

# Leica TerrainMapper-2

## Hybrid Airborne Sensor

### Product Specification





# Leica TerrainMapper-2 Product Specification

## Overview

The Leica TerrainMapper-2 is the successor of the trusted Leica TerrainMapper and significantly increases the operational performance and efficiency during flight execution. This advanced sensor system is equipped with one 150 MP RGB and one 150 MP NIR camera head as well as a fully integrated integrated Sensor Control Module with data storage and an internal GNSS/IMU system. As a hybrid sensor, it also includes a high-performance 2 MHz pulse rate LiDAR scanner that rounds out its enhanced capabilities. The TerrainMapper-2 delivers twice the image resolution of the preceding model with higher performance enabled by the purpose-built low-distortion lenses and a high-performance mechanical forward-motion-compensation (FMC).

## Basic Design

### TerrainMapper-2 System, consists of

- 1 x Leica MFC150 RGB camera nadir
- 1 x Leica MFC150-NIR camera monochrome nadir
- 1 x Leica Hyperion2+ LiDAR Unit
- Integrated NovAtel SPAN GNSS/IMU and GNSS antenna
- Integrated sensor control module & datalogger
- Leica OC60 Operator Console
- Leica IS40-LW Interface Stand for OC60
- Leica PD60 Pilot Display
- Leica PAV100-HPH Gyro-stabilised Sensor Mount
- Interconnecting cables

The Pod assembly contains the 2 camera heads, the internal Sensor Control Module assembly and the LiDAR Scanner assembly (refer to Fig. 1 and 2). The 2 MFC150 camera heads are used to generate a 4-band nadir image. The exposure release positions are controlled by very accurate timing and are fully synchronised with GNSS time. The camera heads are combined with high precision athermalised optics, central shutters and Forward Motion Compensation (FMC) to ensure the highest image quality.

**TerrainMapper-2 imaging components:** The TerrainMapper-2 is equipped with two camera heads, 1 x 150 MPixel 71 mm focal length nadir looking RGB camera, and 1 x 150 MPixel 71 mm focal length nadir looking NIR camera to support a 4-band or false-colour infrared nadir image output. The TerrainMapper-2 is designed to support 5 cm ground sample distance at flying height of 945 m AGL.

**Upgradability:** TerrainMapper-2 can be upgraded to CityMapper-2S or CityMapper-2H by installing the additional oblique camera heads and lenses, as well as exchanging the nadir RGB lens with the appropriate focal length lens and adding the required internal cabling.



Fig. 1: Leica TerrainMapper-2 upper pod overview



Fig. 2: Leica TerrainMapper-2 lower pod sensor view

**LiDAR:** TerrainMapper-2 is equipped with a 2 MHz pulse rate LiDAR allowing a user-selectable field of view from 20 - 40 degrees at flying heights from 300 m to > 5000 m AGL. This LiDAR unit has an oblique scanning system to ensure the best possible coverage on vertical surfaces (e.g., in city areas) and supports an even point distribution.

**Sensor Control Module:** The Sensor Control Module contains assemblies responsible for full system control. It controls all connected systems and brings their individual functions together. It activates the gyro stabilised mount when required while on the flight line and records all GNSS and IMU data. Moreover, it pre-computes the time and position when each image needs to be acquired and when LiDAR data collection needs to start and end. The Sensor Control Module records precisely the triggered exposure event time. It collects luminance and histogram information and deduces appropriate shutter speed and aperture. Besides providing data logging for all controlled sensor components, it also logs all other occurrences, like image overexposure, gyro stabilised mount out of range incidents and any other system warning.

**SPAN CNUS5-H GNSS/IMU Sub-system:** This sub-system provides and records master timing and aircraft position/attitude information using a GNSS receiver, a high-accuracy IMU (mounted inside the TerrainMapper-2 Pod) and an integral processor. The GNSS/IMU sub-system records raw GNSS and IMU data via the data logging function provided inside the Sensor Control Module. The IMU is an export free item (US ECCN 7A994).

**Data Logging:** The Sensor Control Module stores the output pre-processed images for the 2 MFC150 camera heads, as well as the LiDAR scanner data, pulse timing, return signal waveform attributes, synchronisation data, scanner position information, and the NovAtel SPAN GNSS/IMU unprocessed trajectory data. The data are stored on removable solid-state discs (SSDs) in the MM30 removable drives. Four MM30 drives (2 sets of 2) are supplied with the system, allowing rotation of storage media from the field back to the processing centre.

**Operator and Pilot Displays:** The OC60 and PD60 provide airborne-qualified, outdoor-readable display platforms for the supplied operator interface and flight navigation software, respectively. The operator interface software provides a graphical user interface for system set-up, operation, monitoring and flight navigation. The Leica OC60 Operator Console is a 12.1 in screen with a 1024 x 768 resolution, the Leica PD60 Pilot Display is a 6.3 in screen with a 1024 x 768 resolution and designed for cockpit mounting.

**Gyro-stabilised Sensor Mount:** The Leica PAV100-HPH Gyro-stabilised Sensor Mount provides angular motion compensation, keeping the TerrainMapper-2 vertically oriented and providing automatic drift control at the highest level of accuracy. Precise stabilisation during camera exposure is essential to achieve perfect image quality.

**Use Cases:** TerrainMapper-2 can address multiple hybrid-sensor use cases such as flood zone and forest mapping, general topographic mapping, local or regional orthophoto delivery and linear projects (roadway, powerline, pipeline).

## Camera Modules

### CMOS (Complementary Metal-Oxide-Semiconductor)

**Sensor:** The focal plane is a silicon-based imaging sensor with on-the-chip A/D conversion. This technology offers the highest possible dynamic range and Signal-to-Noise Ratio (SNR), and is nearly unaffected by so-called blooming effects. The CMOS sensor within the MFC150 RGB camera head is a Back-Side-Illuminated (BSI) Bayer-pattern sensor. A second nadir looking camera is equipped with a NIR Back-Side-Illuminated (BSI) monochrome sensor. The image sensor has a 3.76 µm pixel size and sensor dimensions of 14192 x 10640 pixels with an extraordinary dynamic range of 83 dB.

**Lenses:** To realise the full CMOS sensor potential, the camera heads are equipped with purpose-built optical lenses. These generate homogeneous, sharp images with a geometric accuracy level that is suitable for photogrammetry in all spectral ranges.

The system is designed to guarantee high production stability, extremely uniform image quality and stable geometric and radiometric performance under all expected temperature and air pressure conditions. A quality assessment shows the extraordinary performance over the complete image FOV and for the entire rated temperature range. Lenses are specially coated for respectively RGB and NIR use to ensure best possible sensitivity.

The lenses are rigidly mounted with a positive mechanical connection to the camera head. In addition, dedicated mounting locations are available for additional oblique camera heads, making it possible to upgrade to CityMapper-2S (Standard Altitude) or CityMapper-2H (High Altitude), as well as to switch between -2S and -2H.

**Forward Motion Compensation (FMC):** FMC is used to precisely shift the sensor frame in the flight direction, in order to compensate for aircraft movement during the

exposure time. This allows fast flight speed over ground even with slow shutter speeds, providing high-resolution imagery with outstanding image quality and no visible motion-induced blurring. The FMC is constructed to operate for up to 500,000 cycles.

