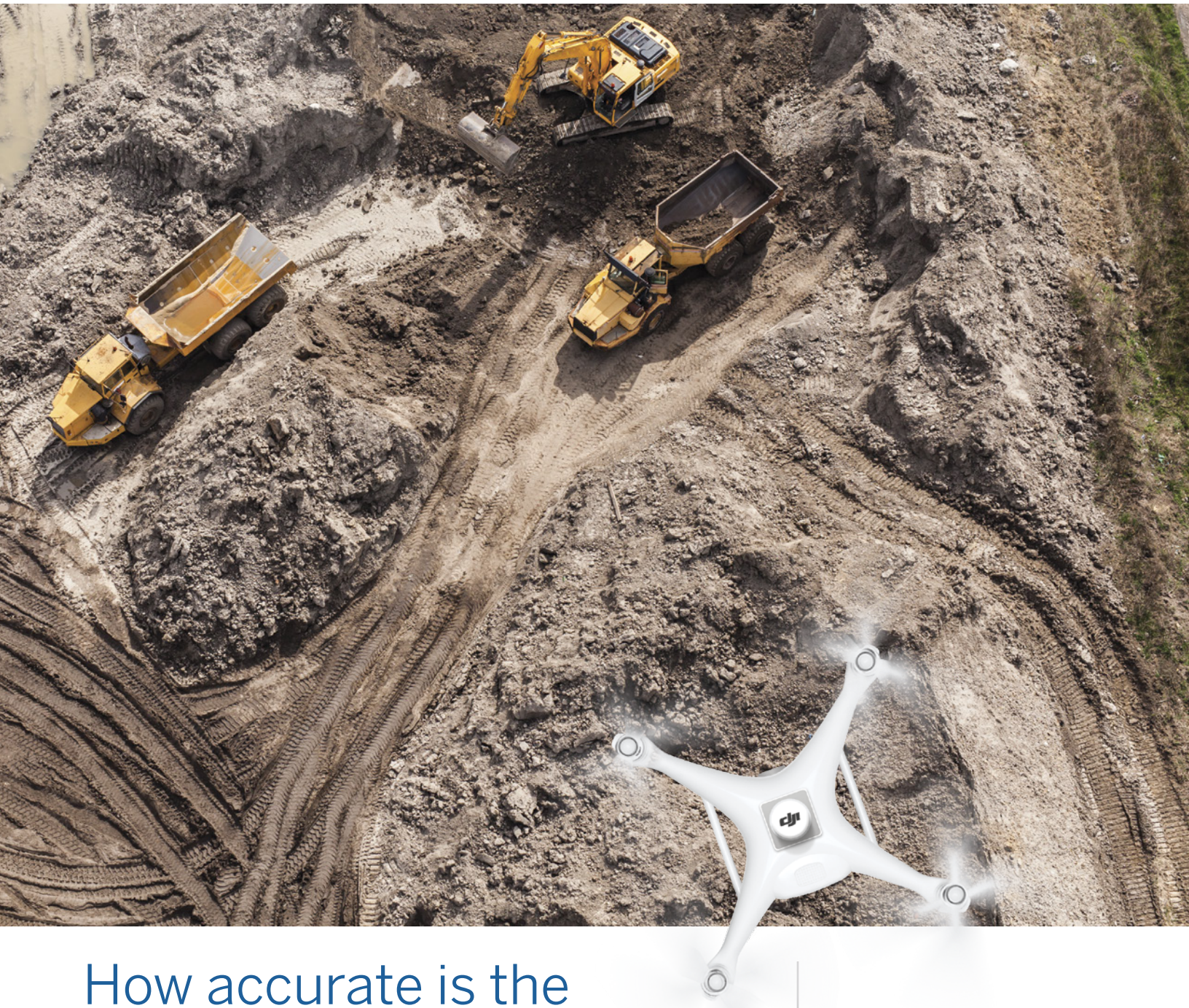
WHITE PAPER

Trimble Stratus

PPK WORKFLOW



How accurate is the PPK workflow?

Find out more at
construction.trimble.com

overview

To get accurate, survey-grade maps, drones without PPK capability require sufficient ground control points to achieve accurate results. PPK drones rely on high accuracy GNSS to create the end product, which improves coarse GPS positions down to a few centimeters level.

This paper will explain our testing methods and results.

HOW AEROPOINTS FIT INTO THE WORKFLOW

AS A PPK BASE STATION

In order to get results relative to a jobsite, one GCP is required. One AeroPoint serving as a passive base over a known point eliminates a bias.

