



TRIMBLE UX5 AERIAL IMAGING SOLUTION

A new standard in accuracy, robustness and performance
for photogrammetric aerial mapping

WHITE PAPER

Dr P. Cosyn & R. Miller
Trimble Survey, Westminster, CO, USA

ABSTRACT

Using Unmanned Aircraft Systems (UAS) for photogrammetric aerial mapping provides surveyors and other geospatial professionals with a revolutionary tool for collecting data that was once reserved for large photogrammetry specialists. Trimble is creating the standard for Aerial Imaging Solutions by simplifying a once complex and time-consuming process. Aerial Imaging Solutions allow survey and geospatial professionals to collect large amounts of data (several square kilometers) in a short time (less than one hour) from a safe location for use in a variety of applications – rapid, safe, flexible.

Trimble's UX5 Aerial Imaging Solution is an ideal and innovative tool that can be utilized for survey, open-pit mine, oil & gas, landfill, and environmental applications such as; topographic surveys, site & route planning, progress monitoring, volume calculations, disaster analysis and as-builts, along with a wide variety of other applications.



INTRODUCTION

Digital imaging is a rapidly expanding and highly valuable technology for geospatial professionals. Imagery is often used to visualize job site conditions, review survey & mapping observations, measure points & features, and create two-dimensional & three-dimensional deliverables. In some cases, the imagery itself could be the desired deliverable. Imaging can be accomplished from both the terrestrial perspective as well as the aerial perspective. Both terrestrial panoramic and overhead point-of-views have advantages for given applications. The aerial perspective is optimal for documenting and measuring large horizontal sites, while the terrestrial perspective is ideal for documenting and measuring vertical structures such as buildings and bridges. Because many sites have a combination of both horizontal and vertical objects that need to be surveyed, there is a benefit to collecting both forms of imagery and merging them.

Trimble prides itself on being a leader in innovation. By setting new industry standards to improve our users' efficiencies and deliverables, we are proud to provide even more breadth and depth to our portfolio by offering the first and only complete Aerial Imaging Solution specifically designed for surveyors and geospatial professionals. The system is comprised of the Trimble UX5 Aerial Imaging Rover for collecting aerial photography; Trimble Access™ Aerial Imaging application for mission planning, pre-flight checks and flight monitoring; and Trimble Business Center Photogrammetry module for processing aerial images and creating deliverables. This white paper discusses Trimble's complete UAS photogrammetric mapping solution and simplified deliverable generation that make it the preferred solution for any demanding aerial surveying or mapping task.

IMAGE ACQUISITION METHODOLOGY

Being successful with aerial mapping is predicated on the planning of flights and the desired deliverables. The typical phases for image acquisition are:

- **Mission planning:** In the office (and in the field) users can define the mission area, add background maps, and define avoidance zones if required. The software estimates the total flight time needed to cover the mission area and allows the user to split the area into multiple flights when required because of the size of the area.
- **Flight planning:** For each flight, the pilot identifies the wind direction, takeoff location, and the landing location, so that the duration of the flight can be re-calculated based on the field conditions at the time of the flight. The launcher is set up and the pre-flight checklist is completed to ensure that the system is ready for flight.

- **Flight operation:** After launching the Trimble UX5 Aerial Imaging Rover, the flight is monitored using the ground control station. No manual interventions are required unless the user wants (or needs) to abort the flight. After the Trimble UX5 Aerial Imaging Rover lands, the post-flight checklist is completed to transfer the data to the computer.
- **Analysis:** This process allows for a completeness check of the data. It ensures that the user is confident that he heads home with data he can process to his deliverables.

