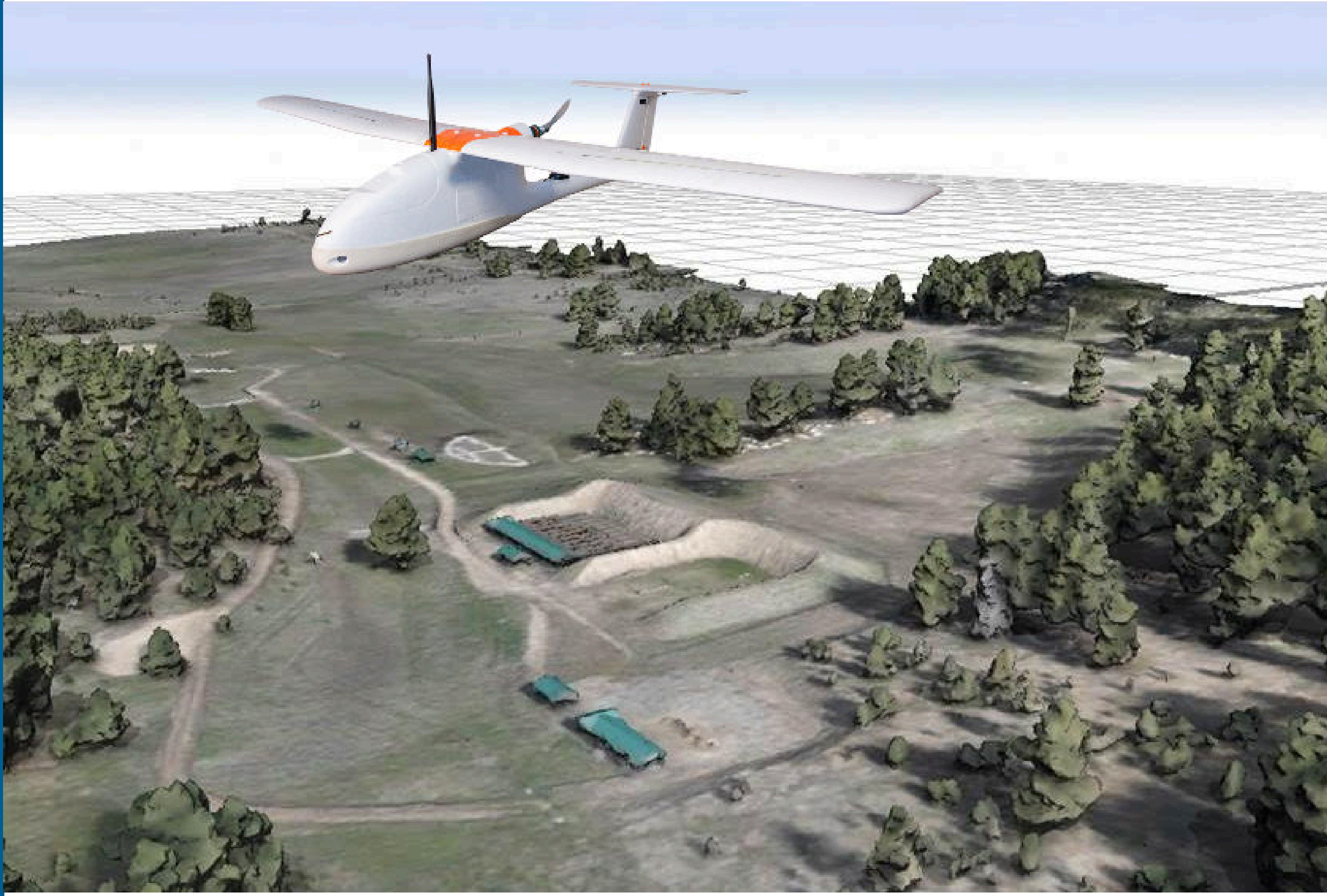

Surveying and Mapping with Fixed Wing UAS

A Fly-Off Between Leading UAS Providers

BlackSwift TECHNOLOGIES

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Introduction

The recent flood of Unmanned Aircraft Systems (UAS) into the GIS industry, although exciting, has generated an increasing number of questions with every new platform and feature that becomes available. Increased improvement in reliability and post-processing capabilities promises to provide a greatly simplified and reduced price option for producing orthomosaic and 3D datasets. Unfortunately, the true value of any particular UAS remains difficult to determine as there exists a distinct lack of information when it comes to aircraft intercomparisons. Paramount to collection of accurate data is the understanding of not only the limitations of the processing software, but the relative errors and their sources introduced by the aircraft and sensor. This white paper will provide a direct comparison of three leading platforms, with data sets obtained over the same area of interest and within one day of each other.

