1. Efficiency maximization

1. Data collection

In order to survey a rectangular area of 2 km × 8 km with a minimum point density of 1 pt/m^2, one can fly with the following parameters:

- Speed of 65 m/s (126 knots)
- Pulse Repetition Rate of 150 kHz
- Altitude of 1300 m (4265 ft)
- Swath of 1500 m

This means that 2 strips will be enough to cover the 2 km width of the project area. At the speed of 65 m/s one roughly needs 125 seconds to complete the full acquisition. In a more detailed fashion:

It takes 2 × 2 minutes to collect the 2 planned strips = 4 minutes

It takes around 3 minutes to make a turn from strip 1 to strip 2 = 3 minutes

Total time necessary to fly an area of 2 km × 8 km with a point density of 1 pt/m^2 and already including a turn between the strips = 7 minutes

2. Data processing

In general, one will need *circa* 5 minutes to process a 5 m coverage DSM, already accounting with the necessary time to setup a full project in Trimble TopPIT software. With the Trimble TopPIT software, it is possible to easily and rapidly create reflight polygons that can be automatically exported into the Track'Air format.

In order to process a point cloud of a 2 km × 8 km area, the following steps are necessary:

- Laser data extraction from the Trimble Harrier system HDD to local HDD: 2 strips × 2 minutes
- Laser data extraction with full waveform analysis: 2 strips × 2 minutes
- GPS data post-processing: 10 minutes
- LE and FE point cloud processing in Trimble TopPIT: 2 strips × 2 minutes

- One needs less than 30 minutes in order to calculate a FE and LE point cloud

2. Change the Harrier system from one aircraft to another

The following steps are necessary in order to perform this exchange – assuming a single person is carrying out this task without any help and that mounts for the scanner rack and pilot and flight operator display already exist:

- Unplug the scanner rack connections from the computer rack: ± 1 min
- Unscrew the scanner rack from the aircraft mounts, i.e. from the securing mounts next to the aircraft hole: ± 2 min
- Unscrew the flight operator and pilot displays from their standing positions and unplug them from the computer rack: ± 2 min
- Unplug the aircraft GPS antenna cable and the aircraft power supply cable from the computer rack: ± 1 min
- Move the scanner rack into the new aircraft: ± 2 min
- Screw the scanner rack in the aircraft mounts: ± 2 min
- Move the computer rack to the new aircraft: ± 2 min
- Plug the necessary scanner rack cables to the computer rack: ± 1 min
- Screw the flight operator and pilot displays to their standing positions in the new aircraft and plug to the computer rack: ± 2 min
- Plug the aircraft GPS antenna cable and the aircraft power supply cable to the computer rack: ± 1 min
- Measure the lever arms in the new aircraft: ± 1 min
- Turn on the Trimble Harrier system in order to make sure that everything is correctly working and implement the new lever arms in the system software: ± 5 min
- Guarantee that all the cables are correctly plugged and that the system is securely installed: ± 1 min
- As no pre- or after-flight calibrations are needed, one can immediately fly a mission

For a single person performing these entire steps, an estimated time of 25 minutes might be required. When two persons are in charge of this setup, 15 minutes shall be enough for all these procedures.

3. Laser Class

The Trimble Harrier 68i is a Class 3R laser product (according to IEC60825-1:2007) with a laser wavelength of 1550 nm, pulse duration of approximately 3 ns and a maximum average output of less than 40 mW.

Safe for the naked eye >1.5 m (NOHD)

Safe for the aided eye >10 m (ENOHD)

4. FOV

The Trimble Harrier 68i is capable of edge-to-edge across-track FOVs between 0 degrees and up to 60 degrees (this last one is the full scan angle), with minimum angle step width increasing linearly to 0.01° at 80 kHz laser pulse repetition rate (PRR). The user can select via software the desired scanning angle.

The Trimble Harrier 68i parallel line scanning allows that the point spacing is always maintained along and across track. This pattern is superior in quality terms to any saw tooth or sinusoidal patterns as the point density and spacing are consistently maintained and there is full usage of the strip width.