PROJECTING TO LOCAL COORDINATES

Worksites typically work on local site coordinate systems.

In order transform from WGS84 coordinates to that of a local coordinate system, two things must be established:

1. A local coordinate system definition, which is typically stored in a Trimble® JXL file or similar format.
2. A point whose position is accurately known in local coordinates.

REMOVING RESIDUAL ERRORS

The AeroPoint operating as a ground control point can function as the correction source for the drone.

GNSS accuracy is related to the distance between the base and rover. Using an Aeropoint onsite results in short baselines with minimal error.

AS CHECKPOINTS FOR ACCURACY VALIDATION

To establish further validation, additional AeroPoints should be used as checkpoints. These are not used to correct the model, but rather to validate the model's accuracy independently.

Checkpoints allow for independent validation of the surface model.

Checkpoints uploaded are checked against the model automatically, and the results are published in the processing report.

CLAIMS

This test will show checkpoints across a given survey. To capture surveys of this accuracy, all that is needed is:

- One AeroPoint on the ground (over a known point if working in local coordinates)
- A flight to be at least 10 minutes or longer

EQUIPMENT USED

- 1x DJI Phantom 4 Pro RTK edition
- 10x AeroPoints (one as a GCP and nine as checkpoints, with some used twice)
- 1x Trimble SPS985 dual-frequency GPS Rover
- 19x checkmarks as captured with SPS985

GLOSSARY

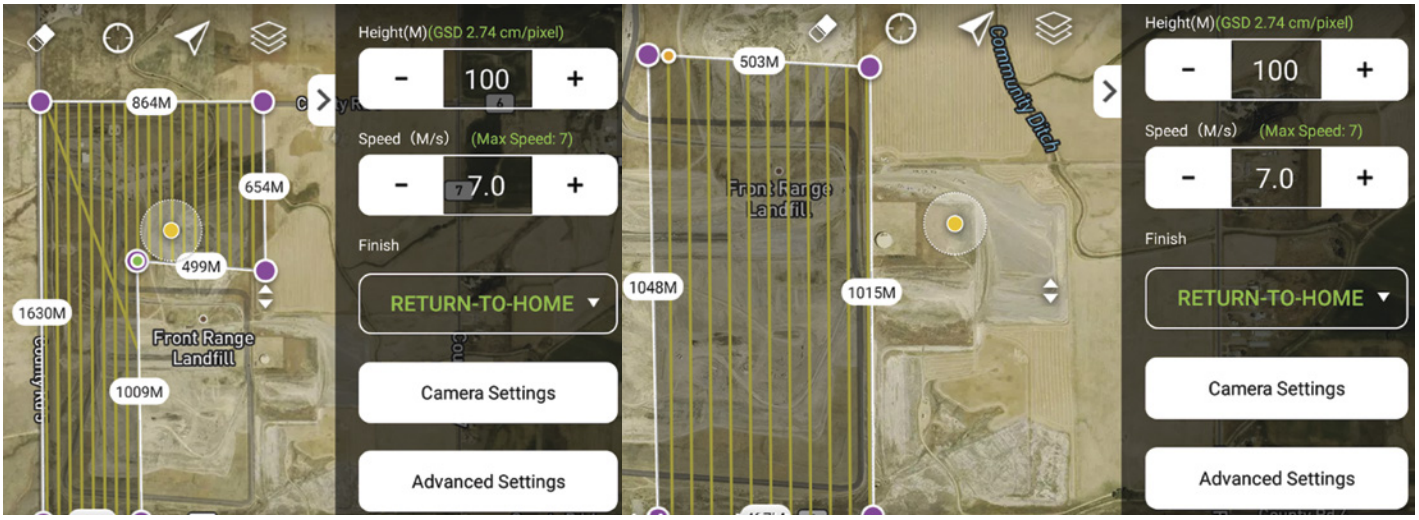
- **P4P** — DJI's Phantom 4 Pro. For the purposes of this whitepaper, we are referring exclusively to the version with integrated L1/L2 GNSS antenna.
- **PPK** — Post-processed kinematic. A method of correcting GNSS positions against a base station after the fact—i.e. no real-time connection between the base station and drone is required.
- **RTK** — Real-time kinematic. A method of correcting drone GNSS positions against a base station in real time, using a radio link between the base station and the drone.
- **GCP** — Ground control point. A visual point measured accurately in 3D which is used to improve the accuracy of aerial models.
- **Checkpoint** — A point measured accurately in 3D, which is not used to improve the model accuracy, but is used to determine the accuracy of the final model.
- **RMS Error:** — Root mean square error is designed to aggregate the errors between equivalent data points in two comparative datasets.

