Statement of Work


Proposal For:

# McKenzie County, North Dakota
# Digital Imagery and LiDAR Data

April 23, 2014

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# 1 EXECUTIVE SUMMARY

## 1.1 Project Understanding

Fugro understands the County is a requiring color aerial photography, LiDAR and options for oblique imagery within the geographic area outlined in the RFP. Fugro's full range of sensor collection capabilities, processing quality and capacity backed by Fugro's ISO9001:2008 quality management system compliments the County's request for diverse data collection and processing needs. Areas to be covered will include:

| Aerial Photography | Products |
|---|---|
| McKenzie County (2,929 Sq Mi) | ▪ 6-Inch Pixel (1" = 100' Scale) |
| LiDAR Area | Products |
| McKenzie County (2,929 Sq Mi) | ▪ LiDAR Point Cloud, Digital Terrain Model including breaklines for water features and 1' Topographic Contour Lines<br>▪ LiDAR data to be collected at 0.7 meter point spacing for 1' contour |
| Oblique Area | Products |
| McKenzie County (2,929 Sq Mi) | ▪ 6-Inch Pixel (1" = 100' Scale) |

## 1.2 Aerial RGB (Natural Color) Imagery, LiDAR and Oblique Acquisition

Following the notice to proceed (NTP) from the County and ground control acquisition, Fugro will mobilize the necessary number of aircraft equipped with the requested digital imagery or LiDAR sensors to McKenzie County where equipment and the flight/acquisition crew will be stationed for the duration of the data collection. Daily status reports will be delivered to Fugro's project manager and daily quality control measures will be taken to ensure raw data quality meets or exceeds standards and no coverage gaps exist.

Fugro will collect:

- Color (RGB) digital aerial imagery at the selected pixel resolution using the Leica ADS80. Resulting imagery will be used to produce orthophotography of the requested area of interest. The imagery be processed to the County's desired GSD (3" 6" 9" or 12").
- Either 1 meter point density or 0.7 meter point density LiDAR data using the Riegl LMS-Q680i adhering to the RFP LiDAR specifications for data collection, processing, point cloud and metadata deliverables
- If the Oblique option is selected, 5-way (4 oblique and one nadir) imagery will be acquired at a GSD and scale that will complement the Orthoimagery using Fugro's PanoramiX system.

## 1.3 Aerial Imagery, LiDAR and Oblique Processing

Fugro has read and understands the requirements of the RFP. Our proposal outlines in detail how we anticipate processing the data and delivering the data products. Deliverables include:

| General Deliverables | |
|---|---|
| ▪ Flight report | ▪ DEM files |
| ▪ Ground control survey report coordinates | ▪ 1' contour data |
| ▪ Triangulation report coordinates | ▪ Oblique imagery |
| ▪ Photo index (trajectory file) | ▪ Metadata files in accordance with the specifications outlined in the RFP |
| • One complete set of digital orthoimagery tiles | • Px Mapper Oblique Imagery Viewing Software – Desktop-based and Web-based versions |

# 2 ORTHOIMAGERY AND LIDAR IMPLEMENTATION PLAN

The technical approach described in the following section details Fugro's methodology to assure timely completion of all work by and/or before the required delivery deadlines. The approach includes project management techniques to demonstrate the organizational requirements to lead a project of this magnitude to success for a very low-risk exposure for your project. As detailed in the previous key personnel section we have included on this project team primary and back-up supervisory personnel for every major area of work. Your project has highly qualified management and supervisory personnel allocated to leading every phase with back-up and support to mitigate any interruption in the work flow and schedule.

## 2.1 Aerial Mission and Ground Control

### 2.1.1 Flight Planning

Flight planning will be performed using Fugro's proprietary J-Flight® software which is specifically suited for the proposed ADS80 SH82 digital imagery sensor as well as the Reigl Q6801 LiDAR Sensor. Using text-based information and the project boundary, the application creates a series of CAD files that include tile boundaries, GPS base station locations, and flight line locations with start/stop points for each acquisition block.

The flight altitude and photo scale are planned to achieve the specified image resolution and LiDAR point spacing for the each project area. The planning process pays particular attention to the specified area of interest in terms of topography, terrain relief and the inclusion of a buffer area extending past each County boundary. The required flight lines are designed in 2D mode. The JFlight software uses an elevation model (USGS 10-30 meter DEM or better) to generate 3D flight lines. The software ensures that image resolution and lateral overlaps remain within the required tolerances. The software pays particular attention to areas of large terrain changes and indicates where adjustments of flight parameters or breaks in flight lines are necessary. This step is seen as a key quality assurance check before finalizing any flight plans. If there are any issues highlighted during this QC phase, remedial action is taken and the check process repeated until the plan meets specification.

The digital files created by the J-Flight application are readable by the Leica Flight Control Management System (FCMS) that is installed onboard all Fugro aircraft. The coverage of the acquisition blocks may require modification due to weather or air traffic considerations, and these changes can be easily incorporated into the overall acquisition design using J-Flight and FCMS. In accordance with Fugro's ISO9001:2008-certified quality management plan, copies of the acquisition plans will be reviewed by our project manager immediately prior to the airborne mission.

A detailed flight plan will be submitted prior to initiation of the acquisition cycle for approval within 15 days prior to the acquisition start date. The accompanying shapefile for the flight plan will include the acquisition block reference; mission number; design altitude; direction of flight per line; sensor ID and description; and the proposed date of flight. Upon County approval, the flight plan will be published for use by the aircrews and ground support teams.

### 2.1.2 Ground Control

Fugro will provide all targeted ground control survey required to meet specifications under the proposed approach. The Fugro team will manage all of surveying requirements and will coordinate and oversee the following vital functions for this project:

- Project planning for GPS control and operation of airborne GPS base stations
- Logistics and coordination of survey crews
- Monumentation and reconnaissance
- GPS control surveying
- GPS data processing and quality control
- Preparation of reports and documentation

**Reconnaissance and Targeting:** Initial field reconnaissance will identify existing horizontal and vertical control monuments and determine if they are suitable for use. This field reconnaissance will also be used to determine new accessible GPS visible monument locations. Should additional ground control be required, the surveying team will select locations for control points using the approved control layout design. A standard photo control recovery form will be prepared for each new control point established to aid in future identification and a digital photograph will also be taken. This information will be used to assist in developing a detailed survey monument recovery sheet for each permanent monument in the network. Survey crews will use a uniform procedure to document new control, which will facilitate record keeping and metadata preparation.

Prior to the mobilization of aircraft, the survey project manager will coordinate the targeting and acquisition of all photo identifiable positions required. For targets selected on hard surfaces, the preference is to paint the target as this provides the most permanence and is most likely to be highly visible during the flight. Typically, white block filler paint is used, because it dries quickly and lasts for the entire flying season. For points selected on other surfaces, panels will be set using waterproof plastic.

**GPS Control Surveying:** Once the monumentation and control identification process is complete, GPS vector measurements will begin. Mission planning for each day's observation schedule is coordinated by the survey project manager. This planning includes scheduled observation time and duration and required travel time buffers for the GPS survey crew. An adequate number of vertical control monuments will be included in the GPS network to provide for the elevation accuracy requirements of the digital orthophotography and elevation development. When variable height tripods are used, survey crews record a minimum of two antenna height offsets for each observation to verify the vertical positions of each monument surveyed. Redundant observations are also included in the network configuration to provide a robust network adjustment.

