily in the office for data analysis and processing. It was also for generating the deliverables for the client, including databases and maps.

Additionally, the following commercial interfaces were also used for data analysis:

- › Pico Envirotec's PEIConvert is a program used for designing the survey flight plan.
- › Pico Envirotec's ANAV is a navigation interface system used by the aircraft crew to monitor real-time flight data.

4. Field Operations

4.1. Health, Safety & Environment Audits & Incidents

There were no major HSE issues observed in this project area. Daily Toolbox meeting and Weekly HSE meeting were held throughout the field operations.

4.2. Permits and Visa Applications

As contracts and documents were ready and there were no restrictions from ITAR (there are some restrictions from the US Government to use FTG technology in some countries) the flight permits were straight forward.

4.3. Pre-Survey Mobilisation

The personnel, aircraft and equipment arrived at Gallivare Airport (GEV) Sweden on 13th July 2025; mobilisation commenced on the same day. Gallivare Airport was the base of operations, including for equipment mobilisation, system calibrations and regular maintenance.

The mobilisation itinerary included, but was not limited to, the following:

- › Positioned the aircraft for power supply.
- › Unloaded the equipment from the aircraft to a designated store room.
- › Static calibrations
- › Aircraft maintenance
- › Tested satellite phone communications.
- › Uploaded final survey plans to on-field computers.
- › HSE meetings.

Static and airborne calibrations were performed on the survey systems 16th July 2025 and during the survey acquisition; further details are in the next section of the report.

4.4. Survey Acquisition

Kiruna Fjallasen surveying officially commenced on 16th July 2025 and was completed on 27th August 2025. A summary of acquisition for the entire survey campaign, of which Kiruna Fjallasen is one block, is shown in Table 4.1.

Table 4.1: Acquisition summary

Days of acquisition	21 days
Downtime (Weather)	12 days
Downtime (Maintenance)	4 days
Standby	6 days

The survey was suspended multiple times throughout the course of the project for various reasons, which are listed in the following table in chronological order:

Table 4.2: Survey downtime summary

Dates	Reason
19 July 2025	Standby due to Airport closed on Saturday
20 July 2025	Standby due to Airport closed on Sunday
26 July 2025	Standby due to Airport closed on Saturday
28 July 2025	Poor weather conditions
30 July 2025	Poor weather conditions
2 August 2025	Standby due to Airport closed on Saturday
3 - 7 August 2025	Poor weather conditions
9 August 2025	Standby due to Airport closed on Saturday
10 August 2025	Poor weather conditions
14 August 2025	Poor weather conditions
16 - 19 August 2025	Aircraft scheduled maintenance
20 August 2025	Poor weather conditions
23 August 2025	Standby due to Airport closed on Saturday
24 August 2025	Poor weather conditions
25 August 2025	Poor weather conditions



A total of 61.97 km was re-flown as the original lines had issues with the data quality for the Kiruna Fjallasen block. Details on the QC methodology are in the next section. Statistics on line kilometres acquired throughout survey campaign including re-flights, are in Figure 4.1; blue statistics are first survey flights (partial or complete) and red statistics are re-flights.