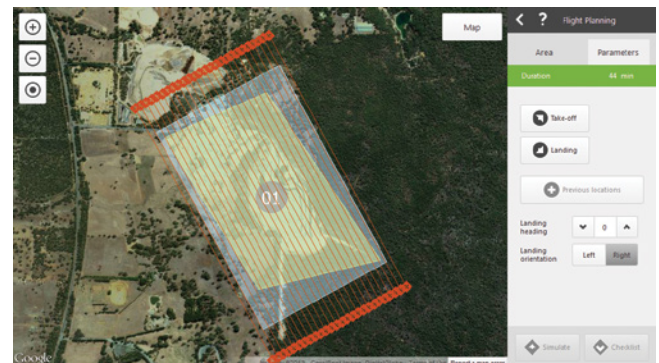


FIGURE 1 Trimble Access™ mission planning



FIGURE 2 Trimble Access™ mission operation

DELIVERABLES

Orthophotos, contour maps, three-dimensional (3D) photos, point clouds, digital surface models (DSMs), and feature maps can easily be created from aerial imagery from Trimble Business Center. Trimble has created a new standard for processing UAS aerial imagery by incorporating more than 30 years of experience in photogrammetry from Inpho, a Trimble software solution, into streamlined workflows in the recently released Trimble Business Center Photogrammetry module.

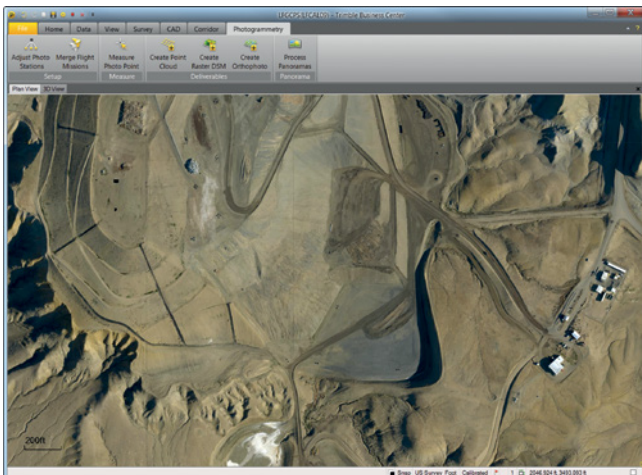


FIGURE 3 Orthophoto produced with Trimble Business Center Photogrammetry module

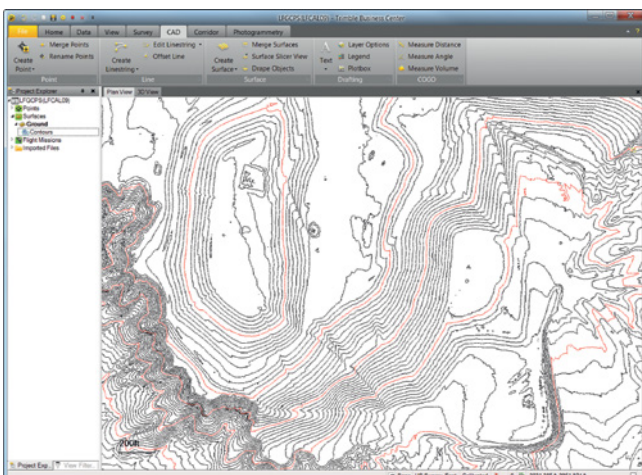


FIGURE 4 Contour map produced with Trimble Business Center Photogrammetry module

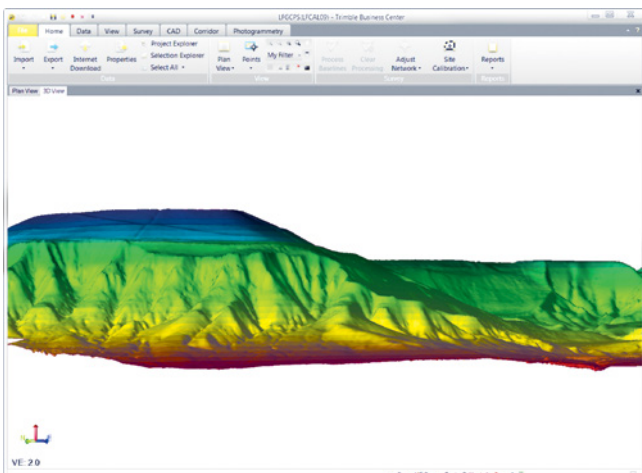


FIGURE 5 3D image colored by elevation produced with Trimble Business Center Photogrammetry module

In addition to producing these typical photogrammetric deliverables from Trimble Business Center, the aerial imagery data can be combined with Trimble VISION products such as the Trimble VISION total stations and Trimble 3D laser scanners for a one-of-a-kind solution in the market. Orthophotos are primarily used to create scaled images of a site that accurate

measurements can be taken from, but this type of data cannot be used to measure vertical structures such as buildings or bridges. By combining data collected with Trimble's leading edge vision technology, such as the Trimble UX5 Aerial Imaging Rover, Trimble VX Spatial Station, and Trimble TX5 3D Laser Scanner, users can visualize their project from multiple perspectives, measure points within the images and create 3D models of the infrastructure and terrain.

