Unmanned Aerial Systems

Construction Research Project

Montana Department of Transportation

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Quality information

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1. Executive Summary

This report provides an analysis and evaluation of the application of UAS technology for MDT to map highway construction projects prior, during, and after construction to aid MDT construction administration staff in determining earthwork quantities. Technical aspects explored include the application of different UAS platform types, planning and execution of UAS activities, environmental (weather) considerations, interfacing with peripheral entities (i.e. landowners, the travelling public at large, and the Federal Aviation Administration (FAA)), attainable data accuracies, volumetric calculations, lessons learned, and digital datasets derived from UAS imagery.

Methods of analysis included area coverage, traffic management methods, UAS system stability, image clarity, radiometric quality and consistency, horizontal and vertical accuracy analyses, as well as volumetric earthwork determination calculations.

UAS technology is evolving rapidly on numerous fronts. UAS adoption by DOTs across the nation, and around the world, is accelerating and new applications for the technology continue to emerge. This report finds the prospects and benefits of leveraging UAS technology for the purposes outlined above to be positive.

A summary of the results are presented below:

For comparative analysis, UAS image data and derivative products were successfully acquired using both fixed-wing and vertical take-off and landing UAS platform types during the Pre-Construction phase of the program. Because of the flexibility in execution associated with the vertical take-off and landing UAS platform both the Intermediate and Post-Construction data collection efforts were performed using this platform type. The experiences, including the benefits and shortcomings, associated with each platform type are discussed throughout this report.

Due to the presence of Livingston airport at the southern end of the Mission Interchange an FAA waiver was required to be obtained prior to any UAS flights. The required waiver was subsequently awarded. Details regarding the steps required to acquire an FAA waiver are detailed in the report, as well as, how the new FAA waiver request process functions.

Due to current FAA restrictions, employing UAS platforms as a low-cost alternative to manned aircraft capturing imagery over public roads posed challenges associated with vehicular traffic. AECOM employed several methods to manage traffic, of which utilization of a pilot car proved the most efficient. Challenges encountered are detailed in the report.

Additionally, FAA requirements demand the UAS platform to remain in visual line of sight at all times. To satisfy this requirement the UAS command center was positioned such that the UAS could capture data one-half mile on either side of the command center, permitting the capture of data in one mile corridor sections. Each section overlapped. Survey control was captured in the overlapping areas as well as on alternating sides of the road surface. Intermingled with the ground control was surveyed checkpoints. Survey and checkpoints were either painted targets on the road surface or plastic targets in the ROW.

Horizontal accuracy tested was exceptionally high (≤ 0.05’ RMSExy), in line to what has been documented in many studies by various public and non-public entities. Likewise, vertical accuracy attained varied from 0.037’ to 1.522’ RMSEz. Ignoring the highest residuals in each of the various flights the RMSEz reduces significantly in several cases. The variance was attributed to UAS platform characteristics, environmental or lighting conditions affecting the image capture and/or processing, vegetation growth and/or survey challenges resulting in less than ideal control available or location of available control. Details of which are presented in this report.

Recommendations as they relate to the various aspects of implementing a UAS program are included for consideration, several key topics of which are presented below:

UAS Flight Planning – UAS flight planning software vendors are numerous. The software continues to evolve and is still not as sophisticated as manned flight planning software. UAS planning software development has been largely in the form of apps for tablets. Most tablet operating systems do not offer a method to define area of interest (AOI) limits with precision, or the software does not yet permit the import of a pre-defined AOI.

UAS Platform – Vertical take-off and Landing UAS platforms offer a lower price point and most flexibility. However, their shortcomings are area coverage due to flight speed and battery life. Additionally, these platforms are more susceptible to cross winds, impacting image quality. While fixed wing aircraft can cover a larger area and have a longer battery life, take-off and landing requires more space which can be difficult in a narrow roadway corridor and raises additional safety concerns while landing at higher speeds.

FAA Waiver – The FAA is continuing to modify the process for requesting airspace authorizations and requires a very proactive engagement by UAS pilots to stay current on evolving processes and tools used for making requests. With the evolution of the LAANC (Low Altitude Authorization and Notification Capability) system the FAA response time has been greatly curtailed. As always, start the process early.

Weather – Weather will play a pivotal role to project success. Experience and careful monitoring of weather is critical to capturing useful data. Moreover, UAS crews must be creative and remain flexible to change flight plans and dates if needed.

Traffic Control – The use of pilot cars was the most efficient to keep traffic moving and abide by FAA regulations during UAS data acquisition.

Ground Control Points/Survey – Work closely with surveyors. Budget into the data acquisition plan the time needed to adapt to changing mission flight plans. Survey ground control points in a timely manner that ensure visibility in the captured image data as construction activity and variable traffic patterns can disturb, obscure, and/or destroy critical ground control and check points.

Data Processing – UAS data processing is extremely computer intensive and data volumes can be onerous. Careful consideration regarding design and appropriate budgeting is required to acquire a processing system that can efficiently convert raw imagery into actionable information. Current cloud based solutions are an option, but offer limited processing control and troubleshooting tools.

2. Introduction

In June of 2016 the Montana Department of Transportation (MDT) awarded AECOM an Unmanned Aerial System (UAS) survey contract to perform photogrammetric mapping, volumetric calculations, and orthophoto production, CN#4338011. The award stemmed from the MDTs RFP, 2016-2018 Unmanned UAS Term Contract, released on May 5, 2016.

The contractual work was broken into three tasks; a Pre-Construction survey, an intermediate survey, and a Post-Construction survey. The key objective of this project was to better understand the benefits and limitations of UAS in support of this type of work. As defined by the MDT proposal, items of particular interest were to include but not be limited to; feasibility, efficiencies and performance of UAS, limitations, FAA restrictions and exemptions, accuracy, safety, and equipment, each of which will be detailed in the report.

3. Scope of Work

Areas of Interest

Two corridors of roadway were defined by MDT to conduct the three UAS aerial survey tasks. These sites were selected as construction projects were about to begin at each site. The original scope was to fly the entire corridor during the first task, Pre-Construction, then a smaller portion of each corridor during construction, and then re-fly each corridor in its entirety as part of the post construction task.

Mission Interchange Corridor

Located approximately 90 miles west of Billings, the Mission Interchange Corridor runs NNW-SSE, resides in an agricultural setting, and is 6 miles in length. The elevation range along the corridor ranges from 4425' – 4600'.

Overview of Mission Interchange Corridor

East of Ashland Corridor

Located approximately 120 miles SSE of Billings, the Ashland Corridor runs east-west, rests along the bottom of a narrow valley, and is 8 miles in length. The elevation range along the corridor ranges from 3150' – 3450'.

Overview of Ashland Corridor

Aerial Survey Tasks

Pre-Construction

Aside from the overall UAS system performance evaluation objectives, the goal of the Pre-Construction aerial survey was to establish a base line of information regarding each corridor. Critical outputs from this task would be orthophotography, a point cloud, and a digital elevation model. Given the length of each corridor it was suggested by AECOM that the Pre-Construction survey could be utilized to evaluate two distinct UAS platforms, a fixed wing and a quadcopter thus allowing a better understanding of performance as there would be a comparative dataset. Of particular interest, the aerial survey focused on the creation of digital surface to be used in later phases as part of earthwork calculations.

Intermediate-Construction

Intermediate-Construction objectives were to capture a section of each corridor during active construction activities. The primary deliverable was a high detail and accurate terrain model derived from the UAS imagery. This model was to be used to quantify earth moving efforts in the form of volumetric data and in turn serve as a means to determine and validate quantities for monthly progress estimates. The current MDT practice is for the Department's Project Manager to estimate the earthwork quantities.

Post-Construction

Post-Construction goals were to capture and document the end state of construction activities. Similar to the Intermediate-Construction effort, using the developed terrain model volumetric calculations, measurements, and profiling can be used to determine final quantities for Contractor Payments.

Deliverables

During discussions between MDT and AECOM it was determined that orthophotography, point cloud data, digital elevation models, and as well as the desired earthwork volumetric data would be required for the Pre-Construction task and that volumetric data was the requirement for the other tasks.

The purpose of the aerial survey work was to meet or exceed a vertical data accuracy of 0.20' at the 95% confidence level and a ground sample distance within 0.08' or better.

The goal of this final report is to capture key details and lessons learned from the three aerial surveys.

The report encompasses the project as a whole and includes the following relevant details:

- Approach and planning
- Description of any difficulties or obstacles encountered with the flight (weather limitations, seasonal constraints) and processing
- Flight plan and flight information (flight overlap, elevation, parameters, ground support, etc.) compliance with FAA and any FAA exceptions needed or considered
- Notifications or agreements with the public or landowners
- Control verification, ground surveys, additional control added, supporting surveys equipment
- Metrics associated with each element of work including: planning, flight durations, data processing and volume calculations, etc.
- Software and processes used to calculate earthwork quantities
- Actions taken to increase immediate and longer term efficiencies, as well as lessons learned
- Accuracy of the results, computed earthwork volume and earthwork report, and any other relevant information

4. Aerial Task One: Pre-Construction

In September of 2016 MDT tasked AECOM with the first aerial survey, Pre-Construction. The objective was to perform the aerial survey prior to the arrival of winter weather which would have greatly impacted the ability to effectively complete the two areas of interest (AOIs). November 15, 2016 was the agreed upon last day of execution for any field operations.

System Selection

AECOM recommended and MDT agreed that during the Pre-Construction task two distinct systems should be utilized. The objective of this effort was to evaluate the applicability of UAS technology in MDT Pre-Construction phases, but to also understand the benefits and limitations UAS technology and different UAS systems. The systems selected were the SkyCatch EVO 3 RTK quadcopter system to be piloted by AECOM and an Altavian NOVA F7200. Altavian was subcontract through AECOM to provide the field acquisition services.

Metric	NOVA F7200	EVO 3 RTK
Air Frame	Fixed wing	Quadcopter
Flight Duration	90 min	20 min
Launch Requirements	Hand launch, belly landing	Vertical take-off/landing
Sensor	29 Megapixel, color	16 Megapixel, color
Gimbaled Mount	No	No
GSD Capable	0.06’	0.03’
Onboard GNSS	Survey grade GPS	Survey grade GPS
Image Size(pixels)	5,184 x 3,456	4000x3000
Maximum Crosswind (MPH)	25	25

RTK

RTK, or Real Time Kinematic, technology is used to minimize, or even eliminate, the need for ground control. RTK supplies real-time corrections to locational data as the survey drone is capturing imagery. The SkyCatch system offers this technology as an upgradeable option to the EVO platform.

To implement real time correction technology a survey grade GNSS base station must be established on a known high accuracy survey monument and must be equipped with a radio transmitter to establish a dedicated connection with the UAS platform. Set on a known control point the GNSS receiver can calculate and broadcast the positional corrections required to accurately reflect the true positional location continuously. The UAS GNSS system must also be survey grade quality and able to receive and interpret the broadcasted correctional information from the base station. Onboard, using the broadcasted correctional information, the UAS recalculates and records the positional information in real time for each photograph, thereby transforming each photo center into a high accuracy XYZ control point, which, in theory, negates the need to capture ground control points across the project area. However, it is good practice to collect additional control points to assess data accuracy. RTK methodology captures very accurate XYZ coordinates for each photocenter, it does not capture orientation data like that of an IMU. RTK based image datasets must be run through an aerotriangulation program to generate orientation parameters.

To achieve high accuracy results the base station must be within radio reception range, and have an unobstructed view of the UAS, hence the distance between the UAS and the base station is quite close. An obvious issue with RTK technology is the need for a high accuracy control point to reside near the project area, and a reliance on a radio connection between the base station and the drone. Should there be intermittent connectivity those images captured during the loss of connection will not have the high accuracy coordinates which in turn will degrade the locational and overall project accuracy. It is also worth noting that not all antennas are light enough to be mounted on small UAS are not geodetic-grade and are not likely to have been calibrated for phase-center variation (PCV), let alone the actual location of the phase center. This may result in degraded solution accuracy, the magnitude of which is dependent upon a combination of the factors noted above as well as the quality of the components employed

Please note, VRS, or Virtual Reference Stations, with the appropriate subscription can be leveraged and function as a base station for RTK activities. A laptop connected to the VRS via the internet that also has a radio link to the UAS is required.

There is a similar technology referred to as PPK, or Post Processed Kinematic, technology. PPK works to correct locational data like RTK except PPK performed in the office after the drone data has been captured. Data is logged in the aircraft and combined with data from the base station when the flight is completed. The technology is similar RTK in that a base station is required; however, in some instances an existing CORS station can be utilized. If a CORS station is not available a survey grade base station is required, but the additional expense of the technology required to broadcast correction information is not required.

With both RTK and PPK technologies, when the rover loses lock, a new integer ambiguity resolution procedure must be initiated. The advantage of PPK is that the ambiguity resolution procedure can proceed from previous and future data relative to the moment of loss of lock. However, RTK solutions cannot leverage data that does not exist. Furthermore, forward and reverse solutions in PPK can be combined and give an estimate of a solution’s consistency. If an RTK system is employed there is no external information for basing accuracy estimates, unless you set ground control.

If positional accuracies of a few decimeters are acceptable, real-time L-band corrections through a subscription service such as TerraStar-D are very viable alternatives that require no base stations at all.

Additional RTK references:

- https://www.youtube.com/watch?v=pCTnrPDEsSM
- https://www.altavian.com/knowledge-base/use-ppk-drone-not-rtk/
- https://www.identifiedtech.com/blog/drone-technology/gcps-ppk-rtk-best-receive-fast-accurate-data/
- https://pix4d.com/rtk-ppk-drones-gcp-comparison/

Planning Details

The elements, considerations and constraints that go into an effective UAS operation all hinge on the mission planning. The amount of information available and able to be gathered in this phase will largely determine the outcome. UAS operational projects also require an in-depth study and analysis to ensure safety and regulatory compliance. The planning phase is a building block for the execution phase and often during execution it is often required to fall back to the planning and revise the overall plan (remaining within the constraints of regulatory compliance). The Mission Interchange Corridor project provided several challenges to overcome during the planning phase requiring coordination with the FAA for the airfield KVLM resulting in a waiver request. During the planning phase software programs such as Google Earth were used to layout the boundaries, review terrain, identify obstacles.

Upon tasking AECOM immediately held an aerial survey kickoff meeting with all key internal stakeholders to ensure that all aspects of flight operations were to be properly addressed. Items covered in that initial kickoff meeting included the following:

Flight planning

– Understanding the AOI and the desired data products so proper forward/side lap flight plans could be developed
– Would flight lines cross the road or simply fly alongside the roadway?
– How long were the flight times of each system being utilized?
– Were there altitude concerns for any of the systems?
– What was to be the flying altitude?
– Based on two large AOIs how long was the acquisition expected to take?
– Were there any FAA restrictions that would delay or restrict the planned acquisition?
– Any powerlines/trees/terrain issues?
– Any landowner communication or cooperation required?
– Site access for suitable launch and recovery locations to include considerations for maintaining line of sight (LOS) with the UAS?

Traffic Management

– Average daily traffic volume for each highway?
– Traffic stoppage – MDT had informed AECOM that they preferred not to stop traffic more than 15 minutes
– What types of traffic controls would be required for the fixed wing systems take-off and landing?

Ground Control Points (GCPs)

– What types of targets would be used?
– Was there useable ground control that already existed?
– What accuracy should be used for the control survey?
– Would there also be checkpoints collected so the data could be validated?
– Define mission overlap with consideration to GCP placement

Weather

– What was the long-term forecast?

- How dynamic was the weather at each AOI during the planned flight windows
- Effect of wind speed and direction

Finalized Plans

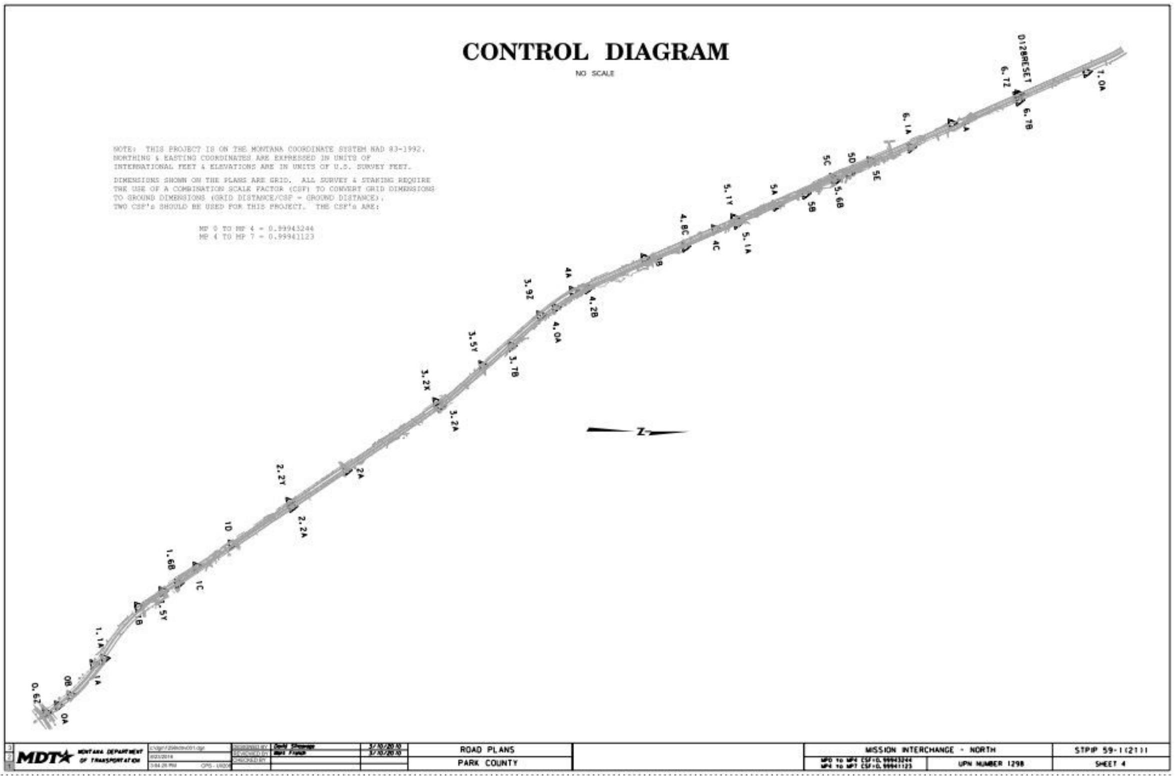
One critical component in finalizing flight plans and control points was an understanding of the safe and practical flying distance of each system so a determination could be made about locations with overlapping flights. Anytime an airframe landed and the pilot and operator switched locations it was planned to include two ground control points within the overlap of the two flight paths. This plan was to ensure that there would be sufficient control in areas deemed as a potential risk during the data processing.

Through careful evaluation it was determined that both the F7200 and the EVO 3 could utilize the same overlapping locations.

Ground Control

A review of the existing MDT project survey control points was conducted to identify project control points that could be used as ground control points (GCP) and if the existing survey control point network had the proper spacing/location, and density required for post flight processing, based on the preliminary flight plans. AECOM identified the spacing and density of the existing survey was not adequate alone for both sites using just the existing control points as GCPs and proposed additional ground control points to fill in spacing and density for preliminary flight plans.

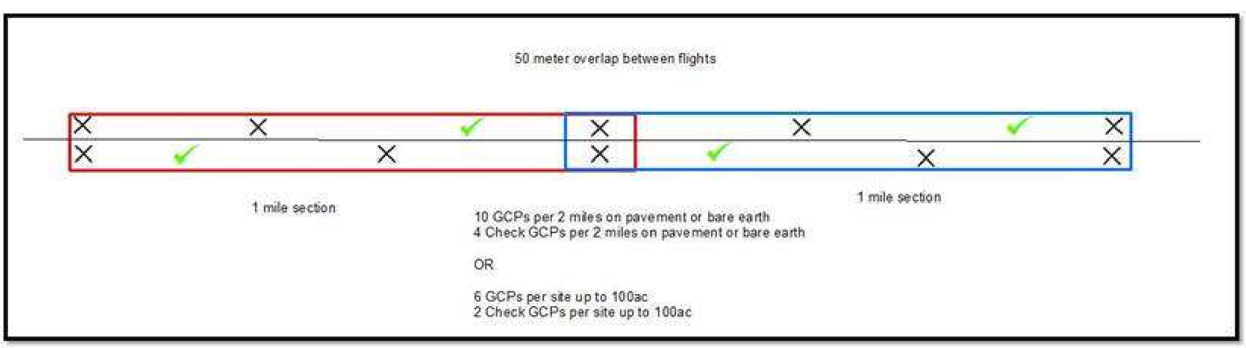
A site visit was conducted to locate existing control points and determine their condition and if they were usable as GCPs in the field. The proposed GCP locations were staked out at or near locations identified in preflight planning.



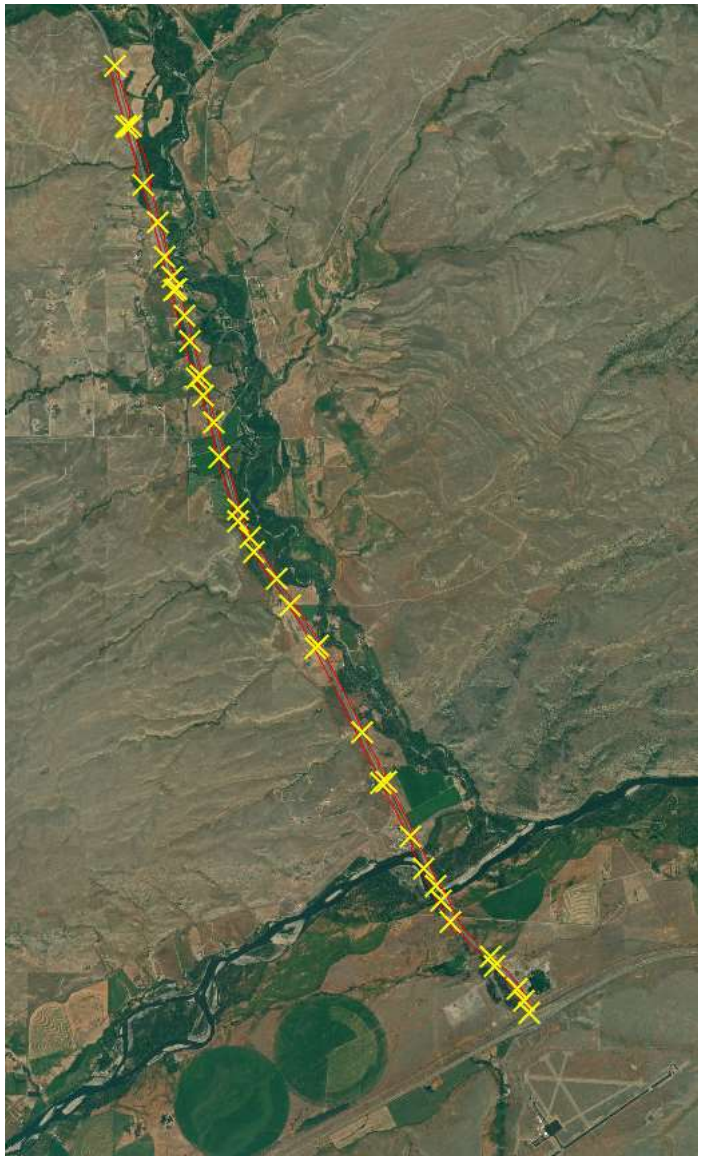
DOT Control Diagram for Mission Interchange

Idealized control layout

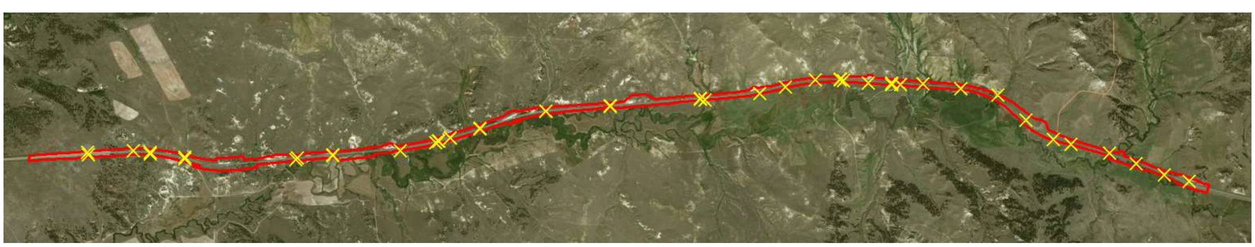
AECOM developed an idealized control plan to ensure proper data processing. In the graphic below, each of the two sections are one mile in length with an overlap of 150’. One mile length sections were delimited to support safe VLOS operations. It is imperative that shared control exist between the two sections as well as control pairs set at the terminus of each section. Within each section two control points and two checkpoints should be set. This equates to 10 GCPs per two mile section and 4 Checkpoints per two mile section. Spacing of the points will be dictated by opportunities within the section where there is bare earth exposed and/or targets painted on asphalt.



Corridor control plan guidance



Mission Interchange Control and Acquisition Boundary



Ashland Control and Acquisition Boundary

Flight Plans

Once boundaries were set, mission planning software specific to the system manufacturer was used to begin flight planning. Each system utilizes specific software for the UAS being operated. Planned pixel resolution for each platform was set to 0.06' or 2 cm.

SkyCatch has gone from a computer-based desktop system to an all tablet system. Below is a sample from the desktop used for the initial Ashland project.

Advantages of a desktop solution, which AECOM prefers, allows for more detailed planning, is easier to manipulate flight limits, and be more precise particularly for large projects when even a small bump in or out of the survey area can change the data collection from either getting too much resulting in increased field time, or not enough, missing a portion of the desired objective area.

Output from a typical UAS mission planning tool – SkyCatch system

For both systems flight plans were developed based on idealized flight conditions. UAS operations are more dynamic than manned system operations meaning that changes in ground and/or wind conditions could necessitate altering flight plans in the field. Should flight plans be altered in the field it was critical to ensure that the overlapping flight locations with additional ground control were utilized.

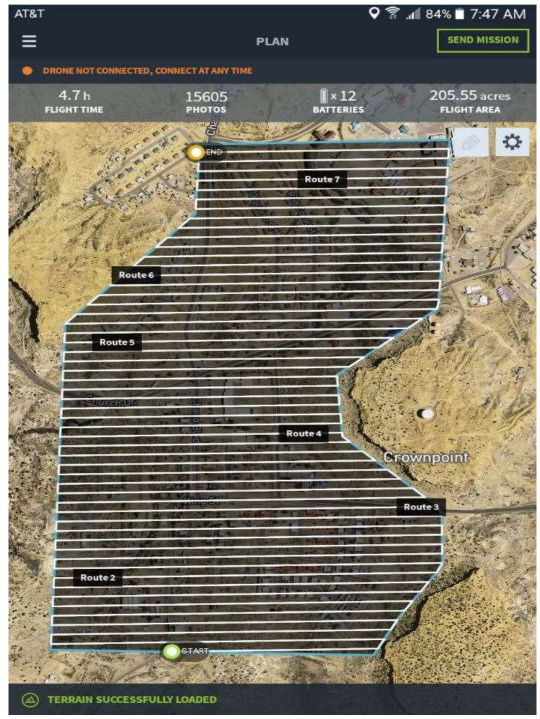
Altavian flight plan for Ashland

Altavian flight plan for Mission Interchange (left)
SkyCatch flight plan for Mission Interchange (right)

Since the initial aerial survey of the Ashland and Mission Interchange corridors SkyCatch migrated the mission planning process to being done on a tablet. From the tablet the user draws the survey area with their finger and the software makes the necessary calculations. The challenge with this, doing it on a tablet is long linear projects as the entire survey area must be displayed on the screen while the user defines (draws the mission area) moving their finger or stylus on a touch screen. Once the area is drawn the user then comes back and makes adjustments, this can be challenging and time consuming even on small oddly shaped areas. As an example, a roughly 300 acre site defined by a customer can come in many forms indicating the survey interest area in red. An option in terms of planning for a project like this is to draw a simple rectangle straight-line shape ensuring to include the entire red area. The consideration for this is the variable terrain. Some UAS systems have terrain following allowing the UAS to maintain a relatively consistent altitude above the ground as it flies its routes. SkyCatch has this capability; however, it is dependent on web elevation models not tied to onboard systems, so the ability to maintain good terrain clearance is only as good as the web data used to calculate altitude. Both the 7200 and EVO 3 reference a terrain database that is used for actually flying the planned mission. On the EVO this database is uploaded automatically if terrain following is selected and there is an active internet connection to the tablet. Flying altitudes get recalculated if there are any changes to the flight plan if the flight was planned in a good stable internet environment. If there is poor internet connectivity the system will revert to a non-terrain following mode which requires the PIC (Pilot In Command) to as best able to estimate terrain variations and either adjust take-off locations so as to maintain a somewhat consistent flight profile based on where the aircraft takes off from or adjust the flight altitude for the mission to maintain a somewhat consistent altitude separation of the sensor relative to the ground. When the terrain following function is active the aircraft will adjust to the terrain during the flight. The system is not a gradual adjustment, when an altitude adjustment is required based on the database the aircraft will stop, descend or climb as necessary, and proceed on the flight versus a gradual adjustment to maintain a constant ground to sensor altitude relationship

Additionally, as part of the preparation before going to the field it is best to understand if it will be an environment having good reliable WiFi connectivity. This provides the user of the planning software the chance to cache imagery maps so that in the field if changes need to occur and internet is not available the base maps are accessible and can be pulled up when that time comes. It is advised to maximize the zoom feature of the entire survey area from the comfort of an office to insure the highest level of terrain detail is available regardless of the location and connectivity.

The screen shot below illustrates the output of the planning done on the tablet. Consideration is to get just enough excess, outside the survey, to ensure sufficient overlap of the imagery data without acquiring too much additional image data. There is a balance and tradeoff to consider between enough and too much while taking into account obstacles, roads, towers, airspace, terrain, property boundaries etc.



Example planning document from client (left)
Sample mission planning output (right)

Other planning considerations are to understand wind effects at the survey area. Key wind considerations relate to the maximum velocity the UAS can effectively handle and not impact image capture and image quality. A quadcopter has relatively good stability in winds up to 20-25 mph sustained or even gusting, however consideration must be given in conditions where winds speeds are at these values a decision to fly or not has to be made. The wind can cause image degradation of the data as the UAS attempts to compensate for the effect by crabbing into the wind causing the aircraft to yaw or in some case dip to a side in order to maintain a track line, in effect causing the camera to be non-nadir during flight. This situation is more of a factor for fixed mounted cameras as found on the EVO 3 and some fixed wing UAS platforms. Autopilots with more sophisticated design and more traditional flight control surfaces are able to provide a much more stabilized platform during flight and overcoming wind effects. Systems that incorporate gimballed cameras experience less of an effect due to winds as the camera remains fairly stable in the nadir position as the aircraft is buffeted. Additionally, there is a point that must be determined that either safety or collecting good data is not feasible and flights must be delayed or canceled to wait for more favorable conditions. In terms of determining suitable wind limits it is highly recommended to not fly in winds of excess of 15 mph due to the negative effects it can have on the data results.

Wind must be considered a factor not only at the launch and recovery point but also at altitude. During the flights conducted in Oct 2017 at the Mission Interchange site the wind speed at altitude was sufficient as to require canceling of flights for the remainder of the day. As an example, wind velocity can be such that the UAS may not be able to overcome the velocity meaning a PIC can input a command and the resulting impact is the aircraft is unable to respond beyond what the motors are capable of generating in terms of thrust due to wind effect.

Small, lighter fixed wing systems, commonly referred to as “foamies” like the Trimble’s UX5, Sensefly’s eBee series, can be even more susceptible to wind effects. Fixed wing with larger wing spans can handle much higher winds and remain stable. Some fixed wing systems carry much more advanced imaging sensors that are able to capture very high resolution imagery even with some airframe movement. A downside of fixed wing systems is they require far more planning and consideration to wind direction for both the launch and recovery phase of the flight with respect to obstacles and physically having enough room to set-up launch and approach paths. All this being said with reference to wind, understanding prevailing wind of a site during the mission planning will help determine how the track lines will be flown to minimize the wind effect.

Impact of flying in high winds:

- Battery life - UAS use more power to maintain stability in winds, resulting in shorter duration flights. Large projects require ability to charge, or have more batteries on hand, in order to complete the survey. Charging can take over an hour for an individual battery. Incorporating a small generator for field operations in addition to having multiple sets of batteries is a consideration for a project of any size.
- Loss of control – Landings are more prone to the aircraft tipping over or not landing in the designated spot for fixed wing systems (worst case going from a strong wind to no wind resulting in a much longer landing).
- Most importantly, poor data output. Wind direction and velocity can create a loss of data quality. It is advisable to restrict operations when wind velocity is in excess of 15 MPH for smaller light weight UAV’s like the types used on this project. Doing so provides the maximum success from a safety and data quality objectives. If operations are decided to continue during periods of winds higher than 15 MPH it is suggested to consider a head wind tail wind flight profile to minimize banking during the data collection and if the camera shutter speed is sufficient to keep up with the increased groundspeed during the tailwind portion of the flight lines so as not to skip areas or generate blurry images. In considering winds in terms of direction of flight operations one of the things to consider is whether or not the UAV has a gimbal mounted camera as with this type of system it is better to choose a flight profile that is perpendicular to the wind direction this provides a more consistent ground speed throughout the flight. Just the opposite is true for a fixed camera set up. Using this type of UAV, it is best to try and configure flights going with and against the winds to minimize bank and drift and the aircraft trying to keep on the designated flight path. The variable is the aircraft will have to adjust power output to overcome winds as it flies into the wind. During the legs that are with the wind the aircraft should reduce power but will still result in increased groundspeed which may adversely impact the data resulting in blurred images or possible gaps due to the shutter not being able to keep up with the increased speed of the aircraft. These are only suggestions for consideration and a careful determination of the site conditions with respect to the size and shape of the site and overall data requirements are some of the other variables to consider when making these types of decisions. Additionally, when flying linear projects a simple change in the flight direction from what was planned can have a significant impact on the logistical considerations for take-off and recovery locations, coordination with traffic control and may impact the survey control points that have already been placed as now the UAS and the survey overlap locations may not effectively coincide making for a much more difficult time during the data processing phase.

Sun angle

During the mission planning phase, another consideration is the angle of the sun. Flying during the shortest shadows, some of the best conditions are when there is a slight overcast or in the early to midafternoon time frame this provides a more uniform output and also significantly reduces the time spent during data processing. The other consideration is how the mission will be flown to minimize the need for the PIC and VO to have to look into the sun to maintain VLOS (Visual Line Of Sight) of the UAS. Obviously, there is never a perfect scenario where, winds, obstacles and sun angle are optimum and consideration must be made to all these factors when planning and flying a UAS.

UAS Planning tools

A couple useful tools specific to wind determination are a hand-held anemometer, good for calculating wind speed at the surface. A good rule of thumb is to add at least 20% to that reading for flights up to a 100ft in altitude. Also looking at local effects on birds, trees, flags are all good indicators. There are multiple apps that are useful for conducting UAS flights. Some of the apps used for the Ashland and Mission Interchange flights:

Hover

Description

– Hover is a free app with features include: no-fly zone map, drone specific weather forecasts, flight logs, flight readiness indicator, and industry news feed.

Features

– International No-fly Zone Map:
– Weather Data: Local current and forecasted weather conditions, along with a detailed breakdown of wind speed and direction, rain or shine, and temperature.
– Flight Logs: Individuals and teams can seamlessly track, log, and maintain their drone fleet. Manage drones, equipment, and personnel.
– Flight Readiness Indicator: Simple to understand flight status to let you know if it's safe to fly your drone or UAV in certain weather conditions and locations.
– News Feed: Stay up to date with what's going on in the drone industry with a live feed of content from company blogs, news blogs, and major media publications.

Screenshots from Hover

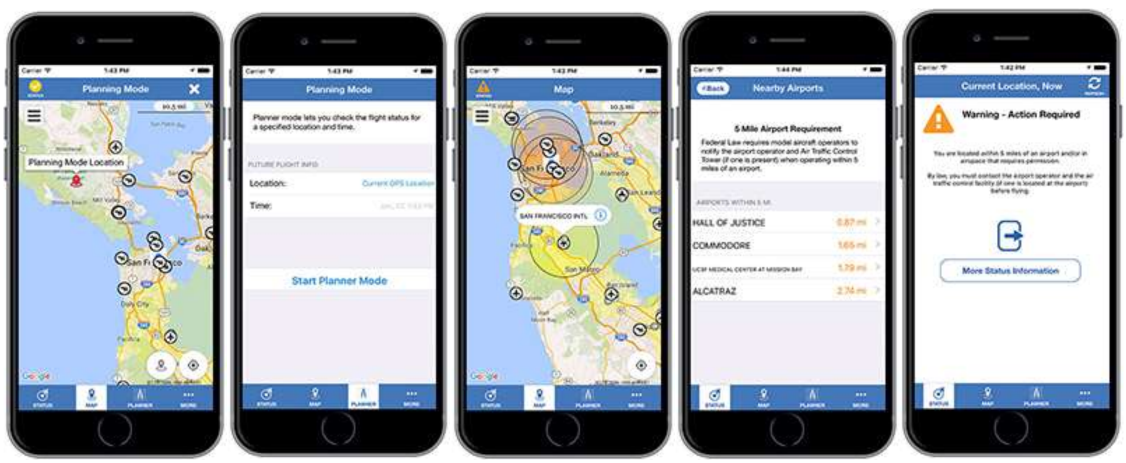
B4UFly

Description

- B4UFLY is a free app put out by the FAA. that helps determine whether there are any restrictions or requirements in effect at the location where they want to fly a UAS.

Features

- A clear "status" indicator that immediately informs the operator about the current or planned location. For example, it shows flying in the Special Flight Rules Area around Washington, D.C. is prohibited.
- Information on the parameters that drive the status indicator.
- A "Planner Mode" for future flights in different locations.
- Informative, interactive maps with filtering options.
- Links to other FAA UAS resources and regulatory information.

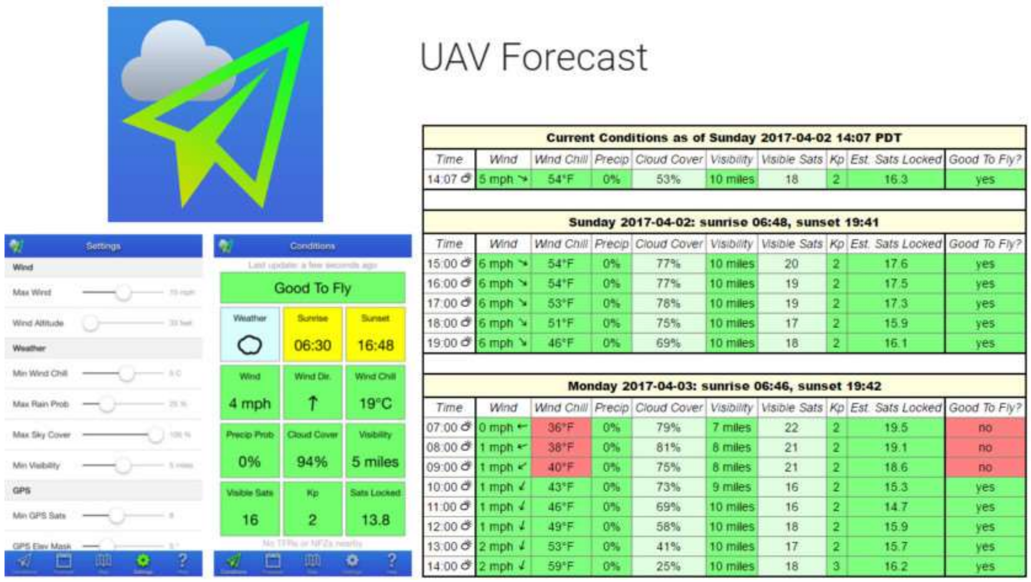


Screenshots from B4UFly

UAV Forecast

Description

- UAV forecast is a free app that provides the ability to see the weather forecast, GPS satellites, solar activity (Kp), No-Fly Zones, and flight restrictions.



Time	Wind	Wind Chill	Precip	Cloud Cover	Visibility	Visible Sats	Kp	Est. Sats Locked	Good To Fly?
Current Conditions as of Sunday 2017-04-02 14:07 PDT									
14:07	5 mph ↘	54°F	0%	53%	10 miles	18	2	16.3	yes
Sunday 2017-04-02: sunrise 06:48, sunset 19:41									
15:00	6 mph ↘	54°F	0%	77%	10 miles	20	2	17.6	yes
16:00	6 mph ↘	54°F	0%	77%	10 miles	19	2	17.5	yes
17:00	6 mph ↘	53°F	0%	78%	10 miles	19	2	17.3	yes
18:00	6 mph ↘	51°F	0%	75%	10 miles	17	2	15.9	yes
19:00	6 mph ↘	46°F	0%	69%	10 miles	18	2	16.1	yes
Monday 2017-04-03: sunrise 06:46, sunset 19:42									
07:00	0 mph ←	36°F	0%	79%	7 miles	22	2	19.5	no
08:00	1 mph ↙	38°F	0%	81%	8 miles	21	2	19.1	no
09:00	1 mph ↙	40°F	0%	75%	8 miles	21	2	18.6	no
10:00	1 mph ↓	43°F	0%	73%	9 miles	16	2	15.3	yes
11:00	1 mph ↓	46°F	0%	69%	10 miles	16	2	14.7	yes
12:00	1 mph ↓	49°F	0%	58%	10 miles	18	2	15.9	yes
13:00	2 mph ↓	53°F	0%	41%	10 miles	17	2	15.7	yes
14:00	2 mph ↓	59°F	0%	25%	10 miles	18	3	16.2	yes

Sample of some of the data available from UAV Forecast

<u>Features</u>

- UAV Forecast provides the ability to see the weather forecast, GPS satellites, solar activity (Kp), No-Fly Zones, and flight restrictions.
- Requires good stable connection to cell or internet to provide the most up to date information.
- In areas that or more isolated the weather information is only as good as the reporting station that the tool uses and obviously proximity of the station and the project site can greatly impact how accurate the data is in comparison to the project location.
- Provides the PIC a custom set of parameters so that it will alert the PIC if parameters for the flight will be exceed.