5. Multiple pulse in air

The Trimble Harrier 68i system is capable of a pulse repetition rate (PRR) of 400 kHz and an efficient measurement rate of 266 kHz when scanning at a FOV of 60 degrees, or an efficient measurement rate of 200 kHz when scanning at a FOV of 45 degrees.

The Trimble Harrier 68i PRR varies between 80 kHz and 400 kHz for scanning angles between 45 degrees FOV and 60 degrees FOV.

The system is capable of multipulse in air technology working for all the flying heights of the Trimble Harrier 68i, allowing the utilization of target echo signals which have been detected out of the unambiguity range between two successive laser pulses.

The Trimble Harrier 68i scan line rate does not diminish with the changing of the FOV. The Trimble Harrier 68i system operates at all times with unlimited number of returns.

The Trimble Harrier 68i is capable of digitizing and recording the full waveform of each backscattered laser pulse. The system is virtually capable of detecting and recording an unlimited number of returning echoes and proceed with the digitization of the full waveform, which in practice is practically only limited by the maximum data rate allowed by the laser data recorder.

For each emitted pulse, the emitted signal and the echoes found by the embedded real-time detection algorithm are given as well as their amplitude and width. Each discrete return is as well recorded with a 16 bit high dynamic range intensity value.

6. Data recording times

Because the Trimble Harrier 68i records as well the full waveform information of the backscattered echoes, a RAID system composed of removal hard drives is provided. These hard drives can also be exchanged during the flight, so theoretically there are no space limitations. You will never run out of space because the hard drives can always be changed during the flight. A pressurized laser data recorder is also an available option for the Trimble Harrier 68i equipment.

The average storage capacity for the Trimble Harrier 68i imagery hard drive is of around 11000 images. Nevertheless this hard drive can be exchanged during the flight, so one will never run out of space.

7. Trimble Harrier 68i power requirements

The Trimble Harrier 68i requires a source feed of 23 Amps at 28 V DC for maximum system power usage. The complete Trimble Harrier 68i system includes the following components:

- Laser scanner
- Medium format frame camera
- IMU
- Laser data recorder
- Image recorder
- Flight Management System
- POS/AV unit
- Pilot display
- Flight operator display
- Harrier Control Computer
- Power Supply Unit

In general, the complete Trimble Harrier 68i system will run with power consumption smaller than 20 Amps. Once the system is connected to the aircraft power supply, one is ready to fly with the Trimble Harrier 68i.

8. Laser Beam Divergence

The laser beam divergence of the Trimble Harrier 68i is better than 0.5 mrad.

9. High scan speed: 10 lines – 200 lines/s

The Trimble Harrier 68i is capable of line scanning rates of 10 to 200 Hz (or 10 to 200 lines/sec).

10. Number of return echoes

The Trimble Harrier 68i is capable of digitizing and recording the full waveform of each backscattered laser pulse. The system is virtually capable of detecting and recording an unlimited number of returning echoes and proceed with the digitization of the full waveform for each echo. In practice this is practically only limited by the maximum data rate allowed by the laser data recorder.

For each emitted pulse, the emitted signal and the echoes found by the embedded real-time detection algorithm are given as well as their amplitude and width. Each discrete return is recorded with a 16 bit high dynamic range intensity value.

The Trimble Harrier 68i includes a software package for post-processing of the digitized waveforms, where the user can manipulate the parameters necessary to perform this action. It is therefore possible to extract discrete targets from the digitized echo signals which are extracted by means of the full waveform analysis provided by the included software package.

The system operates at all times with unlimited number of returns and independently from the altitude. The amount of information that can be extracted from the laser data is directly proportional to the amount of acquired echoes, and here the opportunities are theoretically infinite for the Trimble Harrier 68i.