Testing Description

On September 23, 2018, a team from Trimble went out to a jobsite in Colorado to test the P4P PPK drone's accuracy in a workflow using an AeroPoint as a passive base.

Our test was designed to cover an area of 320 acres, 0.5 x 1 mile. With a large pile located in the southeast half of this site, the flight plan was broken up into lower lying areas (below left) and higher areas (below right).

FLIGHT SETTINGS



- Altitude—85m AGL
- Over- and sidelap—70%
- Shutter Priority setting checked, set to 1/1600s
- Built-in distortion correction—On

GROUND CONTROL SETUP

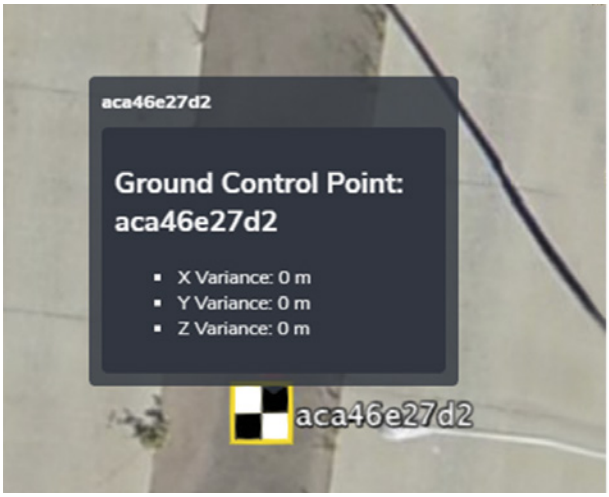
Nineteen checkpoints were placed around the site.

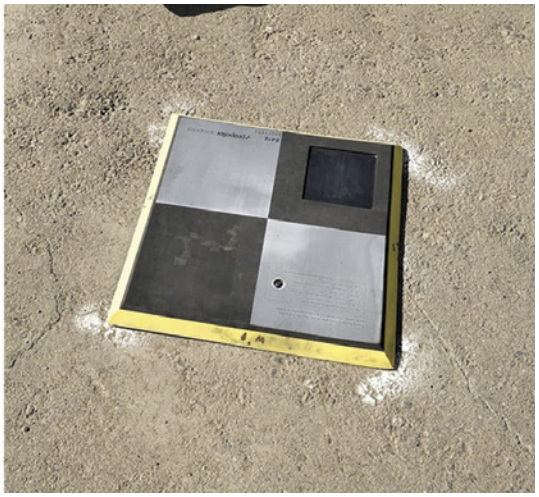
One set of AeroPoints (x10) were also laid out for each individual flight. Once, while flying the higher areas, and again, when flying over lower areas, resulting in 15 unique AeroPoint captures (layout pictured below).

Just one AeroPoint was placed on a known location. This is “aca46e27d2,” and labeled in blue on the right image.