As with any of these tools the PIC must use sound judgment to determine if the conditions are suitable for UAS flights, if the airspace regulations have been complied with and that overall the project is safe to fly and can be conducted without endangering harm to individuals or damage to property.

Using these apps can help provide a clearer picture of the weather and in particular the wind in the region of a survey. Keep in mind the information on the weather reported is from is the nearest weather monitoring facility, usually an airfield.

Regulatory planning tools

As part of the planning process consideration must be given to the regulatory rules governing UAS operations at the state and federal levels. Some states have various right to privacy laws that may impact how a flight will be flown, or if additional coordination with property owners is required. As the project AOI was completely within the DOT ROW no interaction with property owners was required. On a larger scale is the process of coordinating with the FAA is essential, or at least to determine if the project plan complies with FAA regulations without further coordination.

As the UAS industry continues to advance the FAA has partnered with industry to help improve the process of gaining access to airspace and improving or shortening the time required to obtain approval.

However, at the time of planning for the MDT projects none of these new advances where available to be taken advantage of.

By way of reference the FAA has created a system called LAANC which can be accessed through various websites such as Skyward (https://app.skyward) and AirMap (https://www.airmap.com/airspace-authorization-approved-laanc-uas-service-supplier/). Both are available on a desktop and as an app that can accessed on a tablet. If the airspace and specific project area are aligned gaining approval is almost instant vs a 60 to 90 day wait for a FAA Waiver.

The FAA has recently released an airspace map for UAS operators to help facilitate planning and in obtaining approval to fly.
https://faa.maps.arcgis.com/apps/webappviewer/index.html?id=9c2e4406710048e19806ebf6a06754ad

The site provides a visual reference for airspace around airports that has been reviewed by FAA representatives that indicate altitudes that a UAS can be approved to fly. An area with a number other than zero “0” indicates the FAA can approve up to that maximum altitude through the LAANC system. As best practice either Skyward or AirMap have proven effective in obtaining the necessary approvals. FAA approval is required but the approval process is very fast, almost instant. In addition to obtaining the approval there are often special requirements the PIC must follow as outlined in the airspace authorization such as contact the airport 24 hours before conducting UAS flights, followed by letting the appropriate entity know the actual start and stop of UAS flights. These are facility specific depending upon the authorization granted. In areas with a “0” it means the PIC must follow the standard more lengthy process of getting authorization and provide sufficient justification and risk mitigation procedures to the FAA.

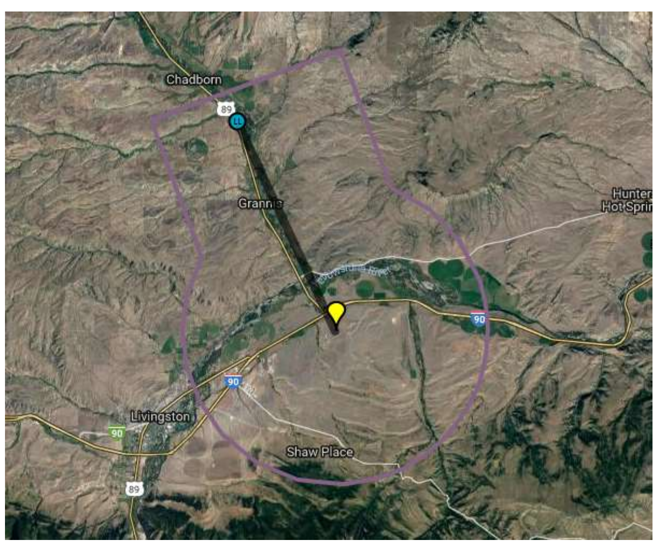
Below is a screen shot of the Livingston airfield airspace within the Mission Interchange AOI as designed by the FAA in the LAANC system. In the case of the Mission Interchange flights there are 2 blocks of airspace that would require FAA authorization via the more lengthy process. While the remainder of the site approvals could be obtained rather quickly if the flights could be conducted at the prescribed altitudes. However, even though Livingston airfield has been incorporated into the LAANC system the airfield has NOT yet been integrated into the LAANC system for real-time authorization and approval. Meaning the PIC must request a waiver via the traditional FAA process which was done for the Mission Interchange flights. In Appendix B is the most recent approval granted by the FAA. Please note, waivers must be renewed and updated periodically as the FAA (at the time) would only provide a 6 month window for each authorization. This however has since been changed by the FAA to grant longer windows, but it also takes longer to get approval for those requests.

Current FAA airspace around the Livingston airfield

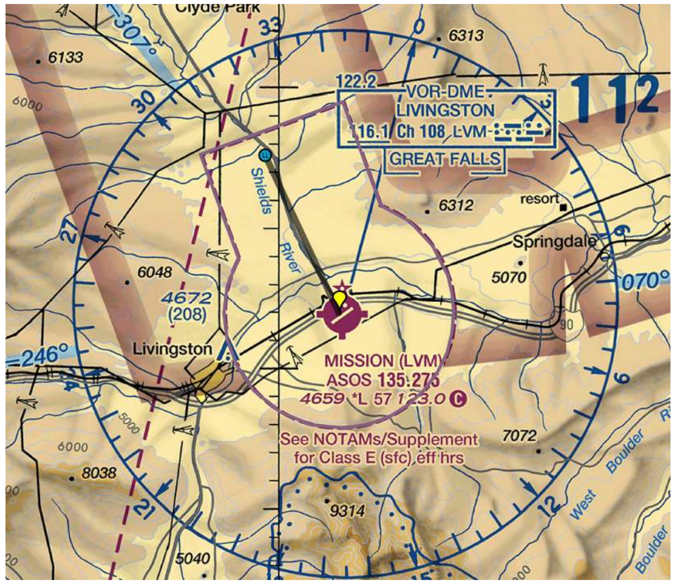
In addition, there are tools that help to more easily identify the location of airspace in relation to a project.

http://www.iflightplanner.com/AviationCharts/ provides the ability to see airspace location on a Google Earth like environment or aeronautical sectional chart. This tool greatly improves the ability to visualize and understand the any possible airspace conflicts that may exist with a project.

Graphics below demonstrate aerial imagery with airspace type, as well as the sectional chart. This information provides some of the necessary details to provide to the FAA to obtain airspace approval for the UAS flights in the Livingston area when applying for a waiver via the traditional process through the FAA website.



Google Earth map with Class E airspace for Livingston airport



Sectional chart of same airspace

The above image shows the sectional chart near the Livingston airport with a pin denoting the start point for the Mission Interchange project and its relation to class E surface airspace.

The two graphics above were extracted from the same website and facilitate planning as well as providing an easy definable description of the location to the FAA more effectively.

Traffic Controls

Traffic control was provided for the initial Pre-Construction flight by Precision Highway Contractors for both the Ashland and Mission Interchange projects. Flaggers were setup between two and four miles apart to stop traffic during the UAS flights. This controlled area permitted multiple UAS flights for both the EVO 3 and F7200 systems to be conducted safely. During the initial flights, traffic was stopped/held during UAS take-off, data acquisition, and landing. The average hold time for traffic varied between 3 to 15 minutes, with two hold times reaching up to 20 and 30 minutes. With respect to take-off and landing, the F7200 fixed wing system does not provide as much flexibility compared to the quad copter systems. The traffic control process was modified, with permission from the UAS PIC, to hold traffic during the take-off and landing and let traffic flow while UAS was performing data acquisition, significantly reducing traffic hold time. The UAS flight was paused if traffic was encountered while flying over the road which allowed traffic to pass before the UAS continued over the roadway.

Labor Effort

- Pre-Construction Flight - Two days per site to complete the data acquisition and installation of survey control for the initial flights, 1 day as backup.
- Ground control & Initial Planning – Planning ~4 hours for each site. Site visit 1.5 days for Mission Interchange and 1.5 days for Ashland.
- During the Pre-Construction task an operations plan was developed by AECOM and provided to MDT, see Appendix A.

Acquisition Details

Task One aerial acquisition began on October 17, 2016 and was completed on October 20, 2016. The GCP installation effort was completed with the placement of the panels; however additional time was required to completely survey the control points. Weather conditions did impact the survey of the ground control points which did not get completed until December 20, 2016 for the Ashland project and March 13, 2017 for the Mission Interchange project.

Based on the data requirements, site conditions/environment and in coordination with the data process team an altitude of 197 feet (60 meters) was chosen for the data collection, this altitude generated a GSD of 0.75 inches per pixel. Cameras setting are automatically controlled in the particular system flown. However other systems do offer more specific camera control to the settings. Based on using both types of systems it has been found the auto settings work very well for this type of data requirements.

During the initial flights, the preliminary flight plans were adjusted in the field to account for take-off/landing areas, line of sight and wind conditions. Wind conditions impacted battery performance which in turn affected flight duration. The flight plans were adjusted for the entire length of the project before the starting the initial flights and the GCP locations were adjusted accordingly using both existing and new survey control points. Additionally, due to the wind conditions and battery life concerns, the EVO 3 flight plans were altered to cover a reduced project boundary.

GCPs were marked using two methods; painted targets were marked on asphalt surfaces within the corridor and 3.3 feet square (1 meter square) premanufactured GCP targets were set in flat grassy areas adjacent to the road surface and within the Right-Of-Way (ROW).

The GCPs were then laid out using the existing survey control and the newly installed survey control. The existing survey control points were equipped with a premanufactured GCP target designed by SkyCatch® for use in automated processing. The newly installed AECOM survey control points consisted of a 24” x 5/8” rebar and capped with a 2” aluminum survey cap and a premanufactured GCP target. AECOM also installed GCP’s using Mag® nails along the shoulder of the existing highway, with a painted 2” wide,1’x1’ white cross. Positioning the GCPs for Mission Interchange required 1.25 days and 1.5 days for Ashland. Flights began after the GCPs were installed for the first two flight/ lifts).

The new control points were surveyed and/or tied into the project at a later date.

Mission Interchange: Existing survey control and newly installed AECOM control was resurveyed by AECOM subcontractor, Stahly Engineering, using a combination of Static and RTK survey techniques to achieve a RMSE 0.02” horizontal accuracy for GCPs. A level loop was run through the both the existing and newly installed AECOM survey control points to achieve a RMSE 0.02” vertical accuracy. These activities occurred over a two week period. Stahly Engineering selected to use Trimble R8-3 GNSS receivers to conduct the control network survey at the Mission Interchange site, and selected to use a Leica Digital Level to perform level loops for vertical control.

System Specifications:

Metric	Topcon GR5	Trimble R8-3
GNSS Tracking	GPS, GLONASS, Galileo,	GPS, GLONASS, Galileo,
	BieDou, SBAS, QZSS	SBAS,
Static Accuracy	H - 3.0mm+0.1ppm	H - 3.0mm+0.1ppm

Metric	Topcon GR5	Trimble R8-3
	V - 3.5 mm +0.4ppm	V - 3.5 mm +0.4ppm
RTK Accuracy	H - 5.0mm+0.5ppm	H – 10.0 mm+1ppm
	V – 10.0 mm +0.84ppm	V – 20.0 mm +1ppm
Communication	Integrated UHF/FH915	450MHz receiver/Transmitter

Ashland: The newly installed AECOM control was resurveyed by AECOM using RTK survey techniques to achieve a RMSE 0.04” horizontal accuracy and a RMSE 0.07” vertical accuracy for GCPs. These activities occurred over a three day period.

Metric	Mission Interchange		Ashland Corridor	
Acquisition Date	Oct. 19 & 20, 2016		Oct. 17 & 18, 2016	
Corridor Length	6 miles		8 miles	
Ground Survey effort (days)	1.25		1.5	
Ground Control Points (Visible/Not Visible (Check Points))	29/1		40/6	
Ground Control RMSE (X/Y/Z) (International Foot (X/Y) US Survey Foot (Z))	0.02”/0.02”		0.04”/0.07”	
	NOVA F7200	**EVO 3 RTK**	**NOVA F7200**	**EVO 3 RTK**
Image Acquisition effort (days)	1	1	2	2
General Weather	Sunny to Partly Cloudy, Breezy	Sunny to Partly Cloudy, Breezy	Sunny, Breezy	Sunny, Breezy
Weather Delays (Hours)	1.0	1.5	0	2.0
Number Missions/Images Acquired	4/2,804	8/1,661	7/1,272	9/1,426
Road Closure (Minutes per flight)	15 to 30	5	10-20	5-15

For most DOT projects the biggest hurdle is related to UAS flights over non-participants, i.e. traffic and pedestrians, as was the case for Ashland and Mission Interchange. The FAA only defines a restriction for moving traffic. Other DOTs interpret this slightly different. AECOM has come across documents for UAS operations that allow for crossing roads with active traffic perpendicular to flow minimizing the time over the roadway.

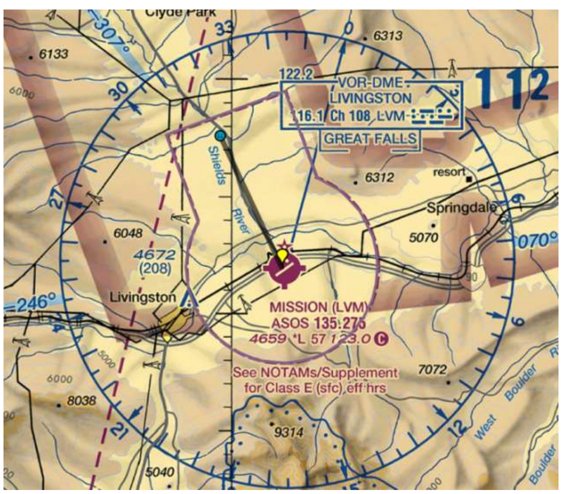
The FAA has not granted permission to any UAS operator to fly over active roadways though they have provided the ability to request a waiver. AECOM has a current waiver request for these areas in Montana as well as other areas in the US pending. The allotted time the FAA has to respond is within 90 days (the waivers submitted to date have not been approved). Once a waiver is submitted the only option available is to wait and therefore it is necessary to provide as much detail and information as prudent to allow the FAA to approve because at the end of a 90 day wait period the request can be denied for whatever reason and the only response offered is to resubmit another waiver and the cycle continues. So, while sometimes a waiver is absolutely necessary to enable a successful UAS mission there must be an evolution of suitable alternatives to allow the flights to move forward as was the case for Ashland and Mission Interchange flights that occurred in October. The resulting solution was to stop traffic during the flights. The impact was increased cost, greater coordination, and resulted in taking longer to execute the project, i.e. moving traffic teams into position, coordinating times to stop traffic when the UAS was ready to be launched (particularly for the fixed wing system).

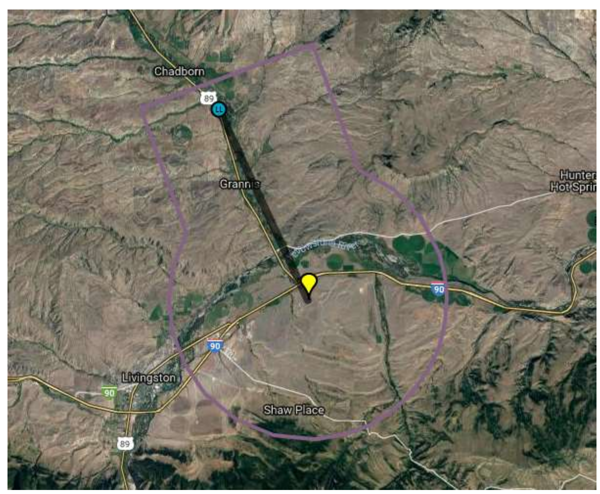
Additionally, using the airspace planning tools described previously it was determined that a waiver was required to be able to conduct flight operations for the Mission Interchange site. At the time of the project a waiver was requested using the FAA website to obtain the approval. As part of the coordination, AECOM reached out to the Livingston Airfield Manager to discuss the operation. The FAA now discourages UAS operators from doing so and is relying on their newly implemented airspace approval process. The new process is much improved and in general provides users greater access with increased speed of approval. However, for the LAANC airspace approval for the Mission Interchange location has not been fully integrated. The following below provides some details as to using the LAANC system for obtaining airspace approval.

(A tutorial on using the newly developed tools and app could be provided by AECOM if desired)

Basic process for planning and requesting airspace approval:

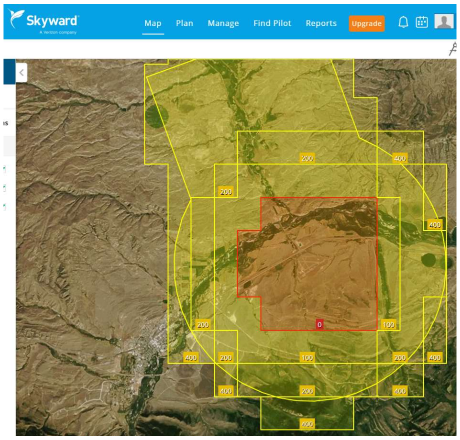
1 Use http://www.iflightplanner.com/AviationCharts/ to better understand airspace associated with the project and being able to see it on Google Earth simultaneously. (Not required but highly encouraged).

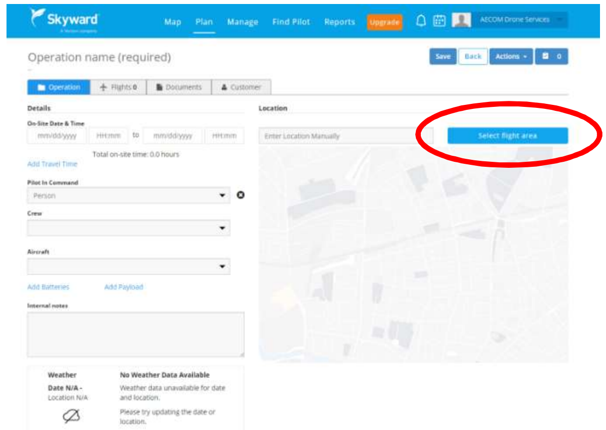




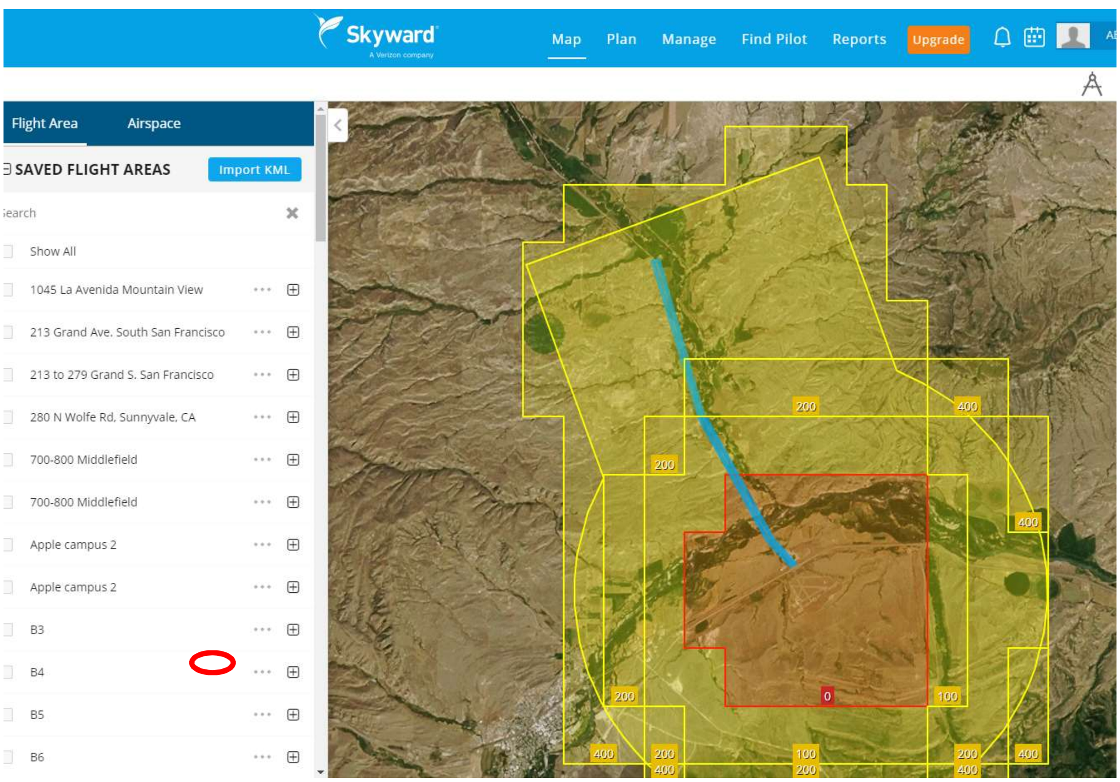
2 Once in the Skyward app site select “Map” and go to the location of the project site. Having a KML of the project site available is extremely helpful in the next step as a KML can be uploaded and will

identify the airspace requiring approval. Once locating the general area for the project go to the tab marked “Plan”. Click the “select flight area” circled in red.





3.   On this screen select “Import KML”, select KML file. The KML is imported on to the map and identifies the relationship to the effected airspace. Areas in the red section will require manual request while the areas in yellow might be approved via an automated process if the location has been incorporated into the LAANC system. Unfortunately, at this time the Livingston airfield has not yet been integrated into LAANC even though it has been mapped by the FAA.



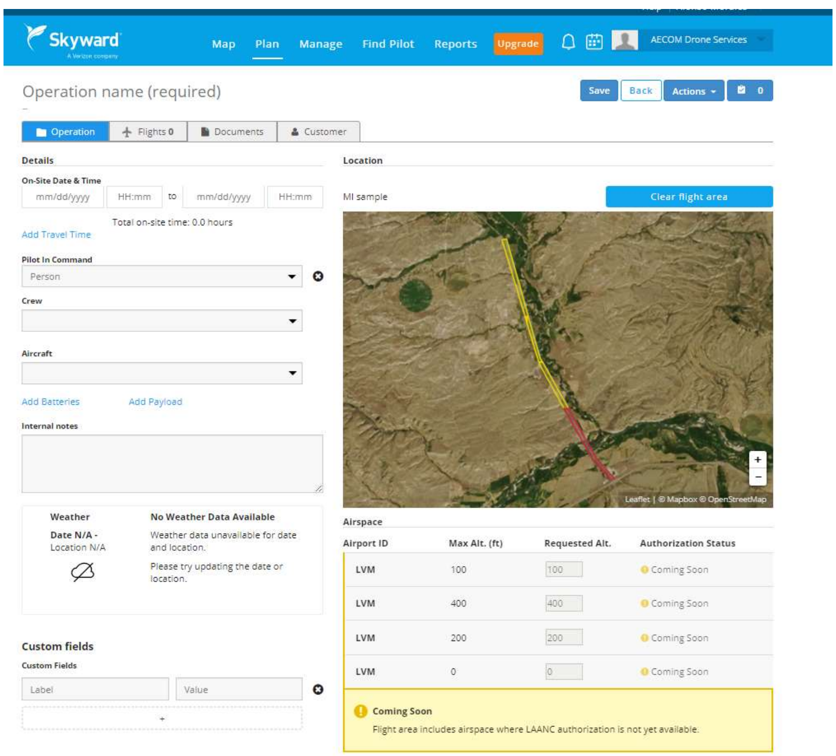
4.   After the import of the KML the user scrolls to the find the name of the project and selects “Add to Operation” by click the three dots (circled in red) to the right of the flight area name. Once this is accomplished a screen showing the flight areas and which airspace can either be approved through As

indicated in the screenshot below the entire mission flight area requires FAA approval using traditional request as the LAANC system is not yet been incorporated into the Livingston facility.

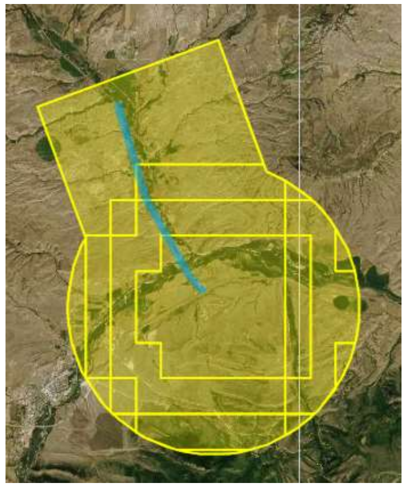
5. As in the case above a forma/traditional FAA authorization request is the required process (which was done for the Mission Interchange site. Note, since that initial waiver request the FAA has changed the parameters as well as the website for users to generate the airspace authorization request). The FAA site is https://faadronezone.faa.gov/#/gateway/organization which guides a user through filling out specific fields. As of note the FAA provides two types of airspace requests, one an authorization which is estimated to be shorter in time to approve but is more specific to a location. The other is a waiver by definition, below.

AIRSPACE WAIVER: *Use this to request a waiver from 14 C.F.R. § 107.41. Airspace Waivers may be issued where the applicant can demonstrate safety mitigations through equipage that their UAS can safely operate in controlled airspace without seeking ATC authorization prior to each operation. Processing times for airspace waivers are significantly longer than processing times for airspace authorizations.*

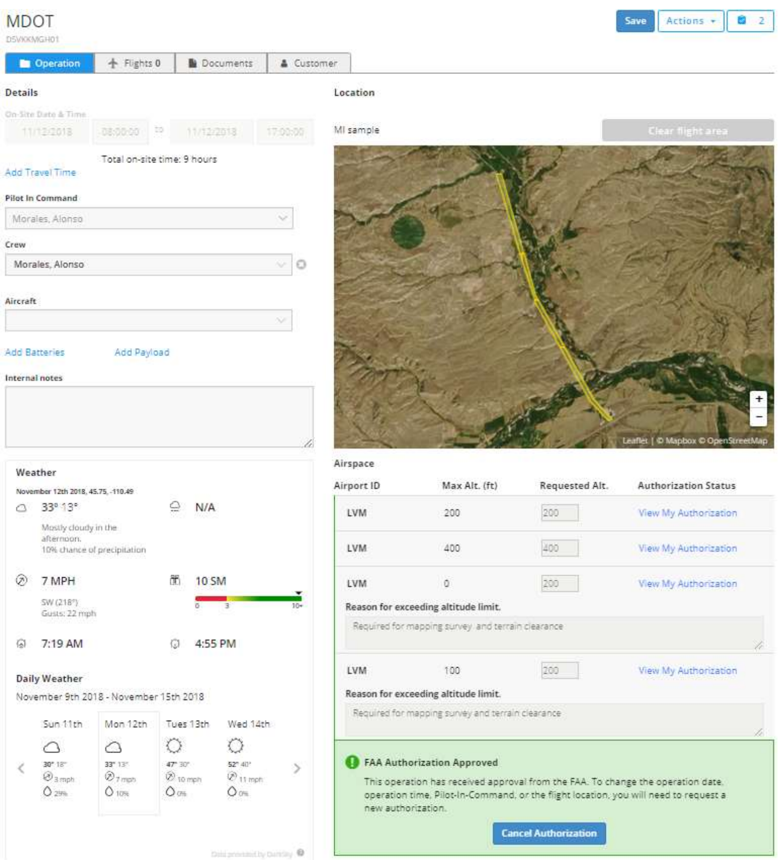
An airspace authorization was used for Mission Interchange. The user fills out the fields, defines the mission parameters and submits. Upon submitting, a FAA number is assigned and the user can now monitor the process as the request moves through the various stages. It is best to anticipate the process to take upwards to 60 days to obtain approval. Often a FAA representative will follow-up requesting additional information which signifies the approval process is getting close to being finalized. Below is an example of the various stages of the FAA approval process with in the LAANC system and example of an airspace authorization under Part 107 rules.



Below is how the LAANC airspace for KLVM is depicted today indicating no red areas and provides the ability to obtain immediate response from FAA for approval. Whereas before the FAA had not finalized this particular airfield within the LAANC system.



Immediate approval is now possible via LAANC system in this particular region at the altitudes required. The FAA continues to add capability and with these new changes in the system resulted in an immediate approval within seconds of submitting the request and is a game changer for UAS operations.



Skyward
A Verizon company

An authorized intermediary for the Federal Aviation Administration USS program

Notice of Authorization

Operation Date
Monday, November 12th 2018

Pilot In Command
Alonso Morales

Beginning Time
08:00 MST (1500 UTC)

Ending Time
17:00 MST (0000 UTC)

Conditions Of Authorization

- Maintain visual line of sight
- Aircraft speed not to exceed 100 mph
- Do not fly over non-participants
- Do not exceed maximum altitude
- Ensure there are no TFRs before flying
- The weather ceiling must be above 1,000 feet AGL when flying in Class E airspace

Airspace and maximum altitudes

1. **LVM 200ft** - **FAA Ref#:** SKDWXDT7S
2. **LVM 400ft** - **FAA Ref#:** SKDQWL7L3
3. **LVM 200ft** - **FAA Ref#:** SKD9FBNH9
4. **LVM 200ft** - **FAA Ref#:** SKDVAP8AR

In accordance with Title 14 CFR Part 107.41, your operation is authorized within the designated airspace and timeframe constraints. Altitude limits are absolute values above ground level which shall not be added to the height of any structures. This Authorization is subject to cancellation at any time upon notice by the FAA Administrator or his/her authorized representative. This Authorization does not constitute a waiver of any State law or local ordinance. Alonso Morales is the person designated as responsible for the overall safety of UAS operations under this Authorization. During UAS operations for on-site communication/recall, Alonso Morales shall be continuously available for direct contact at undefined by ATC or designated representative. Remote pilots are responsible to check the airspace they are operating in and comply with all restrictions that may be present in accordance with 14 CFR 107.45 and 107.49 (a) (2), such as restricted and Prohibited Airspace, Temporary Flight Restrictions, etc. Operations are not authorized in Class E airspace when there is a weather ceiling less than 1,000 feet AGL. If the UAS loses communications or loses its GPS signal, it must return to a predetermined location within the operating area and land. The pilot in command must abort the flight in the event of unpredicted obstacles or emergencies.

Issue Date:
Monday, November 5th 2018 19:34 UTC

Submitted By:
Alonso Morales
through Skyward.io

UAS Flight Execution Details

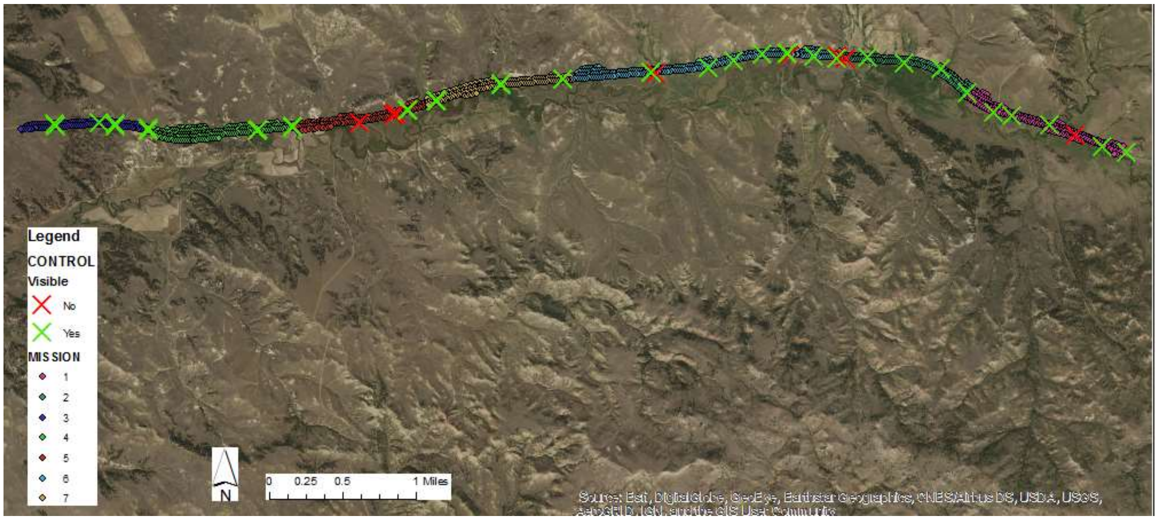
Both Ashland and Mission Interchange were segmented into manageable flights determined during the mission planning phase, originally 8 flights for Ashland and 7 for Mission Interchange During the flight execution phase due to winds and line of site considerations it was determined to shorten each section by a small amount to maintain a higher level of battery reserve. This resulted in doing some on-the-fly field adjustments to the flight profiles previous planned and was the same for the fixed wing system; increasing the number of sections or flights to 9 and 8 respectively.

These types of adjustments should be anticipated based on the complexity of the survey area and the actual conditions encountered once in the field. A good site survey once in field is essential as often an obstacle or feature not readily identified in the mission planning phase will change how a flight is or a survey is conducted. As part of the planning phase for the Ashland and Mission Interchange sites it was determined to divide the roadways into manageable sections of 1 mile stretches then dividing that in half to determine a suitable launch and recovery (LR) location given that the UAV can be seen out to approximately ¾ of mile. This provided some ability to adjust the launch and recovery locations to account for terrain and suitable pullouts on the roads to remain clear of traffic during preflight and system set up while remaining in line of site range.

In addition to coordinating flying activities, it is essential to be mindful of the overall objective is to collect and deliver good data. One of the elements with this project was coordinating critical survey control points. As part of the planning and execution identifying where control was going to be placed, and how that matched up to flight/imagery overlap to ensure that adequate tie points were contained in each flight, but that the same points were in each flight segments that adjoined each other described in detail.

Ashland

NOVA F7200 - 7 missions flown with 1,272 images collected



East of Ashland – NOVA F7200

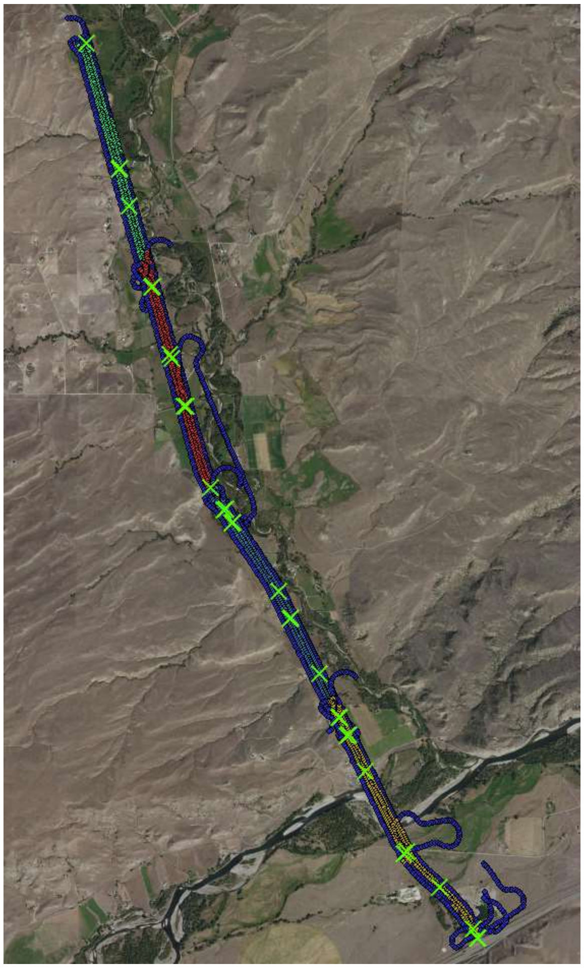
EVO 3 RTK - 9 missions flown with 1,426 images collected

East of Ashland – EVO 3

Mission Interchange

F7200 - 4 missions flown with 2,804 images collected (left image below)

EVO 3 - 8 missions flown with 1,661 images collected (right image below)



Mission Interchange – NOVA F7200

Mission Interchange – EVO 3

Data Processing

AECOM utilized Agisoft Photoscan Pro for the data processing, but similar applications such as Pix4D or Bentley Context Capture would yield a similar result. Most UAS imagery processing software is based on the Structure from Motion (SfM) algorithm; however, the various software packages differ slightly in functionality and ortho rectification. Photoscan allows the imagery to be rectified utilizing a digital elevation model while Pix4D uses a digital surface model. For project locations that are primarily bare earth this difference will not be noticeable. For locations with buildings and canopy cover there can be more observed smearing of trees and buildings when imagery is rectified using a digital surface model. Most software offers reporting capabilities and varying degrees of control for over the processing. In addition to Photoscan the following software was used during the data processing:

- UAS processing – Agisoft Photoscan (Version 1.2.6) on 32 CPU server having 100GB RAM
- Point Cloud editing and processing – LP360 (Version 2015.1.76.7)
- Data Visualization – ArcGIS Desktop (Version 10.2.2)
- MicroStation V8i (Version 08.11.09.578)
- GeoPAK V8i (Select Series 2)

The initial plan was to process all airborne imagery at AECOM's Germantown, MD office as that is the location of the geospatial data team; however, since SkyCatch control panels were used for some of the control points it was decided that in the interest of research the data would also be pushed through their automated processing tools. As it turns out the automated software solution is more ideally suited for smaller less linear projects as it failed to return a useable result.

Aerial imagery data capture is always designed to capture more imagery than is needed to ensure the project area is completely acquired. Buffer imagery is used if necessary, but is excluded if not needed as this additional imagery requires time to process and ultimately offers no end value. An important reason to buffer an aerial imaging project is that there is data degradation along the edges of a project boundary. This occurs as there are far fewer overlapping images.

To satisfy the image processing requirements of SfM processing UAS data is acquired with a very high degree of overlap resulting in a high degree of redundancy. Image photo centers were analyzed and redundant or extraneous images were filtered from the necessary imagery required to be processed.

The below is a summary of various processing results with details provided following the table.

Metric	Mission Interchange		Ashland Corridor	
Platform	**NOVA F7200**	**EVO 3 RTK**	**NOVA F7200**	**EVO 3 RTK**
Image Acquired/Images Processed	2804/1186 (53% reduction)	1661/1198 (38% reduction)	1272/1095 (14% reduction)	1426/1300 (10% reduction)
Image Sorting Time (Hours)	~1.5	~1	~1	~1
Unsorted/Sorted Image Data Volume (GB)	16.8/7.1	9.9/7.1	7.6/6.6	8.5/7.8
Image Radiometric Adjustments (Hours)	~2	~2	~2	~2
Total Tie Point Processing (Hours)	~2[6]	~8	~2[6]	~8
Total Tie Point Count	5,857,200	5,186,104	1,002,615[2]	5,186,104
Tie Point Count/Image	~5000[1]	~4300	~1000[2]	~3600
Ground Control Selection (Hours)	~1.5	~2.5	~1.5	~2.5
Dense Point Cloud Processing (Hours)[5]	~10	~15	~10	~15
Total Dense Point Cloud Count	218,036,173	266,295,170	250,687,079	270,746,419

Metric	Mission Interchange		Ashland Corridor	
Auto-filter Dense Point Cloud (Hours)	~1	~4	~1	~4
Manual Dense Point Cloud Filtering (Hours)	~2[3]	~3[3]	~1	~2
Corridor Bare Earth Dense Point Cloud Count/Ft^2	9.7[4]	19.2	9.9[4]	19.9

[1] The F7200 Tie Point count is higher due to the image dimensions being larger.

[2] Initial Ashland F7200 TPs/image is low as the default tie point collection parameters were used. As a result of consultation with Agisoft more aggressive tie point generation parameters were applied.

[3] Additional hours to include bridges/overpass into terrain model to generate correct bridges

[4] F7200 bare earth dense point cloud is lower as the AOI area was larger than the EVO 3 RTK AOI

[5] Windows 7 Server, 32 CPUs, 100 GB RAM, no graphics card

[6] Fixed wing Tie Point processing 4X faster than quad copter processing

Ashland Processing – NOVA F7200

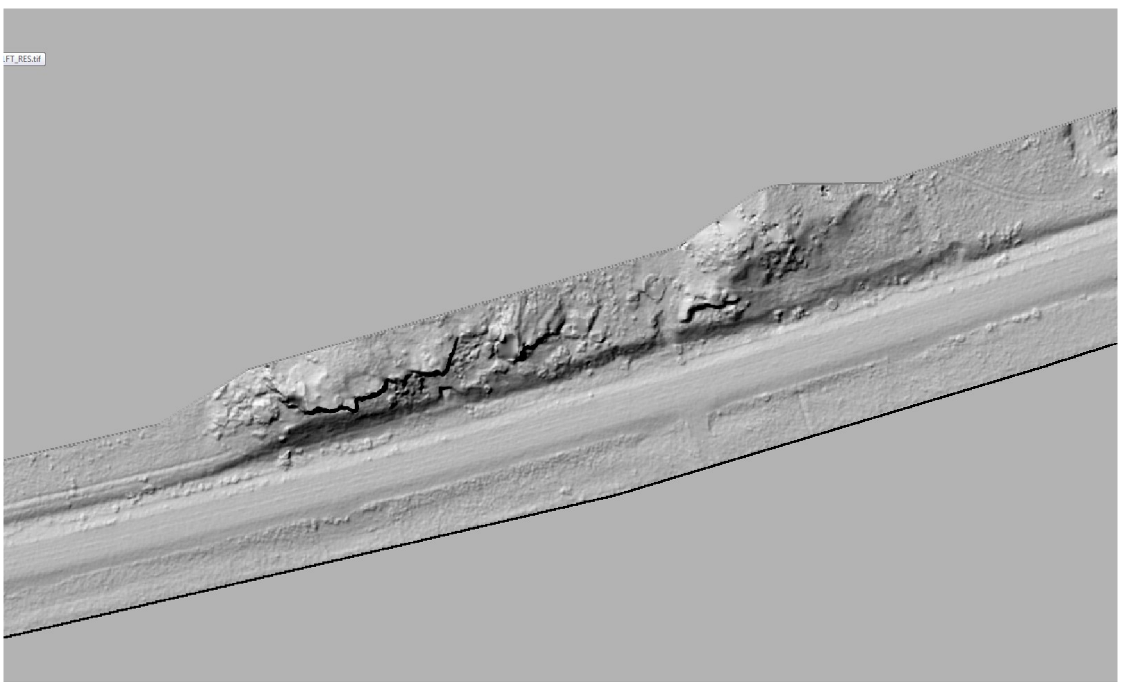
The first UAS dataset processed was the NOVA F7200 data over the Ashland AOI. The NOVA F7200 imagery was processed as one complete block, meaning all imagery was processed as a single area instead of sub-dividing the imagery into smaller processing datasets. Prior to processing the imagery all raw files were reviewed and plotted based on their image EXIF geotag. Plotting photocenters allowed the AECOM analyst to select images that would not be needed during processing. A review of the imagery also allowed the analyst to remove any images with poor quality.