11. Trimble Harrier 68i scan method

The Trimble Harrier 68i Airborne Laser Scanning System laser scanner is based on a rotating polygonal mirror, which only requires one easy yearly calibration. Due to the laser mirror structure, no mechanical wear out and no decalibration issues are to be expected. No previous and after flight calibrations are needed at any time. This is obviously a major budgetary issue, as no fuel and time are consumed for these actions.

The Trimble Harrier 68i parallel line scanning allows that the point spacing is always maintained along and across track. This pattern is superior in quality terms to any saw tooth or sinusoidal patterns as the point density and spacing are consistently maintained and there is full usage of the strip width.

The Trimble Harrier 68i only needs an aircraft hole for both laser and camera sensors. It is possible to fly a standard Trimble Harrier system in both unpressurized and pressurized cabins.

12. Terminal for the operator

The Trimble Harrier 68i system includes a program to control the computer with graphical user interface which runs in a terminal with colour graphics display certified for aviation use. The control program covers normal operating procedures and equipment testing. In normal operation mode, the control program allows the user to select the area of interest, scan rate, maximum and minimum ranges, bounding ranges, modes of intensity and start and stop controls. The control program displays the ranges measured samples and continuous monitoring of the subsystems to detect any

errors that were generated. In the test mode control program allows the monitoring of the subsystems for diagnostic purposes.

The control program also allows real-time visualization of the acquired laser data, state of the recording devices in terms of space usage, plus other system diagnostics.

13. Terminal for the pilot

The Trimble Harrier 68i system provides a compact graphic terminal for use cabin permits. The pilot display shows information navigation for the project to be flow, including area overview, strips to fly, activation of laser and camera, amount of taken photos or not taken photos, other error diagnostics. Also shows normal navigation parameters such as speed, height, number of satellites, etc.

14. Included software

a. Flight Management Software

The Trimble Harrier 68i FMS is the Track'Air mission planning software. The FMS system is fully integrated with the Applanix POS/AV PCS system of the Trimble Harrier 68i system, working both in perfect harmony.

The Trimble Harrier 68i Airborne Laser Scanning System is the only airborne laser scanner system capable of being operated without a flight operator, as it can work in an automatic stand-alone mode. A controlling command can be supplied for these actions so that the pilot can have as well control over the system. This is obviously a great reduction in one's flight costs, as a flight operator will not be needed. One can clearly operate the system in a manual way as well (concerning the laser scanning, as the imagery acquisition is mostly done in an automatic way, though the user might opt as well for a manual release mode).

b. Laser Control Software

The laser control software of the Trimble Harrier 68i allows the flight operator to see all parameters related with the mission, as well as other kind of information such as the sensors' temperatures, used voltage, amount of free space on the laser, imagery and navigation recording devices, etc.

The Trimble Harrier 68i system is capable of displaying pilot real-time coverage for the laser data coverage, as well as a flight operator real-time display of the acquired laser data.

The pilot display shows the flight lines and the project area to the pilot, as well as immediate (real-time) laser coverage of the flown area. This pilot GUI is very user-friendly and intuitive.

c. Camera Control Software

The camera control software is of intuitive usage and allows the user to manually or automatically release images – this last mode demands a flight planning with imagery capture.

At the end of the flight the Trimble Harrier systems have created a set of real-time navigation data and a reduced set of laser data which can be used to make a laser DSM in the space of few minutes – for an inexperienced user, circa 10 minutes.

d. POS Control Software

The system brings a POS control software package, although the GUI developed by Trimble and for the use of the flight operator also displays this kind of information, such as e.g. heading, roll angle, type of attitude and other parameters.

e. Flight Evaluation Software

The Trimble Harrier 68i graphical user interface allows the flight operator to visualize in real-time the acquired laser data, and it is also possible for the pilot to visualize in real-time the acquired laser data as well as real-time imagery acquisition.