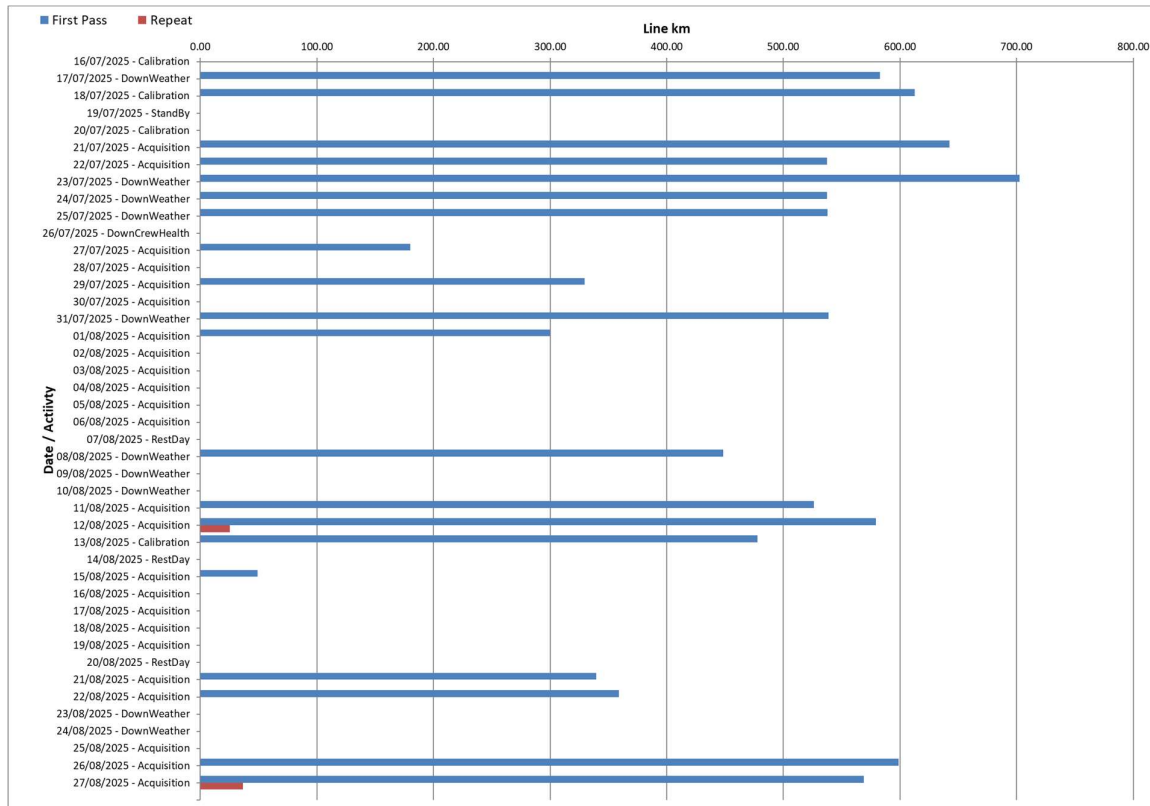


Figure 4.1: Field operations throughout survey.



5. Data Analysis & Quality Control

5.1. Calibrations & Verification Results

Air-FTG: A series of Air-FTG calibrations, both stationary and airborne, was performed for the platform, accelerometers and gyros, optimising the FTG system. The calibrations were undertaken prior to the start of survey and whenever significant changes were made to the FTG system configuration. Air-FTG was also evaluated after every survey flight ensuring optimal performance. Calibration results cannot be provided as they are proprietary by the system manufacturer Lockheed Martin.

5.2. Air-FTG Data Quality Control

Bell Geospace had several controls on Air-FTG data quality, both on field and in the office, and any survey line with poor signal quality was assessed for reflight; a summary of QC specifications is in Table 5.1. Once new lines were acquired, the process was repeated until all survey lines passed the QC checks. Technical documentation on the QC methodology of Air-FTG data is in Appendix 5.

Table 5.1: Air-FTG QC specifications

Full Tensor Gravity Gradiometry		
Signal levels on 3 GGI outputs, torque levels.	Consistency between GGI's, no spiking.	Stop survey to investigate system performance
Standard Deviation of Vertical acceleration over whole line	< 100 mg 100 – 120 mg >120mg	Acceptable Assess for reflights Unacceptable, unless exceptional circumstances
Gaps in Digital Data	> 2 sec	Interpolate if possible else redo line
AILS*	> 17 Eotvos	Unacceptable, unless exceptional circumstances

Figure 5.1 shows the contract Inline sum for all the survey lines flown on Kiruna Fjallasen. As shown in the figure, no several survey lines exceeded QC constraints. However, there are several lines been re flown due to exceeding internal QC specifications and these re flown lines has passed the QC. The average across Kiruna Fjallasen was 6.12 eötvös.

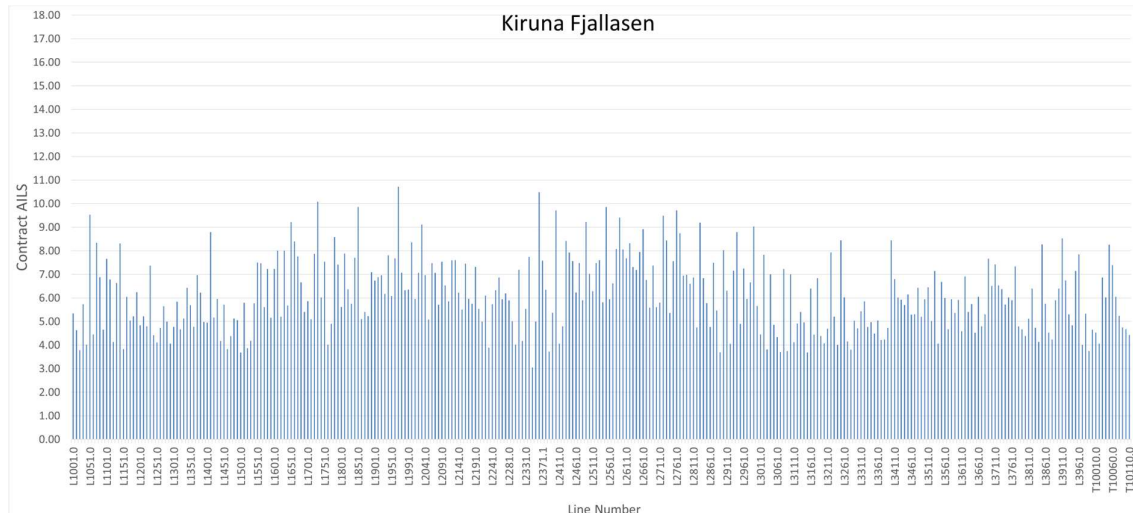


Figure 5.1: Inline sum from the Kiruna Fjallasen

Figure 5.2 shows the maximum vertical acceleration values for all the survey lines flown on Kiruna Fjallasen. As shown in the figure, no survey lines exceeded QC constraints. The average across Kiruna Fjallasen survey was 50.83 ms.