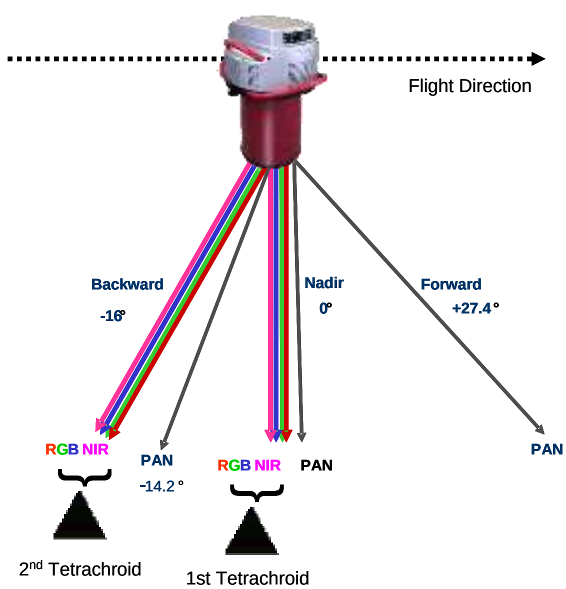
Airborne GPS (ABGPS) will be the primary control utilized on this project, reducing the costs associated with land surveying services while meeting the specified accuracies for the project. A dual frequency GPS receiver is mounted on the aircraft and records data at 200Hz frequency during the aerial photography/LiDAR mission. An onboard inertial measurement unit (IMU) is used to monitor the aircraft's rotational elements in order that the sensor pitch, roll and yaw are defined. The planning of PDOP (positional dilution of precision) of the satellite constellation during the photo flight will be smaller than 5, and GPS measurements will be made on the basis of a minimum of 5 satellites, each greater than or equal to 10 degrees above the horizon. To further ensure the accuracy and integrity of all acquired mapping data and their derivatives, and maximum base line of 30 miles will be used for GPS positioning.

### 2.1.3 Large Format Digital Image Sensor: ADS80-SH82

Fugro will operate the Leica ADS80 Digital Sensor upgraded with Sensor Head 82 (ADS80-SH82) that incorporates the latest in sensor technology, optics, electronics, data transfer, and storage. Fugro has been successfully operating the Leica ADS line of digital imagery sensors for over 10 years.

The ADS80-SH82 is capable of data collection at a wide range of ground sample distances (GSD), depending on the altitude and airspeed of the mission. The typical GSD range for digital orthoimagery or rectified imagery produced from ADS80-SH82 data is 5 cm – 2 m.

This version of the ADS80-SH82 camera collects a total of 12 bands of imagery simultaneously, with 12,000 pixels per band and a pixel size of 6.5 microns. Two tetrachroid beam splitters (nadir and 16° backward viewing angles) allow acquisition of red, green, blue, and near-infrared bands at the same viewing angle for perfect co-registration. Radiometric resolution of compressed data (10-bit and 12-bit) dramatically improves image quality in shadow and highlighted areas.




**ADS80-SH82 Sensor Configuration**

The ADS80-SH82 is also equipped with an Applanix POS inertial measurement unit (IMU) mounted on a PAV80 gyro-stabilized platform. The digital imagery, GPS, and IMU position and orientation data are recorded during each sortie and are written to the flash-disk based mass memory unit (MMU) that is part of the sensor control system. Using flashdisk technology provides higher reliablility and significantly reduces payload weight. The flash disk MMU has a capacity of 480 Gb per unit or 980 Gb joint volume which equates to 9.7 hours of recording 3 pancromatic and 4 spectral bands of ADS80 data.

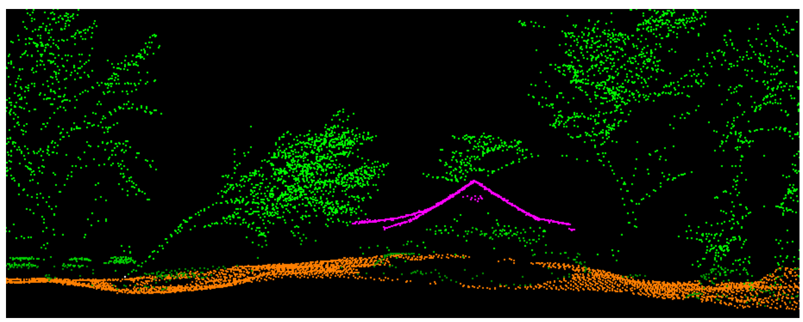
The ADS80 bands can be exported as stereo pairs in all commonly read formats to develop planimetric, topographic, and other types of photogrammetrically-derived data products. The stereo models are accompanied by a digital file containing the exterior orientation parameters derived from the bundle triangulation adjustment and their coverage is controllable by the technician; a typical model size is 12,000 by 5,000 pixels with a 200 pixel overlap between models along track.

It should be noted that all of the CCD arrays are uniform in pixel resolution. All spectral bands are collected at the same native pixel resolution; therefore pan-sharpening of color and IR bands is not necessary. This provides greater radiometric integrity for image classification and thematic mapping applications. There are also no dead pixels in any of the CCD arrays. Digital imagery from the ADS80-SH82 is processed using Leica's XPRO processing software suite combined with Fugro's large parallel processing capacity represented by the Condor© computer cluster with 288Tb of processing memmory. With the system's powerful auto-correlation algorithms, imagery from the ADS80-SH82 can be rapidly developed into orthophotography and DEM products.

### 2.1.4 LiDAR - Riegl LMS-Q680i

The Riegl LMS-Q680i collects high density LiDAR with its powerful laser source, multiple time around (MTA) processing technology and full waveform digitization. With a variable scan rate of 10 to 200 scan lines per second and variable pulse rate from 80,000 to 400,000 ranges per second, the system incorporates a rotating polygon mirror with fixed 60 degree field of view, thus eliminating the torsion errors inherent with oscillating mirror LiDAR Systems. The rotating mirror technology results in improved positional accuracy to the edge of the field of view and greater coverage while achieving overall vertical accuracies of 9-15 cm RMSE with up to 15 discrete returns per LiDAR pulse (offering more foliage detail - exceeding project specifications).

The rotating mirror, variable scan rate and variable laser pulse rate results in a highly uniform point density and distribution in both the laser sensor cross track and along track. This allows for the use of the entire collection swath thus resulting in greater collection efficiency. The rotating mirror provides a continuous view at nadir creating a smooth evenly distributed LiDAR point cloud with reduced point to point variability and thus greater accuracy.



Riegl LMS-Q680i 4ppsm Classified Point Cloud (Cross Section)

### 2.1.5 Flight and Aerial Imagery Acquisition

Following the receipt of the Flight Authorization and the successive establishment of active GPS base, we propose to conduct aerial acquisition for any requested pixel resolution and point density controlled by airborne GPS and IMU with the support of the developed ground control network designed to meet NMAS Accuracy for 1"=100' (200') scale imagery. We will utilize the necessary number of our four (4) matched Leica ADS80-SH82 direct line scanner aboard its dedicated twin-engine aircraft.

During the flight window, it is expected that the frequency of communications will greatly increase. County staff will be notified by phone and by email when aircraft are mobilized within the area. The project manager will provide frequent verbal and email status reports to the designated points-of-contact as imagery is collected. At the completion of the acquisition phase, prior to production, Fugro will submit a quality control report demonstrating compliance with the aerial imagery collection specifications.