**Exposure Control:** The TerrainMapper-2 uses a mechanical central shutter. It is a customised design that fulfils all airborne requirements with shutter speeds up to 1 / 1000 of a second. The shutter speeds and the shutter aperture values are balanced and automatically controlled based on the image scene and the light conditions, supporting 7 half-f-stop steps and guaranteeing optimal exposure performance in all cases. The camera shutters are specially built for airborne applications, with high stability, performance and accuracy. They are constructed to operate for up to 500,000 cycles.

**Lens Protection:** The lenses of the camera heads are protected by rigid optical windows at the bottom of the TerrainMapper-2 Pod.

## LiDAR Unit

The scanner produces controlled movement of the transceiver aim point by a Risley prism refractive scanner. The aim point of the laser output (relative to the scanner housing) is determined by high accuracy optical angle encoders that measure the rotary position of the scanner's two scan wedges.

**Laser:** The laser produces output laser pulses using a diode-pumped transmitter. It also contains an optical trigger output and fiber-linked beam expansion / collimating optics.

**Laser Output Periscope:** An optical periscope brings the laser output to the centre of the scan wedge assembly.

**Receiver:** The receiver collects optical trigger outputs and detects laser pulses reflected by terrain below the aircraft.

**Scanner Mechanisation:** High-performance servo-controlled direct-drive motor assemblies are used to rotate the scanner's two scan wedges.

**Scan Wedge Assembly:** A dual-wedge Risley prism scanner is used, allowing user-selected fields of view from 20 - 40 degrees. Aperture is appropriate for flight heights up to 5500 m AGL.

**Scan Motor Controller:** A servo motor controller is provided that allows scanning at rates as high as 9000 RPM (150 Hz scan rate, or 300 scans per second).

**Scan Wedge Protection:** The LiDAR scanner is protected by a rigid optical window at the bottom of the TerrainMapper-2 Pod.

**Laser Output Shutter:** The system has an integrated shutter allowing full output or complete obscuration of the output laser beam. The assembly is remotely actuated using the graphical user interface software or via pre-configured mission plans. The assembly provides status signals sufficient to allow confirmation of assembly position (closed or open).

**Emission Indicator:** A CDRH-compliant laser emission indicator is provided on the Pod. When the Pod is installed in the aircraft, the emission indicator is readily visible.

**Warning Buzzer:** A CDRH-compliant warning buzzer is incorporated into the Pod.

## System Performance

**Sensor Control Module:** The Sensor Control Module is used to control all sub-sensors that are part of a TerrainMapper-2 system, including up to 6 camera heads (e.g., for upgrade to CityMapper-2 configurations), the LiDAR unit, the gyro-stabilised mount and the deeply coupled GNSS/IMU solution. The kernel of the Sensor Control Module is a 64-bit WIN10, 16 GB RAM processor with 64 GB SSD internal storage. It ensures the collected data is recorded onto the Leica MM30 solid state drives.

**Data Storage:** Removable SSD (MM30), 2 x 7680 GB standard.

**Recording Capacity:** The system has a nominal recording capacity of  $\geq 15$  hours on a pair of MM30 / 7,680 GB Mass Memory units (total capacity of 15.36 TB) when operating at a typical project data rate. Capacity is proportionally longer at lower LiDAR pulse rates or fewer returns per outbound pulse and for missions flown with reduced forward overlap. Capacity is lower when using waveform recording mode for LiDAR and is affected by the waveform subsample rate selected. It is also lower when camera cycle rates are higher (i.e., flying with a higher forward overlap and/or high aircraft speed).

**GNSS/IMU System Performance:** The GNSS part is based on a NovAtel SPAN OEM7 receiver board that supports an update rate of 10 Hz with 555 individual channels over multiple constellations, such as GPS, GLONASS, BEIDOU, GALILEO and others. The IMU is a CNU55-H, Class 5, 500 Hz Fiber-Optic Gyro (FOG) IMU. Both the real-time deeply-coupled solution as well as the tightly-coupled or loosely-coupled post-processing ensures the highest accuracies for position and attitude measurement. Typical achievable accuracies for a post-

# Design Parameters

Parameter	Value
Nadir pixel count across track	14,192
Nadir pixel count along track	10,640
Nadir sensor pixel size	3.76 $\mu\text{m}$
Nadir focal length (RGB)	71 mm (Leica D69.70/4.0)
Nadir FoV across track (RGB)	41.2°
Nadir FoV along track (RGB)	31.5°
Nadir focal length (NIR)	71 mm (Leica D69.70/4.0-NIR)
Nadir FoV across track (NIR)	41.2°
Nadir FoV along track (NIR)	31.5°
Nadir color channels	R,G,B, NIR
RGB : NIR resolution	1 : 1
Frame interval (minimum, all cameras simultaneously)	0.6 sec
Resolution per pixel	14 bit
Spectral bands RGB (Bayer pattern)	R (580 – 660 nm) G (480 – 590 nm) B (420 – 510 nm)
Spectral band NIR (monochrome, nadir only)	NIR (720 – 850 nm)
FMC	Yes
CMOS dynamic range	83 dB
Laser wavelength	1,064 nm
Pulse repetition frequency Flying height dependent	Up to 2 MHz
Scan speed	60 – 150 Hz (120-300 scan lines/sec)
Scan pattern	Oblique scanning, constant point density or constant pulse rate
FOV (LiDAR)	20 – 40°
Onboard storage	2 x 7,680 Tbyte
System weight (incl. all peripherals and 185 mm spacer)	< 105 kg
Power consumption	740 W
Altitude non pressurised	15,000 ft
Operation flight height (LiDAR)	300 – 5,500 m AGL
Operating temperature	-10° to +35°C (-10° after warm-up period)

Tab. 1: TerrainMapper-2 design parameters.

processed GNSS/IMU trajectory for horizontal positions are 2-3 cm and for vertical position 3-5 cm. The typical angular (attitude) accuracies are 0.003° in Roll and Pitch and 0.004° in Heading.

**Gyro-stabilised Sensor Mount Performance:** To achieve stabilisation and motion compensation at this level of accuracy, a highly precise adaptive control module is incorporated to filter out environmental vibrations. Typical residual deviations from vertical and from drift of < 0.2° can be achieved. The overall range for roll compensation is  $\pm 7^\circ$ , for pitch compensation  $-8^\circ$  to  $+6^\circ$  and for drift compensation  $\pm 30^\circ$ .

**OS Installation:** Non-mechanical drive.

**OS Protection:** Protected from improper shutdown via EWF or equivalent on Windows 10 (OC60, integrated Sensor Control Module).

**Feature overview:** Tab. 1 shows a complete overview for the TerrainMapper-2 design parameters.

**Ground Sample Distance (GSD) and achievable point density:** For TerrainMapper-2, flying heights of 300-5500 m AGL are possible. Projects executed at 600 m AGL result in ~3 cm (~1.3 in) resolution and a point

density of  $>40$  pts/m<sup>2</sup>. At a flying height of 4500 m a GSD of 24 cm is achieved while the point density is still  $>1$  pts/m<sup>2</sup>.