Orthomosaic with Ground Control (Blue) and Check Point (Yellow) Locations

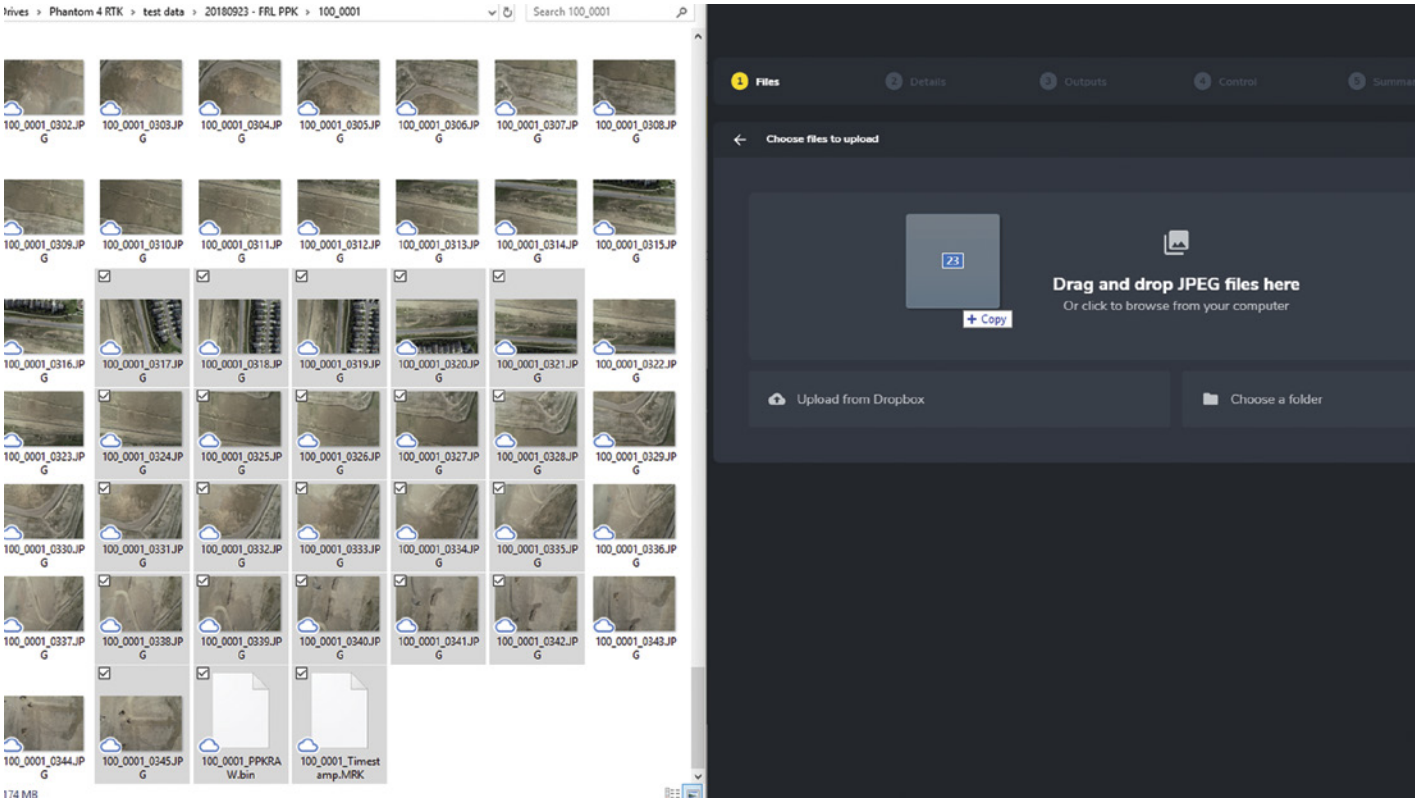
This AeroPoint acted as the sole GCP in the model, and was placed by laying the target on an AeroPoint stencil over a control point known in local coordinates. The drone used five batteries to cover the whole site, and completed the flight in 90 minutes.





Note that the checkpoints along the left side of the site are actually outside of the drone's flight zone. We wanted to test nonoptimal surveying which is dictated by 107 restriction of flying over non-participants, and this layout makes the checkpoint data used here the worst-case scenario when it comes to placement.

Even with this disadvantage, the accuracy still remains at or under 1/10ft (3cm), as we will show further down. All AeroPoints were collected and then SD card data from the drone was uploaded into Trimble Stratus:

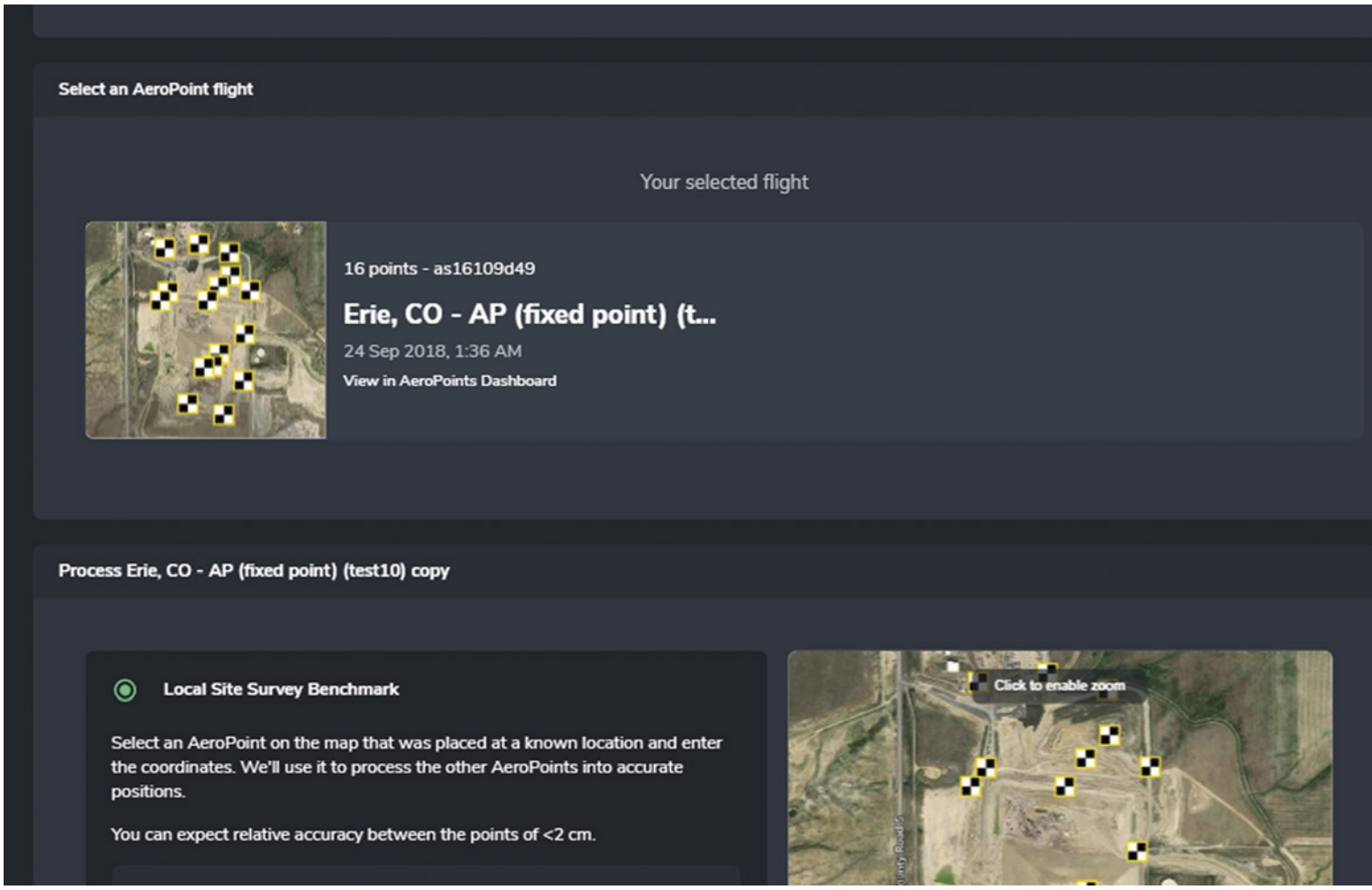


Trimble Stratus automatically checked the dataset integrity.

- ✓ **All files must have names under 255 characters in length**
- ✓ **All files are unique**
- ✓ **Submitting 21 source photos**
- ✓ **All photos must have compatible geotags**
- ✗ **PPK data files must be valid**

  21 images added, but there are 345 PPK timestamps
- ✓ **All images over 8 Megapixels**

The Trimble Stratus interface prompts users through the steps to select an AeroPoint survey (consisting of at least one GCP and/or checkpoints):



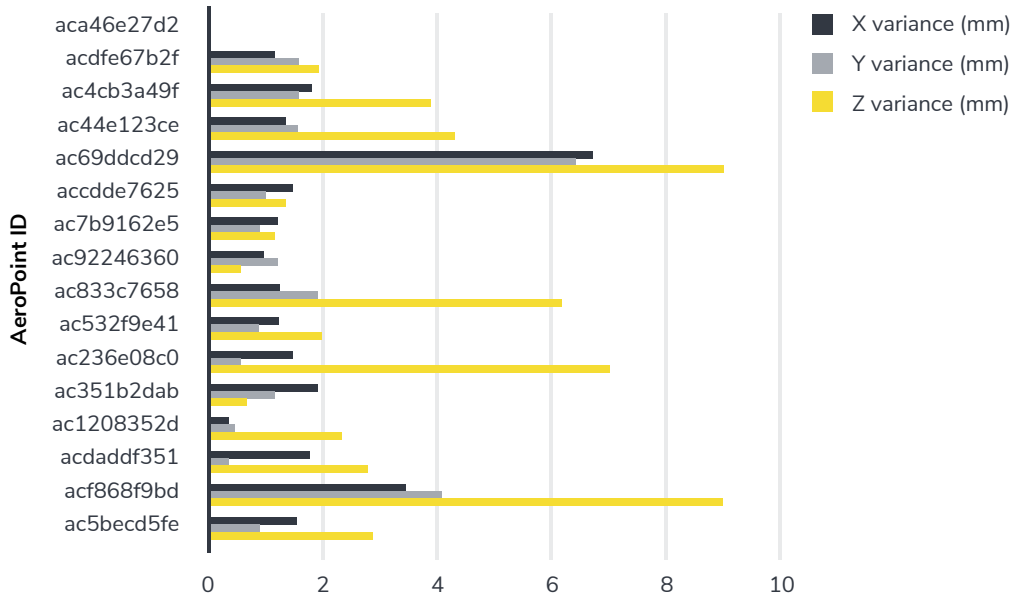
Users then follow the prompts and hit upload. Both the drone images and the PPK data are uploaded.