### 2.1.6 Raw Data Quality Control

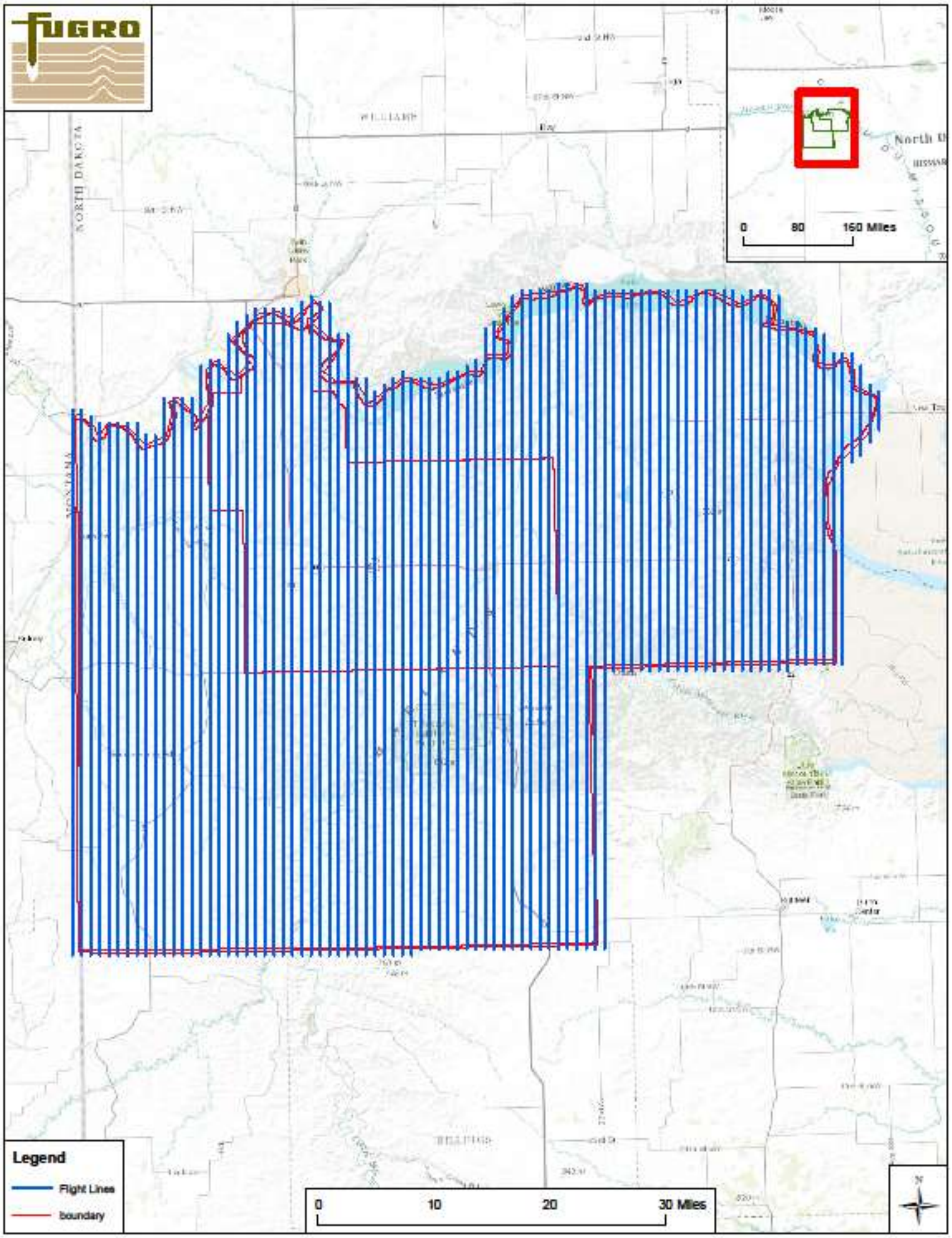
Data (Imagery and LiDAR) from each sortie will be downloaded on-site and reviewed to verify quality and that complete project area coverage has been acquired. Inspection of the original images will check for tilt, overlap, crab, cloud cover, snow cover, and proper sun angle.

Airborne GPS and IMU data will be field processed to ensure that the GPS satellite geometry and that IMU data will support the accuracy requirements. If problems of data quality or project coverage are found, re-flights may be called for immediately. Following successful acquisition of the imagery, receipt of elevation data, Fugro processing center(s) will begin full data production.

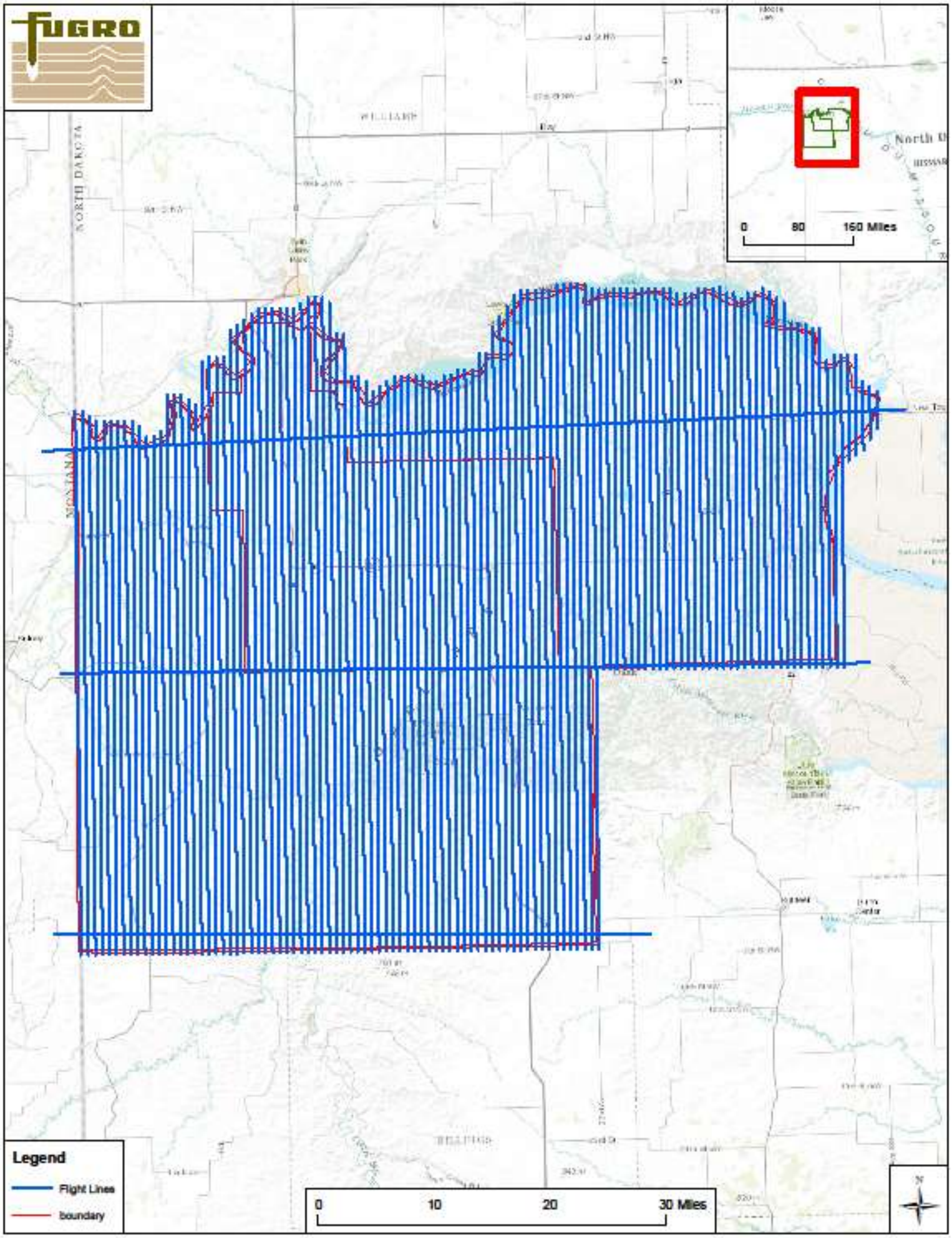
### 2.1.7 Preliminary Flight and Ground Control Layout Plan

The Maps on the following pages detail Fugro's preliminary flight and ground control plan.