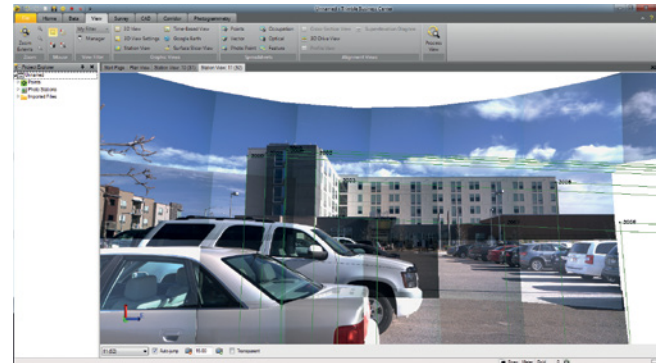


FIGURE 6 Panorama image in Trimble Business Center, taken with the Trimble VX Spatial Station

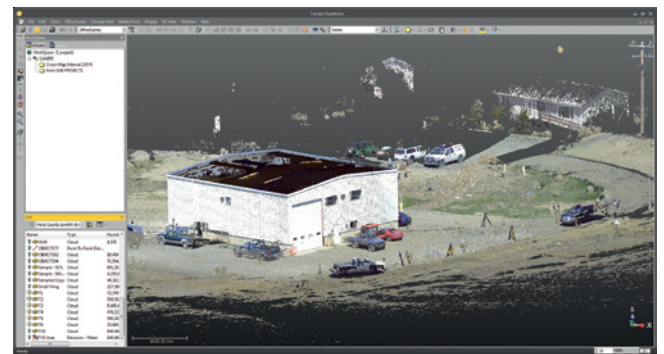


FIGURE 7 True-color point cloud in Trimble RealWorks, taken with the Trimble TX5 3D Laser Scanner

IMAGE QUALITY & PERFORMANCE

The quality of the deliverables is dependent on the quality of the photogrammetric equipment used. The innovative Trimble UX5 Aerial Imaging Rover has been designed to follow the latest developments in the 'prosumer' camera market, ensuring optimal image quality along with maximum photogrammetric accuracy.

Trimble selected the Sony NEX-5R mirrorless camera because of its large APS-C (CMOS) sensor with 16.1 megapixel count. While the 1/1.7" sensor of the Ricoh GRD IV camera used in the Trimble Gatewing X100 was already 1.5 times larger than other compact cameras in the market, the surface area of the Sony NEX-5R sensor is nearly 9 times that of the Ricoh GRD IV. In addition to the significant increase in the pixel count, the size of each individual pixel with the Sony NEX-5R is more than 5x the Ricoh GRD IV pixels. This class-leading pixel size is important because it allows for a sharp increase in light

sensitivity, dynamic range, and signal to noise ratio resulting in drastically reduced noise even at high ISO values. Combined with the much shorter ISO determination time of a system camera compared to a compact camera, it allows the user to use a fixed shutter speed and an automatically adjusted ISO ranging between 100 and 3200, yielding sharp, contrast rich images with a constant brightness, even in adverse and rapidly changing light conditions and shadow areas. This eliminates the need for users to judge brightness and manually set both the shutter speed and ISO to a fixed value throughout a flight.