The data examined here was the result of a fly-off between photogrammetry systems hosted by CH2MHill near Elbert, Colorado[1]. Each of the flights were conducted by independent contractors rather than the aircraft manufacturers, providing a realistic assessment of the quality that can be expected through normal operation of the product. The area of interest was provided several days prior to allow for preparation, and only very limited bandwidth internet access was available on-site. Flight order was determined on a volunteer basis.

Comparison of Fixed Wing Mapping Solutions

The direct comparison provided here was performed using the data products from each of the three fixed wing survey platforms which were flown during the fly-off: The UX5 HP from Trimble, the Ebee from SenseFly, and the SwiftTrainer™ from Black Swift Technologies. Geographical information was provided by the operator of the aircraft for each data set in the form of either a list of images and trigger locations, or by directly modifying the EXIF data within the header of the images. Processing was performed using the OneButton software package provided by Icaros[2], and was done using the exact same settings for each set.

Platform Comparison

	SwiftTrainer™	SenseFly Ebee	Trimble UX5 HP
Minimum time between photos	0.9s	3.8 s	Unknown
Maximum Flight Time	60 min	50 min	35 min
Coverage at 120 m (400 ft)	600 acres	500 acres	250 acres
GSD$^{\beta}$ at 120 m	2.9 cm/px	4.4 cm/px	1.7 cm/px
Launch type	Hand launch	Hand launch	Catapult
Price$^{\alpha}$	$	$$	$$$$

$^{\alpha}$Contact vendor for exact pricing.
$^{\beta}$Ground sample distance
$^{\beta}$The values here are for the systems at the fly-off, see the respective websites for different options.

[1] http://www.xyht.com/aerialuas/uav-fly-off/
[2] www.icaros.us/onebutton

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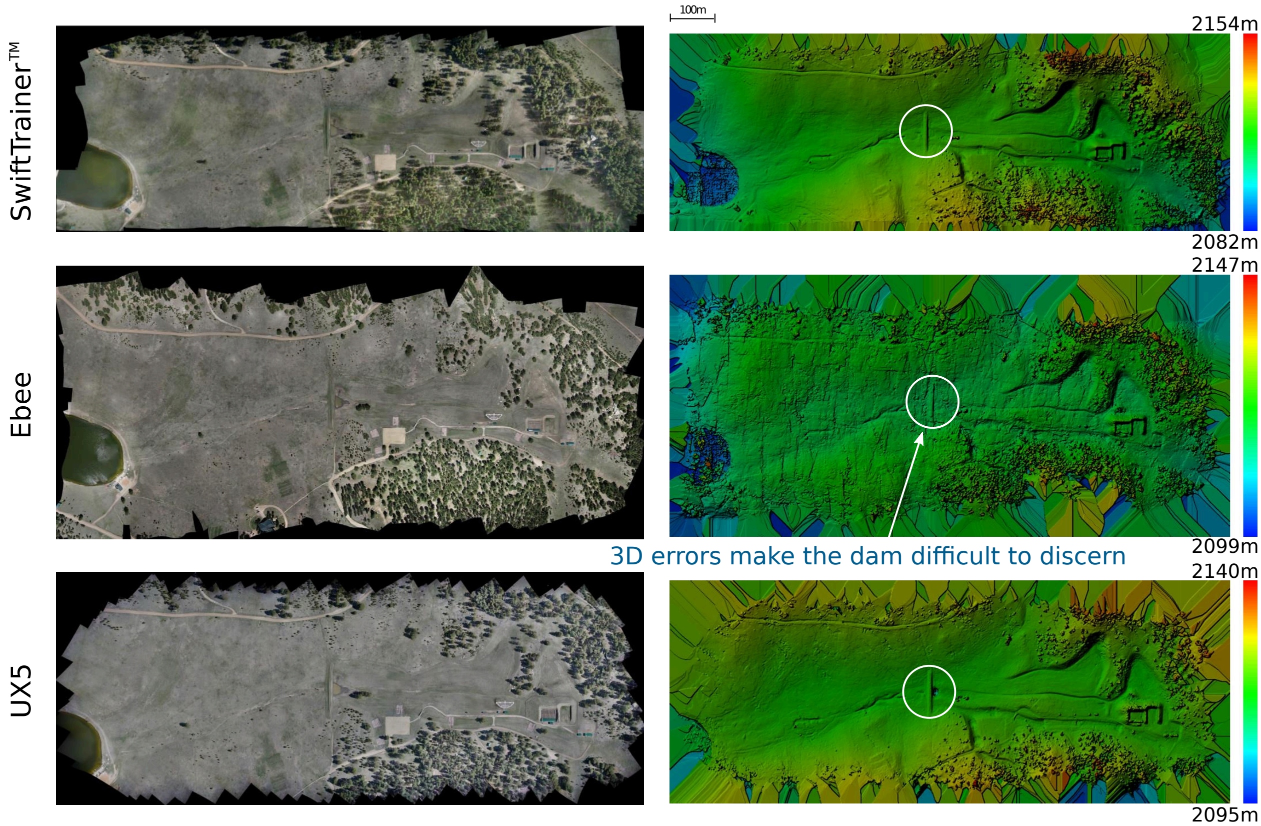