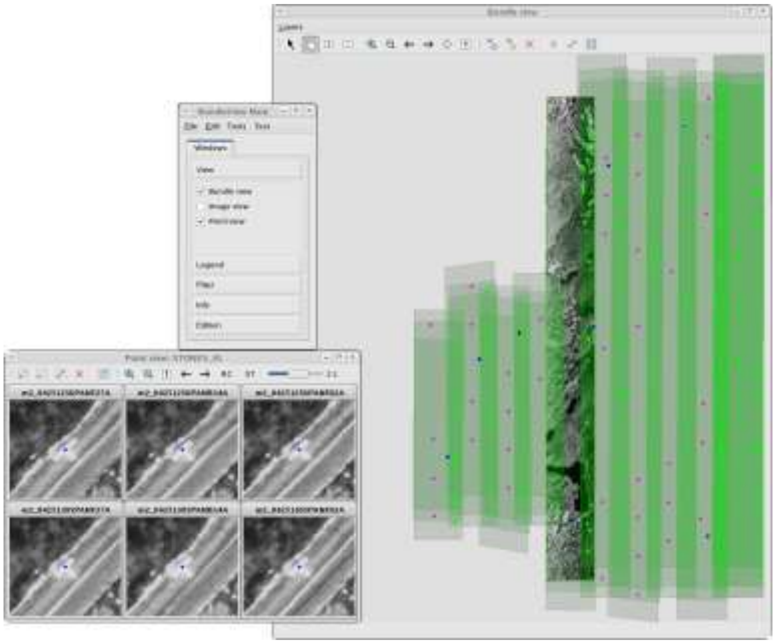
**Line Index of Flight: McKenzie County Imagery 6in GSD**



## Line Index of Flight: McKenzie County Lidar 0.7m post spaced



## 2.2 Aerial Triangulation



Fugro performs aerotriangulation adjustments for imagery acquired from the ADS80-SH82 sensor using softcopy and photogrammetric workstations. Fugro will provide documentation to the County of the results of the aerotriangulation adjustment in the form of a report and a series of digital files showing the final values assigned to the pass and tie points as well as the final RMSE of the final adjustment. The digital file containing the orientation parameters derived from the aerotriangulation adjustment can be read by both softcopy and analytical stereo plotting instruments directly. Once the ADS80-SH82 data has been collected and accepted, Fugro's production center will begin the orthoimagery process.

Following is a step-by-step description of the pre-production QC steps and aerotriangulation (AT) process prior to stereo-compilation. Documentation of this methodology and results of the aerotriangulation adjustment will be prepared and delivered to the County for review.

**Step 1.** The unprocessed ADS80-SH82 data and accompanying GPS and inertial measurement unit (IMU) data for one or more collections are downloaded from the portable hard disks and checked to verify that no files are corrupted and that all data can be sent through production. Sample segments of the imagery are inspected in an uncorrected state to verify the integrity of each data collection.

**Step 2.** The AT is performed on the panchromatic channels using all 3 look angles; facing Forward, Back and Nadir. After the bundle adjustment is processed, the resulting parameters are propagated to all remaining channels in the collection/block.

**Step 3.** Aerotriangulation is accomplished as a component of Fugro's XPro process. The GCPs, GPS, and IMU information are imported and tie points between imagery strips are identified either manually or through an automated matching process.

**Step 4.** The AT produces a bundle adjustment for each data block (consisting of one or multiple collections, averaging 5 to 10). The results of the bundle adjustment are verified through an inspection of the derived residuals for each GCP and tie point. In addition, orthophoto samples are generated over the GCPs to assess the absolute accuracy, while orthophoto samples between adjacent tracks are generated to assess the relative accuracy.

**Step 5.** Final AT results are inspected by the photogrammetric technician to confirm the accuracy meets the proposed specification.

A full report on the methodology and results of the AT adjustment will be prepared and delivered to the County shortly after completion of this phase. **All AT processes will be performed under the supervision of an ASPRS-certified Photogrammetrist to ensure compliance with accuracy standards.**

| AEROTRIANGULATION PROCESSING HARDWARE/SOFTWARE | | |
|---|---|---|
| TYPE MANUFACTURER/MODEL | HARDWARE/SOFTWARE | NUMBER OF WORKSTATIONS/LICENSES |
| XPro | Software | 2 |
| Intergraph SSK | Software | 4 |
| SOCET SET | Software | 10 |
| DAT-EM | Software | 1 |

## 2.3 Orthoimagery and LiDAR Processing

### 2.3.1 Digital Orthophotography Production

The following digital image production process is unique to Fugro and has been developed specifically for push-broom sensors like the ADS80-SH82.

The core application for ADS80-SH82 digital image sensor processing is the XPro software package from Leica. XPro was developed in parallel with the sensor and designed to take the data from the raw state to an intermediate product that can be exploited by more traditional photogrammetry software. Typical intermediate products are stereomodels and strip orthophotos.

| Orthorectification Specifications | |
|---|---|
| Processed Image Type | R,G,B (Color) |
| Pixel Resolution Options | 6-inch GSD |
| Delivery Format | GEOTIFF |
| Delivery Media | USB 2.0 portable HD(s). |

In XPro terminology, the raw images from the camera are called L0 images, stereo viewable images are called L1 images and strip orthophoto images are called L2 images.

Fugro will establish a QC plan for acceptance of all products delivered and will prepare documentation that is consistent with the acceptance review. A key feature in XPro is the ability to apply the factory radiometric calibration along with the recorded integration interval to yield imagery with DN (grayscale) values scaled to true at-sensor radiances. This simply means minimal edits to color contrast which results in more consistent color imagery delivery to the Cooperative.

#### 2.3.1.1 Process for Creating Color Digital Orthoimagery

**Step 1 – Raw Image Download**

On completion of each image acquisition mission, the system operator removes the ADS80 MM80 (mass memory) storage container from the aircraft and using a field workstation, downloads the data using XPro. This enables an immediate real-time look at image quality and coverage. The data is then copied to removable hard drives for shipment to our main processing facility. A duplicate copy of the data is maintained in the field until the data is received and archived.

**Step 2 – Differential GPS and IMU Processing**

Download of the sensor data in step 1 includes the data from the integrated IMU and GPS. Those data sets are differentially post-processed with the Applanix POS GPS software package against one or more ground base stations. GPS base stations may be located at an airport and operated by the flight crew, established and operated within the project area by the ground surveyor, or a CORS station. After the differential GPS solution has been checked and verified, the Applanix POSproc program is used to compute an integrated GPS/IMU navigation solution at one-second intervals.