The processing steps followed were - photo alignment, ground control selection, dense point cloud creation, point cloud classification and editing as needed, DEM creation, and orthophoto creation. These processing steps were repeated for all UAS data captured and discussed within this report.

Of the 1,272 raw images captured over the Ashland AOI by the NOVA F7200 AECOM used 1,095 in the data processing.

The processing presented no issues to address and required approximately two days to complete once started.

NOVA F7200 Ashland Sample Orthophoto



NOVA F7200 Ashland Sample Digital Elevation Model

Ground Control Point Results

GCPs used by the UAS processing software underwent a bundle adjustment during processing to arrive at a best fit solution. The GCP table below illustrates the quality of the solution and does not represent the accuracy of the model with respect to independent check points (next section).

The NOVA F7200 returned an overall RMSEz of 0.142' referencing 36 GCPs. Results of individual control points are listed below.

Target Point Name	X (ft)	Y (ft)	Z (ft)	Point Cloud Elevation (ft)	Difference (ft)
76A_CHECK	2865835.408	499094.843	3384.980	3385.330	0.349
300	2856416.274	501657.961	3308.753	3308.810	0.057
301	2856414.776	501636.926	3308.263	3308.330	0.068
302	2851528.723	500998.254	3270.074	3270.160	0.084
303	2851529.811	500976.277	3270.123	3270.230	0.106
304	2848374.129	500745.001	3244.113	3244.120	0.011
305	2848390.114	500724.853	3244.179	3244.260	0.077
306	2830138.373	499031.964	3263.264	3263.080	-0.185
307	2833504.174	498890.106	3200.879	3200.720	-0.160
308	2832313.783	499109.431	3208.221	3208.000	-0.220
309	2837446.083	498921.394	3178.433	3178.210	-0.221
310	2838672.281	499037.613	3185.764	3185.800	0.036
311	2838674.211	499015.783	3185.737	3185.730	-0.012
314	2843826.321	499954.377	3206.208	3206.180	-0.032
315	2843833.356	499933.661	3206.192	3206.190	-0.001
316	2842794.971	499628.067	3204.449	3204.340	-0.110
317	2842800.897	499607.467	3204.834	3204.780	-0.056
318	2846138.357	500557.898	3222.519	3222.550	0.029
319	2846141.555	500536.767	3222.144	3222.200	0.056
646	2854492.807	501391.651	3287.327	3287.520	0.196
680	2868599.938	498104.392	3428.876	OUTSIDE AOI	
681	2858218.718	501475.397	3332.203	3332.250	0.046

Target Point Name	X (ft)	Y (ft)	Z (ft)	Point Cloud Elevation (ft)	Difference (ft)
682	2859299.164	501500.596	3332.931	3333.100	0.174
683	2832308.041	499052.039	3206.078	3206.130	0.053
685	2833503.920	498956.446	3196.383	3196.330	-0.049
475RW	2862898.004	500250.173	3380.230	3380.300	0.074
649_CHECK	2857387.192	501534.809	3323.329	3323.350	0.023
654_CHECK	2861921.900	501113.903	3354.517	3354.540	0.025
69C	2830123.634	499122.113	3268.914	3268.630	-0.285
69E_CHECK	2831730.176	499167.117	3206.016	3205.830	-0.185
70F	2837389.567	498874.041	3173.745	3173.830	0.084
74A	2853591.761	501162.273	3283.494	3283.410	-0.087
74C_CHECK	2855530.881	501650.027	3296.308	3296.210	-0.100
75B	2860612.572	501322.222	3337.097	3337.030	-0.065
76AA	2864484.327	499408.458	3377.755	3378.060	0.300
76C	2867740.694	498324.262	3406.202	3406.520	0.315
BM810_CHECK	2863844.900	499558.010	3377.504	3377.550	0.046

GCP Vertical Congruency Summary		
36 Points	US Feet	Centimeters
$RMSE_z$	0.142	4.33
95% Confidence Level	0.278	8.47
Minimum	-0.285	-8.69
Maximum	0.348	10.61

NOVA F7200 Point Cloud Bare Earth GCP Vertical Congruency Results

Check Point Results

Nine checkpoints returned an overall $RMSE_z$ of 0.384'. Results of individual check points are listed below.

Target Point Name	X (ft)	Y (ft)	Z (ft)	Point Cloud Elevation (ft)	Difference (ft)
312	2842376.117	499515.659	3201.514	3201.540	0.023
313	2842383.077	499495.263	3201.889	3201.880	-0.007
320	2858219.455	501542.160	3336.464	3336.390	-0.070
71E	2842281.271	499441.734	3197.136	3197.930	0.793
74D	2856523.296	501614.781	3307.957	3308.340	0.383
74F	2858510.803	501470.649	3334.317	3334.460	0.138
76BB_CHECK	2866751.329	498721.138	3396.545	3396.270	-0.274
BM813_CHECK	2851703.032	500943.209	3267.786	3267.160	-0.627
BM815	2841041.026	499184.150	3188.316	3188.560	0.242

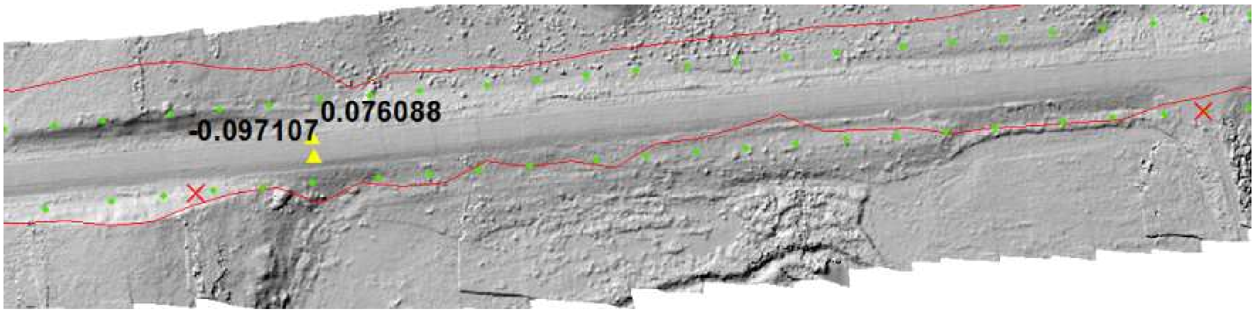
Vertical Accuracy Summary		
9 Points	**US Feet**	**Centimeters**
$RMSE_z$	0.384	11.70
95% Confidence Level	0.752	22.92
Minimum	-0.627	-19.11
Maximum	0.793	24.17

NOVA F7200 Point Cloud Bare Earth Checkpoint Vertical Result and Accuracy Summary

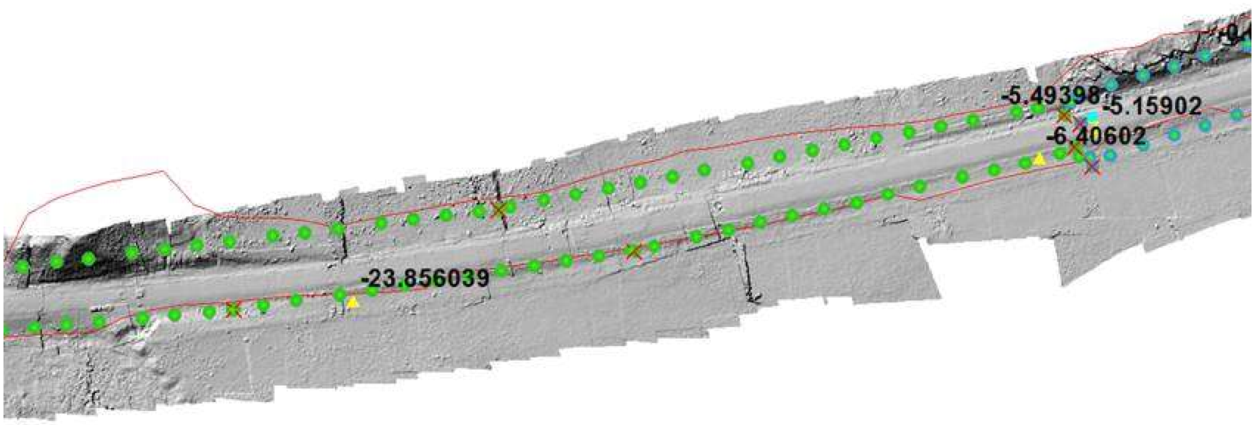
Ashland Processing – EVO 3 RTK

Similar to the NOVA fixed wing data processing AECOM first reviewed the 1,426 raw images captured during the acquisition. As noted above, the extent of the EVO 3 imagery did not cover the planned project boundary as it had been altered due to weather and battery concerns; however, there were more images taken due to a smaller image footprints AECOM selected to use 1,300 images in the data processing.

Initially the processing plan was to process all the imagery as a single block, as was performed in the Altavian imagery; however initial results were unacceptable to the AECOM photogrammetry team. Some key indicators of unacceptable results were a very high RMSE and some control points being off vertically by as much as 23 ft as seen in the graphics below. There was also very visible elevation inconsistency in areas of overlapping flights that necessitated an alternate processing approach. Through examination it could not be determined what factor(s) were directly responsible for the poor initial results.

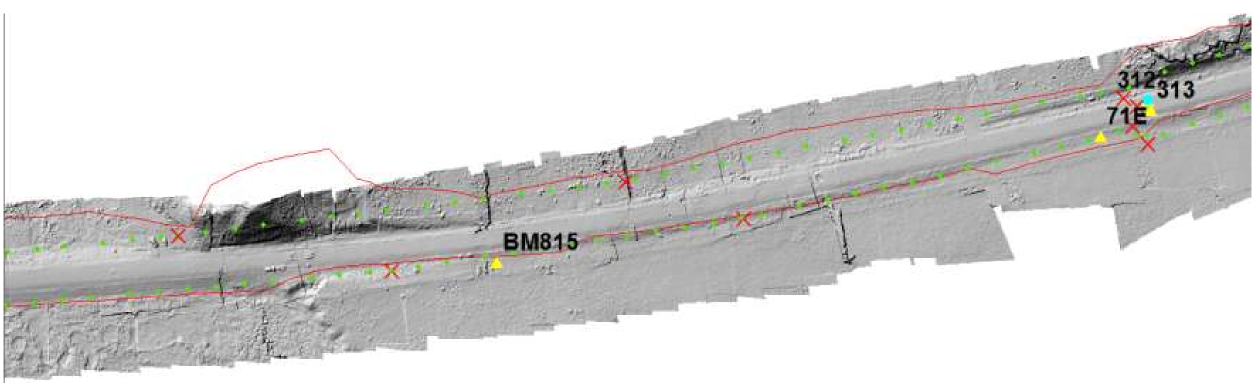


Vertical inconsistencies between flights – see stepping

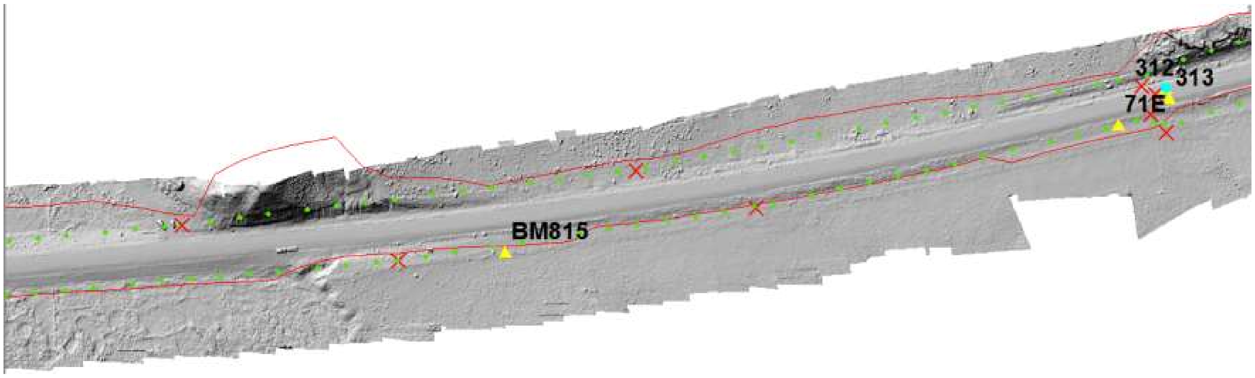


Elevation difference results between control and point cloud

AECOM processed several individual missions and concluded the results to be far superior in comparison to the initial corridor wide approach.



Initial Surface

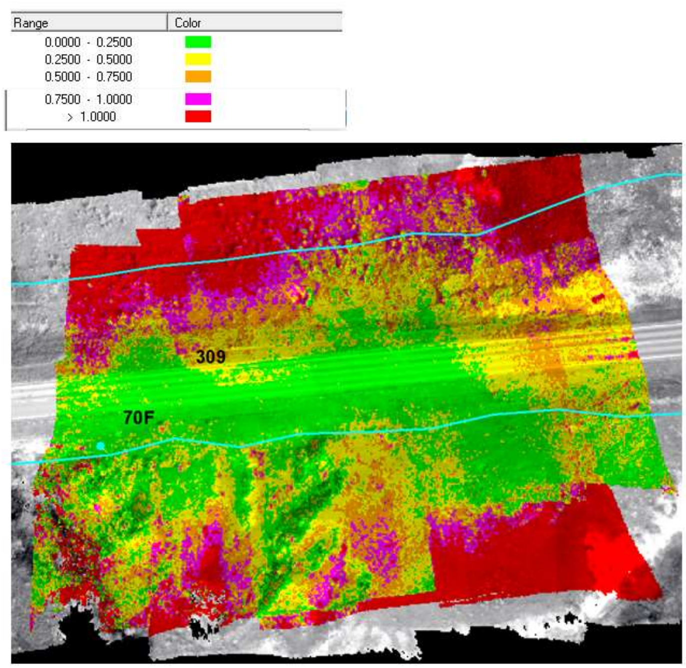


Reprocessed surface

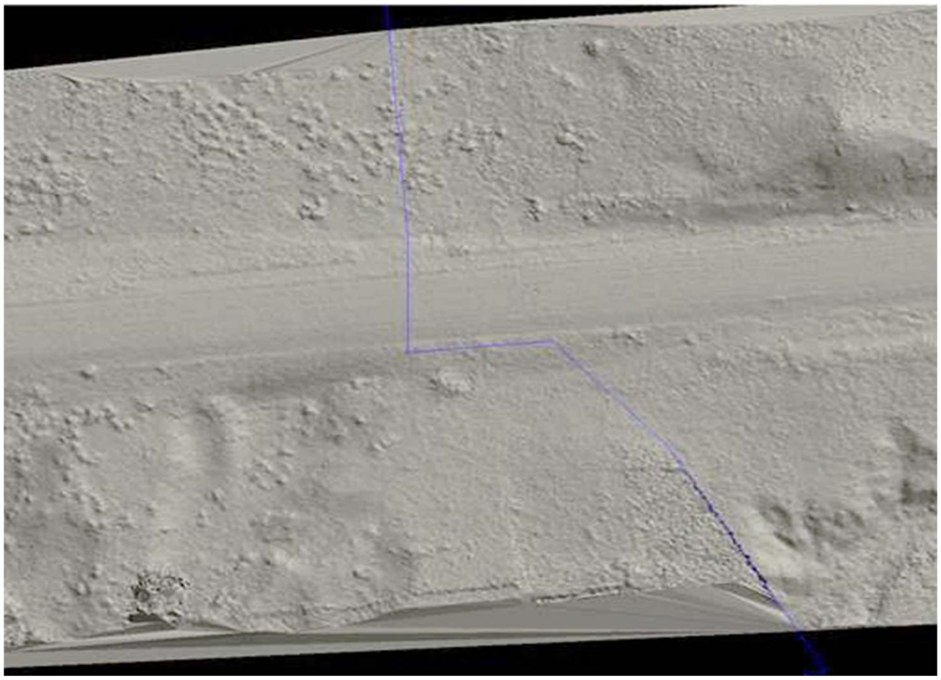
Based on the reprocessing results AECOM created 9 separate subprojects; one for each EVO 3 flight mission. For each mission the control was checked against the point cloud and in each instance the required vertical accuracy tolerance was achieved. Each of these subprojects amalgamated into a single corridor wide point cloud, the process for which is described below.

AECOM used LP360 to manually define seamlines across overlapping auto-filtered mission point clouds through areas having the best vertical alignment.

As seen in the graphic below, the green highlighted areas represent overlapping mission point clouds that closely vertically align. Within these areas a seamline was delineated defining a clipping polygon. Seamline polygons encapsulating point cloud elevations of highest vertical accuracy are extracted and later merged into a single seamless corridor long point cloud dataset.

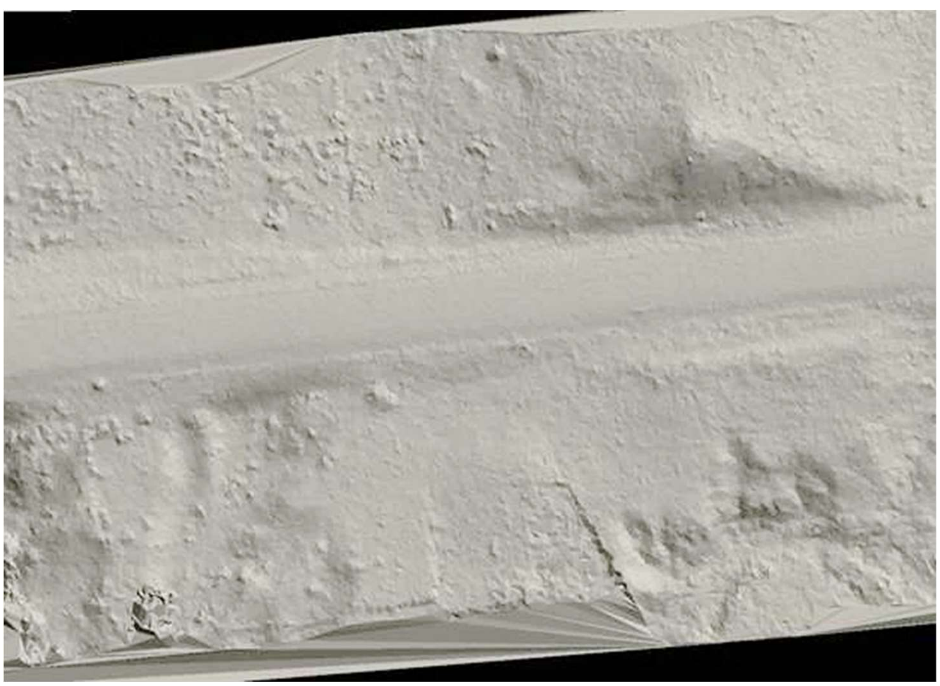


Cyan line is the corridor AOI.

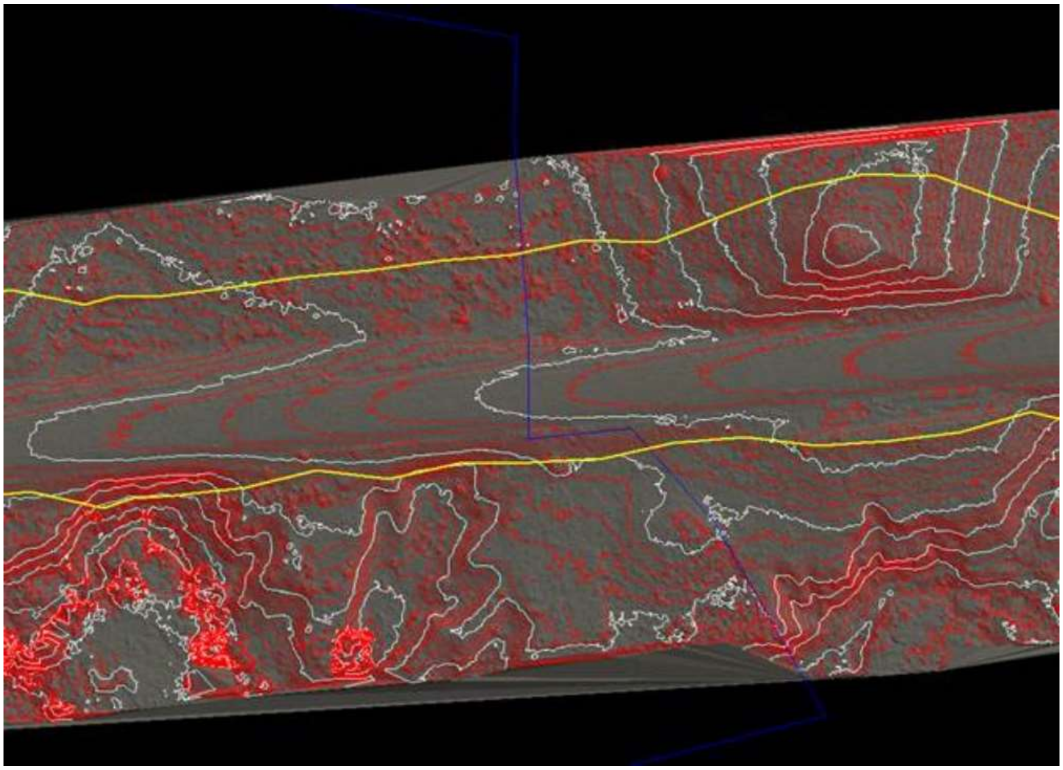


Seamline with hillshade TIN surface beneath with seamline

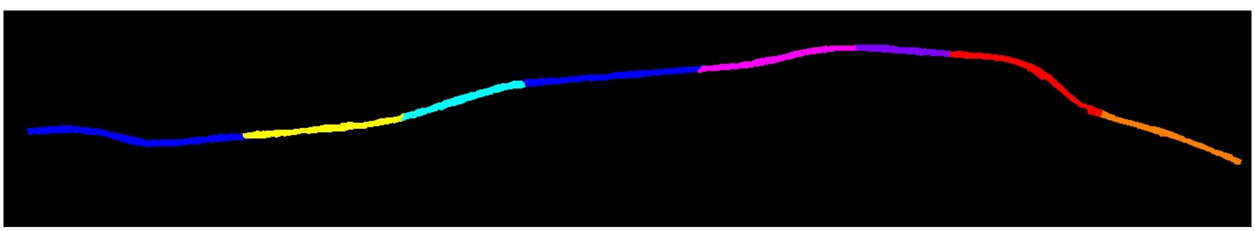
In the graphic below, the seamline is turned off demonstrating seamless transition between mission point clouds within corridor AOI.



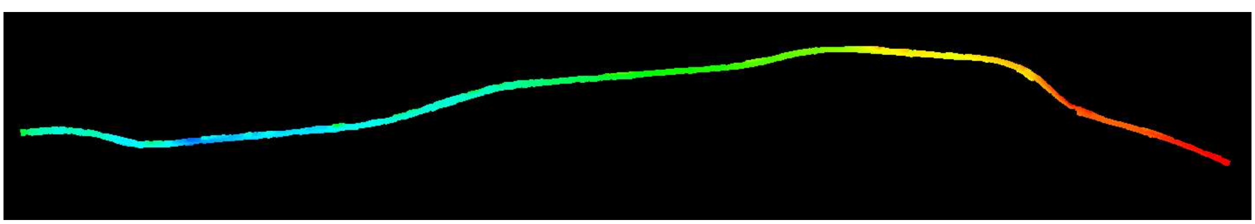
Seamline with hillshade TIN surface beneath without seamline



1 foot contours demonstrate seamless elevation transition between missions



Elevation point clouds of individual missions



Seamless point cloud colored by elevation result

Ground Control Point Results

Using the individual mission processing approach an overall vertical RMSE = 0.087' was realized. Results from individual control points are listed below.

Target Point Name	X (ft)	Y (ft)	Z (ft)	Point Cloud Elevation (ft)	Difference (ft)
300	2856416.27	501657.961	3308.753	3308.82	-0.07
301	2856414.78	501636.926	3308.263	3308.3	-0.04
302	2851528.72	500998.254	3270.074	3270.07	0
303	2851529.81	500976.277	3270.123	3270.08	0.04
304	2848374.13	500745.001	3244.113	3244.11	0
305	2848390.11	500724.853	3244.179	3244.17	0.01
306	2830138.37	499031.964	3263.264	OUTSIDE AOI LIMITS	
307	2833504.17	498890.106	3200.879	3200.79	0.09
308	2832313.78	499109.431	3208.221	3208.13	0.09
309	2837446.08	498921.394	3178.433	3178.36	0.07
310	2838672.28	499037.613	3185.764	3185.78	-0.02
311	2838674.21	499015.783	3185.737	3185.76	-0.02
312	2842376.12	499515.659	3201.514	3201.49	0.02
313	2842383.08	499495.263	3201.889	3201.81	0.08
314	2843826.32	499954.377	3206.208	3206.2	0.01
315	2843833.36	499933.661	3206.192	3206.18	0.01
316	2842794.97	499628.067	3204.449	3204.42	0.03
317	2842800.9	499607.467	3204.834	3204.89	-0.06
318	2846138.36	500557.898	3222.519	3222.52	0
319	2846141.56	500536.767	3222.144	3222.18	-0.04
320	2858219.46	501542.16	3336.464	3336.5	-0.04
646	2854492.81	501391.651	3287.327	3287.48	-0.15
680	2868599.94	498104.392	3428.876	OUTSIDE AOI LIMITS	
681	2858218.72	501475.397	3332.203	OUTSIDE AOI LIMITS	
682	2859299.16	501500.596	3332.931	3333.14	-0.21
683	2832308.04	499052.039	3206.078	OUTSIDE AOI LIMITS	

Target Point Name	X (ft)	Y (ft)	Z (ft)	Point Cloud Elevation (ft)	Difference (ft)
685	2833503.92	498956.446	3196.383	3196.16	0.22
475RW	2862898	500250.173	3380.23	3380.43	-0.2
649_CHECK	2857387.19	501534.809	3323.329	OUTSIDE AOI LIMITS	
654_CHECK	2861921.9	501113.903	3354.517	OUTSIDE AOI LIMITS	
69C	2830123.63	499122.113	3268.914	OUTSIDE AOI LIMITS	
70F	2837389.57	498874.041	3173.745	3173.73	0.01
74A	2853591.76	501162.273	3283.494	OUTSIDE AOI LIMITS	
74C_CHECK	2855530.88	501650.027	3296.308	3296.34	-0.03
74F	2858510.8	501470.649	3334.317	OUTSIDE AOI LIMITS	
75B	2860612.57	501322.222	3337.097	OUTSIDE AOI LIMITS	
76A_CHECK	2865835.41	499094.843	3384.98	3385.06	-0.08
76AA	2864484.33	499408.458	3377.755	3377.65	0.11
76C	2867740.69	498324.262	3406.202	3406.22	-0.02
BM810_CHECK	2863844.9	499558.01	3377.504	OUTSIDE AOI LIMITS	
BM813_CHECK	2851703.03	500943.209	3267.786	OUTSIDE AOI LIMITS	
BM815	2841041.03	499184.15	3188.316	OUTSIDE AOI LIMITS	

Many GCP or CP were noted as being outside the AOI because the AOI was constrained for the EVO flight due to wind and battery concerns. Hence many planned check points had to be used as a control point to generate an accurate solution. Had these points been visible better accuracy results may have been realized.

GCP Vertical Congruency Summary		
29 Points	**US Feet**	**Centimeters**
$RMSE_z$	0.087	2.65
95% Confidence Level	0.171	5.21
Minimum	-0.210	-6.40
Maximum	0.220	6.70

EVO 3 Point Cloud Bare Earth GCP Vertical Congruency Results

Check Point Results

Four checkpoints returned an overall RMSEz of 0.520'. Results of individual check points are listed below.

Target Point Name	X (ft)	Y (ft)	Z (ft)	Point Cloud Elevation (ft)	Difference (ft)
69E_CHECK	2831730.18	499167.117	3206.016	3205.94	0.08
74D	2856523.3	501614.781	3307.957	3308.04	-0.08
76BB_CHECK	2866751.33	498721.138	3396.545	3397.49	-0.94
71E	2842281.27	499441.734	3197.136	3197.57	-0.43

Vertical Accuracy Summary		
4 Points	**US Feet**	**Centimeters**
$RMSE_z$	0.520	15.85
95% Confidence Level	1.019	31.06
Minimum	-0.940	-28.65
Maximum	0.08	2.44

EVO 3 Point Cloud Bare Earth Checkpoint Vertical Result and Accuracy Summary

It should be noted that at the eastern end of the corridor there were no control pairs at flight mission overlaps or at the corridor terminus. During the acquisition there were many activities occurring simultaneously, i.e. traffic controls, UAS flights, and control targeting. This situation caused a few of the areas to be flown without the control being set, making control points unavailable for data processing. Not having control pairs at flight mission terminus and mission overlaps, especially since the flights had minimal overlap between missions had a profound effect on the surface continuity. Because there was no ground control in those critical locations a vertical step of 1.0' exists between missions 7-18 & 8-17 and ~4.0' step where missions 8-17 & 7-17 meet.

AECOM provided the following data deliverables in Montana SPCS, NAD83/2011, International Feet horizontally and US Survey Feet vertically using orthometric heights referencing Geoid03.

- Tile index comprised of 1000'x1000' tiles in SHP format
- Datasets were clipped to the appropriate corridor boundary
- Orthoimagery
    - 3 band, 0.08' pixel resolution, GeoTIFF/TFW format
    - Clipped to 1000'x1000' tiles
- Elevation data

- RGB encoded Point Cloud
  - Elevation data in the form of discrete points was provided in the following formats
    - LAS version 1.2
      - Classification
        - Class 1 (Unclassified)
        - Class 2 (Bare earth)
        - Class 7 (Noise)
        - Class 18 (Bridge deck and surrounding points)
        - Classification was performed within Agisoft. No manual point editing was performed.
          - Clipped to 1000’x1000’ tiles clipped to project boundary
          - Single merged LAS file clipped to project boundary
  - MicroStation
- Bare earth points in MicroStation DTM, TIN, and ASCII XYZ format
- 3D PDFs of bare earth points for each LAS tile

– Rasters
- DSM of all points in a single TIF/TFW having a resolution of 1 foot
  - Single merged raster clipped to project boundary
- DEM of Class 2 points in a single TIF/TFW having a resolution of 1 foot
  - Clipped to 1000’x1000’ tiles clipped to project boundary
  - Single merged raster clipped to project boundary

Mission Interchange Processing – NOVA F7200

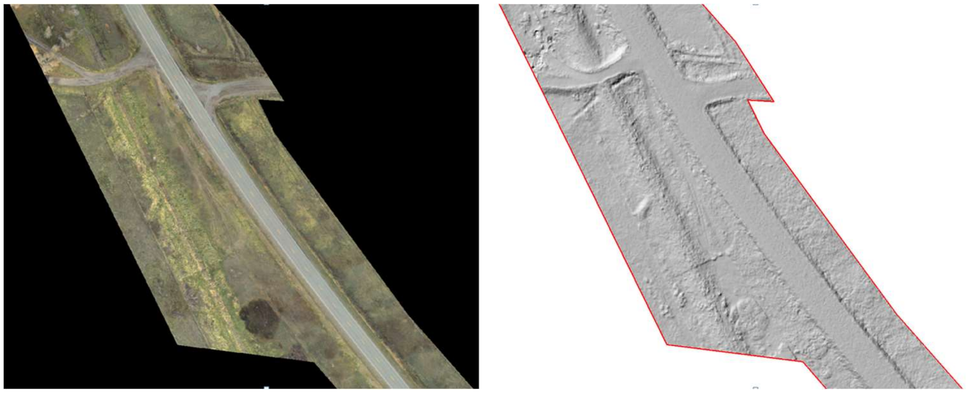
2,804 raw images captured by the fixed wing NOVA F7200 system during the acquisition. After a comprehensive review of the imagery AECOM selected 1,186 images to import into the data processing. A single block processing incorporating all flight missions was applied to the NOVA F7200 imagery.

One observation made during the imagery review was related to the image radiometry. Some of the imagery had localized radiometric issues mission to mission. Additionally, some missions were re-flown due to long shadows in the imagery, which accounts for the higher than average number of images AECOM did not select for the data processing. It was anticipated the color balancing capabilities within Photoscan would be able to address radiometric outliers and generate an aesthetically pleasing orthomosaic.

Examples of radiometric variation and shadows in the NOVA F7200 raw images

Overall the NOVA F7200 image radiometry was more consistent than the EVO 3 imagery, although some NOVA F7200 imagery underwent enhancement by Altavian prior to delivery to AECOM due to low light levels. AECOM further applied image enhancement to the NOVA F7200 data using Adobe Photoshop to make the imagery more consistent and vibrant. Note, users must be careful not to over or under saturate the imagery to a degree that loss of data results. Over or undersaturated imagery can negatively impact the number and quality of tie/key points and dense point cloud results directing impacting data accuracy.

Because of the higher quality NOVA F7200 image sensor, and more stable platform, far fewer instances of blurred images were captured compared to the EVO 3 system.



Sample Mission Interchange ortho and DEM datasets

Ground Control Point Results

The NOVA F7200 returned an overall $RMSE_z$ of 0.159' using all GCPs. Due to schedule and weather issues only ground control points were captured, no checkpoints were available.

Target Point Name	X (ft)	Y (ft)	Z (ft)	Point Cloud Elevation (ft)	Difference (ft)
CP1_AECOM_684	1712129.039	559334.961	4531.228	4531.28	-0.052
CP11_AECOM_690.02/03-1	1715743.544	547633.127	4461.813	4462.06	-0.247
CP14_AECOM_695	1719624.462	540457.271	4429.866	4430.11	-0.244
CP15_AECOM_696	1715967.043	547152.218	4458.671	4458.9	-0.229
CP17_MDT_32A	1717574.276	544780.602	4449.970	4450.28	-0.31
CP18_MDT_2A	1718969.555	541979.527	4424.700	4424.83	-0.13
CP19_MDT_7.0A	1710966.304	563627.035	4583.25	4583.47	-0.22
CP20_AECOM_697	1717950.883	543855.850	4435.930	4436.27	-0.34
CP22_AECOM_691	1719925.203	539835.112	4421.274	4421.49	-0.216
CP24_AECOM_680	1720522.766	538608.528	4415.288	4415.55	-0.262
CP25_MDT_1B	1721866.947	535798.901	4405.220	4405.34	-0.12
CP27_MDT_0.6Z	1724397.021	532876.657	4445.093	4445.16	-0.067
CP3_AECOM_692	1713230.338	555291.193	4512.113	4512.23	-0.117
CP6_MDT_4C	1713818.586	552929.101	4499.450	4499.61	-0.16
CP8_AECOM_693	1714333.060	551141.317	4483.648	4483.76	-0.112

Target Point Name	X (ft)	Y (ft)	Z (ft)	Point Cloud Elevation (ft)	Difference (ft)
PP_NAIL__69284MID	1712448.846	558020.829	4540.037	4540.08	-0.043
PP_NAIL_0.6ZE	1724425.278	532893.429	4446.327	4446.56	-0.233
PP_NAIL_1BE	1721970.155	535854.570	4406.673	4406.75	-0.077
PP_NAIL_4.01	1715236.928	548374.731	4468.930	4468.91	0.02
PP_NAIL_684W	1712070.931	559293.434	4534.859	4534.91	-0.051
PP_NAIL_690.02/03	1715693.677	547603.928	4463.089	4463.11	-0.021
PP_NAIL_691	1719963.582	539858.355	4425.486	4425.57	-0.084
PP_NAIL_692W	1713203.247	555258.313	4513.815	4513.75	0.065
PP_NAIL_693E	1714377.563	551152.948	4484.379	4484.26	0.119
PP_NAIL_695E	1719657.691	540480.252	4430.016	4430.05	-0.034
PP_NAIL_696E	1716001.351	547177.695	4460.717	4460.86	-0.143
PP_NAIL_697E	1717987.234	543877.086	4437.035	4437.11	-0.075
PP_NAIL_C4E	1713917.161	552788.826	4500.406	4500.39	0.016
PP_NAIL_END	1724240.350	533186.744	4445.443	4445.44	0.003
PP_NAIL_MID11A	1723088.370	534636.563	4408.317	4408.28	0.037

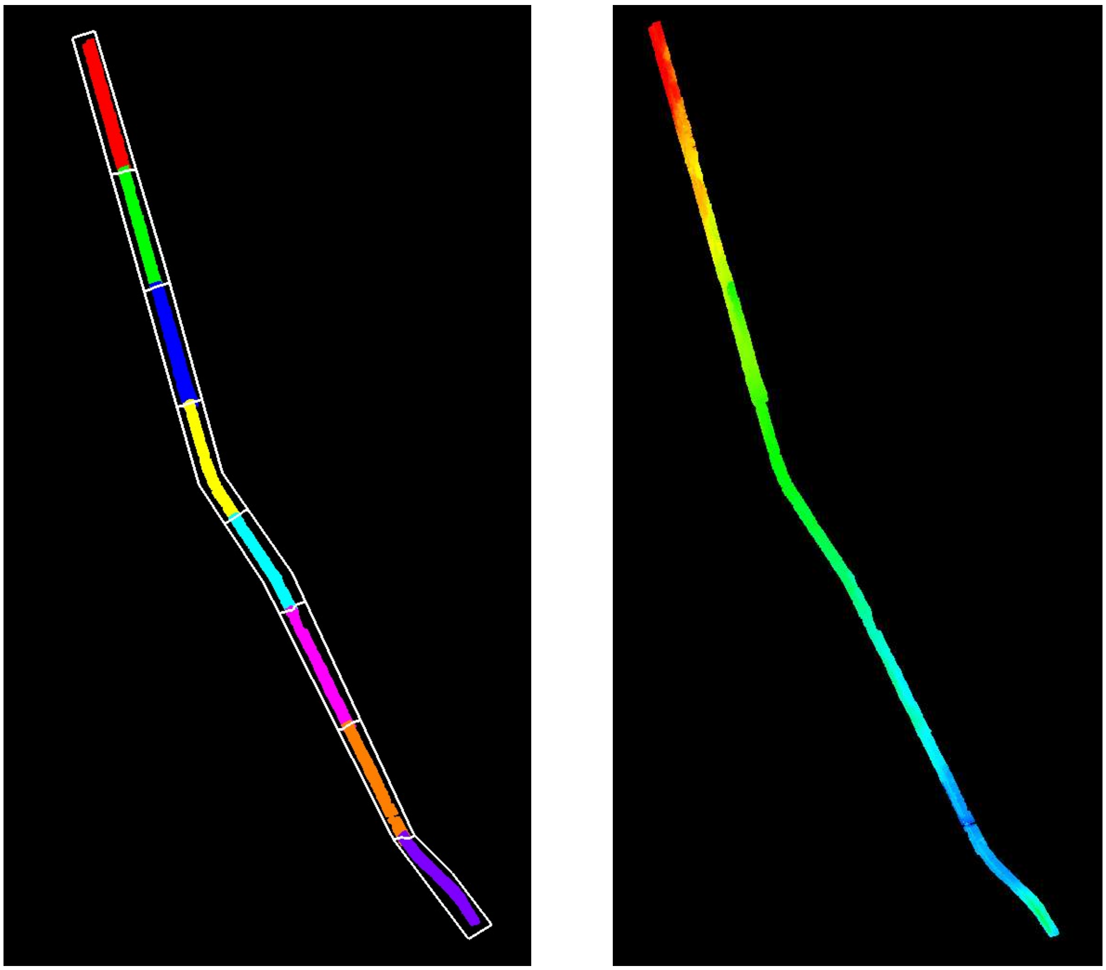
GCP Vertical Congruency Summary		
30 Points	**US Feet**	**Centimeters**
$RMSE_z$	0.159	4.846
95% Confidence Level	0.311	9.499
Minimum	-0.34	-10.36
Maximum	0.119	3.63

NOVA F7200 Point Cloud Bare Earth GCP Vertical Congruency Results

Mission Interchange Processing – EVO 3

1,661 raw images captured by the EVO 3 quadcopter system during the acquisition at the Mission Interchange project site. After a comprehensive review of the imagery AECOM selected 1,198 images to import into the data processing.

AECOM applied the same processing approach to the EVO 3 imagery that was used in Ashland, multi-block processing. Individually processed EVO 3 flight missions were amalgamated into a single corridor long project as seen below.



Individual EVO 3 flight mission point clouds and the clipping seamline polygon (left)
Seamless point cloud colored by elevation result (right)

Ground Control Point Results

The EVO 3 Mission Interchange dataset had an overall vertical RMSEz = 0.13’ that did not include a bust of 8.03’ at “PP NAIL END” (Not visible in imagery). Including PP NAIL END bust raised the results to an RMSEz of 1.15’. AECOMs research into the cause of the PP NAIL END result were inconclusive; however, three possible influencing factors were strong winds, poor image quality, and low image overlap contributed resulting in a poorly derived surface at that location.