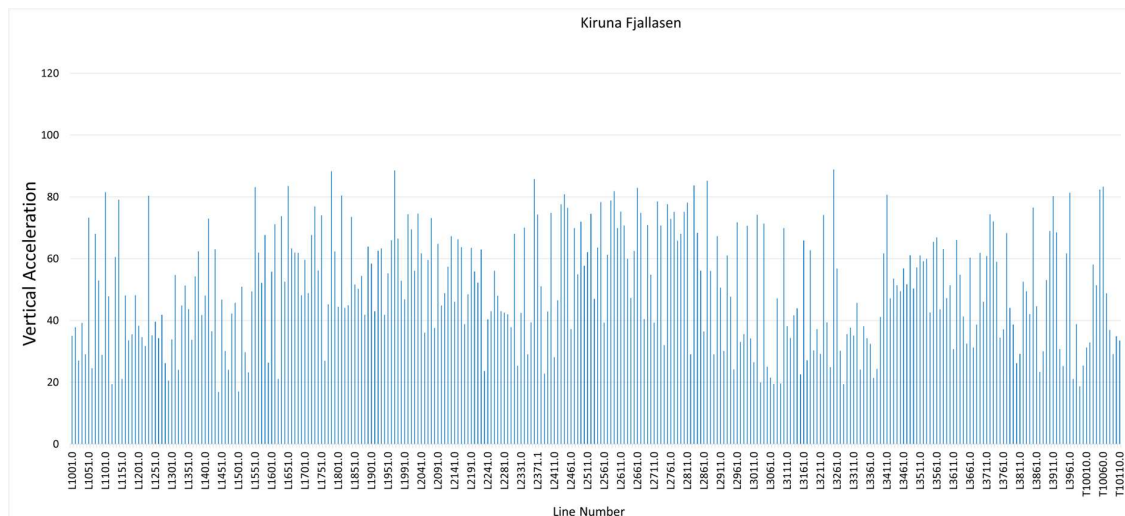


Figure 5.2: Vertical Acceleration values of Kiruna Fjallasen



5.3 iCORUS Data Quality Control

Bell Geospace employed several technical specifications for airborne Transparent Earth Geophysics iMAR iCORUS-02 data quality control. Field practice ensured all instruments were working and the data was extracted and uploaded on a daily basis to the office for assessment. A summary of QC specifications is in Table 5.2.

Table 5.2: GTz QC specifications

<i>iMAR iCORUS-02 Gravimeter</i>		
GPS # satellites	<5 satellites	If longer than 2 minutes duration, redo line (part), else investigate consequences to quality.
PDOP	>3	If longer than 5 minutes duration, redo line (part)
Vertical acceleration	>100 mg	Unacceptable
Drift measurement	Not recorded	Redo line
Drift rates	> 0.5 mgal / hr	Interpolate if possible (COMPANY representative to be informed) else redo line
RMS intersection error on individual flight lines	1.5 mgal over 6 km full wavelength after 1st order levelling	Redo line
Gaps in Digital Data	<5 sec > 2 sec , max 2% per line	Interpolate if possible else redo line

Figure 5.3 shows the iCORUS drift result throughout the Kiruna Fjallasen survey. As shown in the figure, daily drift not exceeded QC constraint.

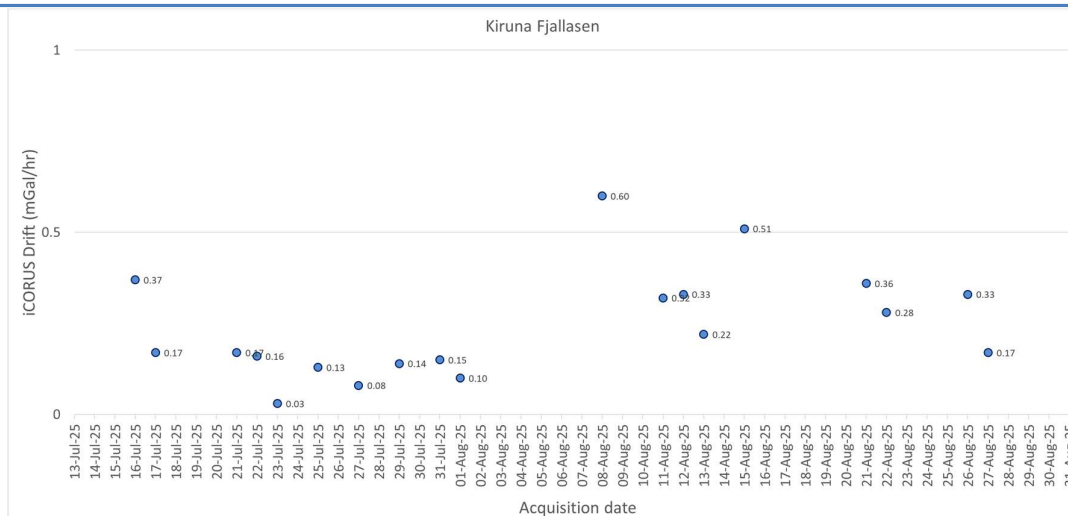


Figure 5.3: iCORUS Drift result throughout the Kiruna Fjallasen survey

Figure 5.4 shows the RMS Intersection error values for all the survey lines flown. As shown in the figure, there are several lines exceeded QC constraints. The overall RMS intersection value for Kiruna Fjallasen survey is 1.23 mGal.