**Step 3 – Georeference of Raw L0 Imagery**

Using the GPS/IMU trajectory and orientations computed in step 2 plus the scan line times recorded by the sensor and the sensor calibration, XPro interpolates x, y, z, omega, phi, kappa exterior orientation for each scan line and each CCD array. The data is written to the Orientation Data File (ODF).

**Step 4 – Creation of L1 Imagery**

Using the ODF produced in step 3 and the L0 imagery, the XPro quick rectifier is run to produce L1 images, which are in effect “flat-plane” orthos scaled to the project’s average terrain elevation. The processing removes most aircraft motion and provides epipolar geometry for stereo viewing, automated aerotriangulation and automated DEM extraction.

**Step 5 – Aerotriangulation**

IMU systems are subject to drift when flown in a straight line for extended periods. To remove such biases and increase the overall accuracy of the orientation data, Fugro restricts flight line length and an aerotriangulation step is performed. Our preferred approach is to use the BAE Socet Set APM program to automatically select many pass points to tie each band of a flight strip together. These become 3-ray points because each unique ground position is imaged at three different times in each of the pan channels. The three "look angles" of, 27° forward, 2° forward, and 14° back provide rigid geometry. In a second APM run, the points are transferred to the adjacent flight strips. Typically several thousand points are transferred between strips. The APM process is computer intensive and is therefore run on the Condor computer cluster. Once the pass points have been successfully transferred, the Leica Orima bundle adjustment program is run to compute the adjusted ODF for all bands and CCD arrays.

**Step 6 – DEM Extraction (if required)**

A Digital Elevation Model (DEM) is required for orthophoto production. In the absence of an existing DEM, the BAE Automatic Terrain Extraction (ATE) program can process the ADS L1 stereo models to produce ortho suitable DEM's. Typical project methods are to provide the ortho imagery using an auto-correlated DEM. This process would speed up the ortho deliverable without having to wait for a compiled DEM or edited LiDAR dataset while meeting NMAS Accuacy and ASPRS Class I Standards up to 1"=40' scale mapping. Typically, grid DEM's are created and then stereo edited with the BAE Interactive Terrain Edit program (ITE). ITE is also used as a quality control tool to examine the correlated DEM produced by ATE. For this project, we will utilize an existing, auto-correlated DEM, compiled DEM to produce any requested GSD imagery.

**Step 7 – Creation of L2 strip ortho images**

With the refined ODF from aerotriangulation and a suitable DEM, XPro is again used to produce a strip orthophoto for all or a portion of a flight line. This task is computer intensive and normally the process is divided across many nodes of the Condor computer cluster. Several processing options are available including creation of single band, RGB, FCIR or 4-band orthophoto images. The factory radiometric calibration is applied and optionally the modified Chavez Atmospheric (haze removal) correction may be applied. The output image is segmented so as to stay under the 4GB tiff file size limit. Each of the segments carries its own geo-reference so further processing may be done on individual segments.

### 2.3.1.2 Radiometry

Fugro image processing ensures that two hundred and fifty six (256) tonal levels ranging from 0 (black) to 255 (white) of image brightness will be represented. There will be no areas of an orthophoto where the process was incomplete due to image gaps or lack of data. Fugro will radiometrically adjust all orthoimagery, as needed, so that adjacent digital orthophotos will be displayed simultaneously without an obvious visual edge seam between them.

Radiometric processing will compensate for the effects of temperature, aperture, and other radiometric factors. A set of intermediate images are generated from radiometric processing and are written to the intermediate storage on the central server. Using our proprietary image color and radiometric balancing software, we implement a process that reduces the lens vignette and any image hotspot effects (sun flare).

**Before Radiometric Adjustment**

**After Radiometric Adjustment**

The program then applies a global histogram manipulation to balance the image in tone, contrast, and color to re-create the "real world" view of the project area. This is accomplished while maintaining the largest dynamic range possible.

This software allows us to easily switch between viewing each individual image and an entire project block for balancing. We use these techniques to confirm the radiometric balance for AT Block on our projects. The natural color, RGB, bands will be color balanced across the entire study area to the greatest extent possible to allow viewing of the image tiles as a visually seamless mosaic.

Care will be taken during radiometric processing to avoid loss of detail in shadows and overexposure on bright surfaces such as bare ground and light colored building roofs. Additionally, the color infrared band will be radiometrically processed in a manner that preserves original image characteristics to the greatest extent practical. Systematic radiometric corrections to reduce sun angle and sensor variations are desired. Corrections for seasonal variations in ground cover are <u>not</u> executed.

### 2.3.1.3 Image Mosaicing

Mosaic lines between adjacent flight lines are initially developed automatically using commercial software. The Geospatial Analyst will QC the result and manually adjust the seam lines to improve the overall quality of the mosaic and where necessary to meet project specification:

- Mosaic lines shall not cross through buildings, bridges, or other man-made structures.
- Join lines between overlapping images shall be interactively selected so as to minimize tonal variations and visible join lines
- The final mosaics must reflect consistent tone and contrast across the entire project area.

**Additional Fugro Mosaic Quality Control**

- Improve localized radiometric balance and minimize abrupt tonal differences between flight lines.
- Avoid smears and omit acquisition issues such as clouds, shadows, and turbulence that are covered by approved reflights.
- Reduce building lean so that roads are visible and utilize filler lines that provide additional sidelap coverage
- Avoid ground features, such as building roof tops, water towers, and radio towers, and elevated transportation structures

### 2.3.1.4 Image Quality

The completed digital orthophotos will undergo a 100% QC for image quality by the Geospatial Analyst.

- Any distortion of bridges, overpasses and elevated roadways and excessive pulling or smearing of ground features from the surface are rejected and edited to acceptable quality.
- Minor artifacts and localized radiometric inconsistencies are corrected using Adobe Photoshop in an interactive editing session.
- It should be noted that large bodies of open water are typically left untreated, unless otherwise specified by customer. Some radiometric inconsistency will remain in these areas; however, all tiles containing water are only filled to their extent.
- Other items left untreated, unless otherwise specified by the customer or limit the usability of the imagery such as smoke from fires, reflective spots or planes at lower attitude.

**Wavy bridge before and after correction and water along seam line left untreated**

#### 2.3.1.5 Final Orthophoto Production Processes

**Step 1:** Digital imagery from the ADS80-SH82 sensor is loaded on to the orthophoto production workstation and visually re-checked for completeness, cleanliness, and image quality on the workstation.

**Step 2:** The digital surface model is imported and written to the correct subdirectory on disk. The coordinate/projection system is verified at this stage in the process. In compliance with the software coordinate system requirements, horizontal values will be expressed in meters in Universal Transverse Mercator (UTM) Zone 16/17, NAD83.

**Step 3**: The surface model is re-inspected for missing or erroneous data points. The digital orthophoto workstation has the ability to add breaklines or additional points interactively while in stereo mode. The orthophoto engineer can modify the DEM/DSM files, as needed, which saves considerable production time. Any interactive modifications to the DEM/DSM data will be saved and will overwrite the previous file to ensure that the most up-to-date version of the elevation data is delivered to the County.