An overview of the full TerrainMapper-2 operational range is shown in Tab. 2 and in Fig. 3, 4 and 5. Typically, a minimum GSD of 3 cm can be achieved with fixed wing aircraft.

**Flight Speed and forward overlap:** For many projects the current trend is toward having a ground resolution  $< 5$  cm. At the same time, most cases require a forward overlap of 80 % for the acquired imagery. With a slow aircraft supporting a flight speed over ground down to 100 knots a GSD of 3cm at 80 % forward overlap is possible for TerrainMapper-2. Fig. 5 gives a detailed overview of maximum flight speed over ground for a given GSD while maintaining 80 % forward overlap. The LiDAR point density is highly dependent on flight speed and flying height. This relationship is shown in Tab. 2 and Fig. 4, giving a detailed overview for a speed over ground of 120 knots.

**Grid based geometric calibration:** The customised lenses are designed to be stable against temperature and pressurisation changes. This results in stable camera distortion values, stable focal length and principle point of autocollimation. The overall lens/sensor distortion is defined using a highly precise geometric distortion grid-based calibration.

**Upgrade to CityMapper-2:** In case the user is adding additional camera heads to convert a TerrainMapper-2 to CityMapper-2, final determination of the focal length and the principle point of autocollimation for the added camera heads is needed. In addition, camera head to IMU misalignment angles need to be determined. A calibration flight is needed to determine these parameters, and this can be performed by the customer following the specific instructions provided. The overall lens/sensor distortion is not affected and will remain stable after the new installation. Upgrade to CityMapper-2 is a task that can be performed under clean office conditions by a Leica customer service engineer.

## Operational Range

Flying height (m AGL)	Data characteristics	
	Typical LiDAR point density (points/m <sup>2</sup> ) @120 knots	Nadir GSD (cm)
600	43.50	3.2
700	37.70	3.7
800	33.30	4.2
900	29.80	4.8
1000	27.00	5.3
1100	24.60	5.8
1200	22.60	6.4
1300	21.00	6.9
1400	19.50	7.4
1500	18.30	7.9
2000	13.80	10.6
2500	7.34	13.2
3000	4.23	15.9
3500	2.67	18.5
4000	1.78	21.2
4500	1.25	23.8
5000	0.93	26.5
5500	0.69	29.1

Tab. 2: Achievable GSD and typical LiDAR point density @120 knots and 40 degrees FOV

## Flight and Data Collection Parameters

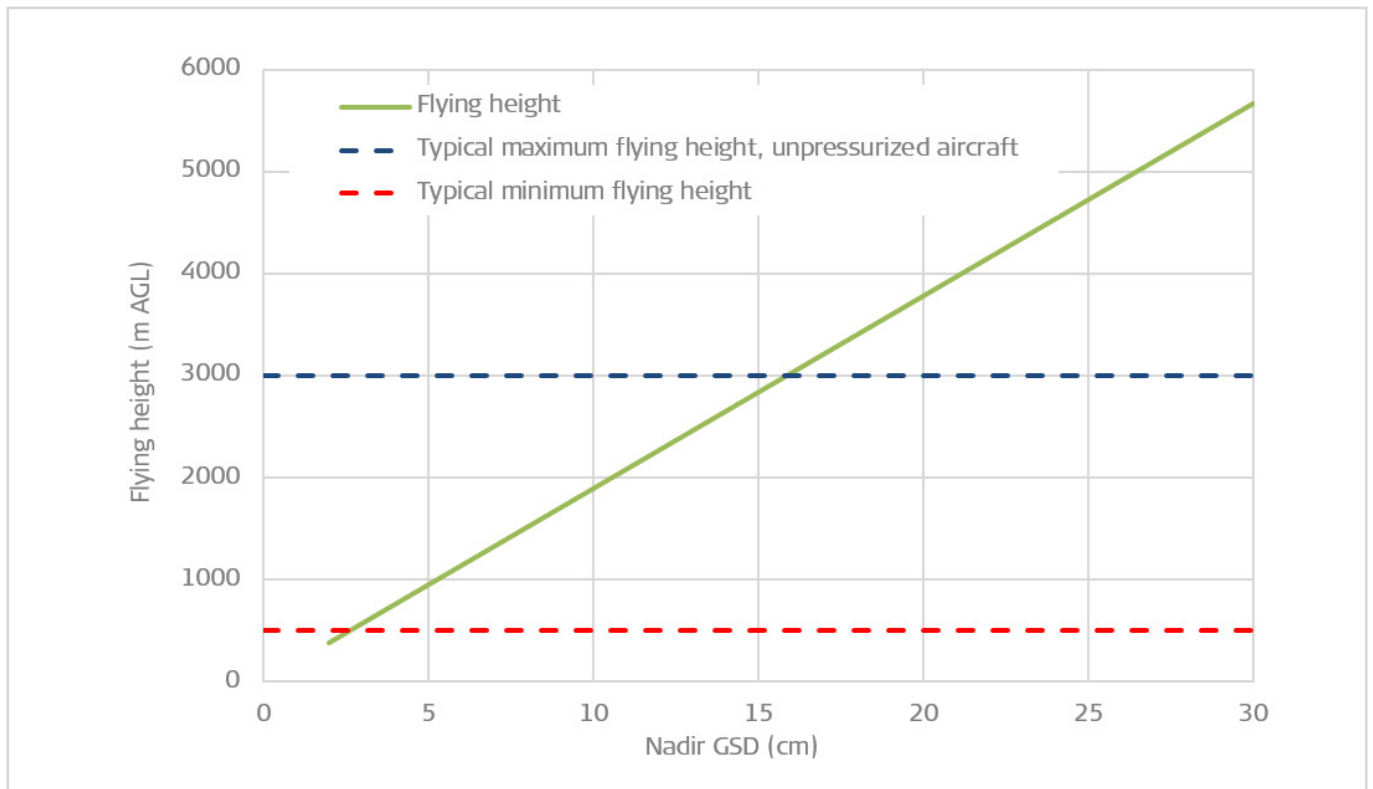


Fig. 3: Flying height versus GSD (nadir)