Figure 1: The orthomosaic (left column) and elevation map (right column). From top to bottom the data products were generated from data gathered by the BST SwiftTrainer™, the SenseFly Ebee, and the Trimble UX5 HP.

Figure 1 contains the resulting information from processing each data set. The images on the left contain the stitched orthomosaic over the area of interest, and the images on the right are colored to coordinate with the height of the mapped terrain and objects. While at first glace, each platform seems to have produced a satisfactory orthomosaic, differences between the platforms become quite apparent when examining the elevation map. The top and bottom elevation maps show a strong correlation, while the middle map (produced by the Ebee platform) contains a fair amount of artifacts in the middle of the elevation data not present in the other two, indicating significant errors in the three-dimensional solution. For many survey applications errors of this magnitude will render the data useless, requiring a costly second deployment to gather the data, or worse, the need for conducting the survey in a different manner. To understand the source of the error, other aspects of the data must be considered.

The source of the differences begins to become apparent when comparing the coverage maps and connected meshes used by the stitching software. Figure 2 shows a graphical illustration of the amount of overlap on the left and the resulting connected mesh (each photo that overlaps at least in some part another is considered connected) generated by the stitching software on the right. Examining the three plots on the left, both the Ebee and the UX5 fail to provide complete, uniform, and high density (10+ image) overlap for the area of interest, and both contain irregular patterns in the overlap.

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This is caused by the photos not being spaced in a regular grid like the SwiftTrainer™. Maintaining a regular overlap pattern is very important for accurate processing particularly in regard to resolving the shape of the terrain and contained structures. Irregular patterns can result in gaps in the 3D data as is evident in the Ebee data from Figure 1. Gaps in a data set at critical points can significantly impact a data set, including reducing the absolute accuracy of the set if the gap is near a control point, or requiring a costly redeployment if the gap is in a location that is to be used by the survey application.

Turning the examination to the number of connections between each image, note that both the Ebee connected mesh plot (middle right data set in Figure 2) and UX5 (bottom right) have gaps around the perimeter of the area of interest. While orthomosaics can be generated with less than fully connected data sets, this could result in areas with insufficient accuracy in the three-dimensional data product, resulting in the need to re-fly missions which can be costly and frustrating for the user.