Target Point Name	X (ft)	Y (ft)	Z (ft)	Point Cloud Elevation (ft)	Difference (ft)
CP1_AECOM_684	1712129.039	559334.961	4531.228	4531.21	0.018
CP11_AECOM_690.02/03-1	1715743.544	547633.127	4461.813	4461.97	-0.157
CP14_AECOM_695	1719624.462	540457.271	4429.866	4430.1	-0.234
CP15_AECOM_696	1715967.043	547152.218	4458.671	4458.73	-0.059
CP17_MDT_32A	1717574.276	544780.602	4449.970	4450.08	-0.11
CP18_MDT_2A	1718969.555	541979.527	4424.700	4424.72	-0.02
CP19_MDT_7.0A	1710966.304	563627.035	4583.250	4583.19	0.06
CP20_AECOM_697	1717950.883	543855.850	4435.930	4435.86	0.07
CP22_AECOM_691	1719925.203	539835.112	4421.274	4421.35	-0.076
CP24_AECOM_680	1720522.766	538608.528	4415.288	4415.28	0.008
CP25_MDT_1B	1721866.947	535798.901	4405.220	4405.16	0.06
CP27_MDT_0.6Z	1724397.021	532876.657	4445.093	NO COVERAGE	
CP3_AECOM_692	1713230.338	555291.193	4512.113	4512.15	-0.037
CP6_MDT_4C	1713818.586	552929.101	4499.450	4499.79	-0.34
CP8_AECOM_693	1714333.060	551141.317	4483.648	4483.94	-0.292
PP_NAIL__69284MID	1712448.846	558020.829	4540.037	4540.2	-0.163
PP_NAIL_0.6ZE	1724425.278	532893.429	4446.327	NO COVERAGE	
PP_NAIL_1BE	1721970.155	535854.570	4406.673	4406.78	-0.107
PP_NAIL_4.01	1715236.928	548374.731	4468.93	4468.96	-0.03
PP_NAIL_684W	1712070.931	559293.434	4534.859	4534.95	-0.091
PP_NAIL_690.02/03	1715693.677	547603.928	4463.089	4462.97	0.119
PP_NAIL_691	1719963.582	539858.355	4425.486	4425.59	-0.104
PP_NAIL_692W	1713203.247	555258.313	4513.815	4513.89	-0.075
PP_NAIL_693E	1714377.563	551152.948	4484.379	4484.43	-0.051
PP_NAIL_695E	1719657.691	540480.252	4430.016	4430.12	-0.104

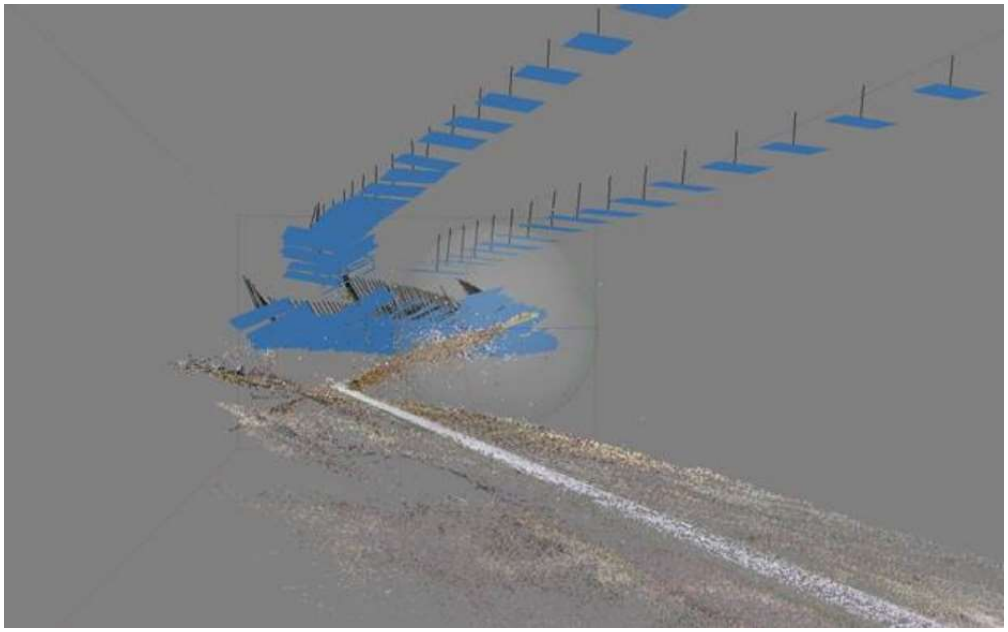
Target Point Name	X (ft)	Y (ft)	Z (ft)	Point Cloud Elevation (ft)	Difference (ft)
PP_NAIL_696E	1716001.351	547177.695	4460.717	4460.84	-0.123
PP_NAIL_697E	1717987.234	543877.086	4437.035	4437.12	-0.085
PP_NAIL_C4E	1713917.161	552788.826	4500.406	4500.51	-0.104
PP_NAIL_MID11A	1723088.370	534636.563	4408.317	4408.33	-0.013

GCP Vertical Congruency Summary		
28 Points	**US Feet**	**Centimeters**
$RMSE_z$	0.13	3.96
95% Confidence Level	0.26	7.77
Minimum	-0.078.027	-2.1
Maximum	0.119	3.63

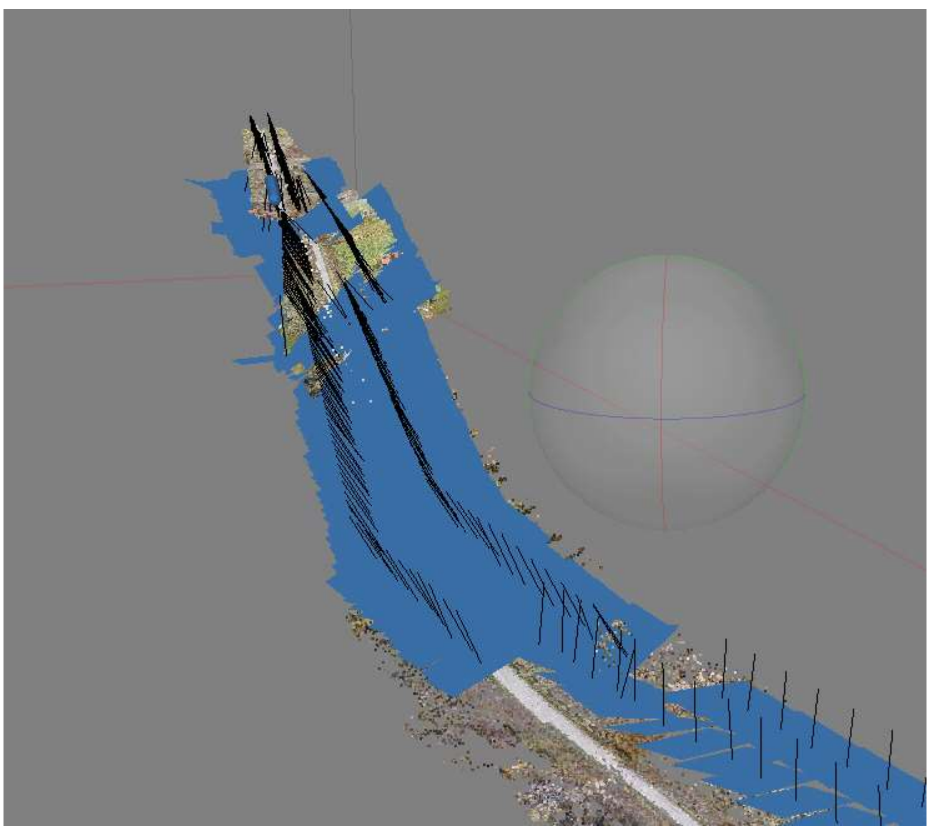
SkyCatch Point Cloud Bare Earth GCP Vertical Congruency Results

The same deliverables as listed above for the Ashland Corridor were provided to MDT.

As noted in the Acquisition section above, the wind was a factor while teams were deployed in the field. Because of that it is believed the EVO 3 system did not capture long segments along the western edge of the Mission Interchange corridor because of strong West to East crosswinds pushing the system eastward. The photogrammetric results show the EVO 3 leaning heavily into a crosswind capturing off-nadir imagery east of the western boundary.



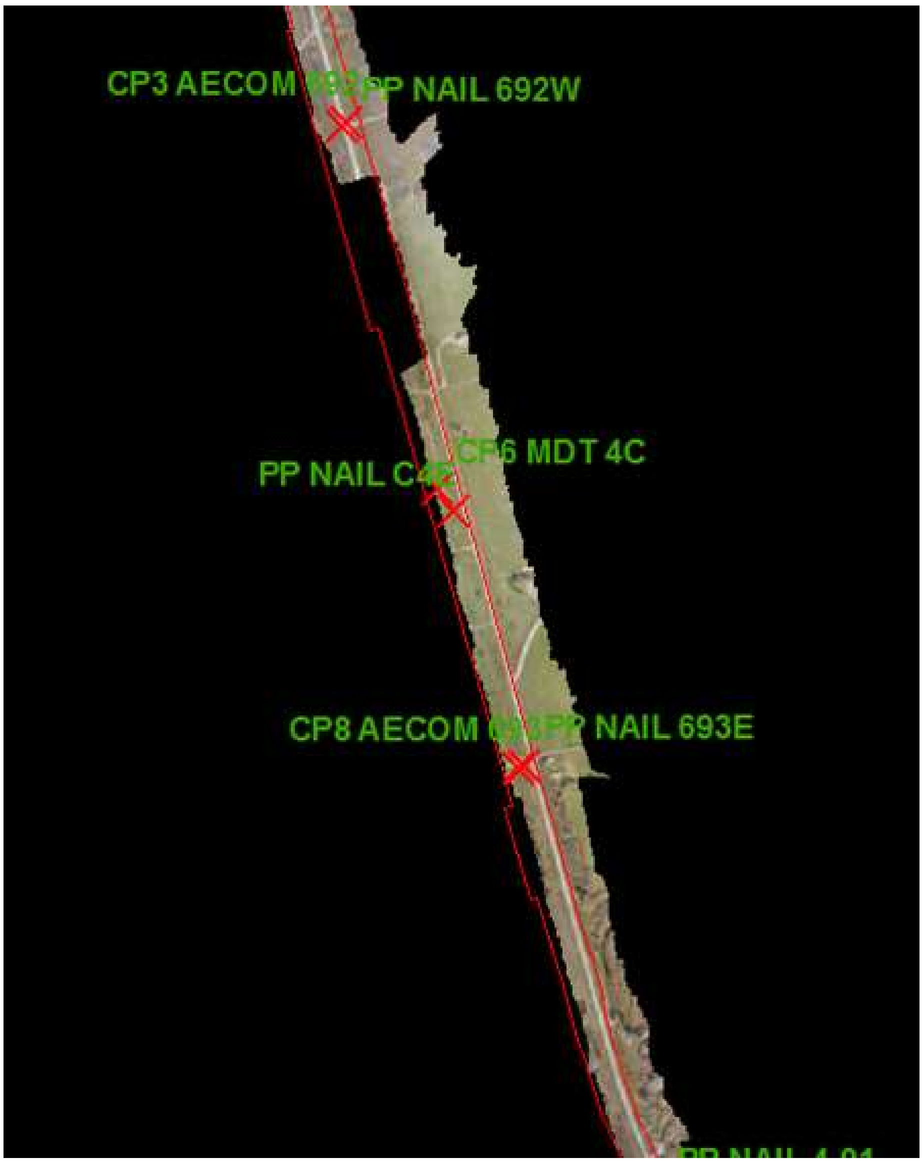
Calculated EVO 3 orientation showing potential wind impact – image 1



Calculated EVO 3 orientation showing potential wind impact – image 2

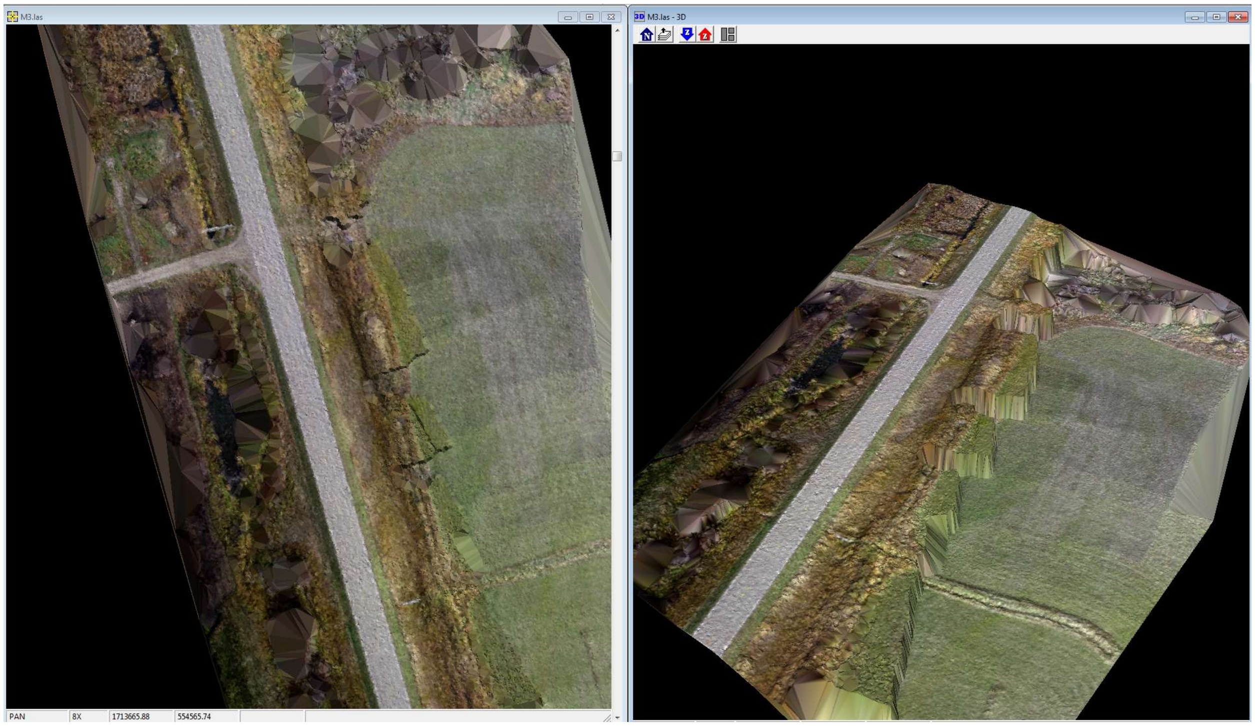
The EVO 3 system is reported to be able to capture nadir imagery in up to 25 mph cross winds. However, AECOM considers 15 mph (depending on gust factor and direction of wind in relation to the direction of flight lines) as the threshold to determine if a mission will be flown or delayed. Based on the processing results AECOM theorizes that the crosswinds where greater than that threshold in one particular area on the flight mission. That particular area was near a bluff that may have experienced stronger winds swirling at altitude around the bluff that were not discernable from the launch point thus causing the observed issue.

The EVO 3 system does not have a gimbal mounted imaging sensor that can compensate for airframe movement. A gimbaled sensor may be able to compensate better in similar wind conditions.

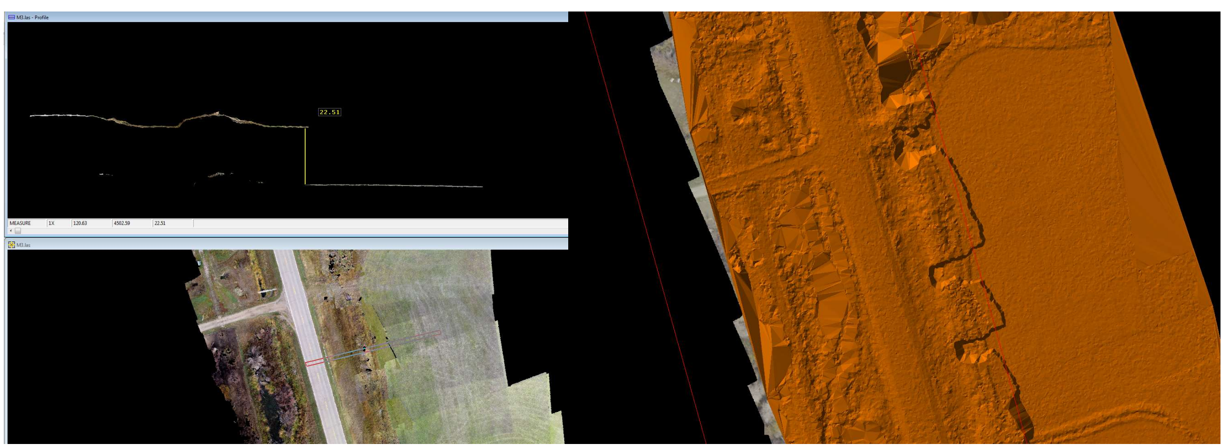


Pre-control imagery void issue due to high winds

The addition of control points greatly aided in adjusting the image orientation as seen in the above image. However, there were significant elevation issues between adjacent flight lines that could not be removed by processing, as can be seen in the images below. Reviewing the elevation of the imagery at time of exposure, the western most flightline is 30' higher than the eastern flightline in this corridor section. In addition to a crosswind situation the scale difference in the imagery negatively impacts the point cloud generation.



Colorized TIN showing stepping created by airframe altitude variation



Profile of stepping on the right; hillshade DEM on the left

5. Aerial Task Two: Intermediate-Construction

In May of 2017 AECOM was tasked with an Intermediate-Construction aerial survey of the Ashland and Mission Interchange project sites. Intermediate-Construction objectives were to capture each corridor during active construction activities. Each project site was only a two-mile section of the larger corridors that had been flown during the Pre-Construction task. The primary deliverable was a high detail and accurate terrain model derived from the UAS imagery. This model was to be used to quantify earth moving efforts in the form of volumetric data and in turn serve as a means to determine and validate quantities for monthly progress estimates. The current MDT practice is for the Department's Project Manager to estimate the earthwork quantities.

System Selection

Given the much shorter overall corridor length it was determined that the flights could easily be accomplished by the SkyCatch EVO 3 quadcopter UAS.

Planning Details

AECOM's internal planning and preparation for the Intermediate-Construction flights for both the Ashland and Mission Interchange AOIs commenced early June 2017. Lessons learned from the various aspects of the Pre-Construction effort were discussed and incorporated by the appropriate AECOM team members. AECOM also coordinated activities with MDT and the construction crews regarding site access during this time.

Planned AOIs

Ashland - 2 mile section from the western end of project attached (derived from the Altavian Ashland limits file)

Mission Interchange – two-mile section from the northern end of project attached (Altavian and SkyCatch limits file same)

The following are a few of the guidelines AECOM established based on lessons learned on the Pre-Construction flights and from other AECOM UAS projects.

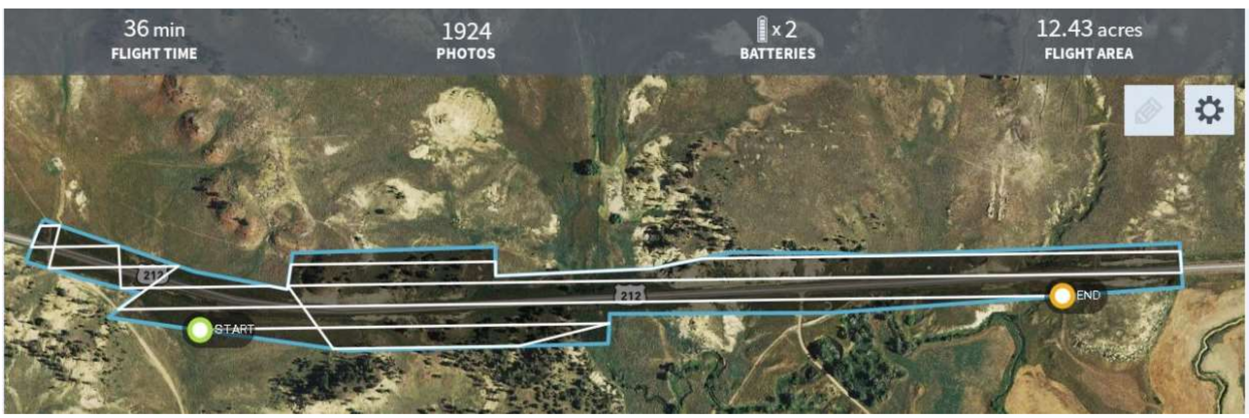
Control

- Ensure all targets are set prior to flight and secure to ground (prevent portions of targets blowing over onto themselves rendering them unusable)
- Preferably stop traffic during flight in case vehicle obscure targets on road surface. If this is not possible then ensure that all targets are set in locations that normal traffic would not obstruct the targets.
- Ensure all targets are within the AOI having an unobstructed view to sky
- Ensure targets are set within the flight missions overlapping area

– Ensure targets are set at either end of corridor
– Ensure all targets rest on bare earth or pavement and not on grass, or trampled down grass

Flight

– Constrict flight during highest sun angle (10AM – 2PM)
– Avoid flying during high winds, especially crosswinds
– Plan photo capture beyond project limits to ensure complete capture
– Field check data prior to leaving field using updated checklist
  - Radiometry consistency assessment
  - Image clarity assessment
  - Confirm each target is visible in multiple images, not just one image
  - Confirm no missed exposures
  - Confirm planned overlap maintained
  - Confirm area coverage
  - Confirm nadir image collect

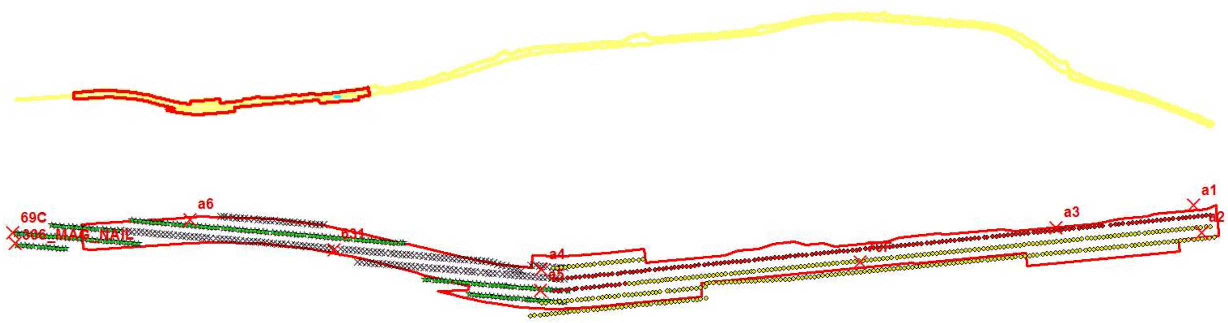


Sample of EVO 3 flight planning - Ashland

Acquisition

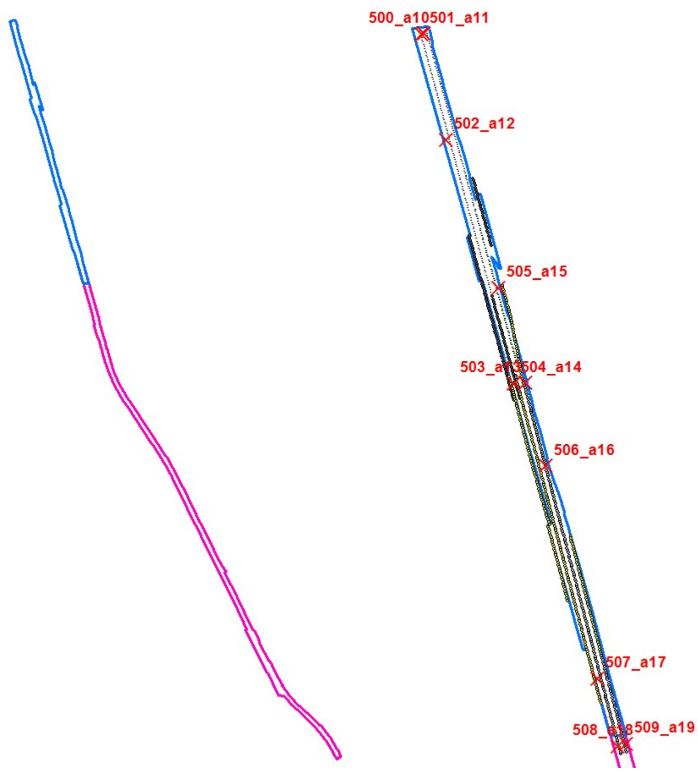
AECOM's UAS team site visits and data acquisition activities mimicked those previously described in the Pre-Construction section. Noted modifications employed are listed below:

– An update to the EVO UAS firmware resulted in planning ~2x as many photos in comparison to the Pre-Construction survey image acquisition for the same flight lines miles.
– New control was set for both AOIs as the Pre-Construction control had been destroyed, with the exception of 4 points (Mag Nails 306, 69C 631 and 70F) in the Ashland AOI.
– The western 1.8 miles of the Ashland AOI was acquired as per the tasking from MDT, highlighted in red below. The yellow polygon represents the Ashland Pre-Construction AOI.



Ashland AOI in red (top image), image photo centers in AOI (bottom image)

- Likewise, the northern 2 miles of the Mission Interchange AOI was acquired per MDT direction, highlighted in blue below. The magenta polygon represents the Mission Interchange Pre-Construction AOI.



Mission Interchange Construction AOI in blue (left image), image photo centers in AOI (right image)

Metric	Mission Interchange	Ashland Corridor
Ground Survey effort (days)	6/19/2017	6/20/2017
Ground Control Points (Visible/Not Visible (Check Points))	10/0	10/0
Ground Control RMSE (X/Y/Z) (International Foot (X/Y) US Survey Foot (Z))	MDT Provided	MDT Provided
Image Acquisition effort (days)	1	1
General Weather	Clear	Increasing winds in late afternoon
Weather Delays (Hours)	None	None
Number Missions/Images Acquired	9/1,193	6/1,097
Road Closure (Minutes per flight)	None	None

During the Intermediate-Construction the project areas were under contract with active construction and both projects had onsite traffic control contractors. Both projects utilized pilot cars to guide traffic through the construction work zones. The AECOM team, MDT inspectors, and the traffic control personnel met prior to the start of each day to plan traffic control efforts. The pilot car traffic stops were setup to accommodate for both the construction activities and the UAS flights. The AECOM team was given a radio to communicate with the traffic control foreman that allowed the AECOM team to stop the pilot car in the event the UAS would fly over the traffic. This allowed the UAS to fly over stopped vehicles, and not moving vehicles which is prohibited by FAA regulations. The use of the pilot cars allowed traffic to be stopped between 10 to 30 seconds, greatly reducing the amount time from the initial Pre-Construction flights.

Data Processing

Despite the need to process each EVO 3 mission separately in the Pre-Construction phase AECOM elected initially to try to process the data as a single block. This approach would save significant time on the data processing. The results of the data processing as a single block were acceptable for both AOIs. The surface model was far superior in quality as compared to the single block surface model created in the Pre-Construction phase.

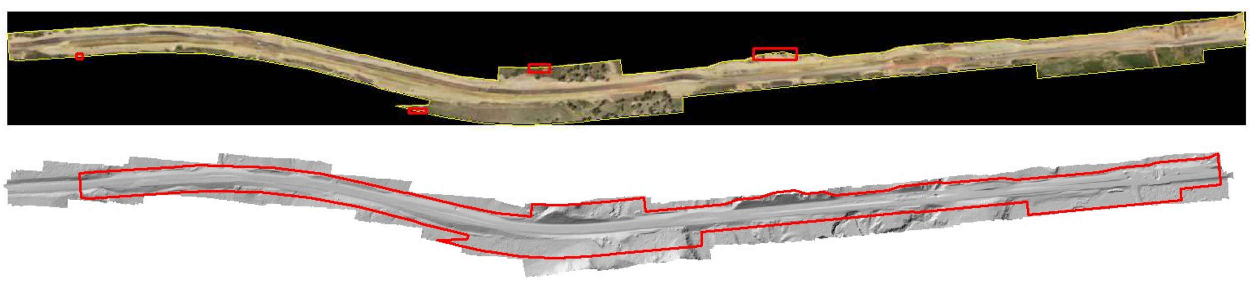
Metric	Mission Interchange	Ashland Corridor
Image Acquired/Images Processed	1,097/983 (11% reduction)	1,193/920 (23% reduction)
Image Sorting Time (Hours)	~1	~1
Unsorted/Sorted Image Data Volume (GB)	5.1/4.2	4.2/3.4
Image Radiometric Adjustments (Hours)	~1	~1
Total Tie Point Processing (Hours)	~8	~8
Total Tie Point Count	4,596,448	5,335,180

Metric	Mission Interchange	Ashland Corridor
Tie Point Count/Image	~4675	~5800
Ground Control Selection (Hours)	~1.0	~1.0
Dense Point Cloud Processing (Hours)	~10	~10
Total Dense Point Cloud Count	111,844,125	109,729,425
Auto filter Dense Point Cloud (Hours)	~2	~2
Manual Dense Point Cloud Filtering (Hours)	~1	~1
Corridor Bare Earth Dense Point Cloud Count/Ft^2	20.85	25.35

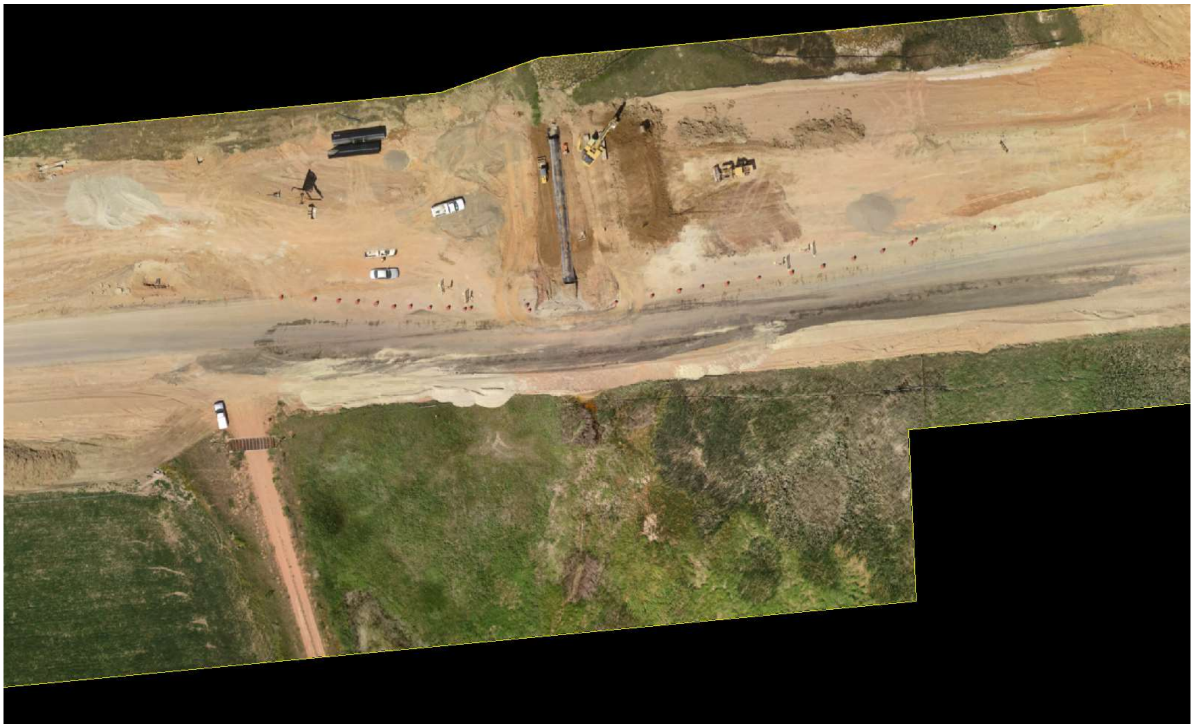
Ashland Processing

A total of 1193 raw images taken over the Ashland AOI during the Intermediate-Construction data acquisition. AECOM selected 920 images to be used in the data processing. All the images were run as one processing block as mentioned above, yielding positive results.

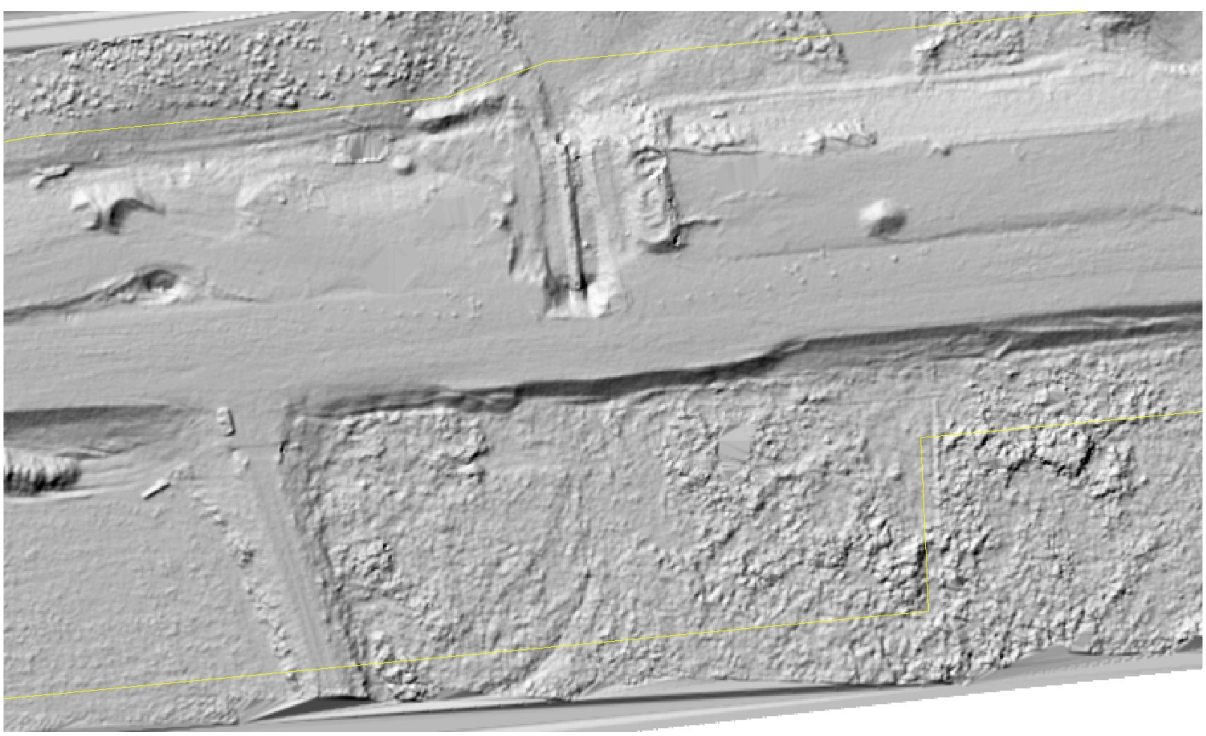
There were four data gaps deemed inconsequential from a terrain volume generation perspective as the gaps reside in undisturbed areas, small red polygons in image below.



Above images provide an overview of the Ashland processing results



Sample of orthophotography of Ashland AOI



Sample of DEM of Ashland AOI

Ground Control Point Results

The Ashland point cloud data had an overall vertical RMSEz = 0.073’. This was a measure of the 10 control points.

Target Point Name	X (ft)	Y (ft)	Z (ft)	Point Cloud Elevation (ft)	Difference (ft)
a1	2840255	499360.2	3186.050	3186.01	0.040
a2	2840319	499126.3	3176.960	3176.97	-0.010
a3	2839073	499167.4	3178.826	3178.87	-0.044
a4	2834653	498810.0	3220.038	3220.15	-0.112
a5	2834646	498634.3	3200.056	3200.05	0.006
a6	2831642	499239.2	3211.152	3211.13	0.022
306_MAG_NAIL	2830138	499032.0	3263.258	3263.11	0.148
69C	2830124	499122.1	3268.850	3268.95	-0.100
631	2832878	498979.7	3210.610	3210.59	0.020
70F	2837390	498874.0	3173.830	3173.90	-0.070

GCP Vertical Congruency Summary		
10 Points	US Feet	Centimeters
$RMSE_z$	0.073	2.237
95% Confidence Level	0.144	4.386
Minimum	-0.112	-3.41
Maximum	0.148	4.51

Ashland Intermediate-Construction Point Cloud Bare Earth GCP Vertical Congruency Results

Check Point Results

Five checkpoints returned an overall $RMSE_z$ of 1.265'. Results of individual check points are listed below.

Check Point Name	X (ft)	Y (ft)	Z (ft)	Point Cloud Elevation (ft)	Difference (ft)
403	2834196.746	498827.831	3195.136	3194.590	-0.543
404	2835346.205	498774.847	3190.222	3191.470	1.249
405	2836958.569	498826.107	3171.265	3172.980	1.713
406	2836962.334	498837.412	3172.170	3173.830	1.660
407	2839289.772	499026.008	3178.448	3177.980	-0.471

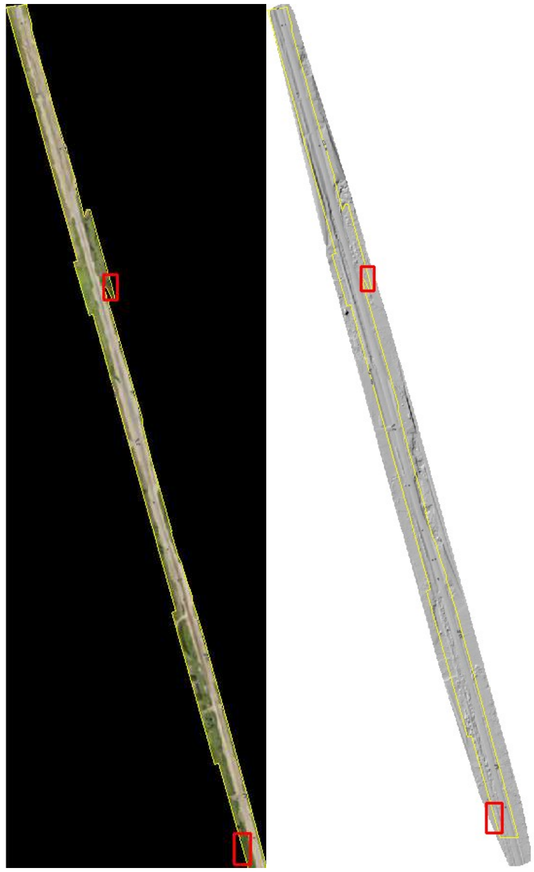
Vertical Accuracy Summary		
5 Points	US Feet	Centimeters
$RMSE_z$	1.265	38.557
95% Confidence Level	2.479	75.572
Minimum	-1.513	-46.12
Maximum	1.713	52.21

Ashland Intermediate-Construction Point Cloud Bare Earth Checkpoint Vertical Result and Accuracy Summary

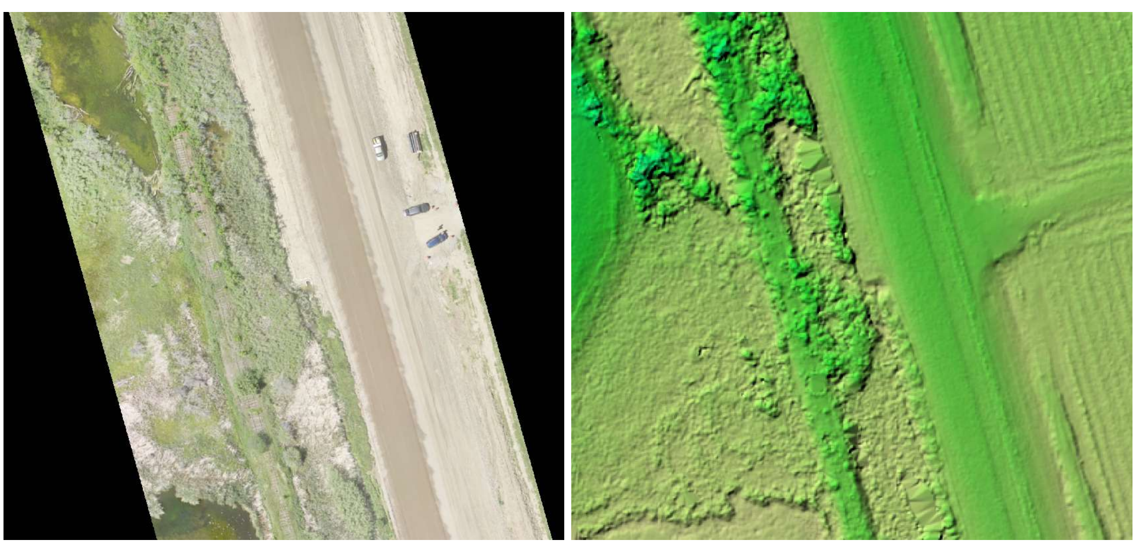
Mission Interchange Processing

There was a total of 1,097 raw images taken over the Mission Interchange AOI during the Intermediate-Construction data acquisition. AECOM selected 983 images to be used in the data processing. All the images were run as one processing block yielding a surface that was far superior to the surface created during the Pre-Construction phase using the EVO 3.

Similar to the Ashland AOI there were just a couple small areas that had data gaps when compared to the project boundary. These gaps were deemed inconsequential from a terrain volume generation perspective as the gaps reside in undisturbed areas, small red polygons in image below.



The above images provide an overview of the Mission Interchange processing results



Sample of orthophotography (left) and DEM (right) of Mission Interchange AOI

Ground Control Point Results

The Mission Interchange point cloud data had an overall vertical RMSEz = 0.116’. This was a measure of the 10 control points.

Target Point Name	X (ft)	Y (ft)	Z (ft)	Point Cloud Elevation (ft)	Difference (ft)
500_a10	1710933	563442.1	4579.497	4579.32	0.177
501_a11	1710904	563433.4	4579.440	4579.31	0.130
502_a12	1711278	561805.5	4571.471	4571.44	0.031
503_a13	1712500	558061.7	4538.147	4538.04	0.107
504_a14	1712314	558055.9	4538.046	4538.15	-0.104
505_a15	1712082	559529.0	4531.522	4531.65	-0.128
506_a16	1712812	556783.8	4521.274	4521.46	-0.186
507_a17	1713604	553514.7	4506.484	4506.56	-0.076
508_a18	1713915	552468.8	4495.473	4495.53	-0.057
509_a19	1714053	552510.2	4495.576	4495.63	-0.054

GCP Vertical Congruency Summary		
10 Points	**US Feet**	**Centimeters**
$RMSE_z$	0.116	3.533
95% Confidence Level	0.227	6.925
Minimum	-0.186	-5.67
Maximum	0.177	5.39

Mission Intermediate-Construction Point Cloud Bare Earth GCP Vertical Congruency Results

Check Point Results

Six checkpoints returned an overall $RMSE_z$ of 0.439'. Results of individual check points are listed below.