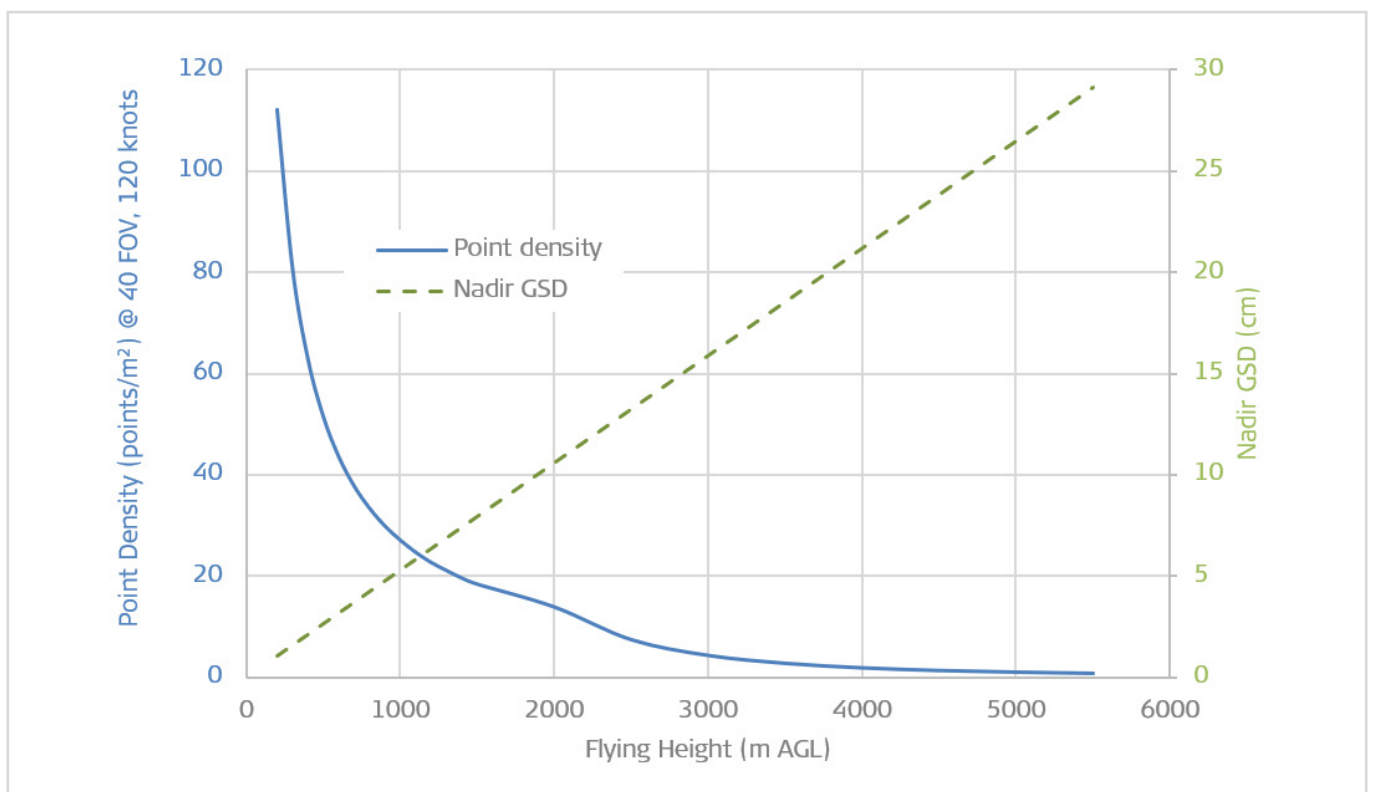


Fig. 4: GSD and Point Density versus Flying height for TerrainMapper-2



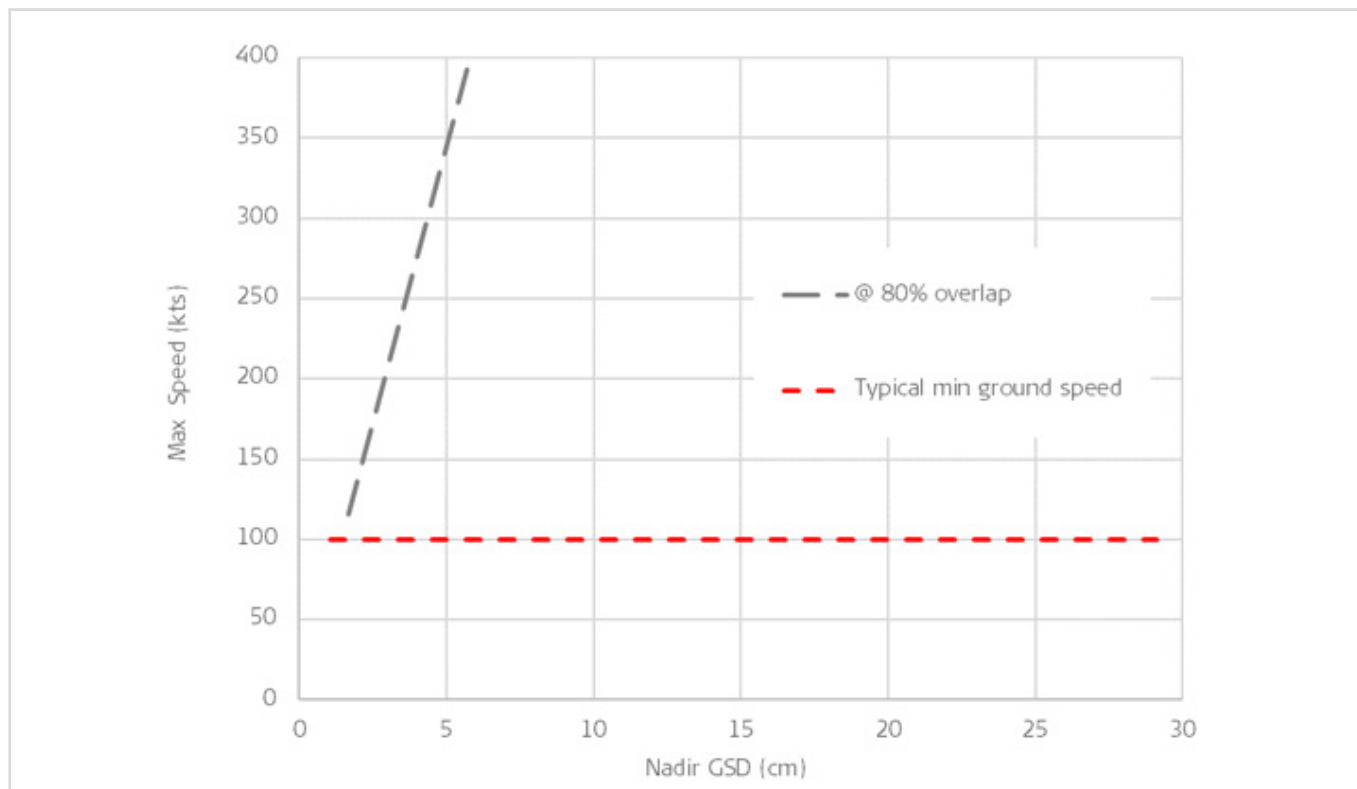


Fig. 5: Maximum Ground Speed vs. GSD at 80% Forward Overlap

## LiDAR Unit Performance

**Flying Height:** The maximum recommended flying height for the LiDAR module is approximately 5500 m AGL. Fig. 7 describes the maximum pulse rate for target detection as a function of flying height. Recommended minimum range is 300 m.

**Field of View (FOV):** System FOV is adjustable over the range of 20 - 40 degrees, in 1-degree increments. Contact Leica Geosystems for inquiries regarding maximum un-vignetted FOV for installation in specific aircraft.

**Scan Pattern:** The system provides 3 scan patterns, all in a plane nominally parallel to the base of the pod, nominally centred around Nadir:

- Conical (circular) scan: with data collection on both forward-looking and aft-looking directions.
- Quasi-sinusoidal scan: with data collection on both left-bound and right-bound scans. Note that sine pattern can be used only at the full 40-degree FOV and is offered as an experimental scan pattern for specialty application, and full accuracy performance cannot be guaranteed.
- Flower scan: with continuous data collection

throughout the scan pattern. Flower pattern is used for calibration and full accuracy cannot be guaranteed if attempting use for production flights.