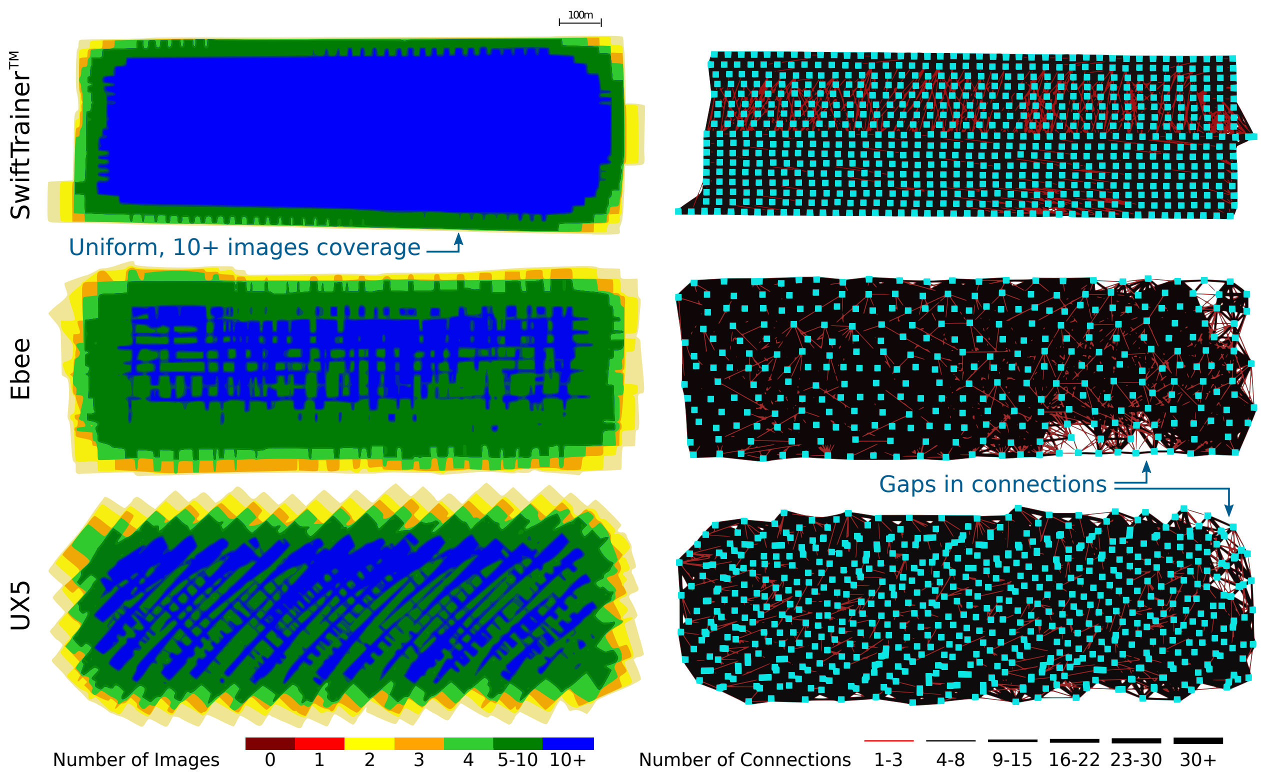

Figure 2: The coverage map (left column) and the connected mesh (right column). From top to bottom the data products were generated from data gathered by the BST SwiftTrainer™, the SenseFly Ebee, and the Trimble UX5 HP.

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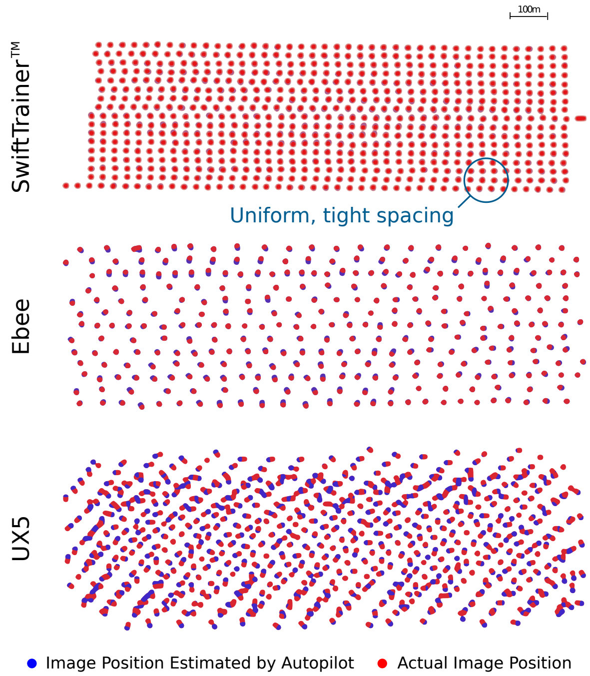

Figure 3: Image initial and calculated positions. From top to bottom the data products were generated from data gathered by the BST SwiftTrainer™, the SenseFly Ebee, and the Trimble UX5 HP.

Finally, a topic of significant discussion is both the absolute accuracy of the data as well as, to a lesser extent, the amount of processing time (which can be costly) required for gleaning data products from image sets. A significant portion of the error associated with absolute positioning is ability of each platform to determine the center location of each photo. Figure 3 shows the anticipated ground location of the center of the images provided by the aircraft (red dots) as well as the corrected locations computed by OneButton (blue dots) following post-processing.