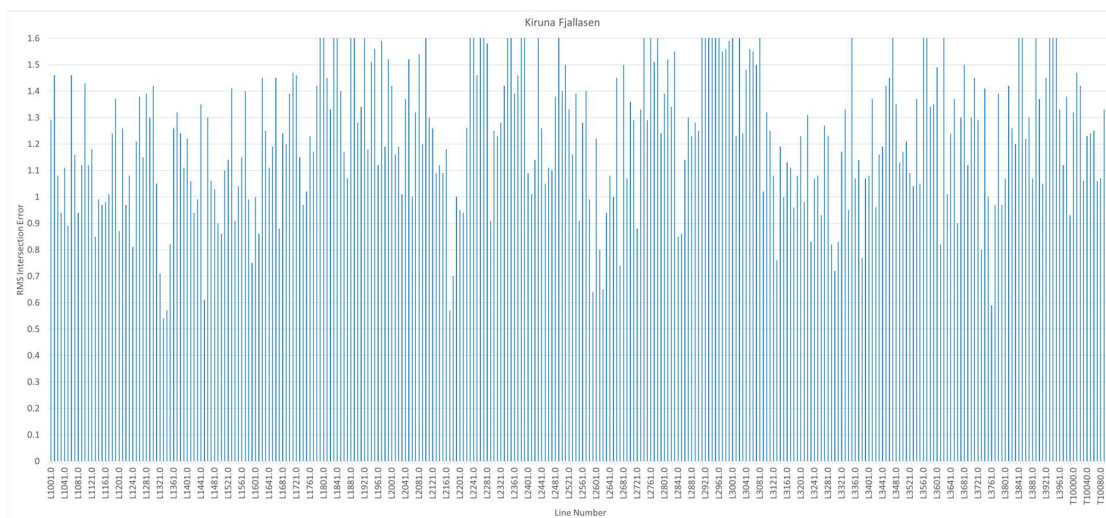


Figure 5.4: iCORUS RMS Intersection Error on Kiruna Fjallasen

5.4 Navigation & Positioning Quality Control

On field, as well as general checks, the GPS sensors continually monitored the number of satellites available at all times. Additionally, on-flight checks were made that real-time differential corrections for the GPS were being received. In the office, the position of the aircraft on each survey line was assessed against an ideal line plan and smoothed drapage surface according to the specified contract specification. A line where the aircraft had been found to deviate horizontally and/or vertically was identified for potential re-flight. The assessment of flight accuracy was determined during the daily processing stage by Bell Geospace's office personnel. A summary of QC specifications is in Table 5.8.

Table 5.3: Navigation/Positioning QC specifications

<i>Navigation and Positioning</i>		
Line navigation	> 20% of line spacing off plan over any stretch longer than 2km	Redo line or partial line
Line navigation vertical positioning	> 20% of terrain clearance off plan over any stretch longer than 1km	Redo line or partial line
GPS # satellites	<5 satellites	If longer than 10 seconds duration, redo line (part), else investigate consequences to quality
PDOP	>5	If longer than 5 minutes duration, redo line (part), else investigate consequences to quality

Line keeping was generally good throughout the survey. Figure 5.5 shows flight trajectories flown over survey area.