Target Point Name	X (ft)	Y (ft)	Z (ft)	Point Cloud Elevation (ft)	Difference (ft)
401	1713941.544	552474.421	4495.269	4495.19	-0.0740083
400	1714021.51	552500.285	4495.838	4495.77	-0.0631668
402	1713718.08	553390.313	4505.573	4505.38	-0.191247
403	1712644.11	557313.602	4532.341	4531.83	-0.507471
406	1712272.487	558766.882	4535.006	4535.53	0.523785
407	1711181.432	562564.974	4574.55	4575.31	0.762261

Vertical Accuracy Summary		
6 Points	US Feet	Centimeters
$RMSE_z$	0.439	13.38
95% Confidence Level	0.860	26.21
Minimum	-0.507	-15.45
Maximum	0.762	23.22

Mission Intermediate-Construction Point Cloud Bare Earth Checkpoint Vertical Result and Accuracy Summary

The purpose of the Intermediate-Construction phase was to derive a high detailed terrain model as input into volumetric determinations to be performed using GeoPAK. No orthoimagery or point cloud data was delivered.

Volumetric Calculations

To compare the Intermediate surface against the Pre-Construction surface, the point cloud files were reduced to a 1 foot spacing and imported into MicroStation. The point files were then converted to Digital Terrain Models (DTM) using GeoPAK. The horizontal and vertical alignment data were inserted into MicroStation using the data presented in the project construction plans. With horizontal and vertical alignment input into MicroStation, along with the Pre-Construction DTM and Intermediate-Construction DTM, GeoPAK analyzed the volumetric data comparing the two DTM datasets.

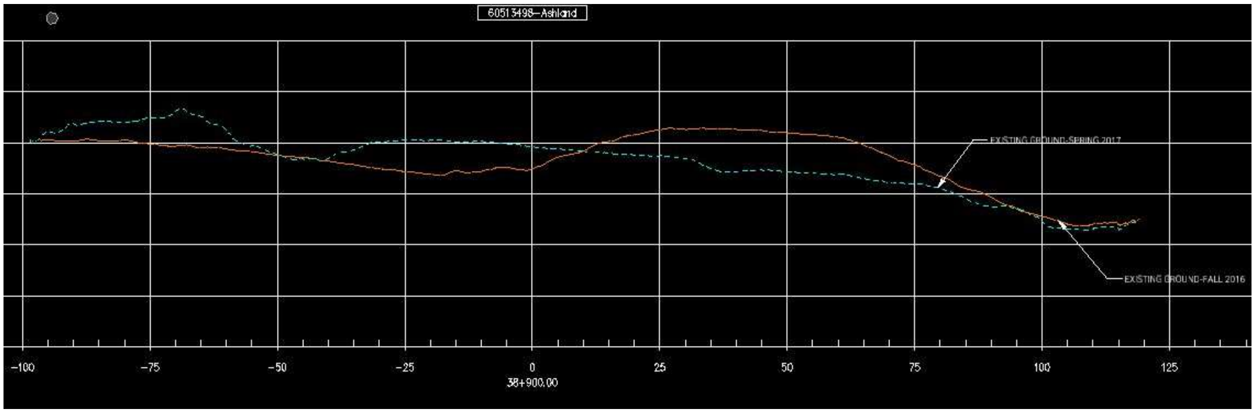
For Mission Interchange, a cut/fill factor of 1.0 was used for the purpose of calculating the volumes. The DTMs were compared for the portion of the project starting at station 225+00 and going to the end of the project at station 337+00, the extents of the Intermediate-Construction flight. The total volume difference between the surfaces amounted to a total cut of 128,231 cubic yards (cy), at total fill of 92,622 cy and a net cut 35,609 cy.

For Ashland, a cut/fill factor of 1.0 was used for the purpose of calculating the volumes. The DTMs were compared for the portion of the project starting at station 225+00 and going to the end of the project at station 337+00, the extents of the intermediate flight. The total volume difference between the surfaces amounted to a total cut of 112,887 cubic yards (cy), a total fill of 206,446 cy and a net fill 93,559 cy.

As requested by MDT, AECOM used GeoPAK to analyze and compute the cut/fill volumes for every 100-foot station, covering the intermediate flight portion of the project. The stationing interval can be customized to any length and significant stations such curves and station equations can be inserted. GeoPAK volume outputs are included in Appendix C. A sample of the GeoPAK output from the Mission Interchange project is below:

	Station Quantities					
	Cut			Fill		
Baseline Station	**Factor**	**Volume**	**Adjusted**	**Factor**	**Volume**	**Adjusted**
225+00.000	1	0	0	1	0	0
226+00.000	1	160.2	160.2	1	239.1	239.1
227+00.000	1	257.4	257.4	1	212.8	212.8
228+00.000	1	324.6	324.6	1	186.6	186.6
229+00.000	1	272.6	272.6	1	127.2	127.2
230+00.000	1	381.7	381.7	1	107.6	107.6
231+00.000	1	420.8	420.8	1	107.5	107.5
232+00.000	1	603.1	603.1	1	54.3	54.3

The computed volumes for both sites are for the total volume difference between the two surfaces. The volume data included general earthwork, topsoil stockpiles and aggregate base material. In order to properly separate the different type of earthwork quantities, the GeoPAK operator would need to be instructed on the location of the topsoil piles to remove or clip them from the surface prior to volume calculations. Any aggregate base material that was placed prior to the data acquisition would need to be subtracted from the computed volume based on quantities calculated or estimated by MDT personnel. A cross section comparing two surfaces below, a topsoil pile can be seen on the left end of the cross section.



Cross Section from Ashland project.

6. Aerial Task Three: Post-Construction

Post-Construction goals were to capture and document the end state of construction activities along the entire corridor. The goal of this task was to develop UAS datasets for use in terrain model volumetric calculations, measurements, and profiling. For the Post-Construction aerial survey the Mission Interchange project AOI was tasked in the Fall of 2017, Ashland was tasked in the summer of 2018.

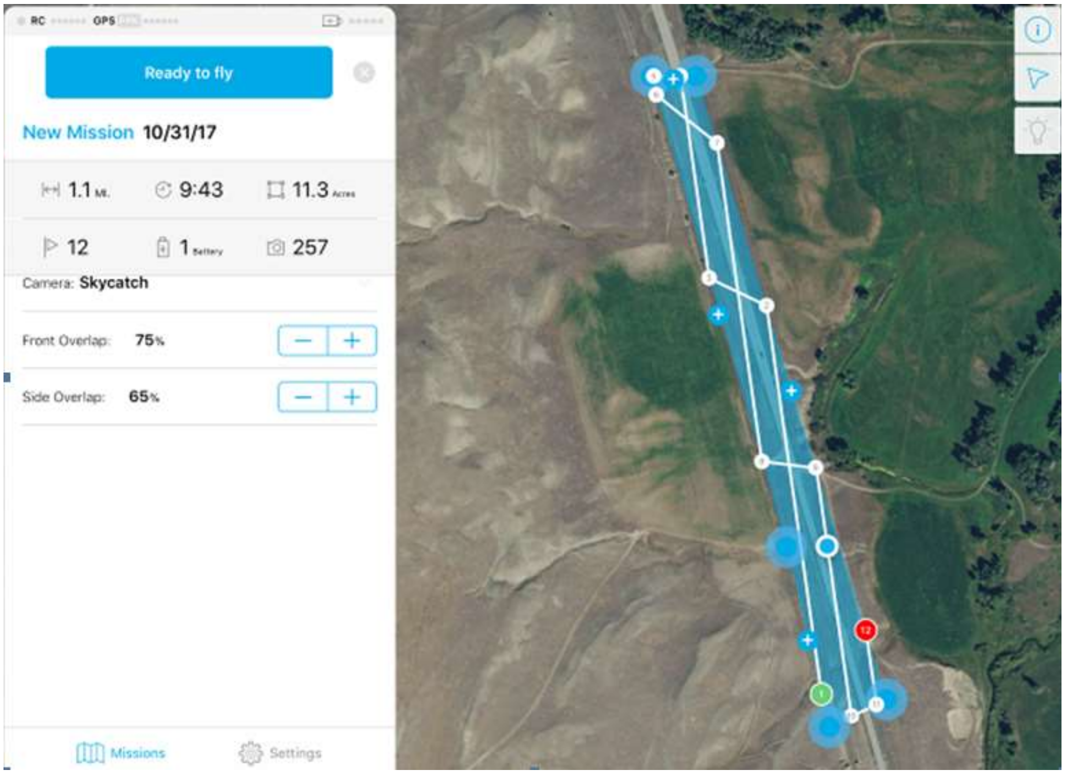
System Selection

Prior to commencement of Aerial Task 3 SkyCatch retired the EVO 3 platform. SkyCatch replaced the EVO with a new system based on a DJI Matrice 100 airframe complemented with a customized SkyCatch sensor; the new system is referred to as the Explore 1.

Metric	Explore 1 (Matrice 100 airframe)
Air Frame	Quadcopter
Flight Duration	20 min
Launch Requirements	Vertical take-off/landing
Sensor	20 Megapixel, color 1" Sony Exmor-R Sensor, Mechanical Shutter
Gimbaled Mount	No
GSD Capable	1 cm
Onboard GNSS	Survey grade GPS For navigation and geo-tagging of images
Image Size(pixels)	4000x3000
Maximum Crosswind (MPH)	20 mph

Planning Details

AECOM's internal planning and preparation for the Mission Interchange Post-Construction flights commenced mid-October 2017. Lessons learned from the various aspects of the Pre and Intermediate-Construction effort were discussed and incorporated by the appropriate AECOM team members. AECOM also coordinated activities with MDT regarding site access during this time.



Sample of the flight plan for one flight mission

Acquisition – Mission Interchange (Fall 2017)

AECOM's UAS survey team site visits and data acquisition activities mimicked those previously described in the Pre-Construction section. Noted modifications employed are listed below:

- SkyCatch's newest UAS platform, the Explore 1 was employed.
- Upgraded flight planning software suggested zig-zag flight line pattern as being most efficient means to collect imagery.
- New control was set as needed. Any existing Pre and Intermediate-Construction control that was available was reused.
- AECOM shortened northernmost acquisition extent to more closely align with traffic control setup point.

Metric	Mission Interchange
Ground Survey effort (days)	10/31/2017 & 11/1/2017
Ground Control Points (Visible/Not Visible (Check Points))	31/0
Ground Control RMSE (X/Y/Z) (International Foot (X/Y) US Survey Foot (Z))	MDT Provided
Image Acquisition effort (days)	2

Metric	Mission Interchange
General Weather	10/31/2017 - Calm to Windy, with winds increasing throughout the day. Overcast 11/1/2017 – Raining /Sleeting/Snowing. Overcast
Weather Delays (Hours)	- 4
Date & Number Missions	10/31/2017 – 10, 9, 8, 7, 6, 5 (partial) 11/1/2017 – 5, 4, 3, 2 (partial) Mission 1 not attempted due to snow
Road Closure (Minutes per flight)	None

During the Post-Construction flight AECOM had onsite traffic control contractors. Pilot cars were again used to guide traffic through the data acquisition zones. The AECOM team, MDT inspectors and the traffic control personnel met prior to the start of each day to plan traffic control efforts. The pilot car traffic stops were setup to accommodate the UAS flights. The AECOM team was given a radio to communicate with the traffic control foremen for each that allowed AECOM team to stop the pilot car in the event the UAS would fly over the traffic. This allowed the UAS to fly over stopped vehicles, and not moving vehicles which is prohibited by FAA regulations. The use of the pilot cars allowed traffic to be stopped between 10 to 30 seconds, greatly reducing the amount time from the initial baseline flights

Weather conditions during the acquisition were difficult and deteriorated each day with increased winds on day one and rain/sleet/snow on day two.

During the first day 5 miles of the project were flown prior to the winds becoming too strong to continue.

Day one survey work was planned to layout 50 control locations. The goal was to place the panels or painted crosses at the exact coordinates as the planning shapefile, however the surveyor was unable to correlate a number of the locations, so the targets were placed based on visual references from PDFs that had been provided. After the targets were set the surveyor was able to shoot in 75% of the targets with one RTK shot and took some intermediate check points along the road on the miles we flew. The team was unable to place any additional targets due to encroaching poor weather.

On day two the weather permitted flights to commence at about mid-day. The team was able to re-fly a mile from the previous day and fly an additional three miles, but there was moderate to heavy sleet beginning. Subsequent flights that day were canceled due to poor weather and based on the forecast no more additional acquisition days were planned.

Day two survey was efforts included shooting in the rest of the GCP’s with one RTK shot and collecting intermediate check points.

The combined flights covered approximately 5.9 miles of the entire project corridor.

Image acquisition began at the north end of the project site. Due to that fact the first four flights had good imagery with little impact from wind of other atmospheric conditions there were no concerns about using the imagery to create a surface and orthophotography. These flights comprise 974 images.

Data Processing

The AECOM processing team was provided 2,633 raw images from the two days of acquisition work. Initial impressions were that the imagery was much sharper in appearance compared to Pre and Intermediate-Construction quadcopter flights, attributed to the new Explorer 1 sensor.

AECOM determined that images from four of the flight missions should not be used for processing due to the appearance of sleet and snow in the images. An additional flight mission showed signs of excessive wind, but it was determined that it should be processed to better understand the impact of wind on the airframe and the processing software. The remaining flight missions were processed totaling 1,474 images imported for processing.

Example of raw image with snowfall visible

Metric	Mission Interchange
Image Acquired/Images Processed	2,633/1,474
Image Sorting Time (Hours)	~1
Unsorted/Sorted Image Data Volume (GB)	8.5/4.51
Image Radiometric Adjustments (Hours)	~1
Total Tie Point Processing (Hours)	~8

Metric	Mission Interchange
Total Tie Point Count	358,744
Tie Point Count/Image	~243
Ground Control Selection (Hours)	~1.0
Dense Point Cloud Processing (Hours)	~10
Total Dense Point Cloud Count	314,550,883
Auto filter Dense Point Cloud (Hours)	~2
Manual Dense Point Cloud Filtering (Hours)	~1

Coverage Analysis

Beyond image clarity it is important to understand if the flight path and footprint of the images will be useable to create an orthophotography and surface that covers the project area. Due to concerns based on weather and wind conditions AECOM prepared and provided MDT a post-flight analysis of each flight mission and the potential usability of the raw imagery prior to image processing. This report was used to determine if additional flights and/or re-flights would be required. It was determined that no additional flights would be needed as there was enough useable data.

Of the ten flights it is clear that four should not be used due to snow in the imagery. Of the remaining six flights, all had imagery that is good enough for processing and the control during an initial test matched well. As part of the inspection above it is very likely that all the six flights can be processed into a single corridor or simply final processed as individual processing block sites. Airframe movement did create a few gaps over the construction zone in a number of the flights; however, in most the impact is negligible even if less than ideal. The sixth flight has the largest construction zone gap as the entire flight appeared shifted to the east. Because it occurs along a linear edge of the data it is not an area where we would interpolate data to fill the void so those would be null data areas. If flights 1 - 5 were only used then the final dataset would cover approximately 3.2 miles of the entire corridor. If the sixth flight were used it would expand to 3.9 miles of coverage along the project corridor.

Ground Control Point Results

The Mission Interchange point cloud data had an overall vertical RMSEz = 0.037’. This was a measure of the 10 control points and not an independent validation of the data accuracy.

Target Point Name	X (ft)	Y (ft)	Z (ft)	Point Cloud Elevation (ft)	Difference (ft)
900	1711161	562632.6	4575.197	4575.19	0.007
902	1710732	564167.1	4581.162	4581.30	-0.138
903	1710709	564129.7	4581.092	4581.04	0.052
904	1711365	561802.0	4566.753	4566.74	0.013

Target Point Name	X (ft)	Y (ft)	Z (ft)	Point Cloud Elevation (ft)	Difference (ft)
905	1711684	560766.6	4543.202	4543.17	0.032
906	1711940	559749.7	4537.928	4537.92	0.008
908	1712171	558926.6	4537.260	4537.24	0.020
909	1712183	558987.2	4536.842	4536.85	-0.008
910	1712443	558055.2	4541.353	4541.36	-0.007
911	1712741	556814.5	4524.008	4524.00	0.008
912	1713038	555988.5	4517.340	4517.32	0.020
913	1712934	555394.2	4518.704	4518.75	-0.046
914	1713184	555349.5	4514.500	4514.51	-0.010
915	1713189	555435.0	4514.905	4514.91	-0.005
927	1711380	561850.4	4567.406	4567.49	-0.084
928	1713366	554684.8	4510.680	4510.69	-0.010
929	1713674	553560.7	4507.858	4507.84	0.018
930	1713896	552875.6	4502.828	4502.80	0.028
931	1714158	551814.1	4491.760	4491.78	-0.020
932	1714177	551848.6	4492.072	4492.07	0.002
933	1714321	551191.4	4484.730	4484.75	-0.020
934	1714598	550202.0	4480.033	4480.05	-0.017
935	1714898	549228.9	4474.210	4474.18	0.030
936	1715224	548358.4	4471.205	4471.21	-0.005
937	1715265	548337.2	4470.141	4470.15	-0.009
938	1715769	547464.8	4463.041	4463.01	0.031
939	1716463	546415.3	4457.709	4457.66	0.049
940	1716731	546089.4	4453.734	4453.73	0.004
941	1717341	545077.7	4449.447	4449.44	0.007
942	1717392	545046.8	4450.376	4450.36	0.016

GCP Vertical Congruency Summary		
30 Points	US Feet	Centimeters
$RMSE_z$	0.037	1.12
95% Confidence Level	0.072	2.19
Minimum	-0.138	-4.21
Maximum	0.052	1.58

Mission Post-Construction Point Cloud Bare Earth GCP Vertical Congruency Results

Check Point Results

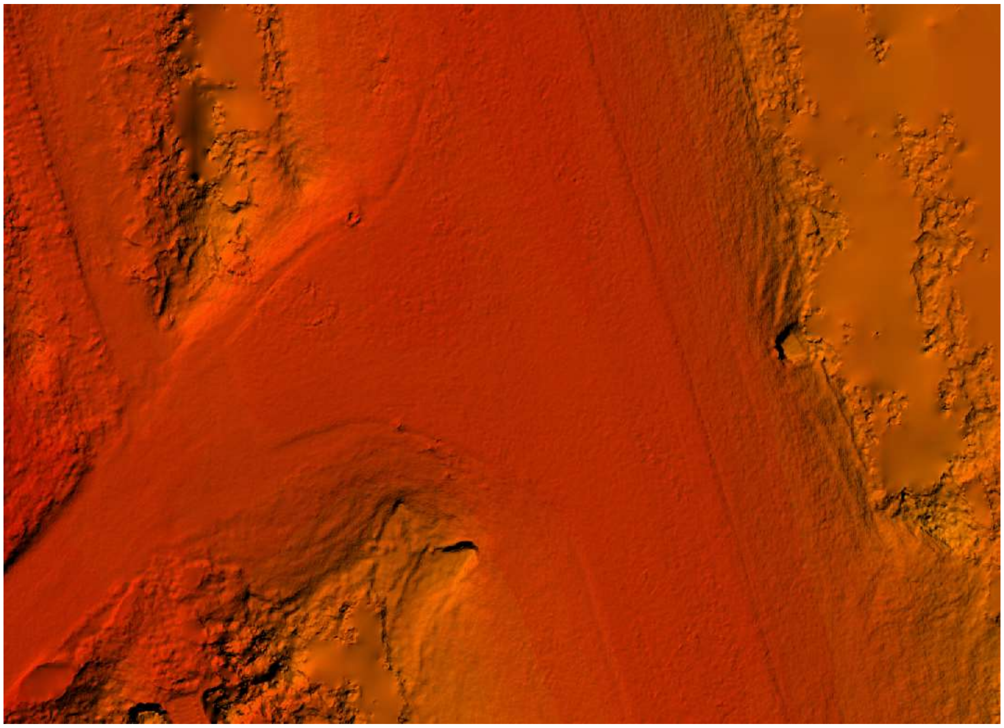
Eleven checkpoints returned an overall $RMSE_z$ of 0.422'. Results of individual check points are listed below.

Check Point Name	X (ft)	Y (ft)	Z (ft)	Point Cloud Elevation (ft)	Difference (ft)
916	1713104.041	555733.748	4516.633	4516.570	-0.059
917	1712894.715	556416.619	4518.421	4518.460	0.037
918	1712649.673	557291.210	4532.266	4532.430	0.161
919	1712268.548	558731.119	4537.349	4536.940	-0.408
920	1711990.295	559524.400	4535.371	4535.560	0.190
921	1711840.794	560266.903	4538.294	4537.590	-0.701
922	1711757.417	560400.587	4540.893	4540.070	-0.821
923	1711667.288	560867.098	4543.437	4543.680	0.239
924	1711536.312	561293.866	4554.915	4555.560	0.646
925	1711419.313	561604.545	4562.780	4563.030	0.251
926	1711394.445	561604.033	4559.529	4559.700	0.175

Vertical Accuracy Summary		
11 Points	**US Feet**	**Centimeters**
$RMSE_z$	0.422	12.862
95% Confidence Level	0.827	25.21
Minimum	-0.821	-25.02
Maximum	0.646	19.69

Mission Post-Construction Point Cloud Bare Earth Checkpoint Vertical Result and Accuracy Summary

Detail from orthophotograph



Detail of DEM

Acquisition – Ashland Corridor (Summer 2018)

AECOM's UAS team site visits and data acquisition activities mimicked those noted above for Mission. Acquisition activities summarized below:

Metric	Ashland Corridor
Ground Survey effort (days)	1
Ground Control Points (Visible/Not Visible (Check Points))	36/31
Ground Control RMSE (X/Y/Z) (International Foot (X/Y) US Survey Foot (Z))	MDT Provided
Image Acquisition effort (days)	2 for data collection and evaluation
General Weather	–Increasing winds through mid-afternoon. Rain showers periodically throughout the day. Overcast
Weather Delays (Hours)	-4
Road Closure (Minutes per flight)	Flaggers were utilized and traffic was not stopped outside of the traffic lights

Sample mid-afternoon weather at Ashland day of flights August 2018

During the Post-Construction flight AECOM had used onsite traffic control contractors. Pilot cars were again used to guide traffic through the data acquisition zones. The AECOM team, MDT inspectors and the traffic control personnel met prior to the start of each day to plan traffic control efforts. The pilot car traffic stops were setup to accommodate the UAS flights since the paving operations were shut down for the day. AECOM stopped the UAS in flight to prevent fly over of moving vehicles.

Weather conditions during the acquisition were difficult with rain earlier in the morning and then increased winds at the end of the day

During the day the entire project was flown prior to the winds becoming too strong to continue. However, conditions continue to change throughout the day providing windows of opportunities to fly.

GCPs were installed at 38 locations using coordinates from the fight plan to have the GCPs located in the flight overlaps to be located in the center of the overlap. As the targets were set, they were shot in with one RTK shot. The majority of the GCPs, 37 out of 38, consisted of a PK nail with a white painted cross and the edge of the pavement and one GCP utilized a panel on a new control point.

Data Processing

The AECOM UAS processing team was provided 3,340 raw images. From these images 698 images were determined as unnecessary (i.e. turn images or images outside AOI) leaving 2,246 images to be processed.

Metric	Ashland Corridor
Image Acquired/Images Processed	3,340/2,246
Image Sorting Time (Hours)	~2
Unsorted/Sorted Image Data Volume (GB)	10.6/8.3

Metric	Ashland Corridor
Image Radiometric Adjustments (Hours)	~1
Total Tie Point Processing (Hours)	~8
Total Tie Point Count	11.8M
Tie Point Count/Image	~5,200
Ground Control Selection (Hours)	~2.0
Dense Point Cloud Processing (Hours)	~48
Total Dense Point Cloud Count	453M
Auto filter Dense Point Cloud (Hours)	~10
Manual Dense Point Cloud Filtering (Hours)	~3

Coverage Analysis

Though there were a few skipped images, a review of the subset imagery suggested that coverage was complete when compared against the corridor AOI. This was further confirmed by the flight team uploading and pre-processing the imagery using DroneDeploy the evening after image acquisition. In the areas of skipped images the 80% overlap flight design addressed any stereo gap issues.

It was noted that the imagery on the eastern most end of the corridor did not include control points as control points A8004 and A8005 were set beyond the corridor AOI. Check point 9000 was also outside the AOI.

Tie Point Processing

The initial Tie Point point cloud contained 11.8M points. Tie Points are XYZ locations where identical matching points are detected on multiple overlapping images, spatially tying all adjacent images to each other creating a rigid network across the block. Tie Point generation is an automated process. As with any automated process less than ideal tie points are generated. Subsequently filtering process is performed within AgiSoft on the tie point cloud removing statistical outliers representing errant tie points, leaving ~5M tie points across the block, still averaging 2,225 ties points per image. The more numerous and accurate the tie points used in subsequent processing the better the AT solution, which in turn equates to more accurate products such as elevation models and orthomosaics.

Ground Control Selection

Thirty-six (36) ground control points were visible in the imagery. After the ground control was imported and the AT residuals meet expectations (less than one-third of a pixel) the process intensive Dense Point Cloud processing was executed.

Ashland Corridor Control (X = Ground Control Point, X = Check Point)

Dense Point Cloud Processing

A total of 453M dense point cloud points were generated requiring 48 hours of processing time. All points were unclassified (Class 0). Running the points through the AgiSoft classification process resulted in 370M points being classified as ground (Class 2).

Like the automated Tie Point generation above, a manual review of the bare earth points ensued. Manual editing of the auto-classified point cloud was performed in LP360. Incorrectly classified points, like those that may have been incorrectly classified as ground points were reclassified to Class 10. Conversely, bare earth points incorrectly classified as ground were manually reclassified Class 10.

Surface Model Accuracy Assessment

The Ashland Corridor point cloud data had an overall vertical RMSEz = 0.68’ when referencing the ground control and check point locations together.

RMSEz of the 36 ground control (GCP) alone is: 0.04’. RMSEz of the 31 check points (CP) alone is 0.94’. A tabular expression of the results are below.

Ground Control Point Results

Thirty-six ground control points returned an overall $RMSE_Z$ of 0.04’. Results of individual check points are listed below.

Target Point Name	X (ft)	Y (ft)	Z (ft)	Point Cloud Elevation (ft)	Difference (ft)
8000R	2867324	498511.8	3402.710	3402.67	-0.038
8003R	2864156	499557.8	3383.446	3383.43	-0.015
8008R	2863387	499955.6	3388.301	3388.30	0.003
8009R	2863328	499865.8	3387.892	3387.88	-0.007
8013R	2858927	501500.9	3335.276	3335.27	-0.007
A8002	2866056	499031.0	3389.636	3389.63	-0.003

Target Point Name	X (ft)	Y (ft)	Z (ft)	Point Cloud Elevation (ft)	Difference (ft)
A8003	2868203	498201.7	3422.452	3422.42	-0.028
A8006	2868858	497925.5	3443.068	3443.06	-0.004
A8007	2867335	498540.9	3402.828	3402.86	0.0296
A8011	2861865	501017.8	3343.708	3343.69	-0.022
A8012	2860072	501457.7	3338.077	3338.00	-0.075
A8013	2858929	501532.7	3335.428	3335.45	0.025
A8014	2856467	501700.9	3308.031	3308.02	-0.015
A8015	2854531	501461.2	3290.147	3290.13	-0.016
A8016	2852902	501153.3	3279.322	3279.26	-0.063
A8017	2852906	501123.2	3280.222	3280.24	0.014
A8018	2850533	500959.6	3263.245	3263.23	-0.019
A8019	2848749	500776.3	3251.020	3251.02	-2.36E-05
A8020	2847315	500696.5	3241.489	3241.38	-0.108
A8021	2847317	500665.6	3241.469	3241.49	0.020
A8022	2845246	500430.5	3228.242	3228.24	0.002
A8023	2843741	499936.1	3216.672	3216.64	-0.034
A8024	2842483	499543.1	3208.385	3208.29	-0.092
A8025	2842475	499573.2	3207.782	3207.83	0.043
A8026	2840313	499250.0	3192.127	3192.09	-0.032
A8027	2839003	499068.0	3184.065	3184.01	-0.052
A8028	2837449	498951.9	3173.566	3173.51	-0.052
A8029	2837452	498921.8	3173.573	3173.57	-0.007
A8030	2835738	498790.9	3182.683	3182.64	-0.041
A8031	2834394	498722.3	3204.898	3204.89	-0.009
A8032	2833422	498927.5	3207.793	3207.81	0.019
A8033	2833430	498956.5	3207.805	3207.78	-0.029

Target Point Name	X (ft)	Y (ft)	Z (ft)	Point Cloud Elevation (ft)	Difference (ft)
A8034	2832600	499128.1	3212.344	3212.32	-0.022
A8035	2831109	499098.0	3231.401	3231.39	-0.008
A8036	2830136	499066.7	3263.134	3263.07	-0.064
A8037	2830138	499032.0	3263.098	3263.13	0.033

GCP Vertical Congruency Summary		
36 Points	US Feet	Centimeters
$RMSE_z$	0.04	1.21
95% Confidence Level	0.08	2.37
Minimum	-0.11	-3.35
Maximum	0.04	1.22

Ashland Post-Construction Point Cloud Bare Earth GCP Vertical Congruency Results

Check Point Results

Thirty-one checkpoints returned an overall $RMSE_z$ of 0.94'. Results of individual check points are listed below.

Check Point Name	X (ft)	Y (ft)	Z (ft)	Point Cloud Elevation (ft)	Difference (ft)
CHK9013	2851782	501015.3	3271.226	3275.33	4.108
CHK9011	2855707	501641.2	3298.506	3300.12	1.610
CHK9014	2849497	500889.0	3254.072	3255.23	1.158
CHK9029	2844532	500248.2	3219.036	3219.79	0.751
CHK9026	2841061	499250.3	3196.658	3197.32	0.665
CHK9030	2844541	500215.9	3222.532	3223.17	0.641
CHK9027	2842793	499649.7	3210.224	3210.68	0.460
CHK9009	2859231	501455.7	3333.371	3333.81	0.440
CHK9018	2830463	499042.1	3253.815	3254.21	0.391
CHK9008	2861019	501376.7	3341.755	3342.06	0.308

Check Point Name	X (ft)	Y (ft)	Z (ft)	Point Cloud Elevation (ft)	Difference (ft)
CHK9017	2830143	499079.2	3261.812	3262.11	0.299
CHK9020	2832880	499040.1	3209.218	3209.48	0.265
CHK9023	2836050	498819.3	3173.727	3173.98	0.255
CHK9024	2838113	498963.2	3176.836	3177.05	0.216
CHK9005	2865028	499342.8	3377.553	3377.73	0.179
CHK9028	2842808	499617.4	3209.863	3210.04	0.172
CHK9022	2834767	498664.9	3199.933	3200.00	0.066
CHK9003	2867047	498673.1	3397.236	3397.26	0.026
CHK9025	2839561	499163.1	3186.318	3186.34	0.022
CHK9007	2862542	500600.4	3360.977	3360.94	-0.032
CHK9001	2868641	497993.7	3436.219	3436.18	-0.039
CHK9002	2867924	498313.0	3414.239	3414.03	-0.204
CHK9016	2846391	500622.9	3236.081	3235.86	-0.224
CHK9021	2833914	498844.0	3205.347	3205.10	-0.251
CHK9006	2863461	499946.2	3387.474	3387.17	-0.308
CHK9019	2831750	499183.3	3215.322	3214.97	-0.353
CHK9004	2866609	498786.9	3394.743	3394.38	-0.363
CHK9031	2846069	500544.9	3231.850	3231.47	-0.375
CHK9015	2847836	500688.5	3242.725	3242.08	-0.643
CHK9010	2857792	501614.6	3328.229	3327.21	-1.015
CHK9012	2853353	501236.1	3280.424	3278.94	-1.480

Vertical Accuracy Summary		
31 Points	**US Feet**	**Centimeters**
$RMSE_z$	0.94	26.65
95% Confidence Level	1.84	52.23
Minimum	-1.48	-45.11
Maximum	4.11	125.28

Ashland Post-Construction Point Cloud Bare Earth Checkpoint Vertical Result and Accuracy Summary

The GCP RMSEz is ~24X smaller than the CP RMSEz. Reviewing the elevation model in the areas of vertical CP deviation greater than 0.5' no issues were detected after defining and reviewing multiple terrain profiles.

Given the magnitude of the CP RMSE discrepancies, and the very successful GCP RMSE results, the Germantown UAS processing team requested the CPs of interest be re-occupied to ascertain if there was a survey issue. Each of the CPs having a delta of 0.5' vertically were resurveyed, the results of which were essentially identical to the original survey elevation values, thereby eliminating the CP survey as a source of the deviations.

Reviewing the imagery associated with each of the CPs of concern no major issues were identified. What was observed were instances of non-nadir imagery that did not differ significantly so from other areas where the vertical deviations we much smaller.

Given the above, AECOM can only surmise that the cause of the deviation is related to not incorporating additional control in the block. Traditional photogrammetry rule of thumb for corridor mapping is to have two horizontal and three to four vertical control points for every 5 stereo models. Given the high degree of overlap and the small footprint of UAS imagery duplicating traditional rules and photo:GCP ratios is unpractical, and cost prohibitive. To address this chasm the SfM algorithm relies upon the high degree of overlap as well as an exorbitant number of tie points to develop a rigid block model in lieu of a high density network of control points. However, bridging across numerous models without adequately dense and positioned control may distort the block in a manner that does not reflect the actual terrain. Corridor mapping magnifies these issues because of the linear nature of the AOI constraining the distribution of the control points.

Exploring the above further, a review of the CP vertical deviation as it relates to the distance to the closest GCP was performed to determine if there was a relationship. The results of that analysis are presented tabularly and graphically below. CPs of greatest interest are denoted with red text.

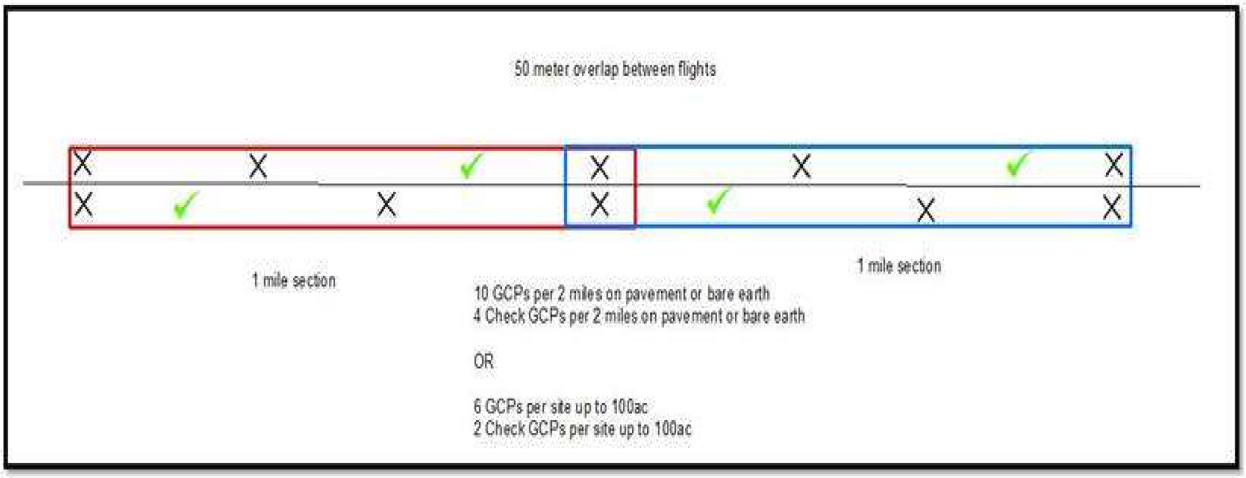
Yellow highlight cells indicate instances where the 1050' threshold between the nearest GCP & CP is exceeded. To assist graph preparation, brown cells indicate instances where a combined distance of 1700' is exceeded where one of the CPs exceed the 1050' threshold.

POINT	CP/ Point Cloud Difference (ft)	Closest GCP West (ft)	Closest GCP East (ft)	Combined GCP Distance Difference (ft)
CHK9013	4.10823	1250	1250	2500

POINT	CP/ Point Cloud Difference (ft)	Closest GCP West (ft)	Closest GCP East (ft)	Combined GCP Distance Difference (ft)
CHK9011	1.6101	1200	762	1962
CHK9014	1.15799	756	1037	1793
CHK9029	0.751106	849	736	1585
CHK9026	0.665011	747	1453	2200
CHK9030	0.64158	846	736	1582
CHK9027	0.460772	326	990	1316
CHK9009	0.440564	307	841	1148
CHK9018	0.391562	325	647	972
CHK9008	0.308928	950	918	1868
CHK9017	0.299723	14	965	979
CHK9020	0.265405	293	554	847
CHK9023	0.25519	312	1405	1717
CHK9024	0.216917	662	896	1558
CHK9005	0.17938	897	1074	1971
CHK9028	0.172651	332	986	1318
CHK9022	0.066871	377	979	1356
CHK9003	0.026759	1053	316	1369
CHK9025	0.022123	565	757	1322
CHK9007	-0.03202	796	1062	1858
CHK9001	-0.03925	485	226	711
CHK9002	-0.20425	632	299	931
CHK9016	-0.22444	1161	927	2088
CHK9021	-0.25114	497	495	992
CHK9006	-0.30802	74	796	870
CHK9019	-0.35374	647	851	1498
CHK9004	-0.36321	604	766	1370

POINT	CP/ Point Cloud Difference (ft)	Closest GCP West (ft)	Closest GCP East (ft)	Combined GCP Distance Difference (ft)
CHK9031	-0.37547	830	1255	2085
CHK9015	-0.64344	518	917	1435
CHK9010	-1.01574	1327	1139	2466
CHK9012	-1.48052	457	1199	1656
		GT 1050	GT 1050	GT 1700

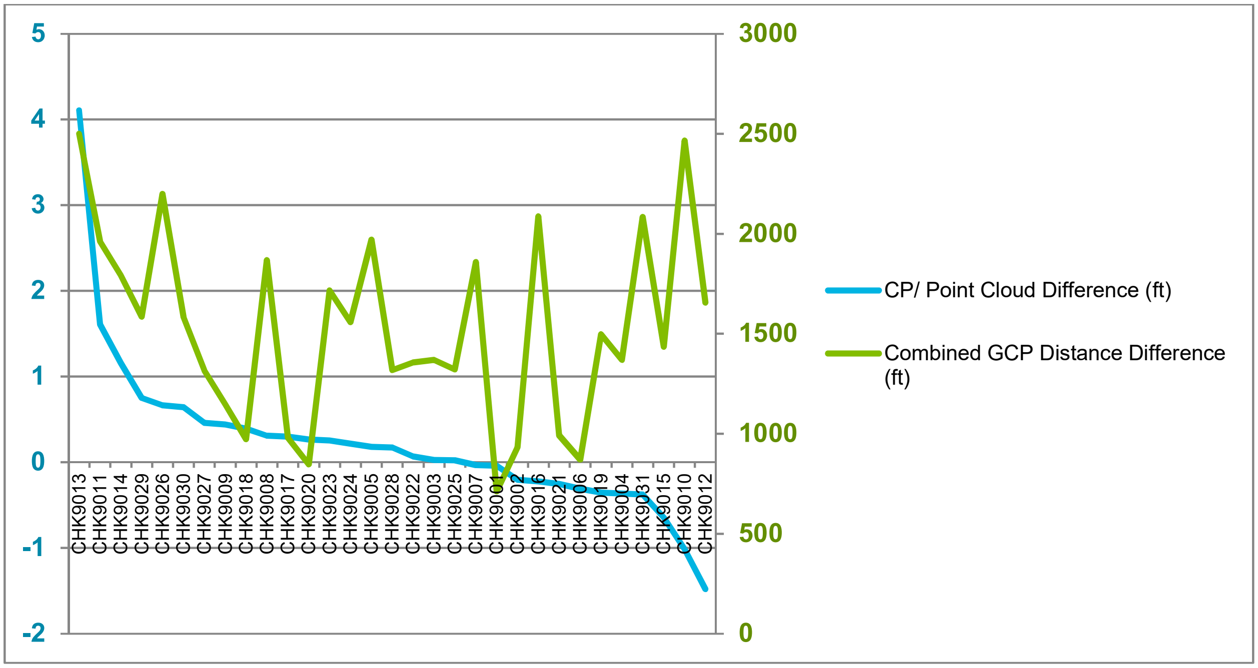
The initial project control design, presented previously and again below, was to have 5 GCPs and 2 CPs per 1 mile section. A one mile section was the maximum distance a single mission could be executed and still maintain visual sight of the drone where the PIC was setup in the middle of the one mile section.



Idealized Control Design

Subdividing the one mile section into 5 subsections, a GCP pair at the end of each section was interspersed with alternating instances of two single GCPs, and two single CPs every ~1050'.

Through this analysis it was anticipated that as the CP-GCP distance exceeded a yet to be defined threshold the CP vertical discrepancy would be directly correlated with that distance. However, while some correlation was found overall where increasing CP-GCP distance resulted in higher CP vertical deviations, which is demonstrated in the graph below, there were instances within the dataset where this is not the case - see CHK9023, CHK9005, CHK9003, CHK9007 in the table above.



GCP-CP distance / Vertical Accuracy Relationship Analysis

Unfortunately, the CPs were not photo-identifiable and therefore could not be used as a control point in the AT. Having these as GCPs would permit the user to tighten the block in these areas.