The SwiftTrainer™ (top row) is able to very accurately determine the location of each photo, demonstrated by the fact the corrected locations (blue dots) are nearly on top of each autopilot geo-tagged location (red dots). The Ebee and UX5 struggle with both uniform sampling, and accurate geo-tagging as is evident in Figure 3. Several factors contribute to these errors including properly triggering the cameras and accurately maintaining orientation of the aircraft and payload. More importantly, the reprojection errors are propagated through the data analysis and will result in longer processing time as well as larger errors when producing geo-rectified orthomosaics and terrain information. Both results can result in higher costs incurred per data set, either in processing time, which can be expensive, or by requiring a re-deployment to gather a second data set without the large errors.

Finally, we summarize the performance of the three systems in the table below. The conclusion here is that the SwiftTrainer™ outperforms both the Trimble UX5 HP and the SenseFly Ebee while coming in at a significantly lower price. Additionally, this quantitative comparison is solely focused on the data product. The SwiftTrainer™ also has significant advantages in ease-of-use, robustness, and other features not outlined in this report.

CH2MHill Fly-off Comparison

	SwiftTrainer™	SenseFly Ebee	Trimble UX5 HP
Mission Time	29.3 min	31.7 min	25.8 min
Number of Photos	693	312	621
Mean Reprojection Error	7.1cm	19.4cm	9.4cm
Average Connections per Pair	190.11	52.17	72.62
Photos used	99.7%	88.1%	95.5%

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SwiftTrainer™ sUAS

The SwiftTrainer™ was specifically designed as an advanced fully autonomous, yet simple to operate, survey and mapping platform. The combination of the ease-of-use of the SwiftTrainer™ along with the improved regulations allow new operators to get up and flying quickly. This allows entities needing this data to focus their efforts on using the data and doing the work rather than be primarily focused on UAS operations and certifications.

The system is ready-to-fly out of the box and includes everything required for conducting survey missions, including the aircraft, batteries, ground station with tripod, tablet computer, field toolbox, carrying case, and RC handset (Figure 4). Unlike other systems, no additional computers or support equipment are required for conducting missions.

The SwiftTrainer™ is capable of conducting fully autonomous flights in unimproved areas. Take-off is performed through a simple hand launch, and the advanced landing algorithm provides for robust and precise autonomous belly landings. The SwiftTrainer™ has a high operational ceiling, and has been used to perform mapping missions at altitudes up to 14,000 ft in Colorado. It has been employed for surveying work, land management, and crop damage assessment and large area ecological studies. The specifications for the SwiftTrainer™ are listed in the table below.

Figure 4: The SwiftTrainer™ mapping solution.

SwiftTrainer™ UAS

Specifications

Area coverage per flight	25 - 600 acres
Ground sample distance	1 inch/pixel at 400 ft
Mapping Camera resolution	24MP
Time between photos	<1 s
Maximum Flight time	60 minutes
Cruise speed	33 mph
Weight	6 lbs
Wingspan	5.5 ft
Propulsion	Electric motor

Key Attributes

- Ready to fly out of the box
- Training requires about half a day
- Uses SwiftCore™ Flight Management System
- Accurate flight tracking

The SwiftTrainer™ utilizes the SwiftCore™ Flight Management System, comprised of the SwiftPilot™, SwiftStation™, and SwiftTab™ user interface, along with support electronics. The entire system is designed for ease of use along with accurate flight tracking, even in high winds. The SwiftCore™ is designed by Black Swift Technologies and is entirely made in the USA. The SwiftCore™ has been approved and used for major scientific missions by NASA, deployments by NOAA, and by a growing list of commercial survey and other companies in the SwiftTrainer™ UAS.

Training and Regulations

A purchase of the SwiftTrainer™ includes 2 hours of training at a test site near Boulder, CO. On-site training is also available. The SwiftTrainer™ has been designed with a simple, intuitive user interface making it possible for users new to UAS to be trained and capable of operating missions in about half a day. This is very important since it allows companies to have multiple people on staff capable of operating the system at very little overhead cost for training. Owners realize the benefits of UAS without the need for a full time pilot or having to pay for the service whenever the data is needed.