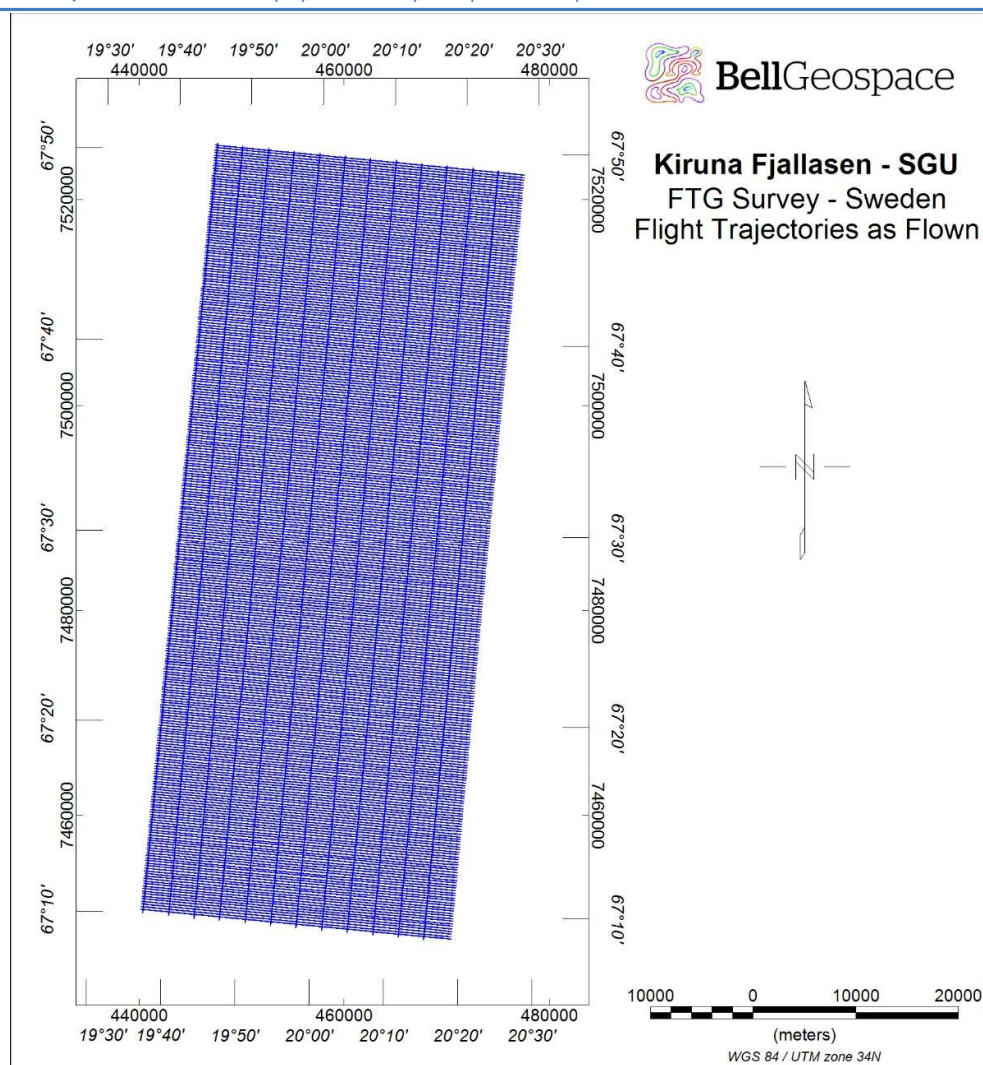


Figure 5.5: Kiruna Fjallasen Flight Trajectories

Appendices



Appendix 1 Basler Turbo BT-67 Aircraft and Crew

The aircraft used for this survey is a Basler Turbo BT 67 (Figure A2.1). This was a Douglas DC3 originally built in 1944 but converted by Basler Turbo Conversions of Oshkosh, USA, in 2008. The conversion includes fitting of more powerful and reliable Pratt & Whitney PT-6 turbine engines, lengthening the fuselage by 40" behind the cockpit, modifying the wing tips and installing a modern avionics suite. The aircraft is well suited for low level airborne survey work because of its low stall speed and stability in turbulent conditions. With powerful twin engines and a requirement for two pilots it is a safe choice for long offshore sorties. The table below lists the specifications of the aircraft.

Table A1.1: Aircraft specifications

Length:	67 ft 8 in
Wingspan:	95 ft 8 in
Height:	18 ft 3 in
Empty weight:	15,750 lb
Maximum take-off weight:	28,750 lb
Powerplant:	Twin Pratt & Whitney Turbine engines, 1,424 hp (1,062 kW) each.
Propellers:	Five-bladed Hartzell
Maximum speed:	215 knots (247 mph)

The aircraft is owned by Bell Geospace but managed and operated in accordance with Transport Canada regulations by a contractor, Enterprise Airlines, based in Oshawa, Canada. Enterprise has a long record of operating Baslers, much of it supporting scientific bases in Antarctica.

The aircraft is continually supported by two pilots and one mechanic, even when on standby. These personnel work monthly shifts dedicated to the Bell Geospace Baslers and, along with the geophysicists, form the core of the survey crew. The pilots are highly experienced in low level survey work and are able to fly safely and accurately. In the field the Captain is in charge of the aircraft but its operation and maintenance are also monitored by the Enterprise Chief Pilot and Chief Mechanic to ensure that they comply with Transport Canada, local regulations and IAGSA guidelines.

The partnership between Bell Geospace and Enterprise is very successful resulting in an excellent safety record and efficient operations.

The geophysical survey equipment (FTG unit, iMAR iCORUS, magnetometer, Lidar, GPS and Laser and radar altimeter) is permanently installed (as shown in Appendix 2) and the aircraft is capable of carrying crew, spares and support equipment to survey locations around the World. This protects equipment from damage and reduces mobilisation times after arrival. The FTG system requires continual electrical power and the plane is fitted with power supplies and transformers to safely use mains or generator power of various voltages while on the ground.



Appendix 2 Equipment Location On-board

Acquisition equipment (permanently installed in Basler BT-67; Figure 5):

- Lockheed Martin Full Tensor Gravity Gradiometer System
- iMAR iCORUS-02 Airborne Gravimeter
- RMS Instruments DAARC 500 real time magnetic compensator
- Geometrics G-822A Cesium Vapour magnetometer
- Laser Altimeter ILM 1200 R
- Pico Envirotec ANAV navigation package
- NovAtel GPS ProPak-LB – Terrastar XP differential corrections