The obvious take away is the control design may need to be densified, perhaps in a manner that each GCP does not exceed 750'

Volumetric Calculations

The Post-construction surface was compared to the Pre-Construction surface, the point cloud files were reduced to a 1 foot spacing and imported into MicroStation. The point files were then converted to DTMs using GeoPAK. The horizontal and vertical alignment data along with the with the typical roadway sections were inserted into MicroStation using the data presented in the project construction plans to create the finished grade design surface. The Post-Construction surface was compared to both the proposed finished grade design and Pre-construction surface to analyze the volumetric date between the two surfaces using a cut/fill factor of 1.0. Results are included in Appendix C. The volumes were calculated using the cross section end area method to be able to compare to the construction staking notes.

For Mission Interchange the DTMs were compared for the portion of the project starting at station 228+00 and going to station 238+00.Cross sections were cut from the Post-construction surface and Pre-construction surface to compare the volumes to the planned quantities that were calculated from the proposed finish grade design and the pre-construction surface . The volume of asphalt and crushed aggregate course was removed from the final quantities. The total volume difference between the surfaces are listed below:

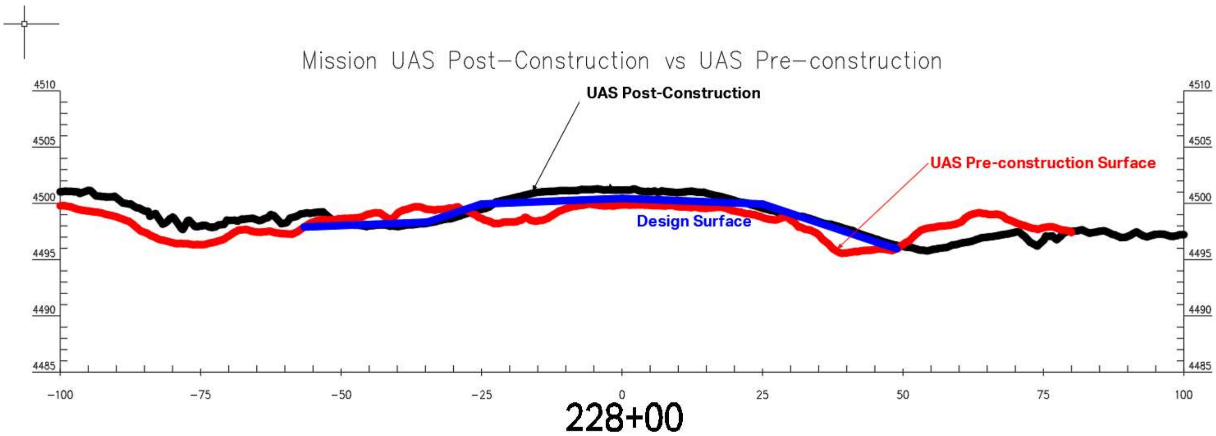
- Proposed Finish Grade Design Surface compared to UAS Pre-Construction Surface :
  - Total Cut: 3 cy

- Total Fill: 4,661 cy

– UAS Pre-Construction Surface compared to Post-Construction Surface:

- Total Cut: 7 cy

– Total Fill: 9293cy



Mission Interchange Volume Comparisons

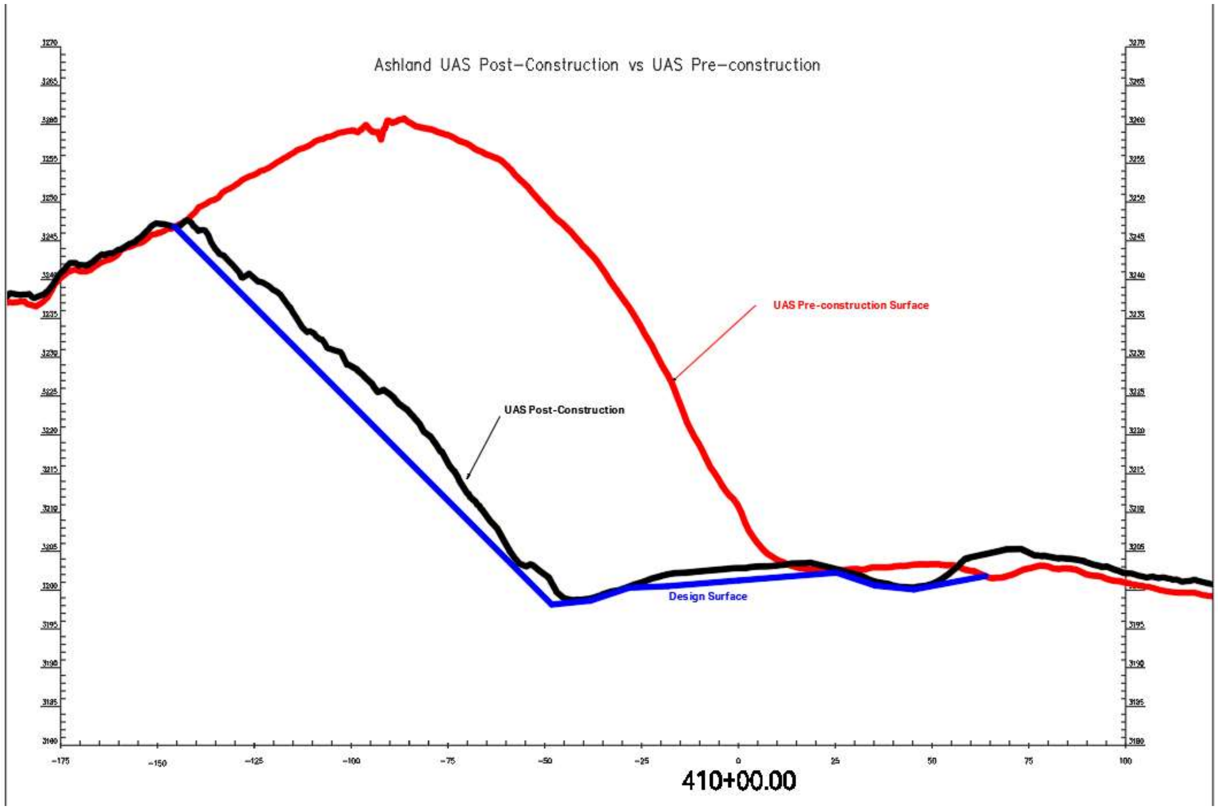
For Ashland, the DTMs were compared for the portion of the project starting at station 405+00 and going to the end of the project at station 415+19. Cross sections were cut from the Post-construction surface and Pre-construction surface to compare the volumes to the planned quantities that were calculated from the original slope staking notes and cross sections. The volume of asphalt, cement treated base and crushed aggregate course was removed from the final quantities The total volume difference between the surfaces are listed below:

– Proposed Finish Grade Design Surface compared to slope staked Pre-construction Surface cross sections:

- Total Cut: 51,792 cy
- Total Fill: 4,347 cy

– UAS Pre-Construction Surface compared to Post-Construction Surface:

- Total Cut: 43,963 cy
- Total Fill: 5,415 cy



Ashland Interchange Volume Comparisons

The current processes used by MDT to calculate the volume of roadway cut and fill material is computed by using the average end area method, comparing the original ground cross-sections elevations and design elevations that are on compiled on the staking notes. The staking notes consist of cross sections that run on 100 ft or 50ft intervals and have the design template stations offsets and elevation along the existing ground station offsets and elevations. Each end of a cross section will end in a catch point that equals both the template and existing ground elevation. The existing ground elevations are collected during the staking process. The staking notes are entered into software that computes the quantity of cut and fill of the project. This quantity is used for contract payment purposes.

The final survey is spot checked by MDT to confirm the project was built to the design surface template elevations. The roadway surfaces are checked multiple times including the final elevations of the subgrade, the crushed aggregate elevations and the depth of asphalt.

As shown in the volume comparison cross sections, the proposed design surface and the Post-Construction surface generally follow each other, especially when along the driving surface of the roadway. The largest differences tend to appear in the slopes of the roadway where additional fill or cut may take place depending on the cross section. These differences could be attributed to flight conditions, angle of the sensor and vegetation.

7. Conclusions

Lessons Learned

Pre-Construction

UAS Flight Planning

Expectedly, UAS flight planning software continues to evolve and is still not as sophisticated as manned flight planning software.

Shortcomings observed with the existing UAS flight planning systems are bulleted below.

- The ability to upload and export existing AOIs and define survey control points in the flight planning software would be very beneficial software features. Some UAS planning software permit this, yet most do not, thus limiting the ability to share this information with project participants.
- Flight planning proved to be more efficient and effective using a desktop application rather than a tablet application. Advantages of a desktop solution, which AECOM prefers, allows for more detailed planning, is easier to define and manipulate flight limits, and be more precise particularly for large projects when even a small bump in or out of the survey area can change the data collection from either getting too much resulting in increased field time and data processing, or not enough resulting in missing a portion of the desired objective area.

Not associated with the flight planning software, but a critical flight planning element is satisfying the take-off and landing requirements for fixed wing UAS.

FAA Waiver Application

The biggest aspect for dealing with FAA airspace request is to start early. The FAA is continuing to modify the process for requesting airspace authorizations and requires a very proactive engagement by pilots to stay current on the process and tools used for making requests.

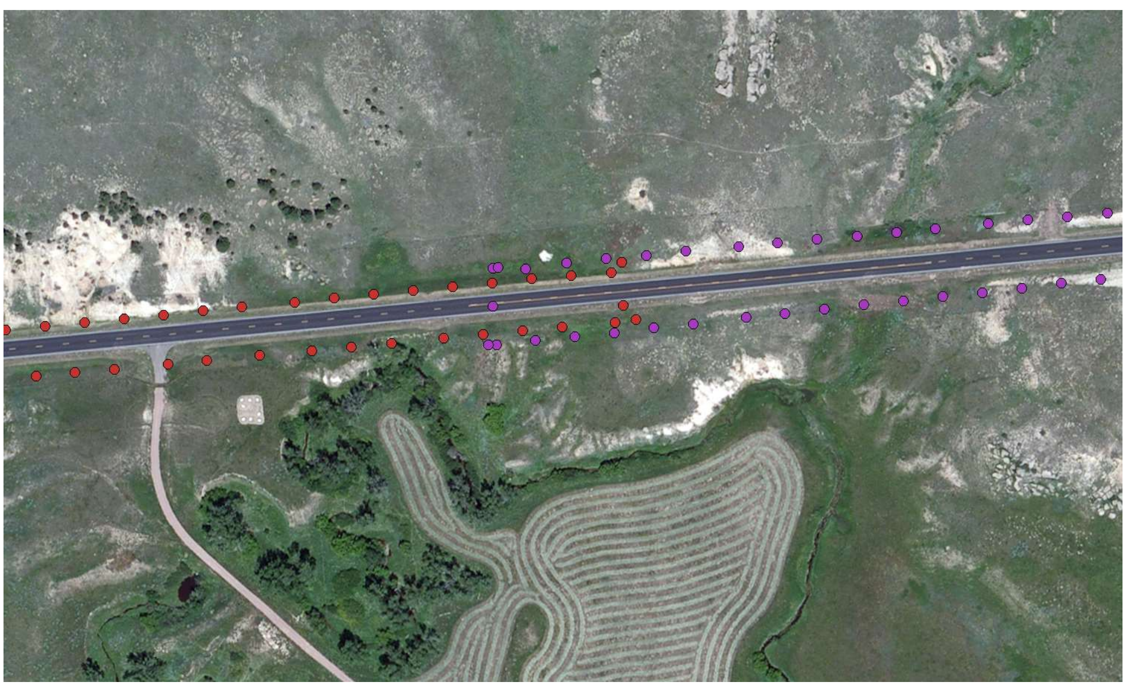
Ground Control and Aerial Survey Field Checks

Very close coordination with the survey, data processing and pilot teams is essential and must be coordinated prior to arriving in the field. Changes must be coordinated if there are any adjustments that deviate from the plan after arriving in the field, as minor changes can have a major impact to a survey project that can create problems in delivering an accurate final product, especially when conducting long linear types of surveys as indicated in the report.

Flight Mission Overlap

The overlap distance between flight missions on corridor projects can have a meaningful impact on the ability to join together separate missions into a seamless dataset. The initial design called for a 164 feet overlap (50 meters) between flight missions. However, in several instances the overlap between flight missions did not meet the initial design resulting in data processing issues where missions intersected. Using SfM software it is also critical that the altitude of the sensor be very similar to overlapping flights so there are minimal scale differences in the imagery, see Altitude Variation section ahead.

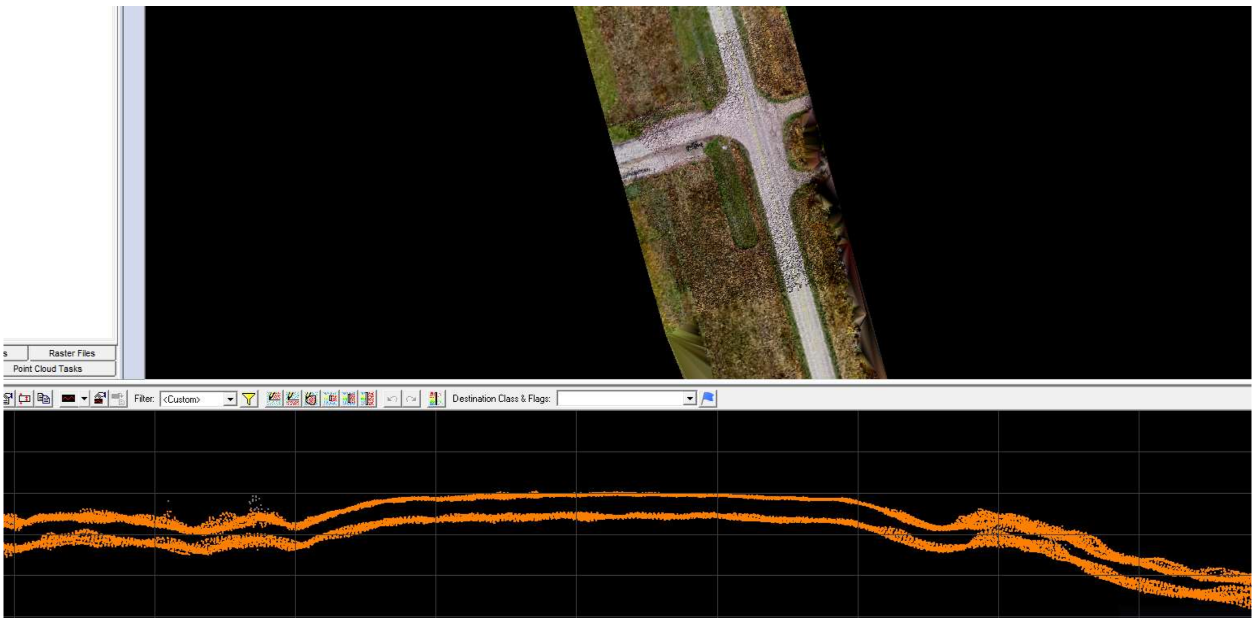
Narrow overlap between missions



Adequate overlap between missions

Altitude Variation

Changes in UAS altitude can occur for any number of reasons from flight planning issues, poor quality elevation data referenced by the planning software, airframe issues, or environmental conditions. The impact on SfM photogrammetrically derived surfaces can be quite significant when this occurs. This most commonly manifests itself when two flight lines have altitude variations, or individual photos having gross perspective orientations similar to low oblique imagery. Images showing the potential impact of altitude variation can be found below.



Surface difference at flight mission overlap associated with altitude variation

Radiometric Consistency

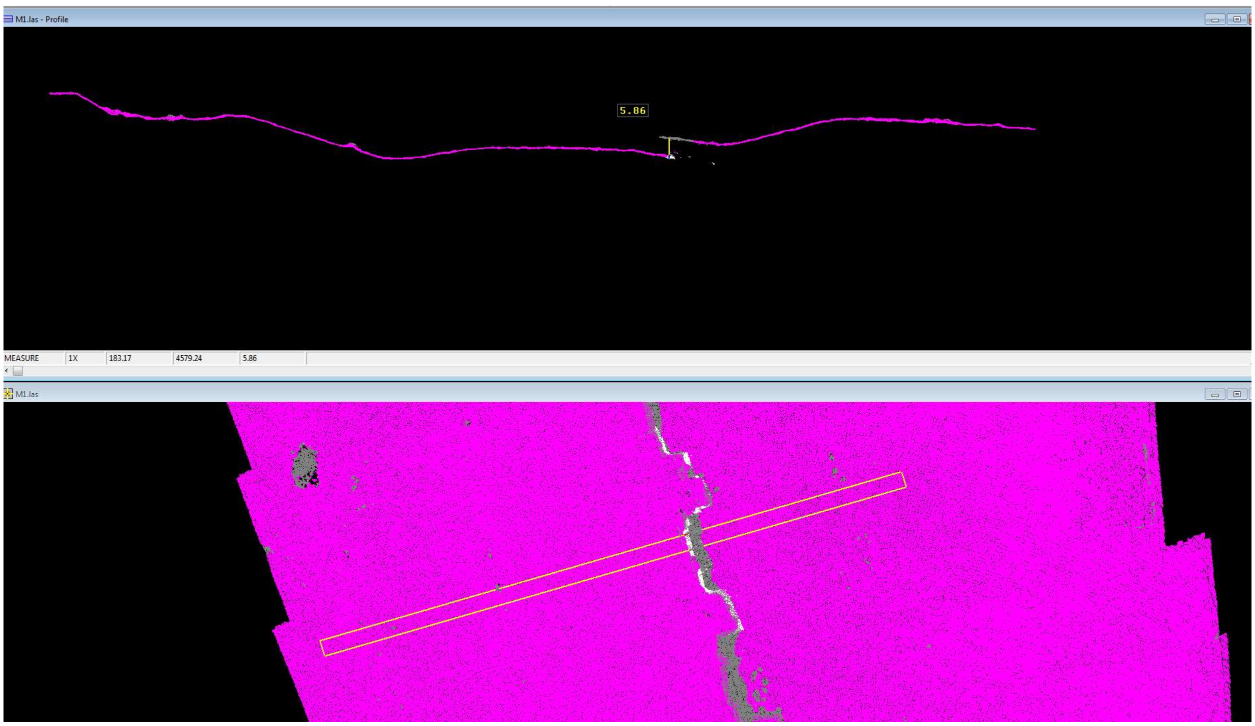
SfM software performs best when the radiometry within the scene is similar, i.e. shadows cast are similar in color and direction. Dramatically different radiometries of adjacent flight lines can have a very deleterious effect on image matching, thereby impacting surface generation. AECOM suggest flights to be performed within the standard 10AM to 2 PM window.

Weather

Strong winds delayed multiple flights and required time consuming adjustment to flight plans in the field. In some instances, winds forced AECOM to curtail flights to compensate for finite battery life, as was the case for the SkyCatch EVO platform in the Pre-Construction Ashland Corridor.

Crosswinds

The large fixed wing NOVA F7200 system proved more stable primarily due to higher groundspeeds (flying faster) and it's imagery did not exhibit quality issues associated to crosswinds most likely attributed to higher resolution sensor. As the fixed wing platform with its larger wing surface exhibited a great deal of wing rocking during its flights while correcting for wind gusts. The fixed wing platform does have the ability to crab into the wind meaning the nose of the aircraft is off centerline while the sensor of the aircraft is more centerline to planned flight line and helps minimize the cross-wind effect. However, the fixed wing systems require much more time to mission plan, set up, make logistical moves through a site and require careful consideration as part of the flight operations. Not allocating the appropriate time to address these characteristics can result in dissatisfaction with respect to data capture quality, particularly if operated in any environment other than very sparsely populated rural areas regardless of the wind conditions. The fixed wing advantage is in the ability to cover much larger survey areas in a shorter amount of time. In comparison the smaller quad copter system proved more efficient in the ability to cover the area, working with traffic control much more effortlessly resulting in less time to actually collect data for the sites. The much smaller EVO 3 quad-copter had noticeable wind related impacts. Smaller VTOL non-gimbaled UAVs are more negatively influenced by varying wind conditions in particular crosswinds. Such as when the EVO airframe is making adjustments to counter crosswinds the direction of the fixed sensor may shift away from nadir. This effect is not as noticeable with gimbaled sensors. When an impacted flight line occurs next to a flight line that did not have crosswinds the SfM software can struggle to create a smooth continuous surface, especially on a corridor project area as there are far fewer images of the same ground location. The below surface elevation shift is attributable to the crosswind impact.



Surface shift between crosswind impacted flight line and none impacted flight line
Top - profile view
Bottom – Nadir view

Impact of flying in high winds:

– **Battery life** - UAS use more power to maintain stability in winds, resulting in shorter duration flights. Large projects require ability to charge, or have more batteries on hand, in order to complete the survey. Charging can take over an hour for an individual battery. Incorporating a small generator for field operations in addition to having multiple sets of batteries is a consideration for a project of any size.

- **Loss of control** – Quad copter landings are more prone to the aircraft tipping over or not landing in the designated spot. Fixed wing systems (worst case going from a strong wind to no wind) result in a much longer landing requirement.
- Most importantly, poor data output. Wind direction and velocity can create a loss of data quality. It is advisable to restrict operations when wind velocity is in excess of 15 MPH for smaller light weight UAV's like the types used on this project. Doing so provides the maximum success from a safety and data quality objectives. If operations are decided to continue during periods of winds higher than 15 MPH it is suggested to consider a head-wind or tail-wind flight profile to minimize banking during the data collection. Be mindful if the camera shutter speed is sufficient to keep up with the increased groundspeed during the tail-wind portion of the flight lines so as create areas having no coverage or generate blurry images.
- Also, be aware, winds general increase with increasing altitude. Winds 100 feet above the ground can be much stronger than experienced on the ground.

Traffic Controls

During the Pre-Construction survey, flaggers were used for traffic control causing excessive traffic delays while traffic was stopped for the entire duration of the flights. Traffic control process was modified, with permission from the PIC, to hold traffic during the take-off and landing and let traffic flow while UAS was performing data acquisition after a change in the flight design detailed ahead, significantly reducing traffic hold time.

AECOM observed traffic did not obey the reduced speed limits through both sites during the Pre-Construction surveys; this was likely due to the perceived lack of construction activity along the highway.

The use of pilot cars versus flaggers greatly reduced the amount of time traffic is stopped. Pilot cars allow for more flexibility during UAS take-off and landings as well as setting GCPs.

Communication with the traffic control staff is critical in starting and stopping traffic in a timely manner. It is recommended that radios that are used to communicate with the traffic control personnel be tested before flights, as the radio can lose signal due to range and terrain.

The most efficient method for flying linear types of surveys is to fly parallel and not directly over the roadways this provided a much lower impact to vehicle traffic. Initially the team managed flights by holding traffic at either end of the project site during take-off and landing phases using flaggers. Once the UAS was safely airborne vehicle traffic was allowed to pass and then once the aircraft entered its last leg of the mission vehicle traffic was stopped at the far end of the project site. Using this method resulted in some disruption of traffic as aircraft was recovered. In order to reduce the overall effect on the traffic flow in the project area it was coordinated with the traffic control team using pilot cars for subsequent flight operations on later deployments to keep traffic moving through the survey and construction sites. The UAS team was able to manage take-off and landings so as to avoid having to over-fly moving traffic. The UAS team would provide a call to the pilot car, have them momentarily stop to allow the UAS to pass overhead as required then allow the pilot car to resume moving traffic through the site. This operational procedure allowed for very effective traffic movement while remaining compliant with regulations. This process proved much more efficient in terms of time required to complete the various flight sections or segments of the road ways with little to impact to UAS operations. The downside to this procedure is where traffic happened to be stopped at a location of a GCP obscuring it from being captured as the UAS passed over head resulting in a negative impact to data processing.

Ground Control Targets

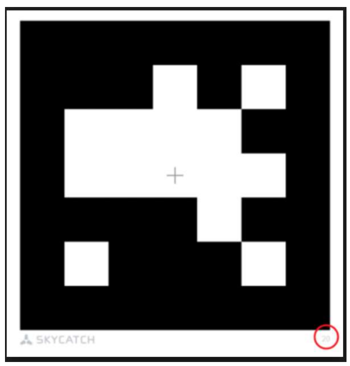
There were quite a number of lessons learned regarding ground control and check point targeting activities. These lessons relate to target design, placement, and communication.

During data acquisition there were many activities occurring simultaneously, i.e. traffic controls, UAS flights, and control targeting. This situation caused a few of the areas to be flown without the control being set, resulting is unavailable control for data processing. Additionally, there were several control points set within the travelled way that were obscured by traffic during the acquisition. GCP and CPs should be set outside the travelled way whenever possible.

Target Design

There were a variety of ground control and check point target representations used during the Mission Interchange and Ashland Corridor data capture efforts. Some worked better than others.

For instance, the SkyCatch target design is similar to that of a QR code, example below. Each target had a different design that was recognized by SkyCatch's proprietary automated in-house processing workflow. Each unique pattern was associated with a Point ID, X, Y, Z value. The design of the target proved difficult to ascertain with 100% confidence the surveyed location within the target. This was particularly true on non-nadir images. The SkyCatch targets do add time to the processing effort as extra care must be taken when selecting the control location.



More traditionally shaped ground control targets were much easier to interpret in the imagery and determine the center point. AECOM also recommends never using an automated mapping solution for high accuracy mapping data.

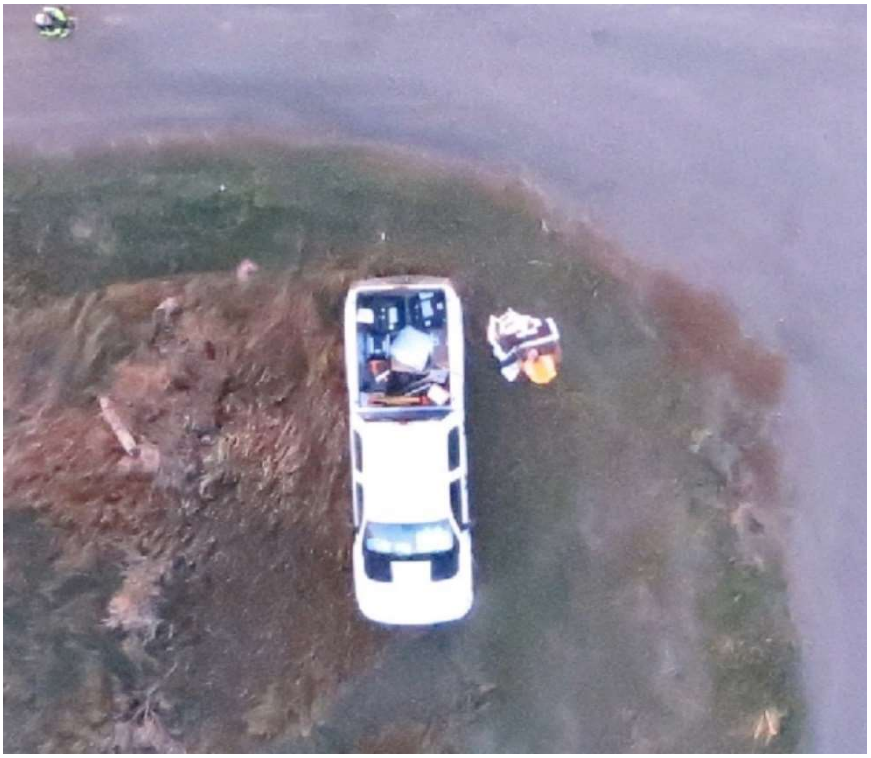
SkyCatch panel on left and painted panel on right

Target Placement and Condition

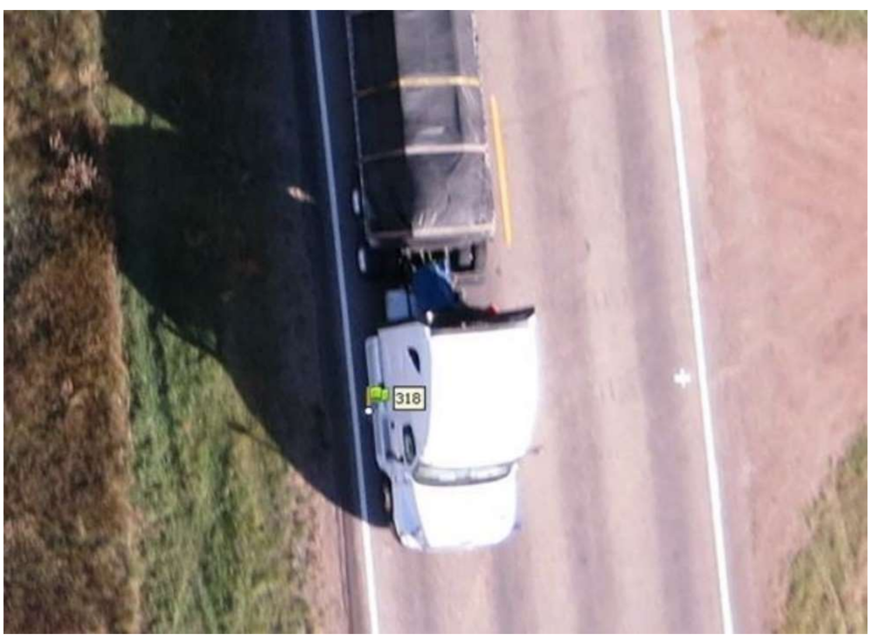
All control points should be visible in numerous images, not just a few, thus control points placed near the edge of a boundary may not be as useful if there are only a few images with visibility. It was observed that not all targets had ideal placement in relation to the flight lines and mission critical overlaps which could be alleviated if the UAS flight planning software was more sophisticated from this perspective. Areas to be aware of for GCP and CP placement include: areas of mission image overlap, areas of corridor termini, and within the corridor boundary

Target had blown over on itself rendering the target unusable

Ensure targets are set on bare earth. Targets should not be set in or on grass unless no other alternative is available. Ensure control is set prior to flights.



UAS flown over prior to setting the target panel



Control point obscured by stopped vehicle

Ground control points and checkpoints were a designed component of the field work effort. However, due to the various issues noted above regarding ground control points or checkpoints not visible in the imagery, points initially identified as checkpoints had to be reclassified as ground control points to generate a satisfactory AT solution, thereby permitting the development of high-quality surface data to permit volumetric analysis.

Checkpoints that were not set, set outside the AOI, set but not painted, or were obscured could not be used. A lesson learned from this result is there must be communication prior to flight that the targets are correctly set and a detailed field check performed of the imagery for targets post flight.

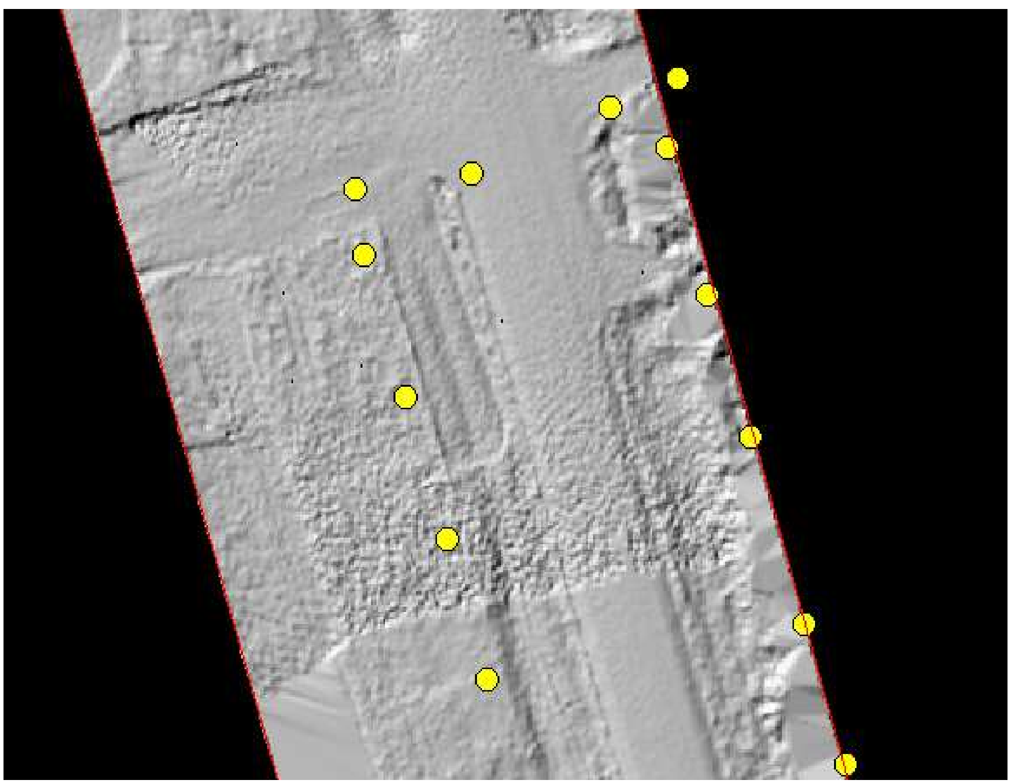
Initial and Actual/Refined Photocenter Location and Coordinates Determination

Initial GPS coordinates of each exposure is stored in the image header within the EXIF (Exchangeable Image File Format) information. As these are coordinates obtained from consumer-grade on-board GPS unit the accuracy of these values is low, generally within a sphere of uncertainty of +/- 10 - 20 feet, similar in accuracy to a smartphone. From a processing perspective this information is used by the UAS processing software to reference the imagery relative to each other and where they reside in the world. After the inclusion of high accuracy ground control and subsequent to performing the AT process the actual photocenter location is calculated to a high degree of accuracy, which can be discerned by the results of how well the ground control aligns with the surface model results. Design of UAS systems are far less sophisticated than manned image sensors where midpoint exposure is a concern when leveraging ABGPS. Midpoint exposure lag effects are a function of aircraft speed. UAS platforms capture imagery as much as 10X slower than a manned system.

Sensor Image Quality

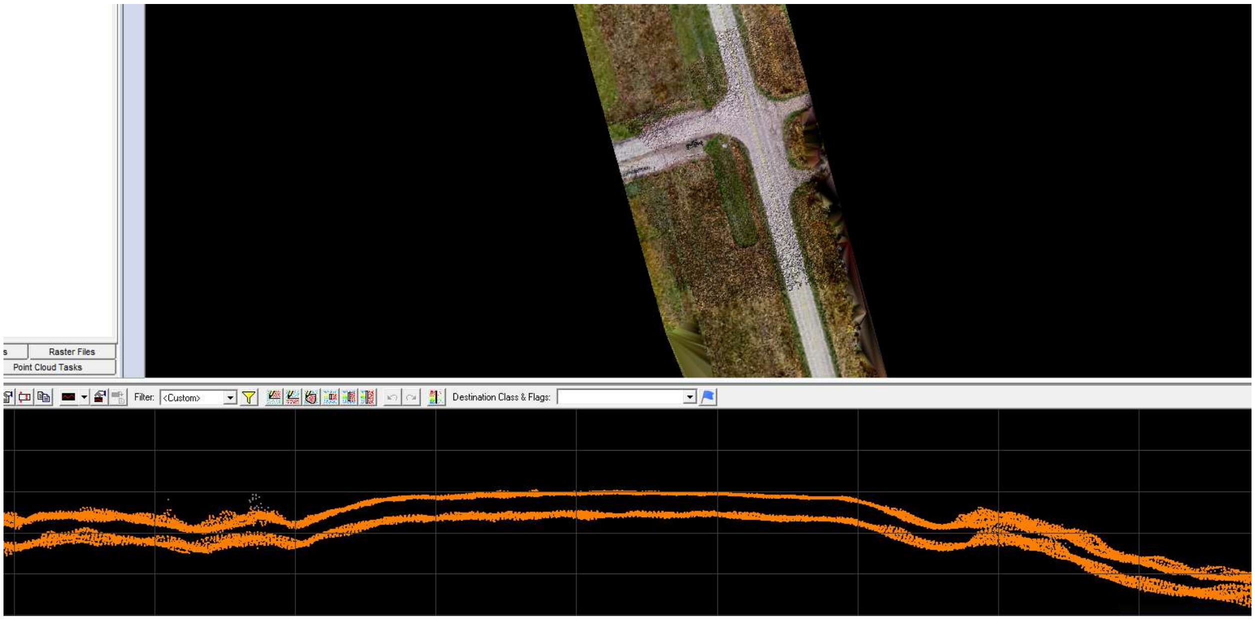
When using a UAS to produce orthophotography and surface data the final products are only as good as the worst image. Crisp imagery is critical to the overall success of the data processing. During this project it was observed that the EVO 3 system had difficulty maintaining a crisp image, likely a function of flight stability due to wind and lack of a gimballed sensor. AECOM removed many images based on quality, but had to utilize some lesser quality images to ensure there were no data gaps. These images often had more blur and radiometric variation then were desired. SfM processing is using image processing and photogrammetry to derive surface data. Image blur or poor quality imagery greatly impacts surface quality and accuracy results. AECOM attributes many reported surface and vertical accuracy anomalies to poor image quality.

Example of poor image quality over a control panel



Surface variation at an overlap location attributed to poor image quality and variable scale example

It is possible to overcome some surface issues caused by the image quality; however, it adds a great deal of manual time to the data processing effort. In the below images the issue was addressed by trimming errant perimeter points and extracting the lowest (or average or highest) points within a grid.



Surface difference at flight mission overlap

Corrected overlap

Camera (lens) Calibration

The vast majority of UAS camera systems are non-metric consumer grade cameras constructed using materials that not exceptionally stable and optical components made from high quality plastics or low-grade glass. As such the lens geometry, radiometry, clarity, and repeatability of these sensors is not high. Those that are familiar with imagery acquired by million dollar metric sensors from Zeiss, Wild, Leica, Vexcel, etc can appreciate these shortcomings.

As noted, UAS cameras are non-metric. As part of the AT process camera calibration information that determines and subsequently corrects distortion associated with lens geometry imperfections and light transmittance characteristics of the lens must be provided. UAS camera calibration information can be acquired via two methods. The first is performing a calibration using calibration grid and lens calibration software such as Agisoft Lens in an office environment prior to, or immediately after, image capture. Calibration information is stored in a database and accessed as needed. This is the least common, more accurate, and expensive method. The method typically employed is a self-calibration that is performed internally by the UAS processing software as part of the initial data processing. The self-calibration approach was employed for each of the corridor AOIs.

Intermediate-Construction

Traffic Control

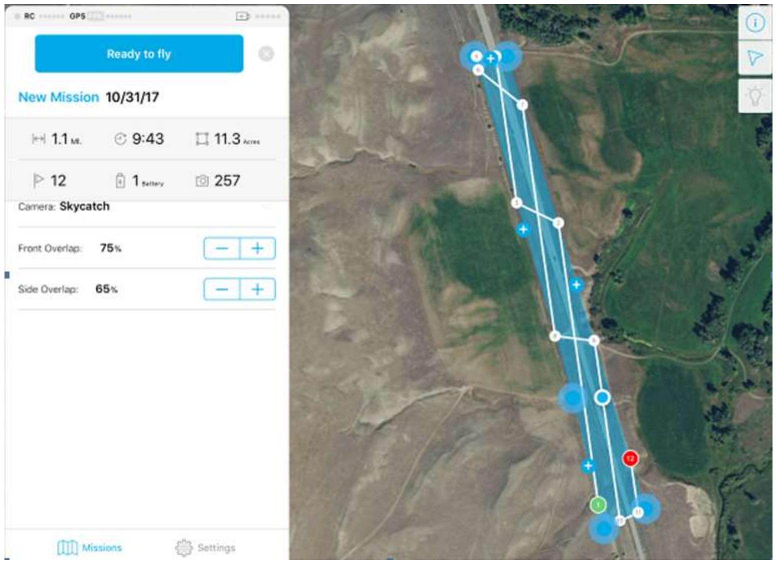
The use of pilot cars vs. flaggers greatly reduced the amount of time traffic is stopped. Pilot cars allow for more flexibility during UAS take-off and landings, as well and setting GCPs.

Data Acquisition

During flights for both sites, the EVO 3 was attempting to communicate via cellular network during take-off. In the take-off areas of the project with poor mobile service, the attempt to communicate with the cellular network would cause the EVO 3 to not initialize, preventing take-off. This was corrected by moving to an area with good cellular service and rebooting the EVO 3, then moving back to the original take-off zone. This was not encountered during the Pre-Construction surveys and is likely a software update causing the issue.

Another item that was encountered in the Intermediate-Construction phase that was different than the Pre-Construction phase was a software update caused the flight planning software to capture twice as many images for the same area. This additional data impacted flight times and data processing times. Additionally, the software now planned zig-zag flightlines where in the past linear flight lines were designed. Zig-zag patterns were not optimal for data acquisition or data processing.

Screenshot of a portion of the EVO 3 flight plan for Ashland



Screenshot of a portion of the EVO 3 flight plan for Mission

Ground Control Points

AECOM found many of the Pre-Construction project control points to be disturbed or removed during construction activities and many of the remaining control points were occupied by construction personnel or equipment. It is invaluable to be prepared and ready to set additional control points to get the recommended GCP coverage.

Data Processing

The imagery and survey work completed during the Intermediate-Construction task varied very little from the project design resulting in very smooth data processing.

Post-Construction

Weather

Weather for the Post-Construction flight at Mission Interchange was hampered by heavy winds and precipitation. Flexibility with respect to flight window is key when flying in the Spring and Fall months due to uncertainty in the weather. While the southernmost mile was not acquired due to snow accumulating on the ground, mid corridor flights were also affected by falling precipitation and high winds. Some of these flights were also deemed questionable to unusable. The northernmost to the mid-corridor sections were successfully processed.

Weather at Ashland caused interruptions to flight operations due to high winds and rain showers requiring some starts and stops but was manageable in terms of being able to effectively accomplish the intended data capture. Notably as the team drove from Billings to the Ashland site they encountered heavy down pours and very gusty winds from a fast moving storm front that was passing through the area. The weather phenomena was monitored very closely and appeared to be breaking up as it moved through Ashland. However, very wet soggy conditions were encountered at the site as well as some intermittent rain and wind events popping up through the day.

Control Targets

During the construction phase, a majority of the preset control has been damaged or removed. Setting GCPs on the shoulder of the asphalt using a mag nail and white cross reduced the amount time to setup targets and to tie in the new GCPs to the existing control network. During the final flight, there was a small section of roadway that was not paved on the eastern side of the project, five of targets were placed on the first layer of asphalt and were consequently paved over prior to the flight.