**Scan Rate:** Maximum scan rate of 150 Hz can be achieved regardless of FOV for conical and sinusoidal scan patterns. The scan speed or scan rate (cycle rate in Hz) for conical and sine patterns is user selectable from 3600 - 9000 RPM (60 - 150 Hz) in 1 RPM increments via the graphical user interface. A minimum scan rate of 3600 RPM must be used for FOVs less than 40 degrees. For the "flower" scan pattern, the total duration of one "flower" scan depends on the speed settings used for the two scan wedges. Note that flower pattern should not be used if the aircraft is equipped with a port glass.

**Port Glass:** System performance in any aircraft using a port glass is dependent on the quality of material, fabrication and coating of the port glass. Specifications for port glass can be provided separately, and system performance cannot be guaranteed with non-compliant port glass.

**Roll Stabilisation:** Automatic stabilisation is provided by the PAV100-HPH stabilised mount, in roll, pitch and heading directions. Refer to PAV100-HPH literature for specifications.



**Illuminated Footprint:** Output beam divergence is 0.23 mr nominal, measured at the  $1/e^2$  point. For reference, this is equivalent to approximately 0.15 mr measured at the  $1/e$  point.

**Pulse Rate:** The maximum achievable pulse rate of the system is related to the maximum flying height to be encountered. Fig. 7 summarises maximum pulse rates at various flying heights, assuming a 40-degree FOV. The range of pulse rate values is from 200,000 Hz - 2,000,000 Hz in 100-Hz increments.

**Multiple Pulses in Air:** The system is equipped with a gateless Multiple Pulses in Air (MPiA) feature, which allows increased maximum pulse rates over that offered by gated MPiA systems when any significant terrain relief is encountered. Up to 35 simultaneous MPiA zones can be accommodated per flight line. Maximum achievable pulse rates are shown in Fig. 7 and apply so long as no more than 35 MPiA zones are encountered within the flight line. Processing software automatically determines the proper zone for any return pulse. There is no significant loss of point density in the transition area between adjacent MPiA zones.

**Target Detection Rate:** The system is capable of detecting 90% of targets having at least 10% diffuse reflectivity and fully intercepting the laser footprint. Return reflection for targets with less than 10% diffuse reflectivity may not produce adequate signal strength

and may result in "drop-outs". The ability to measure range associated with a given return is dependent on the surface having adequate reflectivity and intercepting a sufficient portion of the laser footprint. Targets intercepting less than the full laser footprint will require proportionally higher reflectivity for successful detection.

**Multiple Target Detection:** The system is capable of detecting up to 15 returns for each outbound laser pulse, provided each reflecting surface results in adequate signal strength for detection.

**Minimum Vertical Separation:** The minimum vertical separation (range separation) that can be detected on a given outbound laser pulse is 0.5 m.

**Multi-Return Intensity:** Systems are shipped with a multiple-return intensity measurement feature. With this feature, the sizes of the reflected returns at various elevations are measured in addition to the distances to each reflecting surface measured by the waveform digitiser. A 14-bit scale is used to digitise return signal intensity from the detection channel. A 16-bit scale is used upon output of intensity data from Leica HxMap, after compensating for variations in slant range. The ability to digitise the signal strength is dependent on the surface having adequate reflectivity and intercepting a sufficient portion of the laser footprint. Targets intercepting less than the full laser footprint will require proportionally higher reflectivity for successful detection.



Fig. 6: Leica TerrainMapper-2 system components

**Accuracy:** The system produces data after post-processing with a lateral placement accuracy of 7 –59 cm and vertical placement accuracy of 5 -20 cm (one standard deviation) from full-field-filling targets of 10% diffuse reflectivity or greater with atmospheric visibility of 23.5 km or better for flying heights up to 5500 m AGL and a nominal FOV of 40 degrees at generated surface smoothness settings 3 and 6 cm, as shown in Figure 8. Accuracy estimates for various flying heights above terrain are shown below and can be provided in detail by using the AeroPlan mission planning template. Estimates below are made assuming a 40-degree FOV, CNUS5-H IMU and a nominal 5 cm GNSS error. Note that the accuracy estimates below and provided by AeroPlan are conservative, and typical vertical accuracy of < 5 cm is achieved at a nominal flying height of 1000 m AGL.

**Side Lobes:** The laser output beam does not have any side lobes outside the main beam.

**Laser Output Control:** The system provides control over laser output over an approximate 100:1 range in 1% increments.

**Beam Uniformity:** The laser beam quality exhibits an  $M^2$  value better than 1.3.

**Duty Cycle:** The LiDAR module is capable of continuous operation at maximum pulse rate.

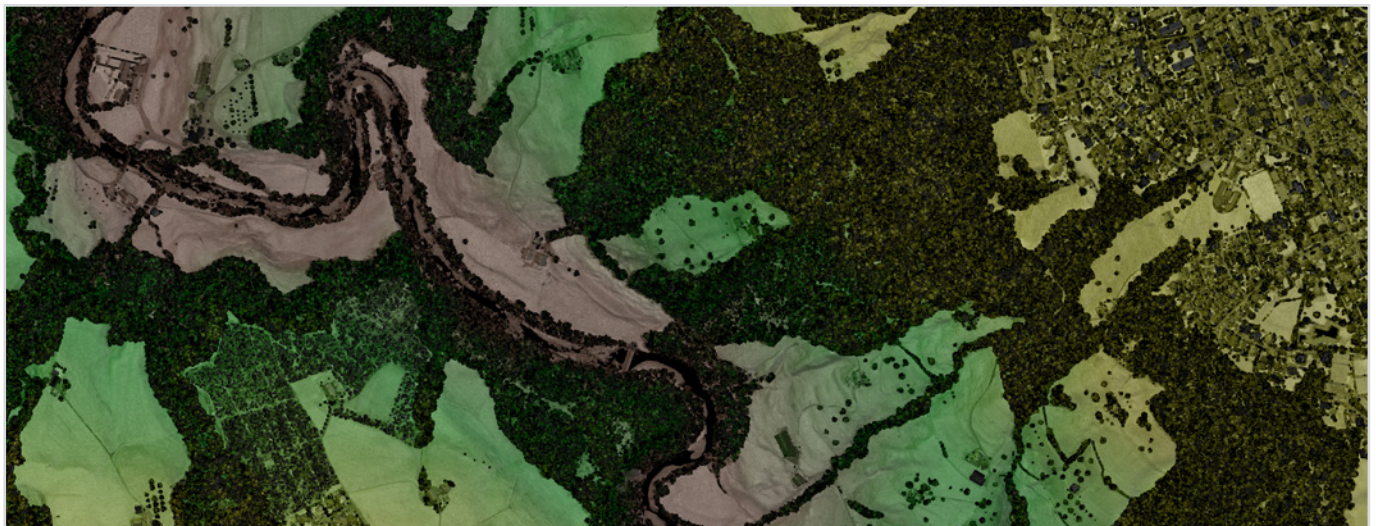
## Mounting

**TerrainMapper-2 Pod:** The TerrainMapper-2 Pod is mounted to the aircraft using the included PAV100-HPH (High Performance and Heavyload) stabilised mount. More information on PAV100-HPH can be found in the section System Performance or on the PAV100 product data sheet.