Results

Survey 1 — September 23, 2018

AEROPOINT ACCURACY

Reported AeroPoint accuracies as processed against single AeroPoint on a known point (mm)



For our first flight, we calculated the variances in each dimension for all the AeroPoints used in this survey. They reported internally consistent numbers as processed using the known-point method.

This is where the coordinates of the AeroPoint placed over the known control point are used as the origin to calculate the positions of the remaining AeroPoints.

IMAGE POSITION ACCURACY

Total Number of Images: 1595
Usable Images: 1595
Average Altitude AGL: 328 usft
Ground Resolution: 1.07 in/pixel

Aligned Cameras	X error (usft)	Y error (usft)	X/Y error (usft)	Z error (usft)	Total (usft)
1539	0.03	0.03	0.04	0.07	0.1

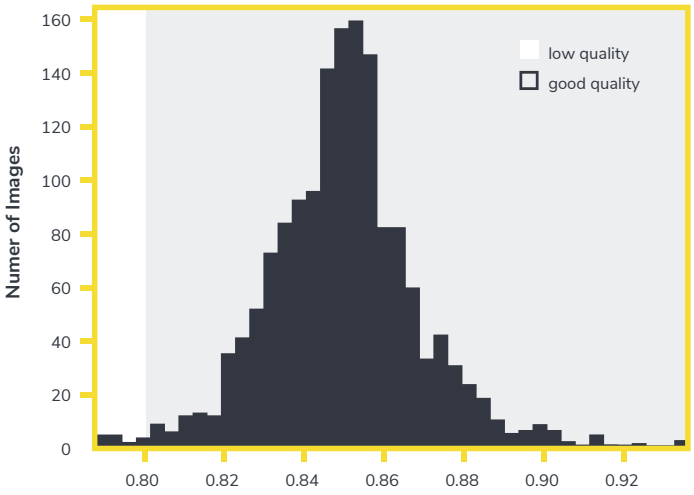
We also computed the accuracy of each image's geotagged position. The errors above indicate how far the processing engine had to shift the imagery from the geotagged camera locations to best fit with each other and the single ground control point laid out on site.

Here, low numbers mean the image positions fundamentally agree with the position of the single GCP position. The right-left distortion was no more than 0.04ft (1.2cm), while the height was 0.07ft (2.1cm).

PHOTO QUALITY

We also we assessed the quality for each drone-captured image. In this chart, you can see the image quality be very high, with most photos coming in with a quality score of 0.85.

Image quality is an arbitrary scale of 0–1, where Trimble Stratus looks at sharpness, contrast, and white balance to test whether images are sharp and properly lit. A vital quality for precise 3D mapping.



CHECKPOINT ACCURACY

Once the data was processed, we calculated the RMS error against checkpoints placed around the site. As shown in the table (lower right), it was at about 1/10ft (3cm), with the average of absolute error values going below that at less than 1/10ft (2cm).