No checkpoints were available to be utilized to perform an independent check of the Mission Interchange.

Numerous checkpoints were surveyed for the Ashland Corridor, however these points were not marked and therefore not photo identifiable in the imagery preventing them from becoming candidate GCPs to tighten up the terrain accuracy.

8. Summary

UAS technology is being embraced globally. Billions of venture capitalist dollars are being allocated to race to understand and reap the rewards of this technology. Industries of all types, as well as government entities at every level, foresee the value and benefits this technology can, and will offer. Because of the rapid advancement and the low cost to innovate, product life cycles are incredibly short. Users are still very much in a period of learning how to best apply the technology, and making many mistakes along the way to enlightenment.

As with every new technology there are those that may have promised too much, or chased a niche market that did not meet expectations. Hundreds of firms, some quite large, have dissolved for one reason or another. Some firms have been acquired by larger firms for pennies on the dollar, but make no mistake UAS, or “drones”, are here to stay. This is no better exemplified by the lobbying efforts large industry are directing toward the FAA to devise and expedite an increasingly frictionless solution to allow UAS technology into the National Air Space. Drones are here to stay, and their growth is only beginning.

Distilling the information provided in this report regarding a technology that is evolving at a pace not seen before into a brief summary is challenging. But, there are fundamental characteristics that should be considered when employing UAS technology.

Flight planning software

There are a multitude of flight planning solutions available as apps and software installations. These packages are evolving, and disappearing, at a stunning rate. Flight planning software should be able to import AOIs as a KML or similar file, permit the user to modify, or buffer, the AOI easily, and ultimately export the AOI as a common spatial file format. Moreover, flightlines should be efficient, linear, and the altitude be determined referencing high quality terrain data. Aided by the presence of the flightlines, control points should be able to be strategically placed and exported.

As a general note, software tools are changing as rapidly as the physical UAS platforms and are a key component to successful operations. Some of the planning tools are proprietary to the UAS and can be limiting depending on the area flights are being conducted and the type of survey being flown. Some of the better software tools come from foreign sources and have very robust capabilities but are difficult to learn and may not always be compatible with the UAS platform being used to collect the data. It takes dedicated effort to stay on top of the latest trends, systems, and tools. The best advice is to keep up with system and firmware updates for each of the tools being used when it comes to conducting UAS surveys.

Flight Execution

Overall flight execution went very smoothly. Time required to reposition traffic control and pilot car signage impacted data collection timing but proved manageable due to some delays associated with weather moving through the area. Bottom-line, flight operations can get ahead of the rest of the team and requires coordination if there are opportunities to help other team members in accomplishing survey actions or assist in relocating traffic control team equipment.

Survey Execution

The survey of the GCPs was performed using standard industry equipment and techniques. The main contributing factor to which equipment and technique is utilized is based on the project required RMSE. The double-tie method outline in the MDT Survey Manual was sufficient to meet the accuracy requirements of this project. It is recommended the GCPs are surveyed in a timely matter to avoid being obscured by traffic or disturbed/destroyed by construction equipment and traffic.

UAS Platforms

Though there are hybrid versions, there are basically two UAS platforms types, either copter like, or fixed wing. Each have their intrinsic pros and cons.

VTOL (vertical Take-Off and Land) copter types offer a great deal of flexibility, in particularly as it relates to take-off and landing, and function well in small, tight areas, and are therefore ideal for inspection work types. VTOL platforms are generally cheaper than fixed wing platforms and typically have a gimballed sensor, the value of which has been documented many times in the report.

Fixed wing solutions are generally more expensive, but can stay aloft for longer periods of time permitting greater data collection. Fixed wing platforms are more stable in strong and/or variable wind scenarios. However, for aerodynamic reasons these platforms generally do not have a gimbaled sensor. These platforms are well suited to long linear projects like those a DOT would perform. A principal consideration of owning a fixed wing platform is accommodating for launching and recovery activities. Sometimes landings can be quite rough and damage either the airframe and/or the sensor load. Logistically, fixed wing systems require much more support are very finicky in trying to get airborne and should be allowed as much time as possible to sort through technical challenges. Additionally, when it comes to gaining FAA airspace approvals a fixed wing system may prove impractical for certain projects. Fixed wing systems preform best when operated at maximum flight altitudes of 400 ft AGL and may not be available for certain airspace requirements. Outlook going forward, as the FAA is able to safely design an airspace structure that incorporates BLOS as a common practice fixed wing platforms will eventually play a more significant role in the UAS arena. Until then VTOL platforms will continue to dominate in this type of work and outnumber fixed wing systems significantly. One leading trend is the development of a system that transitions from a VTOL for takeoff and landing to a conventional fixed wing for forward flight. As batteries and payload capability increase the current advantage a fixed wing system has is fading rapidly. Many of the original manufacturers of fixed wing platforms have completely stopped producing these systems and adopted a VTOL platform for conducting projects to even using VTOL platforms in BLOS types of operations which AECOM has demonstrated in Alaska.

Sensors

As noted in the camera calibration comments, the sensors drones employ are of poor quality compared to traditional mapping cameras. Higher quality sensors are those that have a large a Complementary Metal–Oxide–Semiconductor (CMOS) sensor that in itself possesses large pixel elements. Larger pixel element record more light thereby increasing the level of radiometric fidelity imparting image clarity, which directly translates to image quality, surface quality, and ultimately data accuracy. The sensor shutter type is of extreme importance. Sensors used for mapping should have a mechanical shutter as these shutters capture image data in the instant the shutter is open. Rolling shutters capture image data sequentially resulting in blurred images. Rolling shutters are more common as they are cheaper and less prone to failure. Proper and regular (camera) calibration of sensor is well advised.

Peripheral Technology Opportunities

Leveraging and integrating peripheral evolving technologies such and RTK, PPK, VRS to reduce, or even eliminate ground control, can be challenging to understand and implement, however the benefits can exceed the cost of implementation in the appropriate scenario.

FAA Regulations

As more data is acquired and more fringe test case outcomes are documented as positive experiences the amount of regulation of the technology will dissipate. Flights over people and cars will eventually be commonplace where the technology and training will have matured to a level that the likelihood of a mishap is statistically acceptable. Product deliveries by drones and night flights too will become everyday occurrences.

Processing Software and Hardware

Like UAS vendors there once were many UAS processing software firms. And like the vendors, the level of competition and rate of innovation necessary to survive has narrowed the field considerably. Today there are only three desktop UAS processing software packages that are commonly used in North America – Pix4D, Context Capture, and AgiSoft.

All packages have the same core function and output capabilities, and a fundamental reliance on automation and SfM processing algorithms. Budget, user preference, and experience dictate the package of choice.

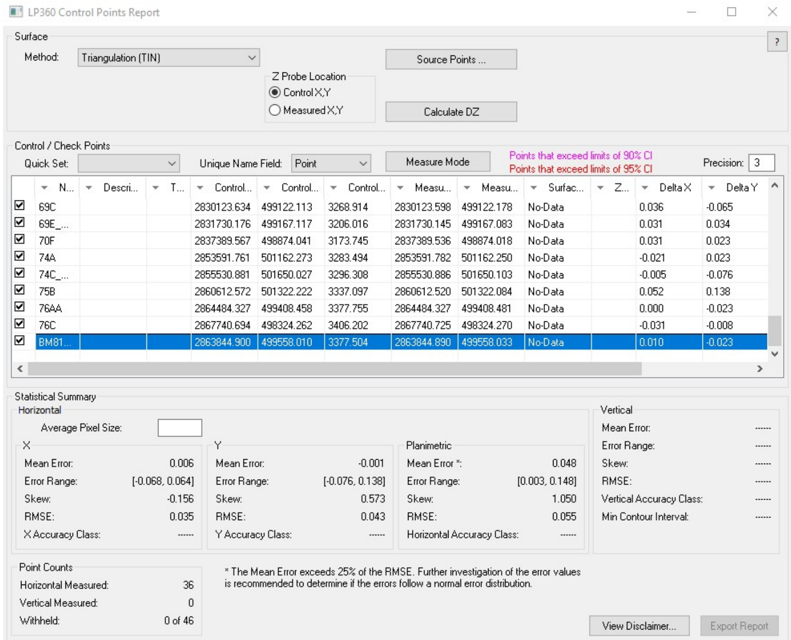
Pix4D is marketed as a “1, 2, 3” processing solution, is a well packaged product, and has a strong online based support system. Agisoft requires a broader understanding of photogrammetry, is ~3X cheaper, and, in our experience, is faster, just as accurate, and offers the user more control and processing options, which is paramount when an issue presents itself. Moreover, Agisoft has processed large datasets where Pix4D has failed to complete the task successfully. Context Capture is a Bentley product. MicroStation users may find the UAS processing integration with CAD appealing.

Cloud based solutions such as Drone Deploy, Pix4D, and Context Cloud as examples, are an option that foregoes the need to design and purchase an in-house processing solution. However, cloud-based systems are designed more for those that do not have a knowledge of photogrammetry. Hence, these solutions typically do not have the breadth of processing options a standalone software package may have, which is critical when encountering processing challenges.

Processing hardware concerns should be to build a dedicated processing workstation that provides the most bang your budget will allow. Separate read and write solid state drives should each exceed 1TB, RAM should exceed 50GB, a gaming grade multi-core CPU should be sought, and at least one high quality multi-core GPU should be installed. Be sure your processing software can leverage the GPU solution.

Horizontal Congruency & Accuracy

Although horizontal congruency was not a primary investigation component of this project, it should be noted that high horizontal accuracy with UAS technology is far easier to achieve than vertical accuracy. During the February 2017 presentation, AECOM demonstrated horizontal accuracy achieved for the 2016 Ashland Altavian dataset. The GCP congruency $RMSE_{xy}$ attained was X=0.035’ and Y=0.043’ using 36 points. This is a common outcome for all UAS datasets we have processed using ground control and independent checkpoints.



Ashland Altavian horizontal congruency results example

Vertical Congruency & Accuracy

Attaining repeatable high-quality vertical accuracy, at minimal cost, is the Holy Grail in UAS technology. Achieving high vertical accuracy is dependent in varying degrees on all the subject areas raised above.

Most notably is the reliance on high quality survey related technologies. As noted initially in this section, users are still in a period of learning how to take advantage of this evolving technology, how best to pair UAS systems with other evolving technologies such as PPK, RTK, Inertial Measurements Unit (IMU), and VRS technologies, while applying minimal additional incurred costs (ground control), maximize benefits, and/or create new utilization avenues for revenue. Market demand and GPS technology evolution in terms of increased accuracy, miniaturization, and decreasing costs will drive integration into the UAS platforms. As more results are shared with the UAS community better estimations, and ultimately “rules of thumb”, can be integrated into project design that suggest the most ideal number and distribution of ground control that is required to attain a desired data accuracy.

UAS stability and sensor quality obviously play a significant part in the vertical accuracy budget, but do not discount the processing software, specifically the processing software’s ability to accurately and efficiently classify the initial unclassified point cloud into bare earth products. UAS point clouds can exceed 300M points. If the classification sophistication is poor the vertical accuracy may be less than optimal and the level of manual effort to achieve the desired accuracy may be significant.

Below is a tabular summary of the $RMSE_z$ and 95% Confidence values attained during this program.

PHASE	PRE-CONSTRUCTION				CONSTRUCTION		POST CONSTRUCTION	
CORRIDOR	ASHLAND		MISSION		ASHLAND	MISSION	ASHLAND	MISSION
PLATFORM	ALTAVIAN	SKYCATCH	ALTAVIAN	SKYCATCH	SKYCATCH	SKYCATCH	SKYCATCH	SKYCATCH
GCP Vertical Congruency Summary $RMSE_z$	0.142’	0.087’	0.159’	1.522’	0.073’	0.116’	0.040’	0.037’
GCP Vertical Congruency Summary @95% Confidence	0.028’	0.017’	0.031’	0.298’	0.014’	0.023’	0.008’	0.007’
CHKPT $RMSE_z$	0.384’	0.520’	-	-	1.265’	0.439’	0.940’	0.422’
CHKPT @95% Confidence	0.753’	1.019’	-	-	2.479’	0.860’	1.842’	0.827’

Appendix A

INITIAL PROJECT PLANNING OVERVIEW:

Project Title: Montana Dept. of Transportation (MDT) UAS evaluation

Client: MDT

Location: Two roadway construction project sites near Ashland and Livingston, MT

Date/Time: 17 Oct 2016

Description: The purpose of this study is to demonstrate the capabilities of unmanned aerial surveys in MDT construction projects. MDT has selected two (2) different construction sites one near Ashland, MT on the eastern side of the state just over two hours east of Billings and the other near Livingston two hours west of Billings. The projects are divided into multiple phases; the first phase of the project is to collect complete imagery data of both sites using both the fixed wing and quadcopter. Both teams will deploy to one location and fly operations to completion at one site before moving to the next location. These particular stretches of road though rural areas have approximately 1800 vehicles per day on them. Due to the nature of the flights, vehicle stoppage will be required during the flights and will be provided by an outside contractor.

Figure 1: The East Ashland site is a stretch of highway over 7 miles long on Highway 212

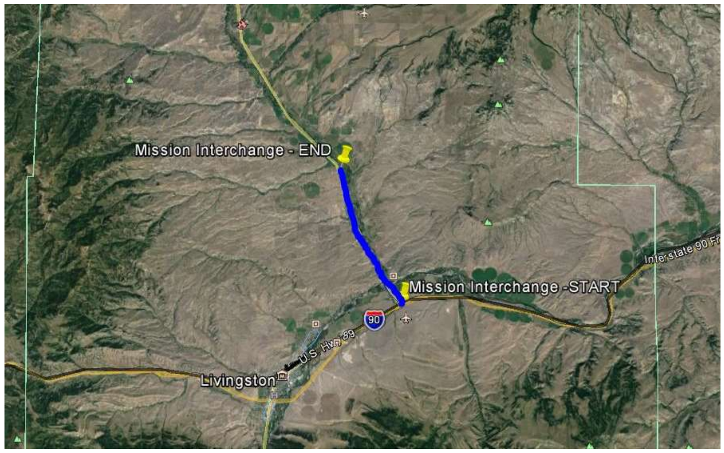


Figure 2: The Mission Interchange site near Livingston is just less than 7 miles in length along Highway 89

AECOM, along with the fixed wing service provider Altavian, will perform UAS operations. The aerial survey project will take five (5) days to complete.

RESOURCES

- **UAS employed:**
  - **Altavian NOVA F7200**

- **The Altavian NOVA is a fixed wing platform and is likely ideal for a large corridor project area. The system can be deployed to collect up to 3,000 acres in one lift.**
  - Up to 18 lbs. fixed wing
  - 9ft wingspan, Hand Launch, Belly Land
  - 90 minute flight duration
  - GSD up to 2cm
  - Accuracies up to 1cm RMSExyz
  - Sensor – 29MP at 5.5 micron pitch with surveying grade GPS navigation

- **SkyCatch EVO 3/RTK QuadCopter**
  - 5.7 pound Quadcopter
  - 30” diameter – 20” height
  - 20 minute flight duration
  - GSD up to 1cm
  - Accuracies up to 1cm x/y, 2cm z - RMSE
  - Sensor – 12.1MP non-metric

- **Back Up Aircraft:**
  - one SkyCatch EVO 3
  - one Nova F7200
  - NOTE: Concerns for this particular operation include vehicle traffic on roadways, obstacles crossing or near the roads such as high tension power lines, and an airfield near the Livingston site.

- **Aerial Survey Team (AST) – AECOM:**
  - Ty Moyers: Former military UAS pilot; Project Supervisor; Visual Observer
- **Aerial Survey Team (AST) – Altavian:**
  - Allan Austria: Pilot
    E: aaustria@altavian.com
    P: (941) 276-3326
  - Joe Schaefer: Visual Observer
    E: jschaefer@altavian.com
    P: (253) 973-4090

AECOM will complete the tasks listed below as part of the Preconstruction Survey during the period from September 26 through November 4, 2016 according to the following schedule.

ACTIVITY	START	FINISH
Project Planning	October 3rd	October 10th
Data Acquisition	October 17th	October 22nd
Data Processing	October 19th	November 20th
Reporting	November 20th	November 23rd

DELIVERABLES: Data processing

- Hi resolution orthomosaic imagery meeting the accuracy requirements described:
- Install and survey ground control targets. The installation of the control points will be performed under the supervision of a Montana Licensed Professional Land Surveyor according to the MDT Survey Manual. Aerial targets will be strategically placed on the newly installed control as well as some existing control points.
- To ensure final dataset accuracies are achieved, all ground survey work will be performed to meet ≤0.02 ft. (0.63 cm) RMSExyz.
- Imagery data will be reviewed by the AST to ensure complete coverage while in the field before moving to the next site.
- Imagery collected by the EVO 3 will be uploaded after each flight along with the GCP and RINEX file data to SkyCatch for processing. The imagery once loaded will be made available to AECOM data processing team from SkyCatch via file transfer for processing.
- Raw imagery from the UAS acquisitions phase along with ground control will be ingested into the geospatial processing software. Outputs from the processing will include natural color orthophotography and a digital surface model (DSM) point cloud.
- The DSM will be filtered to isolate bare earth ground points which will be used to create the DTM.
- The DTM will be cut into 100' segments determined by the project stationing.
- Utilizing the Preconstruction DTM earthwork volumes will be calculated and reported for each DTM stationing segment.
  - After the data is processed for the intermediate/Post-construction surveys volumes will be reported in approximately 100 ft segments or stations. The CAD program MicroStation/GeoPAK will breakdown the quantities (Pe-construction compared to the intermediate/Post-construction) into the desired segments (about every 100 feet and the beginning and end of curves). This will be a final step after the data is processed. (MDT requested this to help them breakdown the earthwork quantities.)
- Imagery collected by the Nova F7200 will be provided to AECOM data processing team in Germantown, MD. At the completion of each job site location. All raw imagery will be provided to Ty Moyers prior to departing the Livingston site and returning to homestation.

AECOM will the fully processed data NLT 2 weeks from completion of the aerial surveys. Final data products will be spatially explicit and compatible with standard GIS and CAD software environments.

A written progress report will be provided at the end of an Intermediate Survey describing the work involved. The following will be included in the progress report:

- Approach and planning of UAS acquisition and data processing
- Description of UAS and associated equipment
- Notifications and/or agreements with the public or landowners
- Ground control surveys, survey verification, information on any additional control required, and supporting surveys
- Equipment utilized, includes hardware and software
- Duration of each element of work to include: planning, flight durations, data processing and volume calculations, etc.
- Software and processes used to calculate earthwork quantities
- Flight plan and flight information (flight overlap, elevation, parameters, ground support, etc.)
- Description of any difficulties or obstacles encountered with the flight (weather limitations, seasonal constraints) and processing compliance with FAA and any FAA exceptions needed or considered
- Efficiencies and actions taken to increase efficiencies
- Accuracy of the results
- Any other relevant information

FLIGHT OPERATIONS PLANNING:

AECOM's AST conducts UAS aerial survey flight collecting imagery data along the selected roadways. The AST will place GCPs in conjunction with MDT control points will conduct the onsite survey of the area to finalize launch and recovery of the aircraft and discuss obstacles not identified in the pre-deployment planning process.

- **Safety and Risk Mitigation:** Safe flight operations are an inherent individual and team responsibility and begin with thorough planning and attention to detail throughout the UAS employment from pre-launch to recovery. Safe operations will be achieved during this demonstration by/through regulatory compliance, safe and reliable UAS systems employment, employing qualified operators experienced on the systems, preventing flight profiles into high hazard environments/situations, and preventing distractions to pilots and visual observers.

- **MDT Health, Safety and Environmental (HSE) Compliance**
- AECOM AST complies with all site-specific safety requirements for on-site personnel and works with the MDT as for any training/compliance requirements prior to start.

- **Regulatory Compliance**
  - AECOM conducts only legal, compliant UAS operations. Our analysis of alternatives evaluates the operational areas to determine compliance under the UAS service provider's FAA regulatory authorization to perform UAS operations: All AST members are responsible for insuring compliance FAA airspace requirements, public and private access requirements and limitations.
    - Mission airfield KVLM has airspace class E to the surface during specific times as described by NOTAMS other times KVLM airspace is 700 ft AGL and above.
    - The AST will monitor the CTAF 123.0 freq for air traffic during UAS operations.
  - Employment compliance. The AST:
    - Is comprised of qualified air vehicle operators and UAS experts that are experienced visual observers
    - Operates the air vehicle within "visual line-of-sight" of the pilot/observer at all times.
    - Launches and recovers the air vehicle in such a manner to present no hazard to persons or property in and around the aerial survey operations area.
    - Flies the air vehicle below 400 feet AGL and well clear of obstacles and hazards to flight.
    - Maintains Aircraft registration and pilot Certification on site and available to present during all operations.

- **Employing Safe and Reliable UAS Systems:**
  - The proliferation of different types of UAS for commercial projects creates potential for selecting air vehicles that have not been adequately flown to ensure reliability. An air vehicle's reliability directly correlates with safety considerations such as, but not limited to lost communications link, departure from controlled flight, operational complexity requiring excessive operator attention to controls, and mechanical failure. AECOM UAS experts only consider systems that have proven performance and have specified operating manuals. After a detailed Analysis of Alternatives (AoA), AECOM selected Altavian and the Nova F7200 for this project. The F7200:
    - Has proven flight records for reliable flight operations for a number of different project types.
    - Has robust communications links that enable positive, controlled flight at all times, and reduces pilot work load by being simple to operate.
    - Is deemed mechanically reliable having been certified by the FAA for operations in U.S. airspace.

- **Employing qualified operators experienced on the systems:**
  - An unqualified operator can put both people and property at risk. AECOM UAS experts verify the qualifications of pilots/operators and ensure they are both current and qualified on the system being flown. "Current" means they have flown the UAS recently enough to ensure

proficiency and "qualified" means they have the mandated FAA qualifications to operate the system. Hobbyists are not qualified to operate UAS for commercial projects.

  - Ty Moyers is the AECOM Management Services, Director Commercial UAS services and will supervise and manage the overall UAS operation and serve as Visual Observer. He is a former USAF UAS pilot, has commanded the USAF Remotely Piloted Aircraft Test Center, is a rated private pilot and aircraft mechanic, and is experienced in the operation of the SkyCatch UAS and is familiar with Altavian capabilities.
  - The AECOM Unmanned Systems Team has thoroughly vetted the qualifications and track record of Altavian. The Altavian operators are certified and current in the operation of the F7200.

- **Preventing flight profiles into high hazard environments:**
  - Operating environments are considered high hazard when:
    - The selected air vehicle's operating parameters are stressed to the point of increasing the potential for collisions with both persons and objects in the flight area.
    - There are vertical obstructions such as towers and wires that could/will interfere with flight operations.
    - They are heavily populated.
    - They have the potential to create distractions that could cause unsafe conditions particularly to traffic.
    - They have the potential for weather phenomena that will negatively impact or create unsafe flight operations.
  - AECOM UAS experts have studied the MDT operating environment and assessed it against the factors mentioned above. The Area of Interest (AOI) offers relatively flat terrain with minimal impact hazards from trees and power lines. Identifying suitable landing areas for the F7200 will be a large part of the site survey to consider suitable departure and approach paths to clear all obstacles and ensure safety to personnel on the ground and traffic. The AST has assessed and identified vertical obstructions through photographs of the area and will be verified and planned around upon arrival. Should another aircraft be sighted within and around the area of interest, flight operations will cease until the airspace is considered well clear.

- **Preventing distractions to pilots and visual observers:**
  - UAS operations are unique in that pilots and visual observers are operating the systems on land, typically in the open, near other people who do not understand flight operations and the need to be laser focused on the tasks of flying. To prevent distractions, a safety bubble will be maintained around pilot and visual observer at all times to prevent unwanted or unnecessary communications from creating distractions.
  - Should distractions occur, persist, and cannot be mitigated, flight operations will immediately cease and the aircraft recovered.

- **Mission Planning Considerations:**

The Altavian flight characteristics for the Ashland and Mission interchange sites: The Nova F7200 fixed-wing UAV will make four passes to accurately survey the road with the ability to create orthomosaic and 3D mapping models. Each flight is limited by the line-of-sight regulations. Each project site will be divided into 4 flights; each flight is approximately 15-20 minutes of flight time.

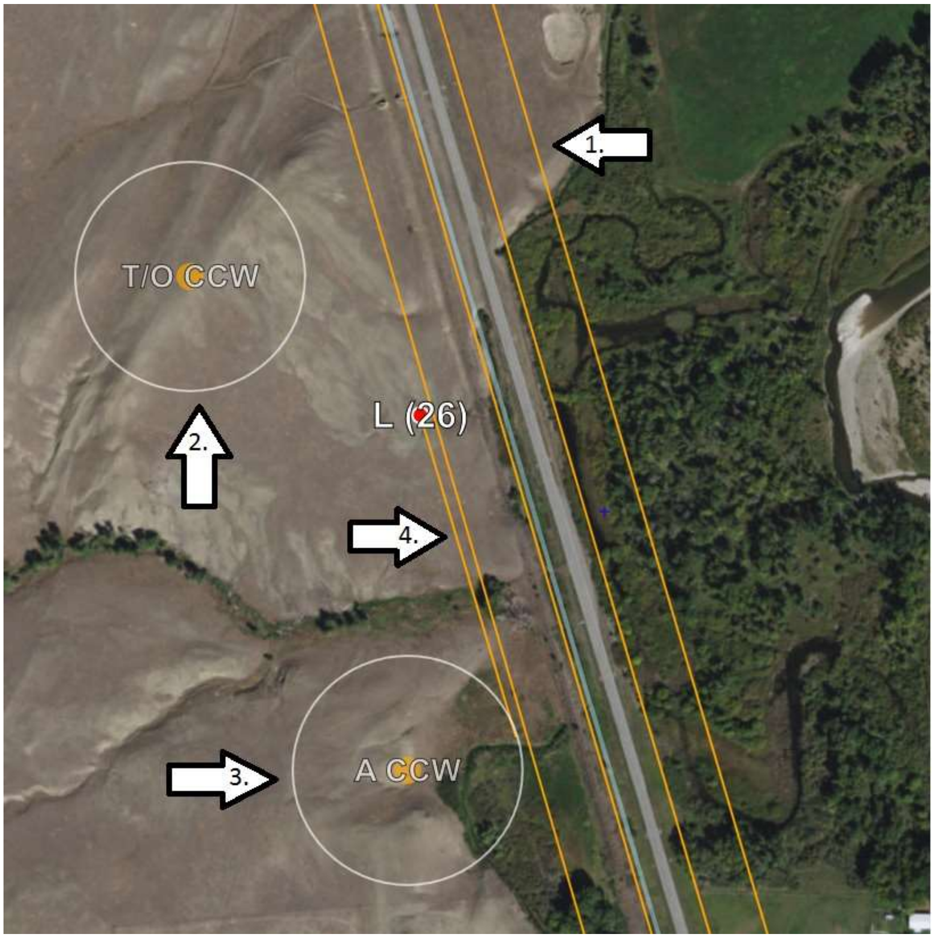


Figure 3: Nova UAS Aerial Survey Flight profile

- The orange lines (arrow #1) represent the flight lines of the Nova. The inner flight lines nearest road are offset from the edge of the road by 20 meters (66 ft.). The outer flight lines farthest from the road are offset from the edge of the road by 66 meters (217 ft.)
- The circle labeled "T/O CCW"(arrow #2) represents the position where the aircraft will loiter after take-off, prior to beginning the data collection. This loiter can be positioned in any location and will always be located further from the road than the outer flight lines.
- The circle labeled "A CCW" (arrow #3) represents the position that the aircraft will loiter prior to the final approach, and during an emergency situation. This loiter can be positioned in any location and will always be located further from the road than the outer flight lines.
- The shortest orange line (arrow #4) leading from the "A CCW" loiter represents the approach path for landing, the red dot at the end of the approach path labeled "L (26)" represents the landing

location. The approach path and the landing location will always be located further from the road than the outer flight lines.

- Overall, the Nova F7200 will be flying 400ft above the road and will be offset from the edge of the road by at least 20 meters (66 ft.). All flight maneuvers that do not pertain to the flight lines will be performed beyond the outer flight lines and offset from the edge of the road by at least 66 meters (217 ft.)

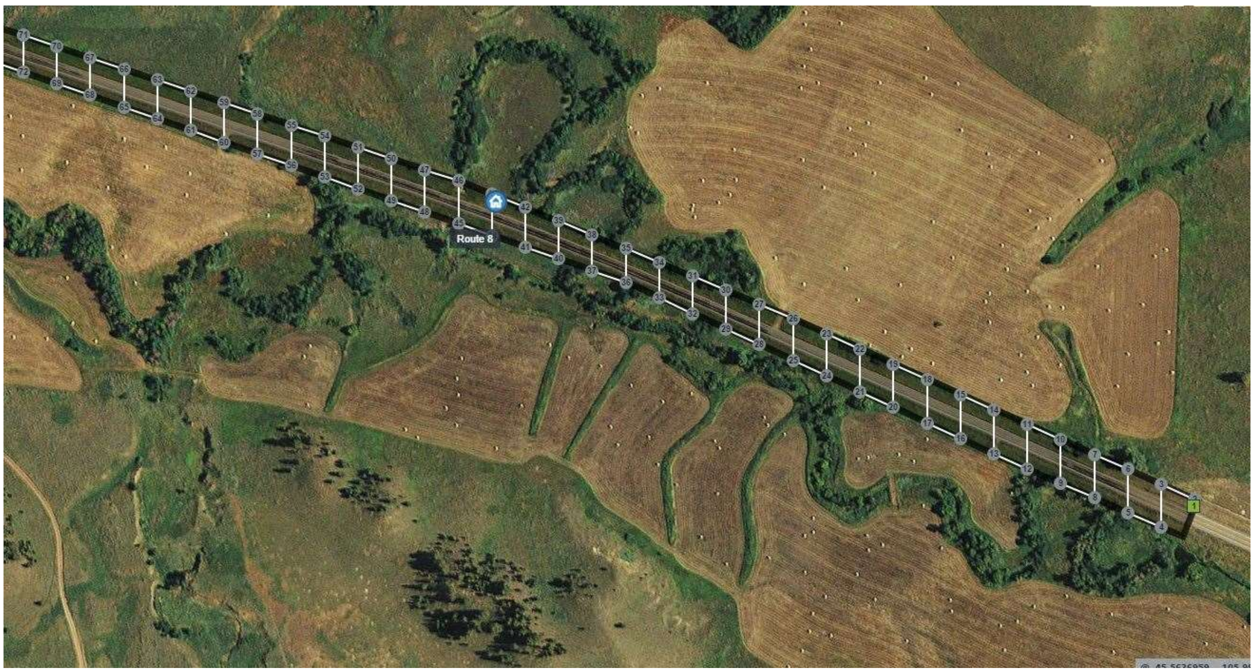


Figure 4: EVO 3 Flight Profile

- The EVO 3 has approximately 20 minute flight duration has an effective LOS range of 1/2 mile. Typical flight will be conducted in one mile sections and as currently planned consist of 8-9 flights for each 2 roadways.
- Each individual flight will launch from the mid-point represented by the blue home symbol. The aircraft will fly to the end section and work its way back towards the operator and continue to the end of the segment and return home.
- Surveyed Ground Reference Points are available - AECOM AST may emplace any necessary Ground Control Points (GCPs) for aerial reference to enable geo-rectification accuracy. Depending on the location of the GCPs, flights will need to overlap the GCP locations to get accurate reference.
- A TOPCON base station will be set up at a midway point to the route segments for the EVO 3 flights as part of kinematics processing to collect RINEX data file for accurate vertical elevation calculations.
- Operations Location: AST conducts all UAS operations at a safe distance from traffic, clear of private drives and intersecting roadways and in a location that provides Visual Line of Sight

(VLOS) with the aircraft in flight as directed by the FAA under the part 107 rules for UAS operations.

- Beginning each day a tailgate safety briefing will be conducted for both ground and flight operations. Ground safety brief will be conducted by Jake Conver. Flight operations brief will be conducted by Ty Moyers for general operational plan and EVO 3 flight ops. Altavian pilot will brief the Nova F7200 flight safety specifics.
- Upon landing the aircraft and data will be reviewed to verify data and establish next flight section to ensure proper overlap for the next flight.
- Flight considerations are powerlines, trees, terrain that can prevent LOS and winds. Flights will be planned at 180-200 ft. AGL

- **Responsibilities:**
  - AECOM
    - Provides overall project oversight
    - Provides UAS operations oversight and interacts with the client
    - Provides trained UAS visual observer
    - Supplies all necessary personal protective equipment (PPE) for AECOM personnel. PPE required includes hardhat, eye protection, hi-vis vest and steel toed boots.
  - Altavian
    - Solely responsible for UAS operational safety throughout all missions, including any pre-flight and post-flight procedures.
    - Conducts all operations in accordance within approved FAA Section 333 and Part 107 regulations and makes available all authorization and coordination documentation to be presented upon request by AECOM, our client(s), or city/state/federal representative.
    - Provides and operates the UAS and support systems to accomplish the project objectives as directed.
    - Sufficient aircraft, systems, batteries and battery charging capability to ensure uninterrupted aerial imaging at a minimum rate of 8 flights per day.
    - Capability of ensuring post-flight imagery collection was successful (laptop or equivalent).

- Supplies all necessary PPE for Altavian personnel. PPE required includes hardhat, eye protection, hi-vis vest and steel toed boots.

Operational Details:

- **Preparation:** Planning for this project has been ongoing since initial notification. AECOM UAS Subject Matter Experts (SMEs) have assessed the Area of Interest (AOI) conducting detailed studies. The Team will continue to refine the analysis through arrival on site and up to launch. The AST conducts pre-mission coordination and briefings prior to each flight. Prior to the first mission of collecting data the AST will conduct a calibration flight to fine tune equipment and reconnoiter the site and AOI thoroughly assessing any potential hazards to safe operations, validate optimum positioning to adhere to line-of-sight requirements, and verify launch and recovery safe areas. Flight operations will be conducted on 18 -21 October 2016 and as needed until mission complete.

- **Deployment:** The AST and equipment will deploy to arrive the day prior to flight operations. The Team has a pre-deployment map and Google Earth analysis understanding of the area and verified that no unforeseen risks beyond the airfield or adjacent power lines and consider potential traffic hazards.

- **Time Line** (*times are subject to change based on weather, environmental conditions, and requests from MDT and TCT)***:**
  - **16 October 16** – Deployment, AECOM AST deploys to Billings MT. (Equipment shipped 3 days prior to team departure).
    - *AECOM C/O Jacob Conver*
    - *207 North Broadway, Suite 315*
    - *Billings, Montana 59101*
  - **17 October 16** Travel to Ashland site.
    - Western 8 Motel - Ashland
    - 2366 W US Highway 212, Ashland, MT 59003-7700
  - **Mon 17 October 16** – Ashland East Site Recon, and Calibration flight, set GCPs
    - Conduct a site reconnaissance identifying hazards to flight, identifying and assessing launch, operations, and recovery sites
    - Conduct a UAS calibration flight to ensure all systems function properly
    - Emplace GCPs
    - Coordinate with traffic control team (TCT)
    - Conduct first Quad copter sortie before 12 noon
    - 2 pm Conduct first fixed wing sortie (WX and TCT pending to complete Ashland data sorties.)
  - **Tue 18 October 16**
    - Complete Ashland Sorties

- Move to Mission Interchange site Conduct site survey
- Accommodations:
    - Yellowstone Pioneer Lodge
    - 1515 W Park St
    - Livingston, MT 59407
- **Wed 19 October 16** - Flight initiated South near I-90 working North
    - Visit with Mission Airfield manger to finalize airspace DE confliction.
        - Russel Ferguson
        - 82 Airport RD
        - Livingston, MT 59047
        - 406-222-6504
    - AST Position GCPs. Coordinates with TCT final preps for flights on 20 Oct.
    - 1100 EVO Flight 1-3
    - 1300 Nova Flight 1
    - 1400 EVO Flight 4-6
    - 1500 Nova Flight 2
        - NOTE: Flight data review and transmission between flights
- **Thurs 20 Oct 16**
    - 0800 EVO 3 Flight 7-8
    - 1000 Nova Flight 3-4
    - Finalize data collaboration/transfer.
    - Project debrief
    - Pack-up equipment and collect GCPs
    - Depart for Billings, MT
- **Fri 21 October 16**
    - Flight contingent day/redeploy to respective home stations (unless the aerial survey objectives are not met AST will remain and continue imagery collection flights until complete.
- NOTE: Crew duty day is limited to 12 hours not exceed 10 hours of flying each day.
- NOTE 2: All flights will be conducted with close coordination of TCT and briefed before take-off of any aircraft. TCT and AST will be in radio communication at all times and will conduct flights to minimally impact traffic on the roadways.

- **Daily Flight Planning -** The AECOM AST Lead will coordinate with the AECOM/MDT Lead and pre-coordinate the meeting site and each day's GCPs, AOI portion and launch sites. The aircrew (pilot and observer) will:
    - Conduct a Preflight Briefing at the start of each Aerial Survey Day (briefing in compliance with AECOM UAS Operations Guide).

- Validate the first flight mission briefing and identify any changes of note for follow on flights. Review the prescribed image goals and flight pattern to be flown. Prior to each flight the AST will conduct a quick but thorough preflight to:
  - Identify any mission changes.
  - Identify any weather changes or impacts.
  - Conduct a hazard assessment at each launch and recovery site and area to be flown taking into account sun angles for both optimum image quality and safety with respect to inhibiting the flight crew's ability to see the aircraft (eg looking into the sun).
  - Conduct a data sync session between the operators and the data process teams. In this session the AECOM/MDT experts will specify special collection goals and identify what changes may improve the data image quality.

- **Daily Flight Operations Briefings –** Prior to the first flight of each day, the flight crews conduct flight briefings and cover the following. The flight crews will verify the flight briefings again at the launch/recovery site prior to take-off.
  - Weather (forecast from launch to one hour after recovery)
    - include mission abort / return to base criteria (winds, visibility, rain, snow, etc)
  - Mission
    - data collection and analysis goals, procedures, tools, timelines and packaging
    - data collection areas
    - data requirement
    - schedule (take-off, time conducting mission, landing, fuel/battery endurance)
    - routes and reporting points
    - altitudes
    - pre-launch, take-off, and landing procedures
  - Communications plan
    - Voice communications (radio, cell, walkie talkie, etc) operating during all UAS ops flights will be pre-coordinated with tower, TCT and VO's prior to flight operations.
  - Hazard identification and risk assessment
    - include populated areas and privacy concerns
    - controls to mitigate hazards and risks
  - Emergency procedures
    - aircraft detection and avoidance technology and procedures
    - mission divert and termination procedures
    - lost link procedures
    - aircraft mishap plan
    - air vehicle recovery procedures

- Actions/events/incidents encountered on the previous shift
- Actions/events/incidents encountered on previous operations to the specific AOI
- Actions on identification of hostile threat to air vehicle
- Aircraft and sensor maintenance status
- Time and location of the post mission debriefing

- Deviations to the planned routes, the timelines, and data target objectives during the execution of the missions are authorized through the AECOM UAS Lead and as long as they can be conducted within the flight plan authorities. Any changes must be cleared with appropriate flight control agencies monitoring this particular airspace. No deviations will come close to exceeding the limitations of the air vehicle to include fuel (endurance), airspeed, altitude, and none will violate any known no-fly areas.
- Upon completion of each day's flights, the AST will conduct a post flight assessment to address all positives and any negatives associated with each day's flight. If there are negative outcomes in the post flight assessment, changes will be made to alter or improve parameters (e.g., flight was either too high or low to cover the AOI or determine proper stand-off and image quality of flights flown.)

- **Flight Profile:** Upon receipt of the execute directive, AECOM will deploy to enable flight operations soon after sunrise and continue to approximately an hour prior to sunset (6:00 am to 8:00 pm); however, this time will be adjusted depending on weather that may impact the ability to operate the aircraft or the data quality.
  - The AECOM AST will thoroughly brief all flights prior to launch each day's first flight. Briefings will include detailed discussion of flight profiles and parameters, data quality objectives, team communications, and emergency procedures. Launch and recovery will be in accordance with aircraft operating instructions.
  - Flight Profiles can be varied after a risk analysis and detailed briefing of changes. At no time will the aircraft be flown in an ad hoc or reckless manner, or outside the parameters established for this project. Aircraft will be flown so as to avoid overflying groups that are not part of the demonstration.
  - The AST will operate at altitudes and distances from to facilitate optimum imagery quality while ensuring safe distances and emergency routes to safety in the event of technical or environmental issues. Aircraft will not be flown higher than 400 feet AGL at any time with the exception of clearing obstacles as required.

- **Communications:** The Pilot and Visual Observer will have direct communications with each other during all phases of flight. Only one official AECOM/MDT representative will be allowed to work with the AST in the event there is a point of interest in which the AST needs to direct their focus. Multiple advisors can distract the operators and pose potential safety risks.
  - Radio frequency will be verified prior to flight operations and monitored closely. Radio communications will adhere to FAA and FCC requirements at all times.

- **Redeployment:** Weather permitting, the AST will remain until the aerial data imaging is complete though we expect to complete the required flying by 21 Oct and redeploy on 21 Oct 16. The AST may remain to meet with the client inspectors as requested or required.

- **Insurance:** AECOM and any subcontractors/vendors that AECOM may employ possess adequate coverage to protect parties affected by this UAS demonstration.