**Height Adapters:** 185 and 50 mm height adapters are available. The adapters are mounted onto the Leica PAV100-HPH. The TerrainMapper-2 pod is then mounted on the height adapter(s). Up to one 185 mm adapter and three 50 mm adapters can be stacked, allowing a variety of sensor mounting heights to be achieved. Correct selection can be used to allow the pod to be lifted sufficiently to allow closure of protective hatch covers and/or to eliminate vignetting.

**OC60 Operator Console:** The Operator Console is designed for mounting to sturdy horizontal or vertical surfaces using the VESA-standard mountings provided for attachment to user-supplied brackets, or to the optional IS40-LW mounting pedestal. Mounting for this assembly should be provided by the user in an appropriate fashion to minimise strain on the high-density electrical connectors used for interface between the TerrainMapper-2 Pod and the OC60 Operator Console and to minimise movement of the assembly or cables when exposed to atmospheric turbulence during flight.

**PD60 Pilot Display:** The Pilot Display is designed for mounting to sturdy horizontal or vertical surfaces using the VESA-standard mountings provided for attachment to user-supplied brackets. Mounting for this assembly should be provided by the user in an appropriate fashion to minimise strain on the high-density electrical connectors used for interface between the OC60 Operator Console and the PD60 Pilot Display and to minimise movement of the assembly or cables when exposed to atmospheric turbulence during flight. The compact display with “hot keys” allows ready switching between available navigation views.



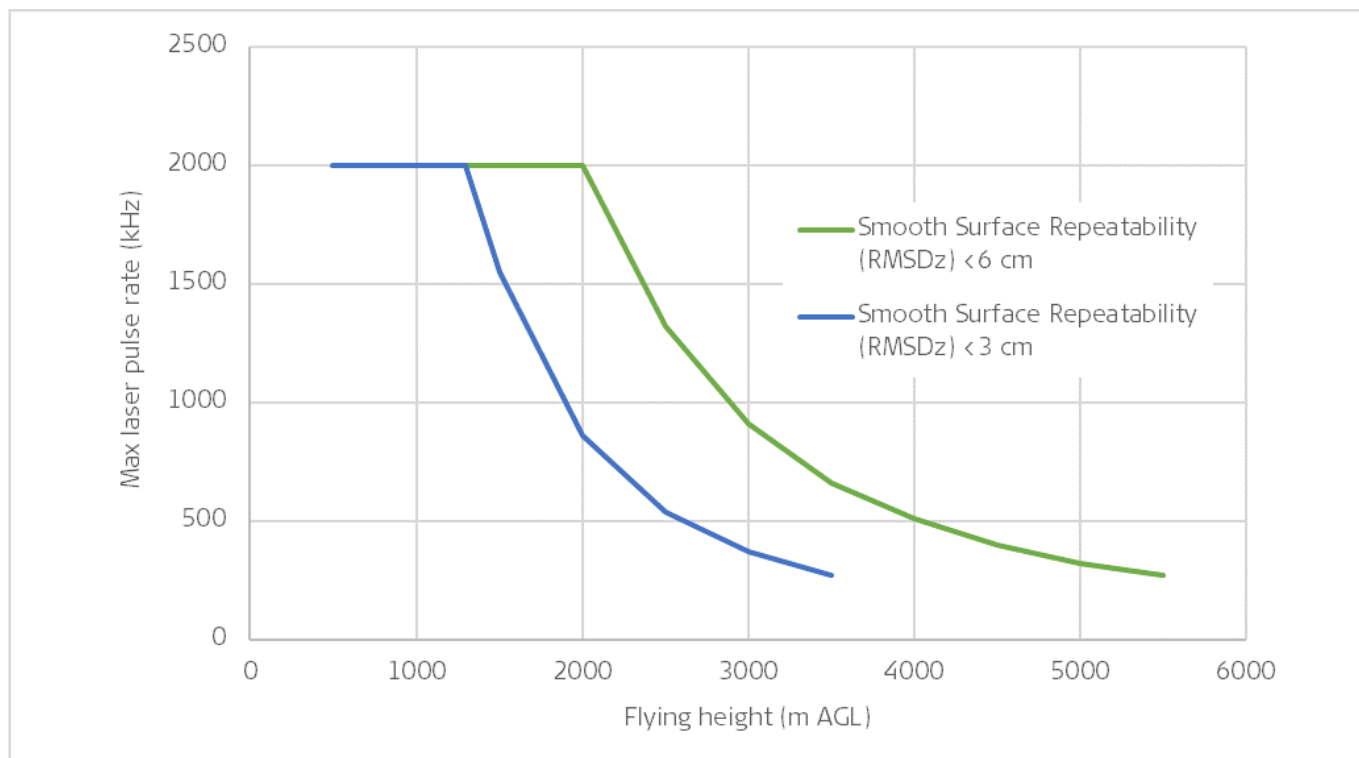


Fig. 7: Performance envelope. Note: higher accuracy and smoothness obtained at lower pulse rates for any given flight height.