RAW RESULTS — September 23

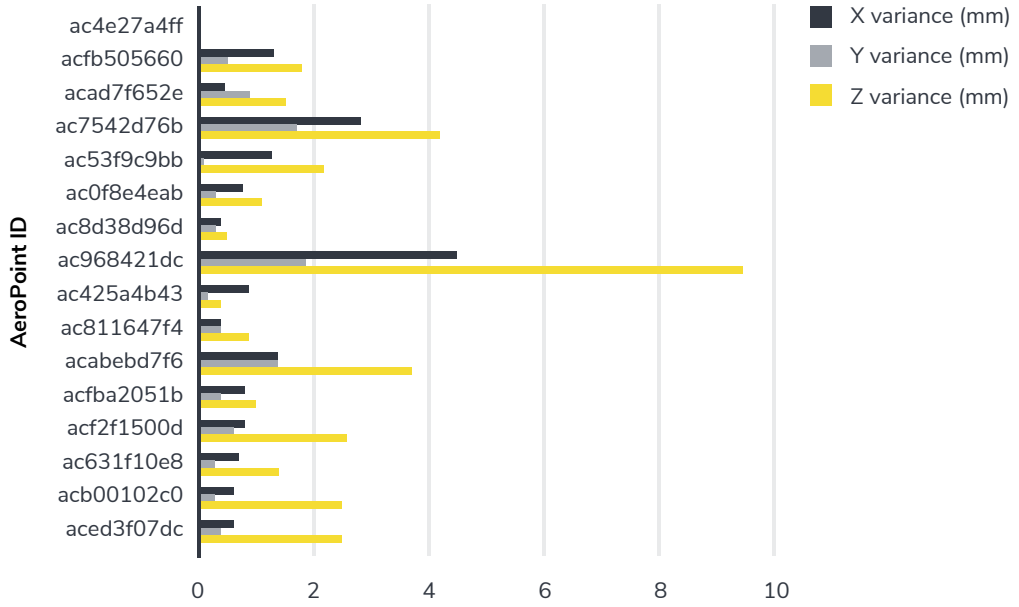
Check Point Label	Check Point Elevation (US ft)	Surface Elevation (US ft)	Difference (US ft)	Difference (m)
acdfe67b2f	5278.253	5278.156	0.097	0.030
ac4cb3a49f	5288.497	5288.430	0.067	0.020
ac44e123ce	5309.961	5309.797	0.163	0.050
ac69ddcd29	5360.303	5360.417	-0.114	-0.035
accdde7625	5386.633	5386.628	0.005	0.002
ac7b9162e5	5418.766	5418.784	-0.018	-0.005
ac92246360	5422.726	5422.702	0.024	0.007
ac833c7658	5419.423	5419.403	0.020	0.006
ac532f9e41	5279.035	5279.101	-0.065	-0.020
ac236e08c0	5295.773	5295.721	0.052	0.016
ac351b2dab	5262.995	5262.883	0.111	0.034
ac1208352d	5256.337	5256.378	-0.041	-0.012
acdaddf351	5257.437	5257.476	-0.039	-0.012
acf868f9bd	5263.513	5263.412	0.101	0.031
ac5becd5fe	5281.870	5281.765	0.105	0.032
20000	5225.116	5224.928	0.188	0.057
20002	5193.800	5193.851	-0.051	-0.016
20003	5192.859	5192.865	-0.006	-0.002
20004	5180.244	5179.894	0.350	0.107
20005	5180.724	5180.671	0.053	0.016
20007	5205.549	5205.608	-0.059	-0.018
20011	5244.292	5244.435	-0.143	-0.044
20012	5247.338	5247.438	-0.100	-0.030
20013	5253.601	5253.693	-0.092	-0.028
20016	5273.731	5273.631	0.100	0.030
20017	5273.237	5273.198	0.039	0.012
20018	5232.216	5232.331	-0.115	-0.035
20019	5269.242	5269.257	-0.015	-0.005
20020	5254.892	5254.893	-0.001	0.000
20021	5284.252	5284.295	-0.043	-0.013
20023	5278.174	5278.156	0.018	0.005
20025	5277.769	5277.704	0.065	0.020
20026	5274.920	5274.854	0.066	0.020
20028	5255.430	5255.382	0.048	0.015

	US feet	Meters
RMS	0.100	0.031
Avg. of absolute value of error	0.076	0.023

Survey 2 — September 30, 2018

AEROPOINT ACCURACY

Reported AeroPoint accuracies as processed against single AeroPoint on a known point (mm)



In the second flight, we again calculated AeroPoint positional accuracy. All AeroPoints again reported internally consistent numbers as processed using the known-point method, with no individual point getting less than 1cm accuracy, and most falling well better than that value in the height dimension.

IMAGE POSITION ACCURACY

Total Number of Images: 1595
Usable Images: 1595
Average Altitude AGL: 328 usft
Ground Resolution: 1.07 in/pixel

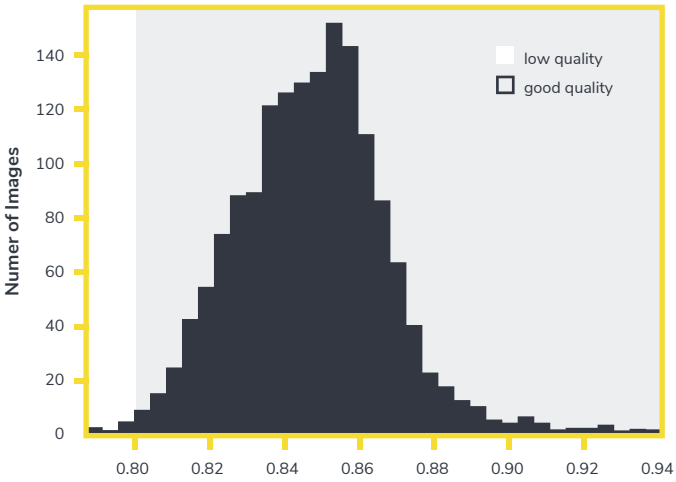
Aligned Cameras	X error (usft)	Y error (usft)	X/Y error (usft)	Z error (usft)	Total (usft)
1539	0.03	0.03	0.04	0.07	0.1

As with the first flight, image position accuracy was very high. The errors shown in the above table show how much Trimble Stratus had to shift the images from the geotagged camera positions in this second drone flight to best fit with each other and the single ground control point we placed on site.