From a photogrammetric perspective, the biggest advantage of the Trimble UX5 camera compared to using a compact camera in Aerial Imaging Rovers is the external lens. External lenses inherently offer a more stable internal geometry resulting in a more reliable camera calibration than that of a retractable lens. For the UX5, a light-weight 15 mm fixed focal length Voigtlander lens featuring mechanical focus and aperture ring, was chosen. To further increase the stability of the internal geometry, a custom adapter was designed by Trimble to replace the standard camera and lens mounts, which allow rotational movements of the principal point, by a two-part screw mount adapter. Additionally, the lens is fitted with a locking screw to fix the focus ring in the manufacturer-recommended position. This position is fixed using a collimator during production, ensuring not only sharp imagery across the flying height range (75 - 5000 m), but also a more stable focal length throughout all projects. The improved stability of the camera directly results in an increased accuracy of the deliverables, especially areas between the ground control points.

Mounted in front of the APS-C sensor, the focal length expressed as 35mm-equivalent of the UX5 camera is 22.5mm, yielding a wide field of view. This means that, at a flying height of 150 m, the Trimble UX5 produces an image footprint of 235 m by 157 m which is 40% larger than other UAS. Combining this field-of-view with the increased shutter speed, the Trimble UX5 has a larger overlap of the images than other systems,

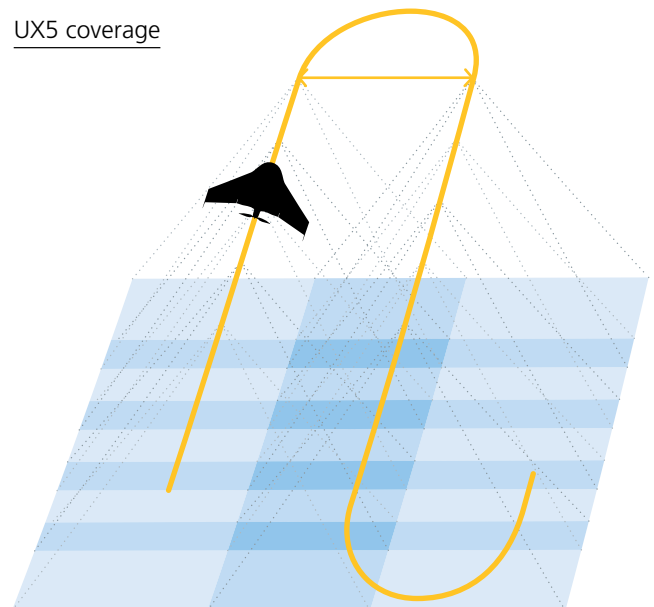


FIGURE 9 Sony NEX-5R camera and Voigtlander lens used in the Trimble UX5 Aerial Imaging Rover

resulting in better accuracy of the DSM that is generated from the photos. The combination of these photogrammetric advancements means that the Trimble UX5 can cover 50-75% more area per flight hour than the X100 and most other UAS products at the same flying height. This translates to greatly enhanced work efficiency and reduced operational costs.

At a flying height of 150 m, the Trimble UX5 produces a GSD of 4.8 cm. In addition, the Trimble UX5 is capable of flying as low as 75 m above ground level (AGL) and producing a GSD of 2.4 cm. Flying at such a low height requires faster shutter speeds on the camera to prevent forward motion blur. The Sony NEX-5R camera used in the Trimble UX5 is capable of using the higher ISO values necessary to compensate the darkness resulting from the fast shutter speeds while keeping noise to acceptable levels for photogrammetric applications.