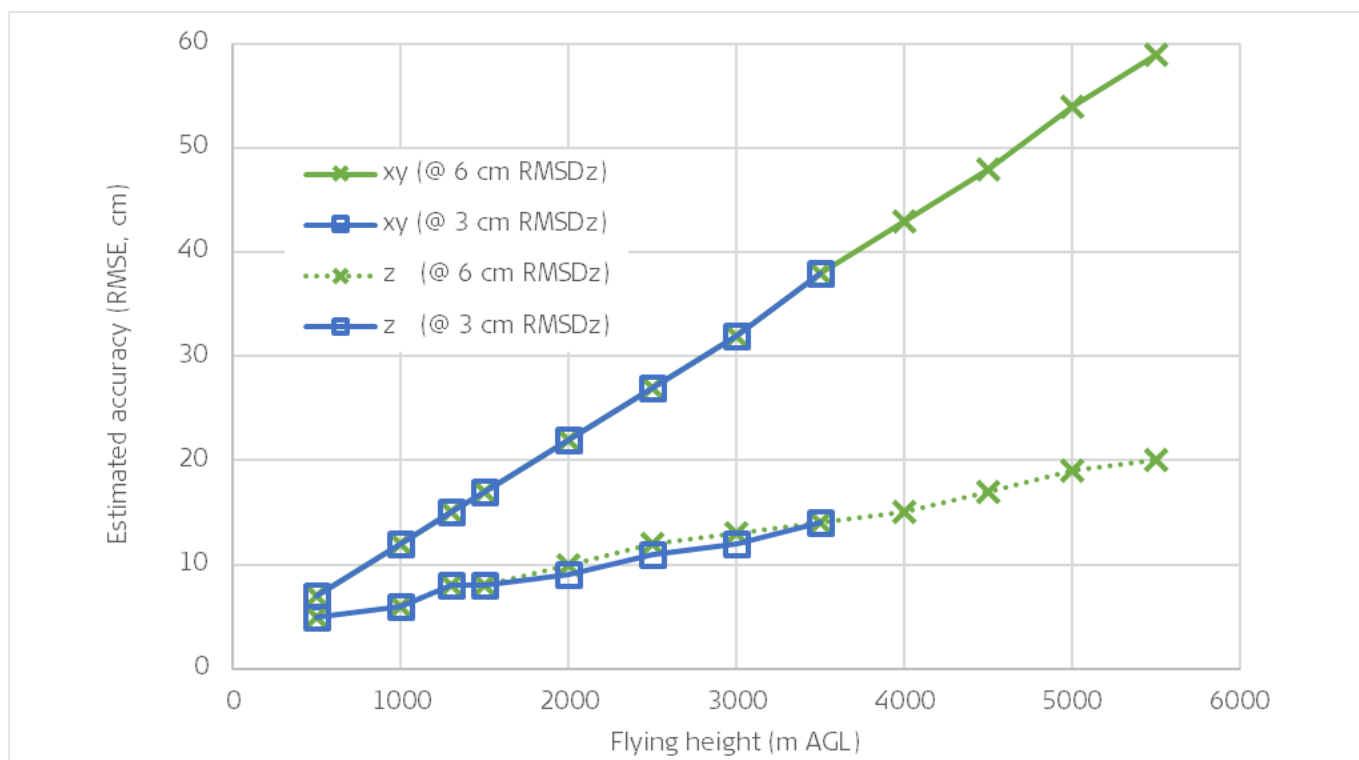


Fig. 8: Estimated accuracy (system level, including GNSS/IMU error).



# Workflow Software

The workflow package addresses all project phases from planning through processed data delivery. The following software is included in the workflow.

## **Leica MissionPro Flight Planning and Evaluation**

**Software:** Calculates optimal flight line layout to fulfil all 3D requirements and embeds flight line layout and optimised system settings in a flight plan database file for transfer to the flight operation system.

**AeroPlan:** This proprietary mission planning template is a subset of Leica MissionPro Flight Planning and Evaluation Software and is provided to aid users in determining proper system set-up and flight line spacing to fulfil LiDAR-related project requirements.

## **Leica FlightPro Sensor Control and Flight**

**Management Software:** Accepts flight plan database files from Leica MissionPro and provides aided navigation for pilot and automatic or manual system operation for the system operator. Leica FlightPro Sensor Control is used to control all integrated sensors, the GNSS/IMU system, pilot flight guidance, stabilised gyro-mount control, data recording and system operating logging.

## **NovAtel Inertial Explorer GNSS/IMU Processing**

**Software:** Provides a data processing engine for NovAtel SPAN airborne GNSS and IMU data. It provides a “tightly-coupled” processing procedure to process and combine the deeply-coupled recorded raw data. Processing combines the GNSS and the IMU data to a combined trajectory either as a DGNSS solution referring to a GNSS Base Station or as a PPP solution referring to satellite clock and orbit information. This provides high frequency smoothed position and orientation data for the TerrainMapper-2. The “deeply-coupled” data recording combined with the “tightly-coupled” post-processing engine, allows steep bank angles during turns between flight lines.

**Leica HxMap Common Workflow:** Leica HxMap is the common processing platform for both image and LiDAR data processing applications. This includes project management via the Workflow Manager, Raw Data QC and Data Ingest. Leica HxMap intuitively guides the user through sensor-specific processing steps. The software provided for processing raw data from the system with the supplied trajectory data produces all data products without the need to exit and/or export data to additional software packages. All processing is from a single unified user interface.

## **Compatibility with distributed processing**

**environment:** Leica HxMap is designed to run under the HT Condor distributed processing environment.

This allows the user to increase throughput for sensors like the TerrainMapper-2, producing a high amount of data and decreasing delivery turnaround time. The software provides the ability to delegate processing to multiple processing computer nodes using the HT Condor environment to increase processing speed. The standard deliverable provides licencing for two operator interface nodes and four processing nodes. Software is scalable to increase the number of processing nodes via additional licences.

**Recommended processing infrastructure:** Detailed information with respect to the recommended HxMap hardware infrastructure can be found within the latest “HxMap Infrastructure Best Practice” document.

**Application-targeted software bundles:** Leica HxMap software bundles are targeted to specific product generation. Leica HxMap RealTerrain provides a complete workflow up to the final data products for hybrid data acquisition.

**Leica HxMap RealTerrain:** Leica HxMap RealTerrain employs the latest algorithms, visualisation and scalability tools that allow customers to process data from various types of sensors in the comfort of a highly efficient and user-friendly processing environment. Leica HxMap is the standard workflow platform for processing the output of the Leica TerrainMapper-2 hybrid sensor. As such, it has developed into a unique platform to generate, visualise and analyse image data and LiDAR point cloud data as well as to output downstream data products. The current modules supported by Leica HxMap RealTerrain are the workflow manager, data QC, automated point cloud matching, aerial triangulation, point cloud generation and orthophoto production, as highlighted in the following paragraphs.

## **Image Generation: The software provides the following functions:**

- Perform Raw data QC
- Ingest raw image data from storage media
- Create developed images (de-Bayering)
- Apply radiometric and geometric calibrations
- Georeference images using the postprocessed GNSS/IMU trajectory data
- Georeference images using APM and Aerotriangulation
- Create orthophoto images
- Create orthophoto mosaics
- Perform IMU boresight calibration
- Upgradable to provide City Modeller
- Upgradable to provide Texture Mapper
- Upgradable to provide 3D Editor
- Upgradable to provide Building Finder
- Upgradable to provide 3D Mesh

**LiDAR Workflow:** TerrainMapper-2 is equipped with a full-capability LiDAR and consequently can be used as a stand-alone LiDAR sensor in addition to use in hybrid data acquisition. The delivered HxMap software provides the point cloud processing functions defined in the following 4 paragraphs.

**Point Cloud Generation:** The software provides the following functions:

- Ingestion of raw data from storage media
- Creation of point cloud
- Creation of gray-scale intensity image output (i.e., x/y/intensity images in \*.tif format)
- Radiometric corrections of intensity data for variations in slant range and visibility
- Colourisation of point cloud without third-party applications
- Calibration of LiDAR sensor
- Generation of intra-line QC data including quality of elevation matching in 4 programmable error bands (typically <4, 4 - 7, 7 - 10 and > 10 cm) including both tabular data and graphical format (Orthoview color-coded by error level, for quick visual interpretation)
- Line-to-line registration of LiDAR data strips
- Generation of line-to-line QC data including quality of elevation matching in 4 programmable error bands (typically < 4, 4 - 7, 7 - 10 and > 10 cm) including both tabular data and graphical format (orthoview colour-coded by error level, for quick visual interpretation)

**Point Cloud Viewing:** The software provides a point cloud viewer accessible from the workflow software menu with the following functions:

- Point cloud viewing in ortho or perspective views
- Display of data, colour coded by elevation, intensity or both (simultaneous)
- Section tool to allow viewing of a limited “slice” of the point cloud with user-defined section thickness. The section tool is not restricted as to section

orientation around a vertical axis

- Measurement tool to allow measurement between locations (slant distance, elevation change, lateral distance) within a section

**Point Cloud Formatting:** Output in LAS 1.4 format, including point cloud colour.

**Projection Engine:** Point cloud data output is available in user-selectable projection, datum and geoid. User-required custom projections or geoid corrections are possible by providing mathematical definitions. All coordinate conversions are compatible with CORPSCON.