**Step 4:** A complete differential rectification process will be carried out using a cubic convolution algorithm that removes image displacement due to topographic relief, tip and tilt of the aircraft at the moment of exposure and that removes radial distortion within the camera. Each final orthophoto is produced at the specified resolution. In the initial stages of production the digital orthophotos will cover the maximum extent of each aerial image footprint.

**Step 5:** Each digital orthophoto image will be visually checked for accuracy on the workstation screen. The absolute accuracy of paneled control that is visible on the image will be compared against a CADD file containing the point locations of the orthos. Accuracy is verified by overlaying and comparing the locations of the control in vector form. The digital orthophotos are edge-matched. Dependent on the outcome of this inspection, the input material is corrected and the ortho is re-run immediately or the input material is returned to the production unit responsible for correction.

**Step 6:** As a block of digital orthophotos are being inspected and approved for accuracy, the files are copied to the network and transferred to the ortho finishing team. This production unit is charged with radiometrically correcting the orthophotos prior to completing the mosaic and clipping of the final tiles. The image-processing technician performs a histogram analysis of several images that contain different land forms (urban, agricultural, forested, etc.) and establishes a histogram that best preserves detail in highlight and shadow areas. Fugro has developed a proprietary piece of software called “Image Dodging.” This radiometric correction algorithm is used in batch and interactive modes. Used in this fashion, this routine eliminates density changes due to sun angle and changes in flight direction.

**Step 7:** At this point, the images have been balanced internally, but there are global differences in color and brightness that are adjusted interactively. The technician assigns correction values for each orthophoto then displays the corrected files to assess the effectiveness of the adjustment. This process is repeated until the match is considered near seamless. These files are then returned to digital orthophoto production to mosaic the images.

Images are mosaicked using automated processing but the location of seam lines are set up interactively by the technician to ensure that mosaic lines are placed in areas that avoid buildings, bridges, elevated roadways, or other features that would highlight the seam lines. The mosaic lines can be feathered using a proprietary software routine that was developed to further improve the transition from frame to frame. Mosaics are produced in sections that correspond to a block of final orthophoto tiles. The final tile scheme provided by the partners is clipped from the mosaics.

**Step 8:** The finishing department performs final Q/C visual checks for orthophoto image quality. Image smear caused by the sheer steep terrain of mountain edges will be processed to minimize this effect in the isolated areas where it may appear. Depending on the size and location of the flaw, Photoshop provides several available tools to remove the flaw.

**Step 9:** The final orthophoto images also are written out in uncompressed TIFF format containing the full 16-bit (per band) radiometric values per pixel and wavelength.

**Step 10:** FGDC compliant metadata files in the specified file format are created and will incorporate individual requirements

### 2.3.2 LiDAR Production

#### 2.3.2.1 Verification of Data Usability / Raw Data Quality Control

All acquired LiDAR data goes through a ***preliminary*** review to assure that complete coverage is obtained and that there are no gaps between flight lines before the flight crew leaves the project site. Once back in the office, the data is run through a complete iteration of processing to ensure that it is complete, uncorrupted, and that the entire project area has been covered without gaps between flight lines. There are essentially three steps to this processing.

#### 2.3.2.2 GPS/IMU Processing

Airborne GPS and IMU data is immediately processed using the airport GPS base station data, which is available to the flight crew upon landing the plane. This ensures the integrity of all the mission data. These results are used to perform the initial LiDAR system calibration test.

#### 2.3.2.3 Raw LiDAR Data Processing

The technician first processes the raw data to LAS format flight lines with full resolution output before performing QC. A starting configuration file is used in this process, which contains the latest calibration parameters for the sensor. The technician also generates flight line trajectories for each of the flight lines during this process.

#### 2.3.2.4 Verification of Coverage and Data Quality

The following steps and quality control measures are performed by highly qualified LiDAR technicians and supervisors and verify complete coverage and ensure data quality:

- ✓ Trajectory files are checked to ensure completeness of acquisition for the flight lines, calibration lines, and cross flight lines.
- ✓ Intensity images are generated for the entire lift at the required nominal post spacing. Visually checks of the intensity images against the project boundary are performed to ensure full coverage to the buffer area.
- ✓ The intensity histogram will be analyzed to ensure the quality of the intensity values.
- ✓ Thorough review of the data is performed to identify any data gaps in project area.
- ✓ A sample TIN surface is generated to ensure no anomalies are present in the data.
- ✓ Turbulence is inspected for each flight line. If any adverse quality issues are discovered, the flight line is rejected and reflown.
- ✓ The achieved post spacing will be evaluated against project specified NPS and also checked to make sure there is clustering in point distribution.

### 2.3.3 LiDAR Data Processing

Data processing includes the following 4 production steps for generating the final deliverables:

- Raw data processing and boresight
- Pre-processing
- Post-processing
- Product development

Quality control steps are incorporated throughout each step and are described in the following sections.

#### 2.3.3.1 Raw Data Processing and Boresight

Raw data processing is the reduction of raw LiDAR, IMU, and GPS data into XYZ points. This is a hardware-specific, vendor-proprietary process. The raw LiDAR data processing algorithms use the sensor's complex set of electronic timing signals to compute ranges or distances to a reflective surface. The ranges must be combined with positional information from the GPS/IMU system to orient those ranges in 3D space and to produce XYZ points. As with any such electronic measuring system, systematic errors can be introduced from a variety of internal and external sources – instrument timing errors, effects of the atmosphere, initialization errors and so on.

The boresight for each lift is done individually as the solution may change slightly from lift to lift. The following steps describe the Raw Data Processing and Boresight process:

- Technicians process the raw data to LAS format flight lines using the final GPS/IMU solution. This LAS data set is used as source data for boresight.
- Technicians first use Fugro proprietary and commercial software to calculate initial boresight adjustment angles based on sample areas within the lift. These areas cover calibration flight lines collected in the lift, cross tie and production flight lines. These areas are well distributed in the lift coverage and cover multiple terrain types that are necessary for boresight angle calculation. The technician analyzes the results and makes any necessary additional adjustment until it is acceptable for the selected areas. The boresight angle adjustment process will ensure proper alignment between different look angles as well as between flight line overlaps.
- Once the boresight angle calculation is complete for the project, the adjusted settings are applied to all of the flight lines of the lift and checked for consistency. Technician utilize commercial and proprietary software packages to analyze the matching between flight line overlaps for the entire lift and adjust as necessary until the results meet the project specifications.

Once all lifts are completed with boresight adjustment individually, the technician will check and correct the vertical misalignment of all flight lines and also the matching between data and ground truth.

The technician will run a final vertical accuracy check of the boresighted flight lines against the surveyed check points after the z correction to ensure meeting the requirement of FVA = 17.64 cm at 95% (Required Accuracy).

#### 2.3.3.2 Pre-processing

The project will be set up for filtering once boresighting is complete for the project and all lifts are tied to ground control. The LiDAR data will be cut to production tiles. The flight line overlap points will be reclassified temporarily for editing purposes.

#### 2.3.3.3 Post-Processing

Fugro has developed a unique, time efficient, and cost effective method for processing LiDAR data.

Once boresighting is complete for the project, the project will be set up for automatic classification fist. The LIDAR data will be cut to production tiles. The flight line Overlap points, Noise points and Ground points will be classified automatically in this process. We utilize commercial software, as well as proprietary, in-house developed software for automatic filtering. The parameters used in the process are customized for each terrain type per project to obtain optimum results. The algorithm has the ability to process large amounts of elevation point data in batch mode. Conceptually, the goal of automated processing is to classify the points to their proper classification as accurate as possible automatically, thereby reducing the amount of manual editing that is required.