UX5 coverage



X100 coverage

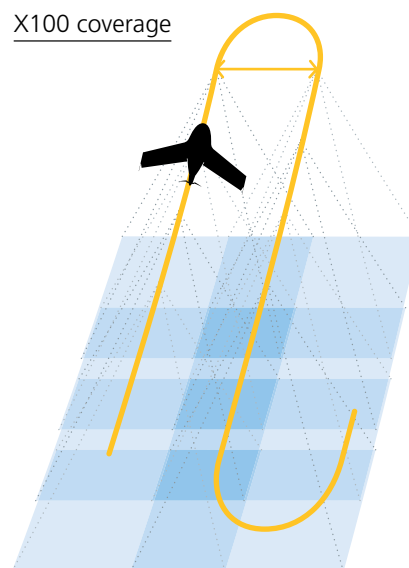
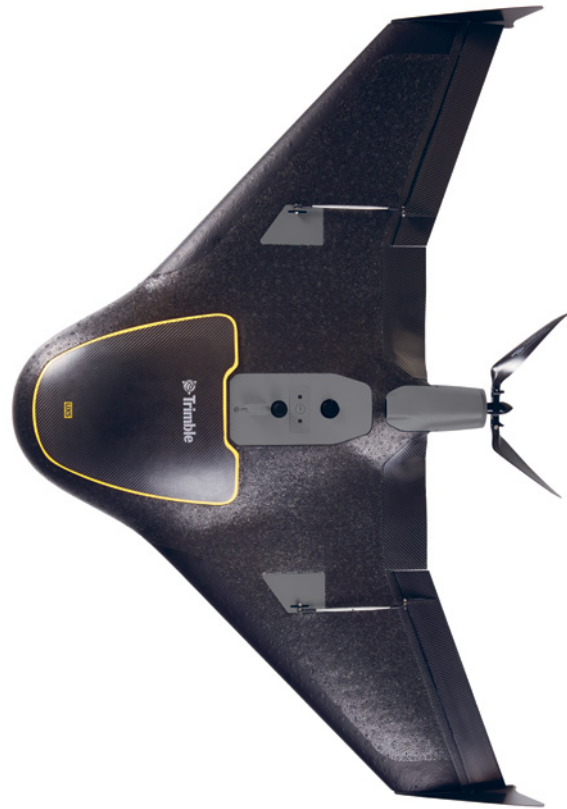


FIGURE 10 comparison X100 coverage and UX5 coverage

RELIABLE & RUGGED DESIGN

The new Trimble UX5 Aerial Imaging Rover builds on the standards set by its predecessor, the first commercial aerial imaging rover on the market, the Trimble Gatewing X100. Key features of the Trimble Gatewing X100 are also available in the Trimble UX5, such as all-weather flight capability, while surpassing its design of the airframe, making it a heavy-use, all-terrain device with the best accuracy and image quality available.

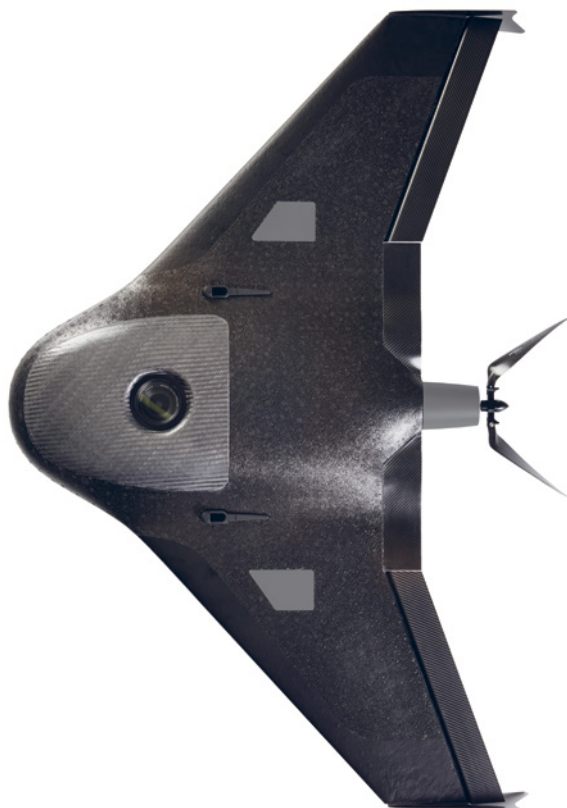
FIGURE 11 UX5 top view



The Trimble UX5 Aerial Imaging Rover is based on a production method patented by Trimble. The base structure consists of a carbon frame inside expanded polypropylene foam. The frame ensures torsional stiffness and rigidity while the foam has exceptional pressure resistance and no memory-effect, which means that it will 'bounce back' to its original shape after impact. The exterior foam protects the internal electronics on impact and reduces the likeliness of any (physical) damage in case of an incident.