## Technical Specifications

**Critical Item Definition:** The system consists of all hardware and software necessary to meet the specifications herein. All assemblies are designed for rugged environments sustained on unpressurised light aircraft. As such, the system is capable of operation while being subjected to variations in temperature, humidity and altitude experienced in-flight. In addition, surfaces of the system exposed during flight are capable of operation during exposure to precipitation and blowing dust.

**Physical Requirements:** The system is within the following envelope dimensions, as shown in table 3.

**Warm-Up Time:** The system is ready for use within 6 minutes of application of primary power, assuming start-up at -10°C or higher temperature.

**Pod Dimensions and Weights:** Maximum dimensions and weights are within those shown in table 3.

**Environmental:** The system is capable of operation under the conditions described in table 4.

**Electrical:** The system is capable of operating with standard aircraft DC power, with total consumption and recommended circuit fusing as indicated in table 5.

<b>TerrainMapper-2 pod (with CNUS5-H IMU)</b>	Diameter 408 mm, Height 747 mm 48.0 kg (105.0 lb)
<b>Sensor mount</b>	Leica PAV100-HPH gyro-stabilised mount for high performance data acquisition 673 x 532 x 240 mm, 42.4 kg (93.4 lb)
<b>Height adapters (optional)</b>	Allows setting of pod installation height; diameter 436 mm, height 50/185 mm, 1.2/2.0 kg (2.7/4.3 lb)
<b>Operator console</b>	Leica OC60 12.1 in screen with 1024 x 768 resolution 340 x 235 x 89 mm, 3.9 kg (8.6 lb)
<b>Pilot display</b>	Leica PD60 6.3 in screen with 1024 x 768 resolution, designed for cockpit mounting 191 x 142 x 49 mm, 1.0 kg (2.2 lb)
<b>Display stand</b>	IS40-LW Interface Stand, pedestal for Operator Display OC60 570 x 110 x 110 mm, 3.2 kg (7.5 lb)
<b>Total system weight:</b>	< 105 kg (231.5 lb) including 2x MM30 and cables

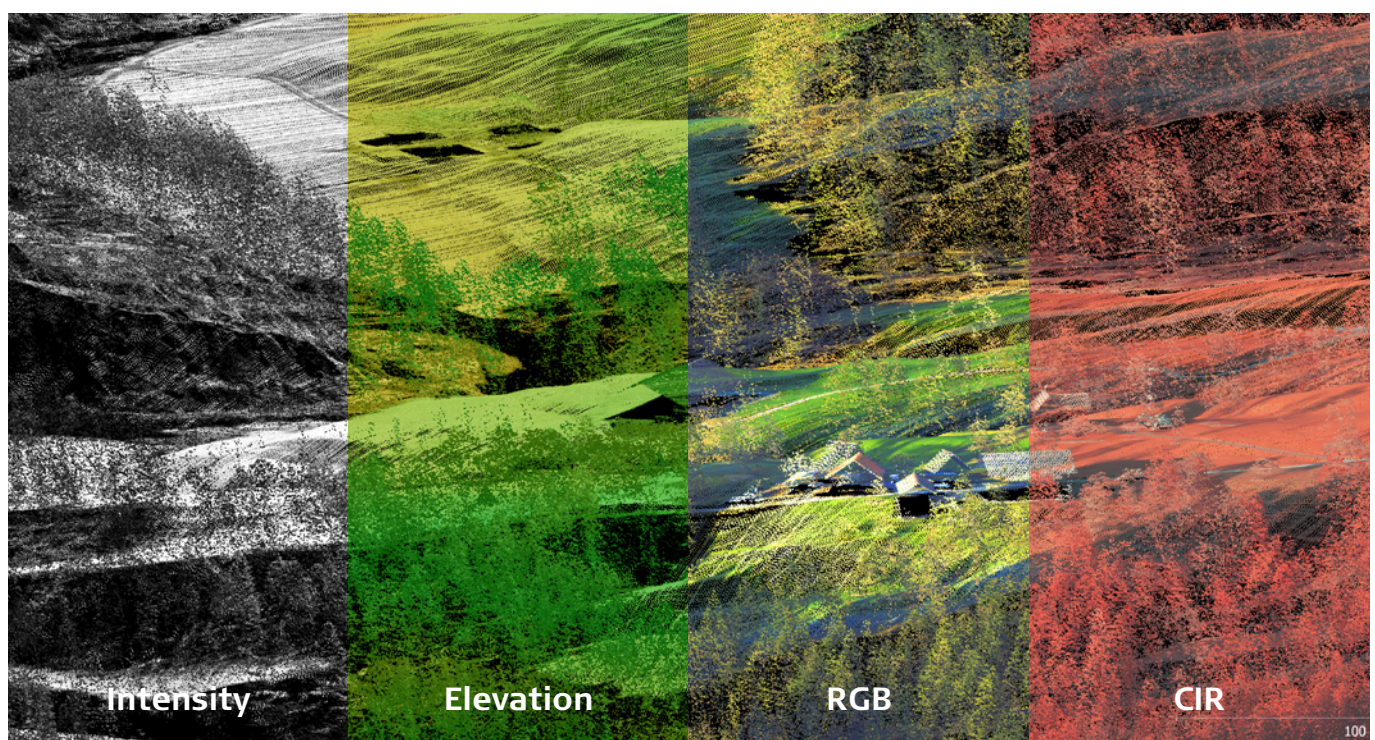
Table 3: Major component size and weight

Specification	Reference to Standard / Environmental Test Index
Pressure	Non-pressurised cabin up to ICAO 15,000 ft
Operating temperature and altitude	RTCA DO-160G, Section 4, Cat B1, Max operating temperature range -10° to 35°C, at 50% laser output, 30°C at 100% laser output
Storage Temperature	RTCA DO-160G, Section 4, Cat B1, -40° to 70°C
Temperature variation	RTCA DO-160GG Section 5, Cat B
Humidity	RTCA DO-160G, Section 6, Cat A, 0 - 95% RH
Operational shocks and crash safety for all fixed-wing aircraft types	RTCA DO-160G, Section 7, Cat B
Vibration	RTCA DO-160G, Section 8, Cat S, Profile M
Magnetic effect	RTCA DO-160G, Section 15, Cat B
Power input	RTCA DO-160G, Section 16, Cat B
Voltage spike	RTCA DO-160G, Section 17, Cat A
Audio frequency conductive susceptibility – power inputs	RTCA DO-160G, Section 18, Cat B
Induced signal susceptibility	RTCA DO-160G, Section 19, Cat BC
Radio-frequency susceptibility (Radiated and conducted)	RTCA DO-160G, Section 20, Cat R
Emissions of radio frequency energy	RTCA DO-160G, Section 21, Cat M
Lightning induced transient susceptibility (antenna only)	RTCA DO-160G, Section 22, Cat A3XXXX
Electrostatic discharge	RTCA DO-160G, Section 25, Cat A

Table 4: Environmental test specifications

Max. avg. power consumption of complete system	740 W / 28 VDC
Max. peak power consumption of complete system	940 W (< 60s) / 28 VDC
Fuse on aircraft power outlet	1 x 50 A recommended
Reverse polarity protection	The system is designed to sustain accidental exposure to reverse polarity applied to the main power input. The system will not operate under such a condition.

Table 5: Electrical requirements





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