Once the automated filtering has been completed, the files are run through a visual inspection to ensure that the filtering was not too aggressive or not aggressive enough. In cases where the filtering is too aggressive and important terrain have been filtered out, the data is either run through a different filter within local area or is corrected during the manual filtering process. Interactive editing is completed in visualization software that provides manual and automatic point classification tools. Fugro utilizes commercial and proprietary software for this process. All manually inspected tiles will then go through a peer review to ensure proper editing and consistency.

After the manual editing and peer review, all tiles will go through another final automated classification routine. This process ensures only the required classifications are used in the final product (all points classified into any temporary classed during manual editing will be re-classified into proper customer specified classifications). During this process, the points originally classified as flight line overlap will tagged as withheld points.

### 2.3.4 Product development

All collected flight lines will be included in generating this product. The flight lines will go through the following processes: 1) assign flight line ID to each points base on flight line trajectory; 2) cut long flight lines to under 2GB file size; 3) Re-project flight lines files to deliverable projection/datum and unit; 4) assign file source ID; 5) final QC of data format and coverage.

#### 2.3.4.1 Classified Point Cloud Data

Once manual inspection, QC and final autofilter is done for the LiDAR tiles, the LAS data will be packaged to the project specified tiling scheme, clipped to project boundary including the buffer and LAS 1.2 format. It will also be reprojected to project specified projection, datum and unit. The file header will be formatted to meet project specification with File Source ID assigned. This Classified Point Cloud product will be use for the generation of derived products.

This product will be delivered in fully compliant LAS v1.2, Point Record Format 1 with Adjusted Standard GPS Time at a precision sufficient to allow unique timestamps for each return. Georeference information will be included in all LAS file headers. Intensity values will be included for each point. Each tile will have unique File Source ID assigned. The Point Source ID will match to the flight line ID in flight trajectory files.

The following classification will be included:

Class 1 – Processed, but unclassified

Class 2 – Bare-earth ground

Class 3 – Low Vegetation

Class 4 – Medium Vegetation

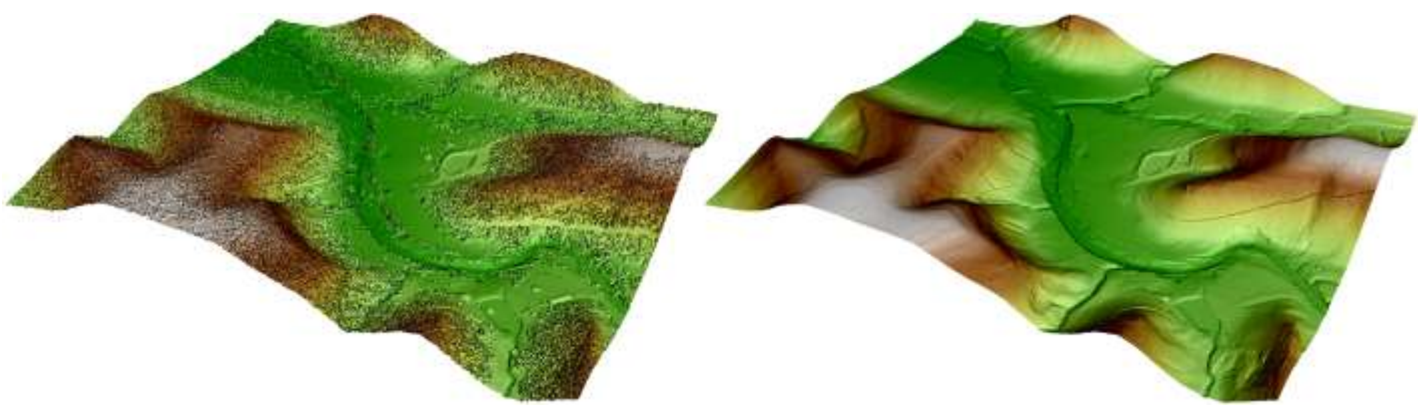
Class 5 – High Vegetation

Class 6 - Building

Class 7 – Noise (low or high, manually identified, if needed)

Class 9 – Water

Class 10 – Ignored Ground (Breakline Proximity)



#### 2.3.4.2 Raw Point Cloud Data

The raw, unclassified data is delivered in fully compliant LAS v1.2, Point Record Format 1 with Adjusted Standard GPS Time. Georeference information is included in all LAS file headers. Intensity values are included for each point. The long swaths will be cut to file size not exceed 2GB, 1 file per swath. Each swath will be assigned a unique File Source ID. The Point Source ID will match to the flight line ID in flight trajectory files and will be the same as what are used in classified point cloud data.

#### 2.3.4.3 Bare Earth Surface (Raster DEM)

The bare earth DEM will be generated using the bare earth points to a resolution => NPS. Once the deliverable LAS files are generated for the entire project area and have been QC'ed they will be used to produce the bare earth DEM.

The bare earth DEM is and the 3D hydro breaklines are generated to the limits of the buffered area, with the accuracy requirements only applying to the defined project area. Once the deliverable LAS files are generated for the entire project area and have been QC'ed, and 3D breaklines have been collected and QC'ed, they are used to produce the bare earth DEM. First the bare earth points that fall within 1*NPS along the hydro breaklines are classified as class 10 to be excluded from the DEM generation process. This is analogous to the removal of mass points for the same reason in a traditional photogrammetrically compiled DTM. This process will be done in batch using proprietary software.

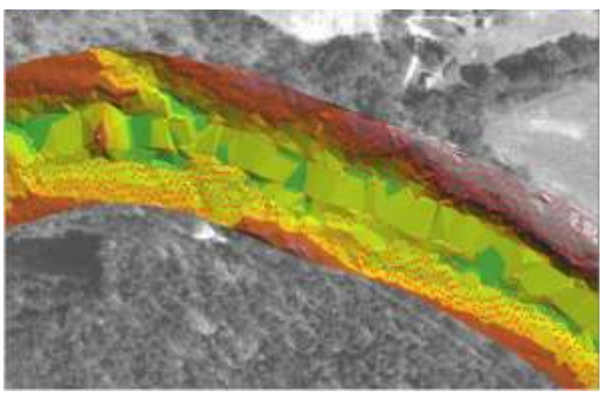
The technician will then use Fugro proprietary software for the production of LiDAR-derived hydro-flattened bare earth DEM surface in initial grid format at 2m GSD. Water bodies (inland ponds and lakes), inland streams and rivers, and other non-tidal water bodies will be hydro-flattened within the DEM. Hydro-flattening will be applied to all water impoundments, natural or man-made, that are larger than ~2 acres in area, to all streams that are nominally wider than 100', and to all non-tidal boundary waters bordering the project area, regardless of size. This process will be done in batch.

Once the initial, hydro-flattened bare earth DEM is generated, the technician checks the tiles to ensure that the grid spacing meets specifications. The technician will also check the surface to ensure proper hydro-flattening. The entire data set will be checked for completed project coverage. Once the data has been checked, the tiles are then converted to ERDAS Imagine format. Georeference information will be included in raster files. Void areas (i.e., areas outside the project boundary but within the tiling scheme) will be coded using "NODATA" value -9999.