Attachments

1. AIR MISSION Brief

AECOM Team Contacts:

Tim Saffold

Executive Vice President Joint Unmanned Systems and Training Solutions

719-424-0958

Ty Moyers

Director Commercial and Government UAS Operations

719-551-0264

Jake Conver, PE

Senior Engineer

406-671-7995

Appendix B

Approved Mission Interchange FAA Waiver

Skyward
A Verizon company

An authorized intermediary for the Federal Aviation Administration USS program

Notice of Authorization

Operation Date
Monday, November 12th 2018

Pilot In Command
Alonso Morales

Beginning Time
08:00 MST (1500 UTC)

Ending Time
17:00 MST (0000 UTC)

Conditions Of Authorization

- Maintain visual line of sight
- Aircraft speed not to exceed 100 mph
- Do not fly over non-participants
- Do not exceed maximum altitude
- Ensure there are no TFRs before flying
- The weather ceiling must be above 1,000 feet AGL when flying in Class E airspace

Airspace and maximum altitudes

1. **LVM 200ft** - **FAA Ref#:** SKDWXDT7S
2. **LVM 400ft** - **FAA Ref#:** SKDQWL7L3
3. **LVM 200ft** - **FAA Ref#:** SKD9FBNH9
4. **LVM 200ft** - **FAA Ref#:** SKDVAP8AR

In accordance with Title 14 CFR Part 107.41, your operation is authorized within the designated airspace and timeframe constraints. Altitude limits are absolute values above ground level which shall not be added to the height of any structures. This Authorization is subject to cancellation at any time upon notice by the FAA Administrator or his/her authorized representative. This Authorization does not constitute a waiver of any State law or local ordinance. Alonso Morales is the person designated as responsible for the overall safety of UAS operations under this Authorization. During UAS operations for on-site communication/recall, Alonso Morales shall be continuously available for direct contact at undefined by ATC or designated representative. Remote pilots are responsible to check the airspace they are operating in and comply with all restrictions that may be present in accordance with 14 CFR 107.45 and 107.49 (a)(2), such as restricted and Prohibited Airspace, Temporary Flight Restrictions, etc. Operations are not authorized in Class E airspace when there is a weather ceiling less than 1,000 feet AGL. If the UAS loses communications or loses its GPS signal, it must return to a predetermined location within the operating area and land. The pilot in command must abort the flight in the event of unpredicted obstacles or emergencies.

Issue Date:
Monday, November 5th 2018 19:34 UTC

Submitted By:
Alonso Morales
through Skyward.io

Appendix C

Volumetric Analysis Results

Ashland 2016-2017 Volume Report_2018-02-14

The volume reports are a comparison of the Pre-Construction bare earth surface model compared against the Intermediate-Construction bare earth surface model. The quantities off cut/fill volumes were analyze and computed for every 100 foot stations using GeoPAK software. The distance increment can be customized in GeoPAK and additional stationing can be added to include PC, PT and POT stations as needed. A shrink/swell factor was not applied.

Basic Volume Report

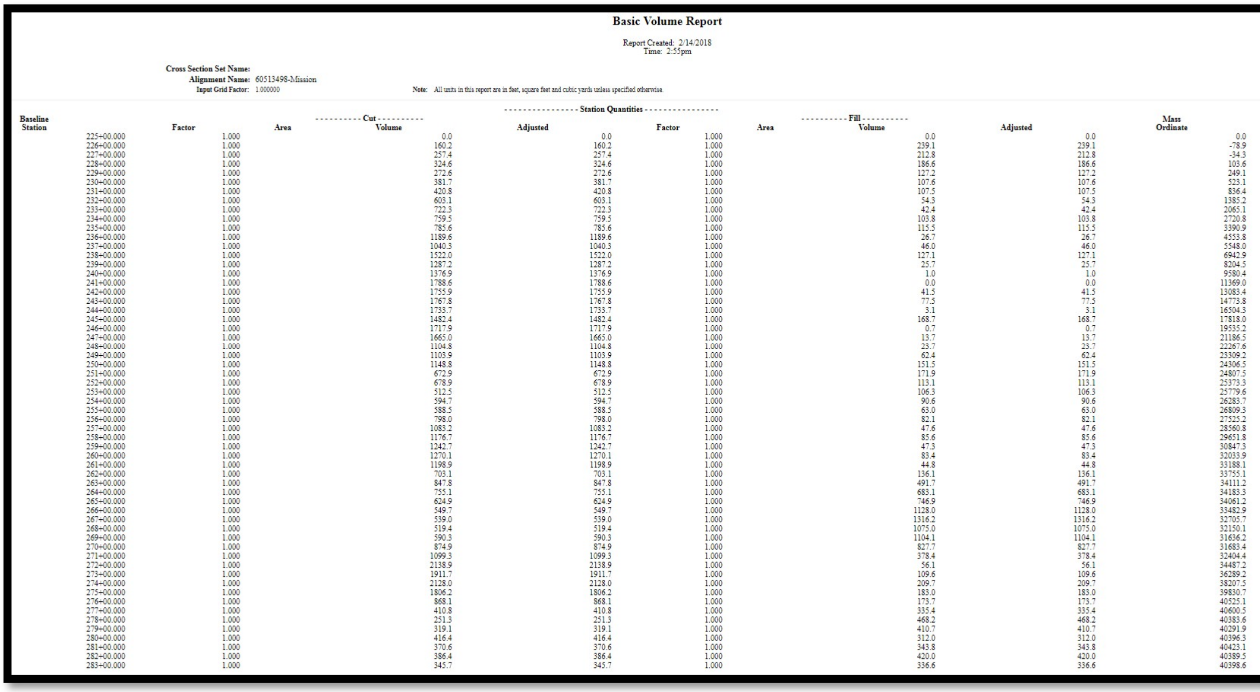
Report Created: 2/14/2018
Time: 3:41pm

Cross Section Set Name:
Alignment Name: 60513498_Ashland East
Input Grid Factor: 1.000000

Note: All units in this report are in feet, square feet and cubic yards unless specified otherwise.

	Station Quantities								
	Cut				Fill				
Baseline Station	Factor	Area	Volume	Adjusted	Factor	Area	Volume	Adjusted	Mass Ordinate
370+00.000	1.000		0.0	0.0	1.000		0.0	0.0	0.0
371+00.000	1.000		401.7	401.7	1.000		219.5	219.5	182.2
372+00.000	1.000		1020.2	1020.2	1.000		42.5	42.5	1159.9
373+00.000	1.000		2179.6	2179.6	1.000		3.3	3.3	3336.2
374+00.000	1.000		2335.7	2335.7	1.000		2.7	2.7	5669.3
375+00.000	1.000		3527.8	3527.8	1.000		0.1	0.1	9197.0
376+00.000	1.000		3988.2	3988.2	1.000		0.1	0.1	13185.1
377+00.000	1.000		3355.2	3355.2	1.000		0.0	0.0	16540.3
378+00.000	1.000		3241.3	3241.3	1.000		4.7	4.7	19776.9
379+00.000	1.000		2323.7	2323.7	1.000		19.3	19.3	22081.3
380+00.000	1.000		3027.0	3027.0	1.000		8.6	8.6	25099.7
381+00.000	1.000		4696.1	4696.1	1.000		0.3	0.3	29795.5
382+00.000	1.000		3982.1	3982.1	1.000		10.7	10.7	33766.8
383+00.000	1.000		4212.6	4212.6	1.000		25.1	25.1	37954.4
384+00.000	1.000		2503.2	2503.2	1.000		5.6	5.6	40452.0
385+00.000	1.000		1253.3	1253.3	1.000		405.1	405.1	41300.1
386+00.000	1.000		1141.3	1141.3	1.000		219.4	219.4	42222.0
387+00.000	1.000		972.6	972.6	1.000		135.1	135.1	43059.4
388+00.000	1.000		1382.6	1382.6	1.000		336.0	336.0	44106.0
389+00.000	1.000		1088.2	1088.2	1.000		628.6	628.6	44565.5
390+00.000	1.000		594.2	594.2	1.000		969.7	969.7	44190.0
391+00.000	1.000		53.5	53.5	1.000		1767.1	1767.1	42476.3
392+00.000	1.000		4.0	4.0	1.000		2381.0	2381.0	40099.3
393+00.000	1.000		76.8	76.8	1.000		2523.9	2523.9	37652.2
394+00.000	1.000		106.2	106.2	1.000		1762.3	1762.3	35996.2
395+00.000	1.000		261.7	261.7	1.000		767.8	767.8	35490.1
396+00.000	1.000		688.5	688.5	1.000		271.2	271.2	35907.4
397+00.000	1.000		1509.4	1509.4	1.000		127.9	127.9	37288.9
398+00.000	1.000		3097.9	3097.9	1.000		7.8	7.8	40379.0
399+00.000	1.000		4048.6	4048.6	1.000		14.6	14.6	44412.9
400+00.000	1.000		4891.3	4891.3	1.000		2.8	2.8	49301.4

Mission 2016-2017 Volume Report_2018-02-14



Basic Volume Report

Report Created: 2/14/2018
Time: 2:55pm

Cross Section Set Name:
Alignment Name: 60513498-Mission
Input Grid Factor: 1.000000

Note: All units in this report are in feet, square feet and cubic yards unless specified otherwise.

	---------------- Station Quantities ----------------								
	---------- Cut ----------				---------- Fill ----------				
Baseline Station	Factor	Area	Volume	Adjusted	Factor	Area	Volume	Adjusted	Mass Ordinate
225+00.000	1.000		0.0	0.0	1.000		0.0	0.0	0.0
226+00.000	1.000		160.2	160.2	1.000		239.1	239.1	-78.9
227+00.000	1.000		257.4	257.4	1.000		212.8	212.8	-34.3
228+00.000	1.000		324.6	324.6	1.000		186.6	186.6	103.6
229+00.000	1.000		272.6	272.6	1.000		127.2	127.2	249.1
230+00.000	1.000		381.7	381.7	1.000		107.6	107.6	523.1
231+00.000	1.000		420.8	420.8	1.000		107.5	107.5	836.4
232+00.000	1.000		603.1	603.1	1.000		54.3	54.3	1385.2
233+00.000	1.000		722.3	722.3	1.000		42.4	42.4	2065.1
234+00.000	1.000		759.5	759.5	1.000		103.8	103.8	2720.8
235+00.000	1.000		785.6	785.6	1.000		115.5	115.5	3390.9
236+00.000	1.000		1189.6	1189.6	1.000		26.7	26.7	4553.8
237+00.000	1.000		1040.3	1040.3	1.000		46.0	46.0	5548.0
238+00.000	1.000		1522.0	1522.0	1.000		127.1	127.1	6942.9
239+00.000	1.000		1287.2	1287.2	1.000		25.7	25.7	8204.5
240+00.000	1.000		1376.9	1376.9	1.000		1.0	1.0	9580.4
241+00.000	1.000		1788.6	1788.6	1.000		0.0	0.0	11369.0
242+00.000	1.000		1755.9	1755.9	1.000		41.5	41.5	13083.4
243+00.000	1.000		1767.8	1767.8	1.000		77.5	77.5	14773.8
244+00.000	1.000		1733.7	1733.7	1.000		3.1	3.1	16504.3
245+00.000	1.000		1482.4	1482.4	1.000		168.7	168.7	17818.0
246+00.000	1.000		1717.9	1717.9	1.000		0.7	0.7	19535.2
247+00.000	1.000		1665.0	1665.0	1.000		13.7	13.7	21186.5
248+00.000	1.000		1104.8	1104.8	1.000		23.7	23.7	22267.6
249+00.000	1.000		1103.9	1103.9	1.000		62.4	62.4	23309.2
250+00.000	1.000		1148.8	1148.8	1.000		151.5	151.5	24306.5
251+00.000	1.000		672.9	672.9	1.000		171.9	171.9	24807.5
252+00.000	1.000		678.9	678.9	1.000		113.1	113.1	25373.3
253+00.000	1.000		512.5	512.5	1.000		106.3	106.3	25779.6
254+00.000	1.000		594.7	594.7	1.000		90.6	90.6	26283.7
255+00.000	1.000		588.5	588.5	1.000		63.0	63.0	26809.3
256+00.000	1.000		798.0	798.0	1.000		82.1	82.1	27525.2
257+00.000	1.000		1083.2	1083.2	1.000		47.6	47.6	28560.8
258+00.000	1.000		1176.7	1176.7	1.000		85.6	85.6	29651.8
259+00.000	1.000		1242.7	1242.7	1.000		47.3	47.3	30847.3
260+00.000	1.000		1270.1	1270.1	1.000		83.4	83.4	32033.9
261+00.000	1.000		1198.9	1198.9	1.000		44.8	44.8	33188.1
262+00.000	1.000		703.1	703.1	1.000		136.1	136.1	33755.1
263+00.000	1.000		847.8	847.8	1.000		491.7	491.7	34111.2
264+00.000	1.000		755.1	755.1	1.000		683.1	683.1	34183.3
265+00.000	1.000		624.9	624.9	1.000		746.9	746.9	34061.2
266+00.000	1.000		549.7	549.7	1.000		1128.0	1128.0	33482.9
267+00.000	1.000		539.0	539.0	1.000		1316.2	1316.2	32705.7
268+00.000	1.000		519.4	519.4	1.000		1075.0	1075.0	32150.1
269+00.000	1.000		590.3	590.3	1.000		1104.1	1104.1	31636.2
270+00.000	1.000		874.9	874.9	1.000		827.7	827.7	31683.4
271+00.000	1.000		1099.3	1099.3	1.000		378.4	378.4	32404.4
272+00.000	1.000		2138.9	2138.9	1.000		56.1	56.1	34487.2
273+00.000	1.000		1911.7	1911.7	1.000		109.6	109.6	36289.2
274+00.000	1.000		2128.0	2128.0	1.000		209.7	209.7	38207.5
275+00.000	1.000		1806.2	1806.2	1.000		183.0	183.0	39830.7
276+00.000	1.000		868.1	868.1	1.000		173.7	173.7	40525.1
277+00.000	1.000		410.8	410.8	1.000		335.4	335.4	40600.5
278+00.000	1.000		251.3	251.3	1.000		468.2	468.2	40383.6
279+00.000	1.000		319.1	319.1	1.000		410.7	410.7	40291.9
280+00.000	1.000		416.4	416.4	1.000		312.0	312.0	40396.3
281+00.000	1.000		370.6	370.6	1.000		343.8	343.8	40423.1
282+00.000	1.000		386.4	386.4	1.000		420.0	420.0	40389.5
283+00.000	1.000		345.7	345.7	1.000		336.6	336.6	40398.6

Mission Design -Post-Construction Volume Report

Alignment Name: 60513498-Mission

Input Grid Factor: 1.000000 **Note:** All units in this report are in feet, square feet and cubic yards unless specified otherwise.

	---------------- Station Quantities ----------------								
	---------- Cut ----------				---------- Fill ----------				
Baseline Station	Factor	Area	Volume	Adjusted	Factor	Area	Volume	Adjusted	Mass Ordinate
225+00.000	1.000		0.0	0.0	1.000		0.0	0.0	0.0
226+00.000	1.000		267.5	267.5	1.000		72.2	72.2	195.3

	- - - - - - - - - - - - - - - - Station Quantities							- - - - - - - - - - - - - - - -	
	- - - - - - - - - - Cut - - - - - - - - - -				- - - - - - - - - - Fill - - - - - - - - - -				
Baseline Station	Factor	Area	Volume	Adjusted	Factor	Area	Volume	Adjusted	Mass Ordinate
227+00.000	1.000		195.4	195.4	1.000		258.1	258.1	132.6
228+00.000	1.000		204.7	204.7	1.000		105.4	105.4	231.9
229+00.000	1.000		113.5	113.5	1.000		156.0	156.0	189.4
230+00.000	1.000		146.7	146.7	1.000		137.3	137.3	198.8
231+00.000	1.000		133.1	133.1	1.000		118.3	118.3	213.6
232+00.000	1.000		80.7	80.7	1.000		128.5	128.5	165.9
233+00.000	1.000		38.3	38.3	1.000		172.2	172.2	32.0
234+00.000	1.000		98.8	98.8	1.000		85.6	85.6	45.2
235+00.000	1.000		56.6	56.6	1.000		132.8	132.8	-31.0
236+00.000	1.000		50.2	50.2	1.000		169.9	169.9	-150.8
237+00.000	1.000		95.5	95.5	1.000		302.2	302.2	-357.5
238+00.000	1.000		79.4	79.4	1.000		279.5	279.5	-557.6
239+00.000	1.000		82.7	82.7	1.000		209.0	209.0	-683.9
240+00.000	1.000		21.7	21.7	1.000		172.4	172.4	-834.6
241+00.000	1.000		42.5	42.5	1.000		267.3	267.3	-1059.4
242+00.000	1.000		61.9	61.9	1.000		269.1	269.1	-1266.6
243+00.000	1.000		33.0	33.0	1.000		417.0	417.0	-1650.6
244+00.000	1.000		27.2	27.2	1.000		477.0	477.0	-2100.4
245+00.000	1.000		66.4	66.4	1.000		203.1	203.1	-2237.1

	- - - - - - - - - - - - - - - - Station Quantities - - - - - - - - - - - - - - - -								
	- - - - - - - - - - Cut - - - - - - - - - -				- - - - - - - - - - Fill - - - - - - - - - -				
Baseline Station	Factor	Area	Volume	Adjusted	Factor	Area	Volume	Adjusted	Mass Ordinate
246+00.000	1.000		68.9	68.9	1.000		264.3	264.3	-2432.5
247+00.000	1.000		35.3	35.3	1.000		216.2	216.2	-2613.4
248+00.000	1.000		50.5	50.5	1.000		246.5	246.5	-2809.4
249+00.000	1.000		4.5	4.5	1.000		543.1	543.1	-3347.9
250+00.000	1.000		299.0	299.0	1.000		209.7	209.7	-3258.6
251+00.000	1.000		65.5	65.5	1.000		191.0	191.0	-3384.1
252+00.000	1.000		116.3	116.3	1.000		114.9	114.9	-3382.7
253+00.000	1.000		170.5	170.5	1.000		92.4	92.4	-3304.7
254+00.000	1.000		83.5	83.5	1.000		120.2	120.2	-3341.3
255+00.000	1.000		44.1	44.1	1.000		242.5	242.5	-3539.7
256+00.000	1.000		171.5	171.5	1.000		86.6	86.6	-3454.9
257+00.000	1.000		75.7	75.7	1.000		99.0	99.0	-3478.1
258+00.000	1.000		27.9	27.9	1.000		169.8	169.8	-3620.0
259+00.000	1.000		56.8	56.8	1.000		307.8	307.8	-3871.0
260+00.000	1.000		31.3	31.3	1.000		257.1	257.1	-4096.8
261+00.000	1.000		73.0	73.0	1.000		334.9	334.9	-4358.7
262+00.000	1.000		33.4	33.4	1.000		320.9	320.9	-4646.2
263+00.000	1.000		196.4	196.4	1.000		193.5	193.5	-4643.3
264+00.000	1.000		635.5	635.5	1.000		99.1	99.1	-4107.0

	- - - - - - - - - - - - - - - - Station Quantities - - - - - - - - - - - - - - - -								
	- - - - - - - - - - Cut - - - - - - - - - -				- - - - - - - - - - Fill - - - - - - - - - -				
Baseline Station	Factor	Area	Volume	Adjusted	Factor	Area	Volume	Adjusted	Mass Ordinate
265+00.000	1.000		745.0	745.0	1.000		121.6	121.6	-3483.6
266+00.000	1.000		649.7	649.7	1.000		227.4	227.4	-3061.3
267+00.000	1.000		596.9	596.9	1.000		471.6	471.6	-2936.0
268+00.000	1.000		376.9	376.9	1.000		489.6	489.6	-3048.6
269+00.000	1.000		259.7	259.7	1.000		406.5	406.5	-3195.4
270+00.000	1.000		200.8	200.8	1.000		456.4	456.4	-3450.9
271+00.000	1.000		218.2	218.2	1.000		329.5	329.5	-3562.2
272+00.000	1.000		81.4	81.4	1.000		174.7	174.7	-3655.6
273+00.000	1.000		23.8	23.8	1.000		178.2	178.2	-3810.0
274+00.000	1.000		49.1	49.1	1.000		208.9	208.9	-3969.8
275+00.000	1.000		28.4	28.4	1.000		373.0	373.0	-4314.5
276+00.000	1.000		1.4	1.4	1.000		313.7	313.7	-4626.8
277+00.000	1.000		9.1	9.1	1.000		408.4	408.4	-5026.1
278+00.000	1.000		31.3	31.3	1.000		502.1	502.1	-5496.9
279+00.000	1.000		66.6	66.6	1.000		312.0	312.0	-5742.3
280+00.000	1.000		127.3	127.3	1.000		238.4	238.4	-5853.3
281+00.000	1.000		92.8	92.8	1.000		231.1	231.1	-5991.7
282+00.000	1.000		125.2	125.2	1.000		133.1	133.1	-5999.5
283+00.000	1.000		203.3	203.3	1.000		136.2	136.2	-5932.4

	Station Quantities								
	Cut				Fill				
Baseline Station	Factor	Area	Volume	Adjusted	Factor	Area	Volume	Adjusted	Mass Ordinate
284+00.000	1.000		131.9	131.9	1.000		374.5	374.5	-6175.1
285+00.000	1.000		548.3	548.3	1.000		69.3	69.3	-5696.1
286+00.000	1.000		655.1	655.1	1.000		53.3	53.3	-5094.2
287+00.000	1.000		832.5	832.5	1.000		73.9	73.9	-4335.6
288+00.000	1.000		931.7	931.7	1.000		99.3	99.3	-3503.1
289+00.000	1.000		954.3	954.3	1.000		111.2	111.2	-2660.1
290+00.000	1.000		744.8	744.8	1.000		147.8	147.8	-2063.1
291+00.000	1.000		668.0	668.0	1.000		268.3	268.3	-1663.5
292+00.000	1.000		358.2	358.2	1.000		388.6	388.6	-1693.8
293+00.000	1.000		32.0	32.0	1.000		335.2	335.2	-1997.0
294+00.000	1.000		2.1	2.1	1.000		611.7	611.7	-2606.6
295+00.000	1.000		1.5	1.5	1.000		315.0	315.0	-2920.1
296+00.000	1.000		12.2	12.2	1.000		262.6	262.6	-3170.6
297+00.000	1.000		19.0	19.0	1.000		466.5	466.5	-3618.1
298+00.000	1.000		3.7	3.7	1.000		304.0	304.0	-3918.4
299+00.000	1.000		8.4	8.4	1.000		284.0	284.0	-4194.0
300+00.000	1.000		15.9	15.9	1.000		260.6	260.6	-4438.7
301+00.000	1.000		72.9	72.9	1.000		241.6	241.6	-4607.4
302+00.000	1.000		101.4	101.4	1.000		215.2	215.2	-4721.2

	- - - - - - - - - - - - - - - - Station Quantities - - - - - - - - - - - - - - - -								
	- - - - - - - - - - Cut - - - - - - - - - -				- - - - - - - - - - Fill - - - - - - - - - -				
Baseline Station	**Factor**	**Area**	**Volume**	**Adjusted**	**Factor**	**Area**	**Volume**	**Adjusted**	**Mass Ordinate**
303+00.000	1.000		217.3	217.3	1.000		104.8	104.8	-4608.7
304+00.000	1.000		89.0	89.0	1.000		131.5	131.5	-4651.1
305+00.000	1.000		154.9	154.9	1.000		106.1	106.1	-4602.4
306+00.000	1.000		266.0	266.0	1.000		62.4	62.4	-4398.7
307+00.000	1.000		285.9	285.9	1.000		146.7	146.7	-4259.5
308+00.000	1.000		503.7	503.7	1.000		82.3	82.3	-3838.1
309+00.000	1.000		462.6	462.6	1.000		161.3	161.3	-3536.9
310+00.000	1.000		206.1	206.1	1.000		74.1	74.1	-3404.9
311+00.000	1.000		188.6	188.6	1.000		34.4	34.4	-3250.7
312+00.000	1.000		115.6	115.6	1.000		80.5	80.5	-3215.6
313+00.000	1.000		57.2	57.2	1.000		190.4	190.4	-3348.8
314+00.000	1.000		62.7	62.7	1.000		331.0	331.0	-3617.1
315+00.000	1.000		395.8	395.8	1.000		306.2	306.2	-3527.5
316+00.000	1.000		606.5	606.5	1.000		282.6	282.6	-3203.6
317+00.000	1.000		595.6	595.6	1.000		402.9	402.9	-3010.9
318+00.000	1.000		905.0	905.0	1.000		158.5	158.5	-2264.4
319+00.000	1.000		712.3	712.3	1.000		252.0	252.0	-1804.1
320+00.000	1.000		859.1	859.1	1.000		218.0	218.0	-1163.0
321+00.000	1.000		1208.6	1208.6	1.000		117.1	117.1	-71.6

	- - - - - - - - - - - - - - - Station Quantities - - - - - - - - - - - - - - -								
	- - - - - - - - - - Cut - - - - - - - - - -				- - - - - - - - - - Fill - - - - - - - - - -				
Baseline Station	Factor	Area	Volume	Adjusted	Factor	Area	Volume	Adjusted	Mass Ordinate
322+00.000	1.000		1219.2	1219.2	1.000		72.0	72.0	1075.6
323+00.000	1.000		830.5	830.5	1.000		87.5	87.5	1818.7
324+00.000	1.000		564.7	564.7	1.000		106.1	106.1	2277.3
325+00.000	1.000		560.1	560.1	1.000		89.7	89.7	2747.8
326+00.000	1.000		495.2	495.2	1.000		91.7	91.7	3151.2
327+00.000	1.000		703.8	703.8	1.000		68.6	68.6	3786.5
328+00.000	1.000		665.4	665.4	1.000		70.4	70.4	4381.5
329+00.000	1.000		529.5	529.5	1.000		279.3	279.3	4631.7
330+00.000	1.000		608.3	608.3	1.000		88.5	88.5	5151.5
331+00.000	1.000		600.0	600.0	1.000		64.2	64.2	5687.3
332+00.000	1.000		486.3	486.3	1.000		70.8	70.8	6102.9
333+00.000	1.000		331.9	331.9	1.000		121.1	121.1	6313.7
334+00.000	1.000		405.9	405.9	1.000		119.4	119.4	6600.3
335+00.000	1.000		128.2	128.2	1.000		228.6	228.6	6499.8
336+00.000	1.000		250.6	250.6	1.000		105.8	105.8	6644.6
337+00.000	1.000		354.8	354.8	1.000		70.7	70.7	6928.7
338+00.000	1.000		432.2	432.2	1.000		214.9	214.9	7146.0
339+00.000	1.000		87.1	87.1	1.000		54.1	54.1	7179.0

Ashland Design -Post-Construction Volume Report_

Cross Section Set Name:

Alignment Name: 60513498_Ashland East

Input Grid Factor: 1.000000 **Note:** All units in this report are in feet, square feet and cubic yards unless specified otherwise.

	---------------- Station Quantities ----------------								
	---------- Cut ----------				---------- Fill ----------				
Baseline Station	Factor	Area	Volume	Adjusted	Factor	Area	Volume	Adjusted	Mass Ordinate
370+00.000	1.000		0.0	0.0	1.000		0.0	0.0	0.0
371+00.000	1.000		1878.5	1878.5	1.000		411.8	411.8	1466.6
372+00.000	1.000		1021.3	1021.3	1.000		133.7	133.7	2354.3
373+00.000	1.000		887.1	887.1	1.000		650.8	650.8	2590.6
374+00.000	1.000		918.3	918.3	1.000		1180.0	1180.0	2328.9
375+00.000	1.000		848.0	848.0	1.000		1563.9	1563.9	1613.0
376+00.000	1.000		893.8	893.8	1.000		1213.8	1213.8	1293.1
377+00.000	1.000		742.7	742.7	1.000		211.9	211.9	1823.9
378+00.000	1.000		583.6	583.6	1.000		36.6	36.6	2370.9
379+00.000	1.000		557.8	557.8	1.000		43.6	43.6	2885.1
380+00.000	1.000		695.5	695.5	1.000		135.8	135.8	3444.9
381+00.000	1.000		799.0	799.0	1.000		192.3	192.3	4051.6

Baseline Station	Cut Factor	Cut Area	Cut Volume	Cut Adjusted	Fill Factor	Fill Area	Fill Volume	Fill Adjusted	Mass Ordinate
382+00.000	1.000		498.7	498.7	1.000		245.8	245.8	4304.4
383+00.000	1.000		462.3	462.3	1.000		134.7	134.7	4632.0
384+00.000	1.000		452.4	452.4	1.000		193.3	193.3	4891.2
385+00.000	1.000		892.3	892.3	1.000		1.1	1.1	5782.3
386+00.000	1.000		775.5	775.5	1.000		2.4	2.4	6555.5
387+00.000	1.000		726.5	726.5	1.000		16.7	16.7	7265.3
388+00.000	1.000		318.9	318.9	1.000		70.3	70.3	7513.9
389+00.000	1.000		298.9	298.9	1.000		125.1	125.1	7687.6
390+00.000	1.000		655.6	655.6	1.000		133.9	133.9	8209.3
391+00.000	1.000		668.4	668.4	1.000		33.6	33.6	8844.1
392+00.000	1.000		706.0	706.0	1.000		0.0	0.0	9550.1
393+00.000	1.000		591.1	591.1	1.000		1.0	1.0	10140.2
394+00.000	1.000		764.9	764.9	1.000		87.3	87.3	10817.8
395+00.000	1.000		758.3	758.3	1.000		316.3	316.3	11259.8
396+00.000	1.000		445.0	445.0	1.000		105.9	105.9	11598.9
397+00.000	1.000		324.2	324.2	1.000		40.3	40.3	11882.7
398+00.000	1.000		466.2	466.2	1.000		40.1	40.1	12308.8
399+00.000	1.000		718.1	718.1	1.000		67.5	67.5	12959.4
400+00.000	1.000		907.6	907.6	1.000		169.5	169.5	13697.4

	- - - - - - - - - - - - - - - Station Quantities - - - - - - - - - - - - - - -								
	- - - - - - - - - - Cut - - - - - - - - - -				- - - - - - - - - - Fill - - - - - - - - - -				
Baseline Station	**Factor**	**Area**	**Volume**	**Adjusted**	**Factor**	**Area**	**Volume**	**Adjusted**	**Mass Ordinate**
401+00.000	1.000		1079.5	1079.5	1.000		143.3	143.3	14633.7
402+00.000	1.000		1044.9	1044.9	1.000		251.1	251.1	15427.4
403+00.000	1.000		1376.5	1376.5	1.000		70.3	70.3	16733.6
404+00.000	1.000		996.0	996.0	1.000		63.2	63.2	17666.4
405+00.000	1.000		689.6	689.6	1.000		191.1	191.1	18164.9
406+00.000	1.000		481.9	481.9	1.000		62.0	62.0	18584.8
407+00.000	1.000		879.8	879.8	1.000		6.8	6.8	19457.8
408+00.000	1.000		907.4	907.4	1.000		6.2	6.2	20359.0
409+00.000	1.000		1247.7	1247.7	1.000		6.4	6.4	21600.3
410+00.000	1.000		2598.6	2598.6	1.000		17.1	17.1	24181.8
411+00.000	1.000		2497.2	2497.2	1.000		86.6	86.6	26592.5
412+00.000	1.000		2548.1	2548.1	1.000		166.2	166.2	28974.3
413+00.000	1.000		2598.5	2598.5	1.000		253.7	253.7	31319.1
414+00.000	1.000		2656.3	2656.3	1.000		437.1	437.1	33538.3
415+00.000	1.000		2212.8	2212.8	1.000		595.0	595.0	35156.1
416+00.000	1.000		1202.6	1202.6	1.000		751.5	751.5	35607.2
417+00.000	1.000		1163.4	1163.4	1.000		494.6	494.6	36275.9
418+00.000	1.000		277.1	277.1	1.000		130.2	130.2	36422.9
419+00.000	1.000		182.8	182.8	1.000		61.0	61.0	36544.7

	- - - Station Quantities - - -								
	- - - Cut - - -				- - - Fill - - -				
Baseline Station	Factor	Area	Volume	Adjusted	Factor	Area	Volume	Adjusted	Mass Ordinate
420+00.000	1.000		220.1	220.1	1.000		126.1	126.1	36638.8
421+00.000	1.000		248.7	248.7	1.000		161.9	161.9	36725.6
422+00.000	1.000		271.2	271.2	1.000		173.4	173.4	36823.3
423+00.000	1.000		346.2	346.2	1.000		149.5	149.5	37019.9
424+00.000	1.000		389.8	389.8	1.000		104.6	104.6	37305.2
425+00.000	1.000		343.6	343.6	1.000		129.4	129.4	37519.4
426+00.000	1.000		727.7	727.7	1.000		53.0	53.0	38194.1
427+00.000	1.000		1961.8	1961.8	1.000		5.1	5.1	40150.8
428+00.000	1.000		444.8	444.8	1.000		0.0	0.0	40595.7
429+00.000	1.000		677.3	677.3	1.000		0.0	0.0	41273.0
430+00.000	1.000		558.1	558.1	1.000		5.9	5.9	41825.2
431+00.000	1.000		467.1	467.1	1.000		0.0	0.0	42292.3
432+00.000	1.000		423.4	423.4	1.000		11.2	11.2	42704.5
433+00.000	1.000		458.6	458.6	1.000		0.2	0.2	43162.9
434+00.000	1.000		365.9	365.9	1.000		2.3	2.3	43526.4
435+00.000	1.000		364.6	364.6	1.000		3.1	3.1	43888.0
436+00.000	1.000		177.4	177.4	1.000		13.2	13.2	44052.1
437+00.000	1.000		265.3	265.3	1.000		22.6	22.6	44294.8
438+00.000	1.000		256.0	256.0	1.000		25.5	25.5	44525.4

	Station Quantities								
	Cut				Fill				
Baseline Station	Factor	Area	Volume	Adjusted	Factor	Area	Volume	Adjusted	Mass Ordinate
439+00.000	1.000		218.9	218.9	1.000		27.2	27.2	44717.1
440+00.000	1.000		335.9	335.9	1.000		6.8	6.8	45046.2
441+00.000	1.000		489.5	489.5	1.000		14.0	14.0	45521.7
442+00.000	1.000		1765.4	1765.4	1.000		168.7	168.7	47118.4
443+00.000	1.000		829.0	829.0	1.000		260.0	260.0	47687.3
444+00.000	1.000		504.7	504.7	1.000		446.6	446.6	47745.4
445+00.000	1.000		1014.8	1014.8	1.000		333.7	333.7	48426.5
446+00.000	1.000		1052.6	1052.6	1.000		559.8	559.8	48919.3
447+00.000	1.000		1759.7	1759.7	1.000		738.2	738.2	49940.8
448+00.000	1.000		2396.6	2396.6	1.000		719.6	719.6	51617.9
449+00.000	1.000		2037.3	2037.3	1.000		307.3	307.3	53347.9
450+00.000	1.000		1101.5	1101.5	1.000		92.2	92.2	54357.2
451+00.000	1.000		297.2	297.2	1.000		124.1	124.1	54530.2
452+00.000	1.000		342.8	342.8	1.000		24.9	24.9	54848.1
453+00.000	1.000		361.8	361.8	1.000		18.4	18.4	55191.5
454+00.000	1.000		242.8	242.8	1.000		31.4	31.4	55402.9
455+00.000	1.000		159.7	159.7	1.000		62.5	62.5	55500.1
456+00.000	1.000		135.4	135.4	1.000		89.6	89.6	55545.9
457+00.000	1.000		238.2	238.2	1.000		88.1	88.1	55696.0

	Station Quantities								
	Cut				Fill				
Baseline Station	Factor	Area	Volume	Adjusted	Factor	Area	Volume	Adjusted	Mass Ordinate
458+00.000	1.000		312.6	312.6	1.000		86.7	86.7	55921.9
459+00.000	1.000		296.7	296.7	1.000		62.4	62.4	56156.2
460+00.000	1.000		361.0	361.0	1.000		88.2	88.2	56429.1
461+00.000	1.000		421.1	421.1	1.000		175.4	175.4	56674.8
462+00.000	1.000		372.4	372.4	1.000		60.5	60.5	56986.7
463+00.000	1.000		328.0	328.0	1.000		111.4	111.4	57203.3
464+00.000	1.000		335.0	335.0	1.000		77.0	77.0	57461.3

Mission Pre-Construction -Post-Construction Volume Report

End Area Volume Report

Cross Section Set Name: Mission Plan Vs Final

Alignment Name: 60513498-Mission Full

Input Grid Factor: 1.0000 **Note:** All units in this report are in feet, square feet and cubic yards unless specified otherwise.

Baseline	Plan Station Quantities[1]				Final Station Quantities[2]				Δ Plan and Final			
Station	------ Cut- ----		------ FILL- ----		------ Cut- ----		------ FILL- ----		------ Cut- ----		------ FILL- ----	
	Area	Volume	Area	Volume	Area	Volume	Area	Volume	Δ Area	Δ Volume	Δ Area	Δ Volume
228+00.000	1.499	2.8	28.989	170.3	3.998	7.4	46.173	224.0	2.499	4.628	17.184	53.715
229+00.000	0.000	0.0	62.979	279.8	0.000	0.0	74.801	300.5	0.000	0.000	11.823	20.696
230+00.000		0.0	88.127	401.9		0.0	87.480	395.3	0.000	0.000	-0.646	-6.647
231+00.000		0.0	128.908	513.8		0.0	125.965	556.1	0.000	0.000	-2.943	42.294
232+00.000		0.0	148.538	577.0		0.0	174.320	624.1	0.000	0.000	25.782	47.074
233+00.000		0.0	163.067	550.6		0.0	162.705	565.0	0.000	0.000	-0.362	14.443
234+00.000		0.0	134.240	473.0		0.0	142.401	556.4	0.000	0.000	8.161	83.316
235+00.000		0.0	121.206	575.9		0.0	158.036	667.0	0.000	0.000	36.830	91.091
236+00.000		0.0	189.785	515.5		0.0	202.145	1145.7	0.000	0.000	12.360	630.295
237+00.000		0.0	88.560	603.5		0.0	416.560	1259.1	0.000	0.000	328.000	655.610
238+00.000		0.0	237.347			0.0	263.376		0.000	0.000	26.030	0.000
	Total:	2.776		4661.395		7.404		6293.282		4.628		1631.887

Notes:

1- Quantities were calcluated using the 2016 UAS orginal ground survey and the design/plan alignement and typical sections

2- Quantities were calcluated using the 2016 UAS orginal ground survey and the final as-built 2017 survey

Ashland Pre-Construction -Post-Construction Volume Report

End Area Volume Report

Cross Section Set Name: Ashland Staked vs UAS Final

Alignment Name: 60513498_Ashland East

Input Grid Factor: 1.0000 **Note:** All units in this report are in feet, square feet and cubic yards unless specified otherwise.

Baseline	Plan Station Quantities[1]				Final Station Quantities[2]				Δ Plan and Final			
	------ Cut- ----		------ FILL- ----		------ Cut- ----		------ FILL- ----		------ Cut- ----		------ FILL- ----	
Station	Area	Volume	Area	Volume	Area	Volume	Area	Volume	Δ Area	Δ Volume	Δ Area	Δ Volume
405+00.000	0.000	16.2	867.720	1405.0	0.00	0.00	903.90	1550.09	0.000	-16.2	36.180	145.1
405+50.000	17.520	54.5	640.690	961.3	0.00	0.00	770.20	1223.52	-17.520	-54.5	129.510	262.2
406+00.000	41.310	116.8	397.500	642.9	0.00	4.14	551.20	887.41	-41.310	-112.6	153.700	244.5
406+50.000	84.800	280.7	296.810	520.6	4.47	14.90	407.20	703.15	-80.331	-265.8	110.390	182.5
407+00.000	218.330	349.3	265.450	430.6	11.62	130.20	352.20	564.26	-206.710	-219.1	86.750	133.6
407+50.000	158.910	312.4	199.610	264.6	129.00	217.59	257.20	362.41	-29.910	-94.8	57.590	97.8
408+00.000	178.430	600.6	86.170	97.5	106.00	617.29	134.20	124.26	-72.430	16.7	48.030	26.7
408+50.000	470.170	1217.4	19.140	20.9	560.68	1642.14		0.00	90.505	424.8	-19.140	-20.9
409+00.000	844.570	2911.5	3.380	3.1	1212.84	2819.29		0.00	368.265	-92.2	-3.380	-3.1
409+50.000	2299.830	7040.6	0.000	0.0	1832.00	5951.87		0.00	-467.830	-1088.7	0.000	0.0
410+00.000	5304.020	6356.3	0.000	0.0	4596.02	5216.12		0.00	-708.005	-1140.2	0.000	0.0
410+30.000	6137.340	4378.6	0.000	0.0	4793.00	3418.70		0.00	-1344.340	-959.9	0.000	0.0
410+50.000	5685.000	7830.0	0.000	0.0	4437.50	6161.59		0.00	-1247.500	-1668.4	0.000	0.0
411+00.000	2771.360	4104.2	0.000	0.0	2217.02	4145.09		0.00	-554.340	40.9	0.000	0.0
411+50.000	1661.190	2952.9	0.000	0.0	2259.68	3137.94		0.00	598.485	185.0	0.000	0.0
412+00.000	1527.970	2773.7	0.000	0.0	1129.30	2114.25		0.00	-398.670	-659.4	0.000	0.0
412+50.000	1467.590	2622.6	0.000	0.0	1154.09	2073.72		0.00	-313.500	-548.9	0.000	0.0
413+00.000	1364.840	2422.6	0.000	0.0	1085.53	1898.10		0.00	-279.315	-524.5	0.000	0.0
413+50.000	1251.590	2082.8	0.000	0.0	964.43	1625.94		0.00	-287.165	-456.9	0.000	0.0
414+00.000	997.860	2056.0	0.000	0.0	791.59	1704.71		0.00	-206.270	-351.3	0.000	0.0
414+65.090	707.870	1312.2	0.000	0.0	622.67	1069.29		0.00	-85.200	-242.9	0.000	0.0
415+19.090	604.300		0.000		446.62				-157.680		0.000	
Total:		51791.8		4346.5		43962.87		5415.09		-7828.9		1068.6

Notes:

1- Quantities were calculated using the MDT Slope staking notes and cross section of original surface

2- Quantities were calculated using the 2016 UAS original ground survey and the final as-built 2018 survey