The Trimble UX5 has a longer life expectancy than many other similar aircraft and is considered a wing suitable for heavy use. This new wing design produces a more rigid aircraft without compromising flight efficiency. Parts used in the motor assembly, the container for the flight electronics (also called 'eBox') and servos are made of impact resistant plastics. The composite fiber parts of the elevons, the moving and fixed parts of the trailing edge of the wing, are light-weight and have an internal matrix structure that absorbs energy. The vertical winglets are made of a composite that allows bending in one direction to absorb energy during rough landings. Further, the Trimble UX5 belly plate is uniquely designed to absorb energy during landing as well as reduce abrasion from rough terrain such as rocks or tarmac.

FIGURE 12 UX5 bottom view



Due to its structural strength and additional energy absorption, maintaining the Trimble UX5 is easy. The Trimble UX5 offers operators a user-friendly design with replaceable parts such as vertical tails and propellers. The wing component is extremely durable and ideal for tough terrain. Some users will be able to work with just one airframe (or wing component) for years. This level of durability results in low yearly operation and maintenance costs of the Trimble UX5, which makes it a favorable system for the frequent (daily or weekly) use.

ACCURATE LANDINGS

The Trimble UX5 starts its final landing phase at a height above ground level (AGL) of 75 m only 200 m from the designated landing location. The touch down is, on average, within a 10 m (radius) circle of the designated location. Offsets that double this value are extremely rare.

A traditional landing for an Aerial Imaging Rover has limitations that must be considered and addressed: the glide slope and landing speed. An efficient aircraft with good range and coverage has a disadvantage over an aircraft that consumes a lot of energy to stay aloft: the glide angle is rather small. A steeper approach would be means to reduce this offset but would result in a higher approach speed.

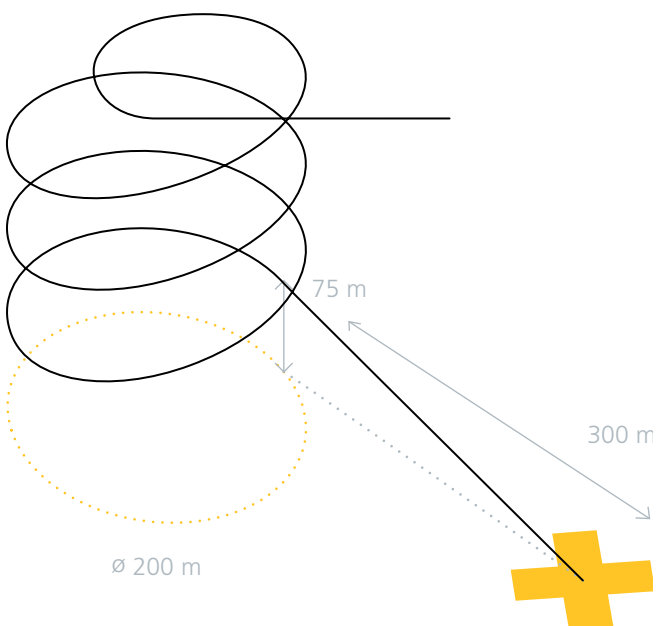


FIGURE 13 Landing pattern UX5

The Trimble UX5 has been engineered to overcome the limitations of a traditional landing with the addition of an advanced control method and improving the height measurement resulting in accurate and predictable landings. The advanced control method included in the Trimble UX5 is a thrust reversal on approach. During thrust reversal, the motor and propeller direction is reversed. This has the same effect as using a propeller with opposite pitch. By reversing the thrust, the propeller starts pulling air instead of pushing it. This gives the aircraft a means to counteract the speed increase that results with a steep descent.

Thrust reversal (or also called 'reversed thrust') allows for an advanced control method that relies on changing the propeller from forward to reversed speed. This challenges aerodynamics, electronics and control algorithms. It challenges aerodynamics because applying a pulse of reversed thrust can result in stall effects of wing and elevons. It challenges electronics because

having smooth control from forward to reverse is difficult for electronic speed controller (ESC). And it challenges control algorithms because it needs to cope with limits set by the aerodynamics and electronic speed controller and non-linear behavior because of asymmetry in the reversed and forward mode. A propeller that turns in reversed mode delivers thrust but also creates torque and aerodynamic effects that need to be monitored and controlled.