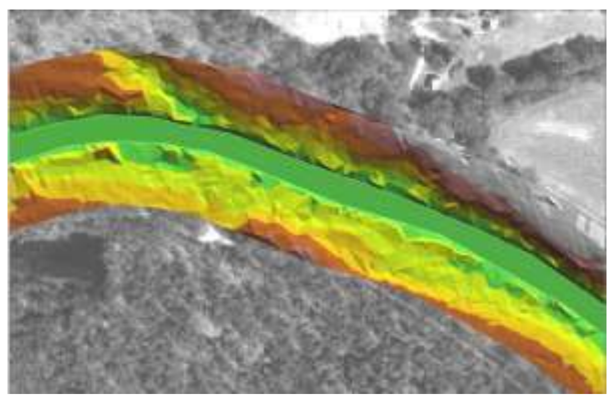
#### 2.3.4.4 Generate Hydro-Flattening Breaklines

Breaklines representing the banks of streams, rivers, ponds, lakes, oceans, and islands are extracted and converted into polygon shapefiles. These are used in the classification process of the LiDAR point cloud data where points that exist within water bodies are re-classified to Class 9. The 3D hydro breakline vectors are also used in Hydro Flattened Bare Earth DEM creation where the water bodies defined by these vectors are flattened in the DEM surface. This process ensures that the bare-earth LiDAR product matches seamlessly with the hydro breakline data.

LiDAR data consists only of points, which are not suited to defining water flow through the terrain. Hydro breaklines are required to flow in a downhill direction and may deviate from the underlying LiDAR terrain surface. Please refer below to an illustrated example of why hydro breaklines are important:



TIN unsuitable for H&H modeling prior to hydro enforcement.



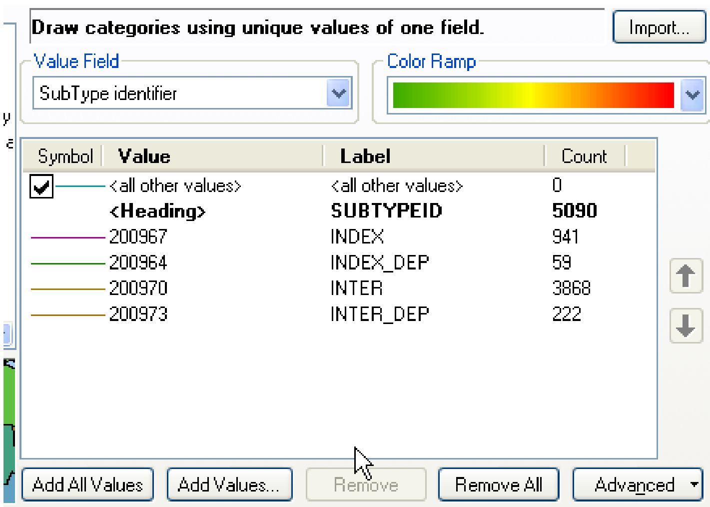
Resulting TIN after hydro flattening

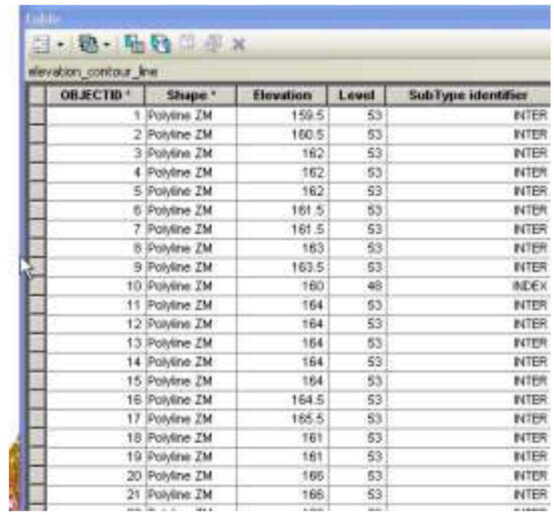
### 2.4 Topology / Contour Development

We've completed a thorough review of the project area, base LiDAR specifications and deliverables. To create contours using LiDAR data, Fugro will:

- Review the project area and hydro features. Fugro's compilers will collect additional hydro flattened breaklines of water features that are outside of the base project scope (smaller ponds, skinnier streams and rivers) to properly route the contours for a more cartographically correct dataset
- Bring LAS and breakline data into MicroStation using the software overlay package of TerraSolid (TerraScan and TerraModeler modules) and create contour key points. Different than a model key point typically used for DEM creation. Ultimately choosing LiDAR points that best represent the contour lines vs a grid
- Contour key points are created in batch mode to ensure the tying of all contours from edge to edge

- Contours key points run through a quality and completeness check prior to running the contours
- Contours are now generated over the entire project area in tied tiles before converting to an Arc GeoDataBase.
- Final edit is accomplished on the project wide dataset and converted to the desired GeoDatabase:
    - Contour index: intermediate, index depression and intermediate depression are represented in the GeoDatabase




| OBJECTID * | Shape * | Elevation | Level | SubType identifier |
|---|---|---|---|---|
| 1 | Polyline ZM | 159.5 | 53 | INTER |
| 2 | Polyline ZM | 160.5 | 53 | INTER |
| 3 | Polyline ZM | 162 | 53 | INTER |
| 4 | Polyline ZM | 162 | 53 | INTER |
| 5 | Polyline ZM | 162 | 53 | INTER |
| 6 | Polyline ZM | 161.5 | 53 | INTER |
| 7 | Polyline ZM | 161.5 | 53 | INTER |
| 8 | Polyline ZM | 163 | 53 | INTER |
| 9 | Polyline ZM | 163.5 | 53 | INTER |
| 10 | Polyline ZM | 160 | 48 | INDEX |
| 11 | Polyline ZM | 164 | 53 | INTER |
| 12 | Polyline ZM | 164 | 53 | INTER |
| 13 | Polyline ZM | 164 | 53 | INTER |
| 14 | Polyline ZM | 164 | 53 | INTER |
| 15 | Polyline ZM | 164 | 53 | INTER |
| 16 | Polyline ZM | 164.5 | 53 | INTER |
| 17 | Polyline ZM | 165.5 | 53 | INTER |
| 18 | Polyline ZM | 161 | 53 | INTER |
| 19 | Polyline ZM | 161 | 53 | INTER |
| 20 | Polyline ZM | 166 | 53 | INTER |
| 21 | Polyline ZM | 166 | 53 | INTER |

- Contour data is reviewed in Arc for topology errors, spikes, alignments, etc. and adjusted manually for best terrain representation
- Contour data runs through topology checks until all topology errors pass QC

# 3 ADDITIONAL INFORMATION

## 3.1 Deliverables

| | Area |
|---|---|
| ▪ 6” Pixel Resolution Oblique imagery | 860 Square Miles |
| ▪ 6” Pixel Resolution Color Orthoimagery – TIF format | Project-Wide |
| ▪ LiDAR Point Data – LAS Format | Project-Wide |
| ▪ 3’ Resolution DEM files, 32-bit floating point – IMG format | Project-Wide |
| ▪ 1’ foot contours – Geodatabase format | Project-Wide |
| ▪ Photo index (trajectory file) - | Project-Wide |
| ▪ Ground control survey report coordinates | Project-Wide |
| ▪ Metadata files – XML format | Project-Wide |
| • Px Mapper Oblique Imagery Viewing Software | Desktop-based and Web-based versions |
| • FugroViewer LiDAR Data Viewing Software | |