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Black Swift Technologies (BST) also has a long history of getting flight approvals with the FAA. BST personnel have been intimately involved with UAS FAA regulations and certifications for 8 years and have been responsible for hundreds of flight approvals some of which include unique and difficult missions. With the advent of the new Part 107 rules[3], operator certification has been greatly simplified. An untrained individual can learn the material and write the test with about one day of studying. With the operator certificate in hand, operations can be conducted by a single operator with limited overhead.

Simplified Photogrammetry Workflow

The SwiftTrainer™ system features a simplified workflow to go along with industry leading performance for a photogrammetry platform. This allows users to focus on the job of utilizing the orthomosaic images and point clouds rather than on operating the UAS or having to refly missions due to issues with the data.

The workflow is comprised of 4 mains steps shown in Figure 5: 1) Planning and Simulation, 2) Flight, 3) In-Field Check and 4) Data Processing. Mission planning prior to deployment allows users to have flight plans ready to go before deploying and minimizes time in the field. It should be noted that planning can also be done in the field or even while the SwiftTrainer™ is airborne if needed. The flight portion takes as little as 5 minutes to setup and launch, while the flight itself can take up to an hour depending on the size of the area to map. After that the images are tagged in the field and verification is performed to ensure quality and completeness of the data. The final step is to process the data, resulting in contour maps, 3D point clouds, and/or orthomosaic images.

Beyond the ease of use and the robustness of the system, three key features of the SwiftTrainer™ enable it to produce industry leading orthomosaics and point clouds. These are 1) the accuracy of the ground tracks (even in strong winds), 2) the accuracy of the geotag of the images, and 3) the speed at which the camera is triggered. These three factors are critically important to generate accurate and rapid orthomosaics.

[3] http://www.faa.gov/uas/

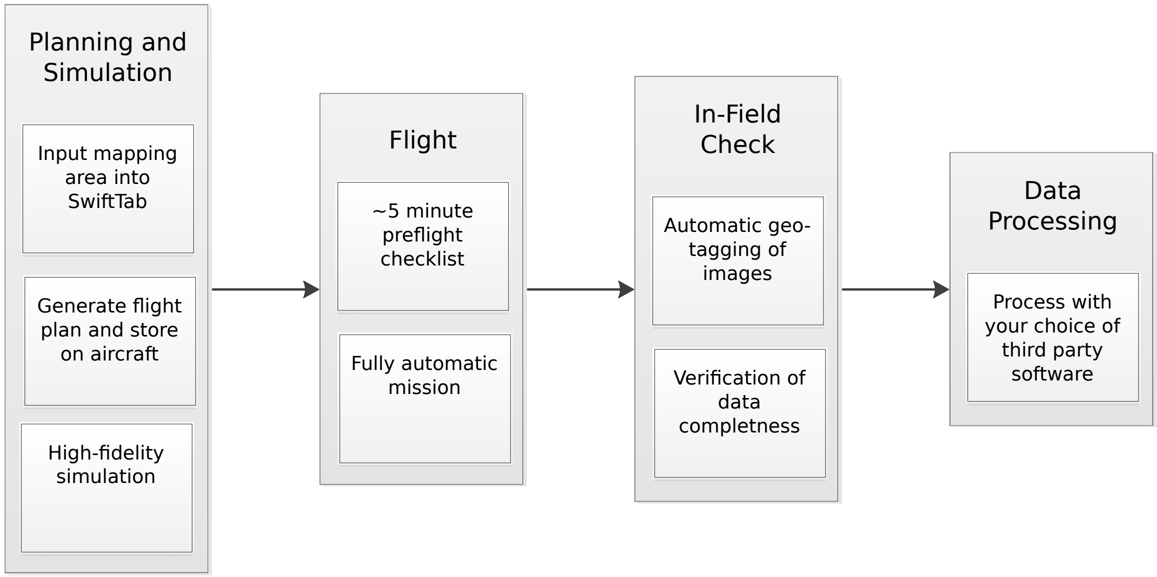

Figure 5: Simple and intuitive process that simply integrates into the existing workflow.