It is also possible to test the correct functioning of the Trimble Harrier 68i before starting a mission. The Trimble Harrier 68 system tests both laser and camera by running a simulation of the project to fly but with real triggering of laser and camera, and while still on the ground.

f. Flight Planning Software

The Trimble Harrier 68i includes the Track'Air software for both laser and imagery flight planning purposes. This software includes many useful functions as e.g. automatic calculation of the most economical flight planning mission parameters by making use of the desired mission flying details.

g. Laser Data Pre- and Post Processing + Imagery Post-Processing

Trimble develops its own software, TopPIT, a full suite for laser data processing. All the basic laser products – DSM LE, DSM FE, DTM, FDTM and so on – can be calculated with the TopPIT software. True-Ortho imagery can be easily calculated as well with TopPIT.

Since the software suite is fully embedded into a single package, one will never find any problems with data transfers and file formats not being accepted. All the integration has been tightly conceived to facilitate the whole laser data processing, without ever leaving TopPIT working environment.

TopPIT offers its user a GUI, batch files generators and a powerful command line. This allows one to have full control over all the parameters that deal with the data development/processing. The fact that one can work with batch files and command lines can save precious time, as the batch files can

be left running during the night and weekend, and only a final control check and some other minor steps are required to ensure that everything has been correctly calculated.

These are obvious huge advantages in terms of time and money costs as most things can be totally automated, and be left running without any human interference. It is possible for example, to set up an unlimited amount of batch files, and make them run in on ordered fashion, so that by the end of these entire procedures you already possess either an intermediate, either a final result. It is natural that some processing steps require a higher human interference, such as DTM data filtering or the setup and choice of new files and parameters, but these are natural outcomes in every software package.

TopPIT is very flexible, as the user has total control over each parameter that he is using. One can influence all the data processing and all the way the data are processed into an extreme extent due to the command line features. This allows one to really shape and obtain data as needed to fulfil the hardest requirements. Even when not working in a command line mode, it is possible as well to easily edit the batch files in order to adjust the parameters to one's wishes. The GUI generates as well batch files that can be simply edited.

TopPIT can output the point cloud data into LAS format and several ASCII and binary formats, which are compatible with all the major GIS and laser data processing software packages.

TopPIT allows its users to create/edit and implement as many coordinate systems and geoids as the user desires, in its database. The geographical database of TopPIT already has a considerable number of geographical coordinate systems, but an endless number of these systems can be added to this database.

Flown strips can be outputted in a tilewise or stripwise fashion, and the software can output the various laser products, e.g. DSM, DTM, etc, in tiles with any kind of dimensions (square or rectangular).

TopPIT also has tools for quality control such as e.g. strips levelling GUI or statistics files generated based on the developed models and their comparison with reference data.

h. POS Processing

The Applanix POSPac MMS software is the included software for GPS pre- and post-processing. With this software, the pre- and post-processed GPS data can be directly used in the Trimble TopPIT software without any need of data conversion.

Functions such as Single Base Station, Multiple Base Station or PPP Processing can be used with this software.

i. Camera orientation, LIDAR calibration, camera calibration

Since the Trimble Harrier 68i system is built in a very solid, efficient and advanced way, it only requires a yearly calibration. Due to this fact, Trimble does not provide any kind of software for the

system calibration. Trimble proposes to its Customers to opt for a maintenance contract – either In-site Check of Factory Check – in order to assure that the system is running on a quality level, and together with this maintenance contract, a boresight calibration calculation is as well included.

After the Customer has delivered all the necessary data for the boresight calibration, e.g. GCPs, raw GPS data, raw laser data, etc, Trimble estimates that a single working day will be enough to provide to the customer the new laser boresight values in an official Trimble protocol. For the camera calibration, a simultaneous laser and camera flight has to be done, and Trimble estimates that a two working days will be enough to provide to the customer the new laser and camera boresight values in an official Trimble protocol. The Customer can still fly the Trimble Harrier 68i and keep on collecting data even without having the new boresight values. The data can be later adjusted with these new values.

The Trimble Harrier 68i only requires a single aircraft hole for both the laser and camera sensors.