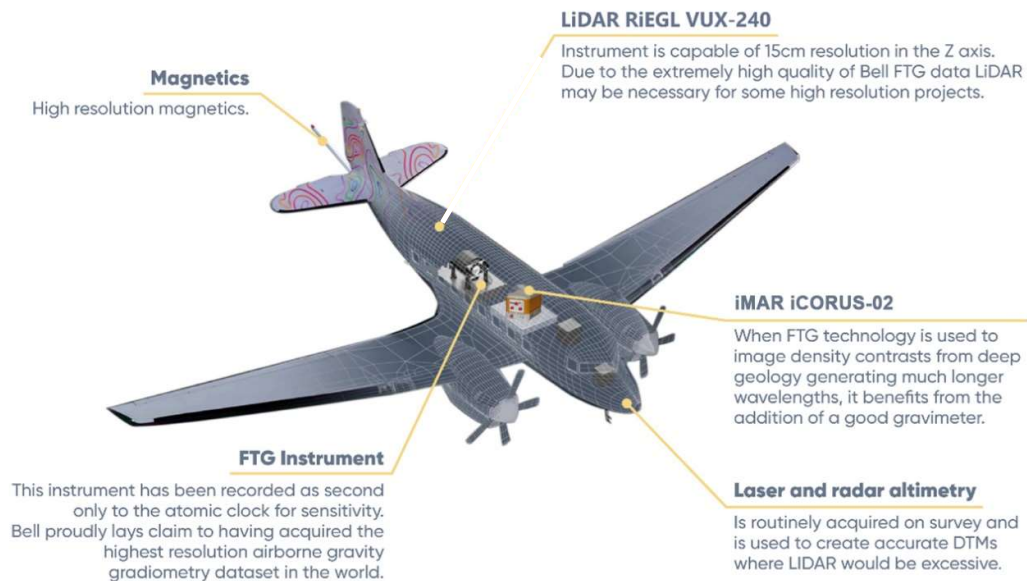


Figure A2.1: Instrument locations on the survey aircraft (top view)

Appendix 3 Air-FTG System and Operating Details

The Full Tensor Gradiometer (FTG) system used on this project is owned by Bell Geospace and manufactured by Lockheed Martin.

Platform and binnacle:

The FTG is comprised of three gravity gradient instruments (GGIs) mounted on a stabilised platform, shown in Figure A3.1. The platform is housed in a closed 'binnacle' in which the air temperature, humidity and pressure are tightly controlled. The platform has roll, pitch and azimuth gimbals that are torqued, in response to gyro and navigation information, such that the frame holding the GGIs is always level and faces a constant operator-selected heading regardless of aircraft motion. The binnacle is isolated from high frequency vibrations (above 5Hz) by pneumatic mounting pads and accelerometers and gyros within the platform continually measure motion data that is used to compensate for rotations that affect the gradient data.



Figure A3.1: A photograph of the FTG system, with the binnacle cover removed to reveal the roll gimbal.

GGIs and accelerometers:

The three GGIs are mounted in an internal coordinate frame of axis of which the gradiometers are mutually perpendicular and deviate by an equal angle from the vertical, shown in Figure A3.2. Each gradiometer outputs two channels of signal (Cross and Inline) each, totalling six. This is the equivalent of all nine components of the gradient tensor.

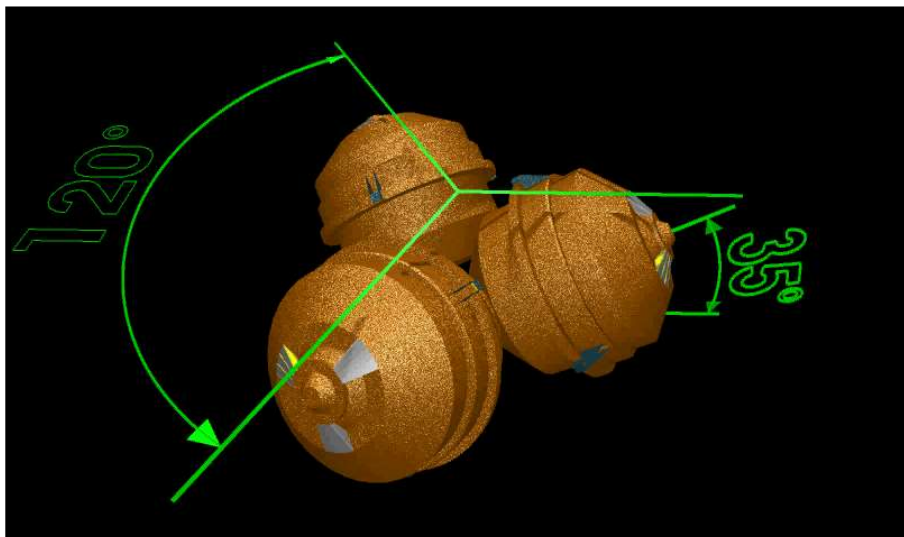


Figure A3.2: A diagram showing the relative positions of the GGIs inside the binnacle.

The GGIs are based on pairs of accelerometers mounted 10cm apart on opposite sides of a disk rotating at 0.5Hz, shown in Figure A3.3. The accelerometers in a pair are aligned so that they are only sensitive in the direction of travel around the axis and are sensitive in opposite directions. There are two pairs of accelerometers in each GGI and their output is summed; if they are perfectly matched, unless there is a gravity gradient or a rotation of the whole assembly, the net output will be zero. A gravity gradient marks a difference in the gravity field over the 10cm distance between the accelerometers and causes a non-zero output. Rotation causes the paired accelerometers to move at different rates. As the output is indistinguishable from a gradient, rotations, which are independently measured by the platform gyros, can be isolated and their effect removed in processing. The main advantage of a gradiometer over a gravimeter (a single accelerometer) is that translations affect the accelerometers in a pair equally and are naturally cancelled out.