AUTOMATED CHECKS & IMPROVED WORKFLOWS

The new Trimble Access Aerial Imaging application is a single software tool for planning Trimble missions, performing pre-flight checks and monitoring flights – all with intuitive workflows that ensure reliable results and safety of the individuals involved.

Trimble Access Aerial Imaging application offers mission planning that can be performed in the office or on the Ground Control Station (GCS). The project area and avoidance zones are drawn on top of an industry-standard map interface. The flight height above ground level (AGL), Ground Sample Distance (GSD) and photo overlap are defined and Trimble Access calculates the number of flights, flight pattern and duration of flight(s). The locations for takeoff and landing are proposed and then the project is taken to the field for the flight.

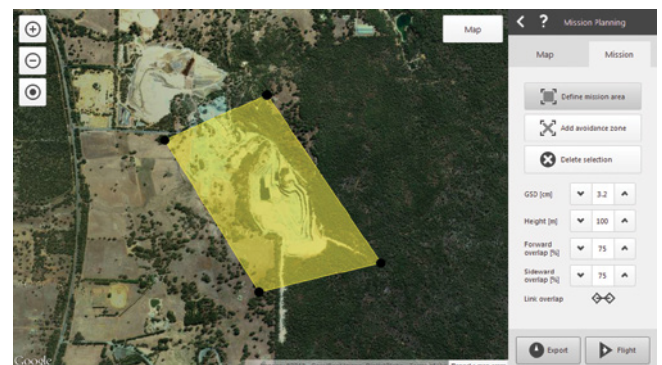


FIGURE 14 Trimble Access™

In the field, the operator is guided through the pre- and post-flight sequences with step-by-step digital checklists. Many of the Trimble UX5 checks are automatically verified by the software and sometimes run in the background (self-check routines) and do not require any interaction from the operator. This makes the setup process (before launch) and data recovery (after landing) easy and reliable.

With these wizard-like digital checklists, it is impossible for the operator to forget or bypass a critical step, ensuring reliable and safe flights. The software also requires the operator to follow a fixed post-flight procedure for downloading the data and verifying the data. This safeguards that the user does not leave the field with a dataset that is incomplete or inconsistent.

Some examples of automated pre-flight checks are:

- ▶ battery connection and status
- ▶ ground control station connection and status
- ▶ aircraft parameter self-check (when arming the system)
- ▶ camera trigger check
- ▶ elevon response check
- ▶ sensor and gps checks

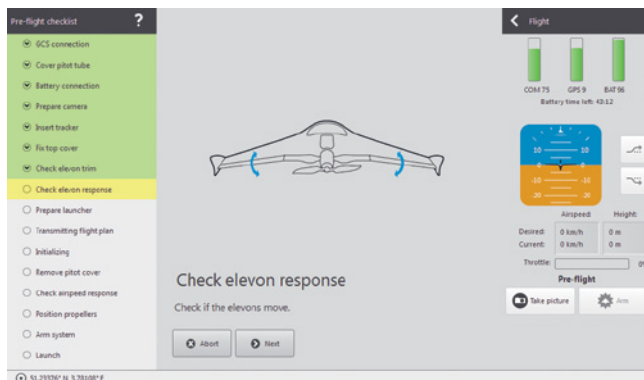


FIGURE 15 pre-flight check

CONCLUSION

The Trimble UX5 Aerial Imaging Solution sets a new standard in accuracy, robustness and performance for photogrammetric aerial mapping. The imaging performance of the Trimble UX5 Aerial Imaging Rover and the streamlined workflows of Trimble Business Center Photogrammetry application allow for the creation of professional deliverables with unprecedented accuracy and quality. Costs for data acquisition are drastically reduces when compared to collecting the same level of detail using traditional methods and technologies.

What was once reserved for large photogrammetry specialists is now available for a variety of geospatial applications. Trimble's innovation in aerial photography can now be used to generate very detailed and useful deliverables by itself, however, by coupling UAS technology with other survey technologies such as GNSS, imaging total stations and 3D laser scanners, Trimble offers an unparalleled way to visualize and measure the world.

For more information visit trimble.com/uas