- **Accurate Ground Tracks:** The SwiftTrainer™ flies extremely accurate ground tracks compared to competing systems. It's critical to have a regularly spaced grid for sampling. Not holding tight to those flight lines could cause loss of image overlap and may require the operator to re-fly missions, which can be very costly. Figure 6 shows the results from a SwiftTrainer™ mapping mission.
- **Accurate Geo-tags:** Significant R&D effort was used to produce accurate tags which are critical for rapid generation of orthomosaic images from raw photos.
- **Fast image acquisition:** The SwiftTrainer™ can trigger the camera at a rate of less than 1s per image. In comparison, other competing survey platforms can have a delay of greater than 3s between images. The fast rate of the SwiftTrainer™ is critical to flying at 400ft or below with an overlap of greater than 60%, which is important for producing high quality orthomosaic images with the resolution needed for most survey and mapping applications.

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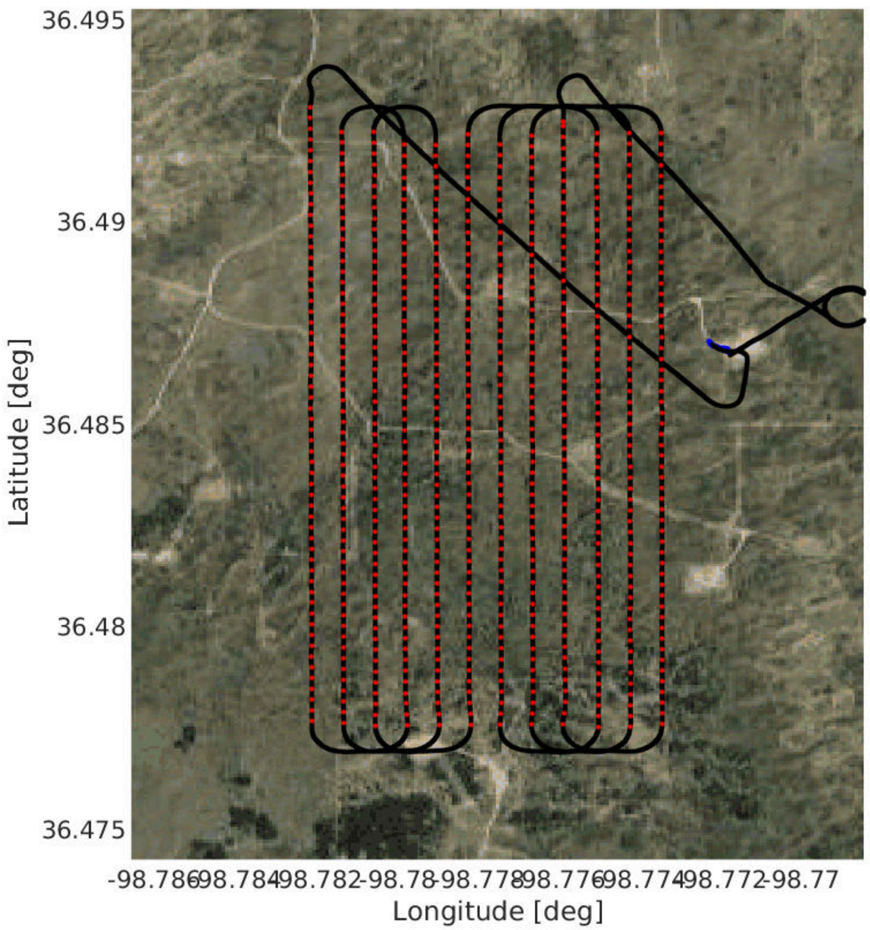

Figure 6: Path and photo locations (in red) from a SwiftTrainer™ flight.

About Black Swift Technologies
Black Swift Technologies (BST) is based in Boulder, CO and has been in operation since 2011. BST produces our own line of customizable autopilots, ground stations and supporting avionics. This affords control of the critical parts of our products, including the design of all electronics for both the avionics and ground systems, software, mechanical assembly, along with the QC process for all outgoing systems. All UAS sold by BST are built upon the SwiftCore™ FMS that includes the autopilot, ground station, user interface, and support electronics. Unlike many competing systems that rely on open-source and low-quality avionics, BST is able to guarantee quality, robustness, and supply of the most critical components of our systems.

Furthermore, BST uniquely couples avionics expertise with consulting services, and has delivered products and engineering services to many government entities including NASA, NOAA, various universities along with commercial sales to end-users and aircraft integrators. Concurrently, it offers consulting services for customers attempting to navigate the ever-dynamic and often confusing application process for legal access to airspace as granted by the Federal Aviation Administration through Certificates of Authorization (COAs) and Section 333 exemptions. – http://ApprovedFlight.com