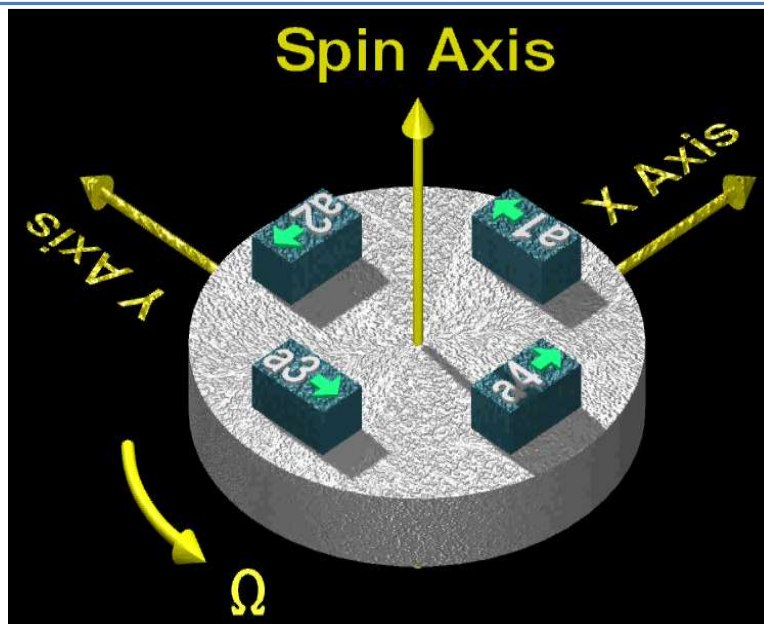


Figure A3.3: A diagram showing the relative positions of the accelerometers inside a GGI.

The matching between the accelerometers is crucial to the GGI performance. Non-linearity in their responses and off-axis sensitivity are controlled by several parameters set in the controlling software. Despite being tightly regulated by heaters and being housed in sealed units, the GGIs are sensitive to temperature, pressure and humidity changes and as these cannot be compensated for analytically they must be minimised by controlling the environment in the binnacle.

On-site operations:

The platform is mounted in the centre of the aircraft, minimising the effects of aircraft motion on the readings, as shown in Figure A3.4.

Once set up the FTG runs automatically with the platform stabilisation and GGI tuning handled continually by the circuits and software housed in the electronics cabinet. The user interface is through a computer called the System Control Processor (SCP) that allows the operator to monitor performance and status parameters and change settings such as calibration values. A second passive computer, the online monitor, picks up the data output from the SCP for further analysis and data recording.

During normal operations the FTG is kept running continually. Uncontrolled shutdowns, for

example due to power failure, cause loss of temperature control and deactivate the electromagnetic fields constraining the GGI accelerometers. Once restarted the GGIs generally require recalibration, ensuring that the system runs continually is an important responsibility of the field crew.



Figure A3.4: Air-FTG system installed in Basler aircraft

Calibrations:

The FTG platform and inertial navigation system and the GGIs (gravity gradient instruments) were calibrated according to standards set out by the manufacturer, Lockheed Martin. They were performed while the aircraft was immobile. This created a table of calibration factors that was used during data processing to remove the gradient effects of the variations in pitch, roll, and yaw experienced by the aircraft in flight.

The platform calibrations ensured that the FTG platform is correctly oriented and that the accelerometers and gyroscopes used for inertial navigation and platform stabilisation were accurately aligned and scaled. This was essential for good platform stability and in order to be able to accurately convert the gradient data from the GGIs' internal reference frame to real world coordinates.

GGI calibrations calculate instrument alignment and scale factors and correct for local

system and in-aircraft gradients. Any significant bias in the raw gradients is removed by resetting to prescribed values. The calibrations also result in GGI parameters that are used in the high rate data processing to optimise gradient calculation.

In addition to the static calibrations, GGI control parameters that minimise the FTG's sensitivity to external accelerations and vibrations were calculated from data recorded and processed during dedicated 'tweak flights'. Tweaks were also determined from routine survey data and were assessed after every flight to ensure that the system was working optimally.

Survey acquisition & recording:

Air-FTG flight planning at Bell Geospace involves three interlaces. Each interlace is made up of every third line of the survey plan. In addition to flying every third line, between each interlace the FTG platform is rotated 120 degrees which is referred to as the carousel angle. For example, the first interlace might have GGI 1 oriented at 000 degrees North, the second interlace might have GG1 at 120 degrees from North, and the third interlace might have GGI 1 oriented at 240 degrees from North. The intention of flying these interlaces and rotating the FTG platform is to help to isolate each GGI's noise characteristics across the survey area as an aid in noise analysis and reduction.

Data was acquired continuously throughout a flight, usually at ground speeds of around 215 km/hr. The system generates approximately 400 megabytes of data per hour, which is stored on a computer hard drive and backed up to external hard disk drives. Much of this data is high rate motion data that is used to calculate compensated gradients in post-processing and other information such as environmental status is monitored and recorded continually. After processing and exportation of the gradient and navigation data at 1Hz sample rate, 1GB of data will compress to around 2MB.

Gradiometer data was initially acquired in an internal coordinate system that is referenced to the axes of the three GGIs, which are the primary measurement components of the FTG. This data was later transformed into an East-North-Down coordinate system with x and y in the plane of the earth's surface and z perpendicular to that plane downward towards Earth.

Appendix 4 Positioning & Magnetometer System Details

Global Positioning System (GPS):

GPS data (position and Coordinated Universal Time) was acquired from a Novatel ProPak LB receiver system connected to a combined L1/L2/RTCM antenna. TerraSTAR's XP service was used to provide real-time differential corrections to the GPS data, enhancing the accuracy to approximately 0.1m for 95% of positions.