Lower values mean less correction required. We see again very little variation as we did in the first flight, with the X and Y accuracy valued at 0.03ft (0.9cm) with a Z value of the same.

PHOTO QUALITY

We again assessed the image quality for this flight. When testing the image quality on a scale of 0–1 for sharpness, white balance, and contrast, most photos for this second flight have a score of 0.85.



CHECKPOINT ACCURACY

We checked the RMS error against the checkpoints for this second flight in the table (lower right). The values deviated very little, consistently falling at about 1/10ft (3cm), with the average of absolute error values again going a little below that, at less than 1/10ft (2cm).

RAW RESULTS — September 30

Check Point Label	Check Point Elevation (US ft)	Surface Elevation (US ft)	Difference (US ft)	Difference (m)
acfb505660	5278.261	5278.09277	0.168	0.051
acad7f652e	5268.849	5268.91601	-0.067	-0.021
ac7542d76b	5300.98	5300.99365	-0.014	-0.004
ac53f9c9bb	5332.253	5332.29296	-0.04	-0.012
ac0f8e4eab	5360.384	5360.34765	0.036	0.011
ac8d38d96d	5386.674	5386.53808	0.136	0.042
ac968421dc	5416.98	5417	-0.02	-0.006
ac425a4b43	5420.508	5420.45263	0.056	0.017
ac811647f4	5424.11	5424.07666	0.034	0.010
acabebd7f6	5296.9	5296.70166	0.199	0.061
acfba2051b	5262.766	5262.69921	0.067	0.021
acf2f1500d	5256.574	5256.49804	0.076	0.023
ac631f10e8	5257.875	5257.80029	0.075	0.022
acb00102c0	5261.969	5261.86474	0.104	0.032
aced3f07dc	5260.075	5259.89697	0.178	0.054
ac5d964ea3	5281.98	5281.8374	0.143	0.044
20000	5225.116	5225.23339	-0.117	-0.035
20002	5193.8	5193.70898	0.091	0.027
20003	5192.859	5192.80957	0.049	0.015
20004	5180.244	5180.15283	0.091	0.027
20005	5180.724	5180.74316	-0.019	-0.005
20007	5205.549	5205.58691	-0.038	-0.012
20008	5227.41	5227.47558	-0.066	-0.020
20009	5254.164	5254.27783	-0.114	-0.035
20010	5245.529	5245.41503	0.114	0.035
20011	5244.292	5244.35156	-0.06	-0.018
20012	5247.338	5247.2666	0.071	0.022
20013	5253.601	5253.52343	0.078	0.024
20016	5273.731	5273.66015	0.071	0.022
20017	5273.237	5273.09814	0.139	0.042
20018	5232.216	5232.08984	0.126	0.038
20019	5269.242	5269.13671	0.105	0.032
20020	5254.892	5254.70214	0.19	0.057
20021	5284.252	5284.33886	-0.087	-0.026
20023	5278.174	5278.09277	0.081	0.025
20025	5277.769	5277.63134	0.138	0.042

	US feet	Meters
RMS	0.102	0.031
Avg. of absolute value of error	0.091	0.028

CONCLUSION

In this repeated test, the Trimble Stratus PPK solution consistently delivered accuracy down to or below 1/10ft (3cm) across all check points with the use of a single AeroPoint serving as a base station.

The images captured with the Phantom 4 Pro PPK are of consistent high quality, with only 0.07ft (2.1cm) total vector distortion. After independent accuracy validation from multiple checkpoints across the site, Trimble Stratus delivered accuracy at or below 1/10ft (3cm).

The simple workflow of the Trimble Stratus PPK solution—place anAeroPoint, fly the Phantom 4 Pro PPK drone, upload GCP data and drone images—is unique to the current market.

The Phantom 4 Pro PPK and AeroPoints solve the issue of working in local site coordinates. They have the ability to capture accurate data and transform between coordinate systems easily by placing an AeroPoint on a local known point.

Trimble Civil Engineering and Construction
10368 Westmoor Drive
Westminster, Colorado 80021 USA
800-361-1249 (Toll Free)
+1-937-245-5154 Phone
construction_news@trimble.com

construction.trimble.com