Airborne Magnetometer:

The Earth's magnetic field was recorded using a Geometrics 882 caesium magnetometer mounted in a boom (stinger) extending from the aircraft's tail. Data was recorded at 10Hz and compensated in real time by an RMS DAARC500 data acquisition system. The table below lists some of the optimal specifications as stated by the manufacturer Geometrics.

Table A4.1: G-882 Magnetometer specifications

Operating Principle:	Self-oscillating split-beam Cesium Vapor (nonradioactive)
Dynamic Range:	20 000 – 100 000 nT
Sensitivity:	< 0.0005 nT/√Hz rms
Heading Error:	< 0.15 nT over entire 360° polar and equatorial spin
Absolute Accuracy:	Better than 3 nT throughout range

Real-time compensation of local magnetic interference for the airborne magnetometer was provided by RMS Instruments' DAARC500 Data Acquisition System & Adaptive Aeromagnetic Real-Time Compensator. This system uses a three-axis fluxgate magnetometer to monitor the aircraft's position/motion and derive a mathematical solution that accurately describes the magnetic interference of the moving aircraft. The compensation accounts for the effects of permanent and induced magnetism, Eddy currents and heading errors from the sensors. A figure of merit (FOM) was performed to verify the effectiveness of the compensation system.

The DAARC500 system was also used for logging the differential GPS data as well as the magnetometer and radar altimeter data.

Base Magnetic Station:

The base station, used to monitor diurnal variations in the background field, was a GEM Systems GSM-19 Overhauser magnetometer. It was situated at a magnetically quiet location within the airport vicinity and left to record at 1Hz. A second station, of the same model, was situated nearby as a back-up measure. The stations were set to start recording before each flight commenced and the batteries were recharged at the end of the day. The following table lists some of the optimal specifications as stated by the manufacturer GEM Systems.

Table A4.2: GSM-19 Magnetometer specifications

Operating Principle:	Overhauser effect
Dynamic Range:	20 000 – 120 000 nT
Sensitivity:	0.022 nT @ 1 Hz
Resolution:	0.01 nT
Absolute Accuracy:	0.1 nT

Radar Altimeter:

In addition to the GPS receiver, the altitude of the aircraft was recorded in real-time with Honeywell Aerospace's KRA 405B radar altimeter. Unlike the GPS which provides altitude above the geoid every 1 second, the radar altimeter provides altitude above ground level every 0.1 second. A customised bias and drift correction was applied post-survey. Note that radar altimeters are generally ineffective at surveying offshore as they cannot measure readings that are below the water surface. The following table lists some of the optimal specifications as stated by the manufacturer Honeywell Aerospace.

Table A4.3: KRA 405B Radar Altimeter specifications

Frequency:	4.2 – 4.4 GHz
Operating Range:	0 to +2500 ft.
Accuracy:	3ft (0.91m) or $\pm 4\%$ (whichever is greater) at 0 to 500 feet and $\pm 5\%$ at 500 to 2500 feet.

Appendix 5 Air-FTG Data Quality Control

Bell Geospace has developed numerous methods over the course of its history to monitor and evaluate the quality of acquired Air-FTG data, both on and off field.

Real time QC:

Accelerations measured by the instrument during data acquisition were closely monitored along with many other indicators of instrument performance. On the main screen, the operators visually inspected the inline sums and cross gradients, position and temperature of the gyros, GGI case and block temperatures and the north, east, and vertical accelerations being measured. Any variances beyond the norm were closely monitored and whenever an error was detected, the acquisition was interrupted with appropriate action taken. Many other factors were also monitored that would help alert the operator to any unusual performance of the FTG system. These included strip charts, coefficient tables and on-site off-line analysis of the data.

Besides monitoring physical characteristics such as temperature, humidity and power draws, the operator watched instrument position, rotation rates and other parameters that would indicate data problems. Individual GGI signals were also observed on the scope for indicators of quality deterioration.

Office based QC:

As well as visual inspection of the Air-FTG data for noise content, the following numerical analytic criteria were applied:

- › Vertical Acceleration (Vacc) – This assessed accelerations from standalone accelerometers that were in the system but not used to measure the gradient. This gave indication of the induced (non-gravity related) accelerations that the system was being exposed to which may add noise to the signal.
- › Inline Sum – By definition the in-line energy of the data should sum to zero since it is a Laplacian Tensor. Practically, this is unachievable, thus threshold limits were determined that indicated if there was too much noise. For this, an



alternative method for evaluating the inline sum noise was derived. It is the normalised sum of the in-line energy ($= \text{sum (Inline)} / \sqrt{3}$), band=pass filtered at 0.033 – 0.1 Hz with a filter length of 256.

- › Line to Line QC – During processing the lines are compared to their neighbours. Since 3D-FTG is a truly three dimensional measurement, it is being affected by density variations in all directions. Therefore, signals on one line will be evident (perhaps larger or smaller) on neighbouring lines. By gridding neighbouring lines and comparing we can get an indication of noise. Bell Geospace has a patented system (Auto Evaluate) that does this automatically and provides a numerical analysis of the results which we compare to a determined threshold.

