Propeller PPK with DJI's Phantom 4 RTK How accurate is it?

Introduction

DJI's Phantom 4 RTK (P4R) is the workhorse of the commercial drone industry.

To get accurate, survey-grade maps from previous DJI drones, users needed to place 10-plus ground control points to improve coarse GPS positions down to centimeter level.

DJI worked with GPS experts at Propeller to get our smart ground control points, called AeroPoints, to integrate with the P4R's L1/L2 GNSS receiver in order to bring easy, affordable and highly accurate maps to the wider commercial drone industry.

Propeller and DJI—and validated by experts at Trimble—claim centimeter-grade accuracies are now possible with just one ground control point. This is the first totally integrated PPK solution on the market.

This paper will explain our testing methods and how our results support this level of drone mapping accuracy.

Glossary

- **P4R**: DJI's Phantom 4 RTK. 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 (x,y,z) which is used to improve the accuracy of aerial models.
- **Checkpoint**: A point measured accurately in 3D (x,y,z), 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. It is very common in GIS workflows, where, for example, you'd want to compare a LIDAR survey to a traditional survey.

Configuration as shipped

The box includes:

- 1x Phantom 4 RTK
- 1x AeroPoint, smart ground control point
- 1x AeroStencil, to create permanent GCPs
- 2x Accessories Pack (2 batteries, 1 charging hub)

How AeroPoints fit into the workflow

Removing residual errors

Despite the aggressive marketing claims with other solutions of getting survey-grade results with zero GCPs, surveyors around the world still recommend that, in order to get the best possible results, at least one GCP should be used. In order to get very accurate results, the following elements need to be properly modeled:

- Position of the drone in 3D space, down to 2cm
- Camera sensor position relative to the drone
- Camera sensor orientation relative to the drone
- Exact timing of when the camera shutter is open
- Errors present in the lens of the camera causing distortion

Propeller has worked with DJI to ensure these requirements are addressed and included in the solution. However, given the drone is typically flying through the air at 32ft/s (10m/s), it is possible that one of the above loses accuracy momentarily, which can compromise the model accuracy.

Having just one AeroPoint serving as a passive base on ground level in the model all but eliminates any remaining errors in the solution. This happens by comparing the projected positions from the sky to that of a real point stationary on the ground.

Projecting to local coordinates

In construction, surface mining, aggregates, and waste management, it is common for a worksite to operate on its own local coordinate system—primarily to avoid the adjustments that happen to large published systems over time.

In order transform from WGS84 coordinates (as are default with built in GNSS systems) to that of a local coordinate system, two things must be established:

1. A defined new grid, which is typically stored in a Trimble JXL file or similar format.
2. A point whose position is accurately known in both the WGS84 grid and the new, custom grid.

Placing the single AeroPoint on a known point addresses the residual errors as mentioned above, but it also allows all the camera positions to be calculated relative to the site's local coordinate system.

As a PPK base station

AeroPoints also work using PPK methods, so the AeroPoint operating as a ground control point can function as the correction source for the drone, too.

The corrected GNSS error is proportional to the distance from the base station to the drone or rover, so an AeroPoint a few hundred feet from the drone provides significantly higher quality position fixes as compared to a network base station potentially miles away.

As checkpoints for accuracy validation

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

By setting up one or more checkpoints, users can ensure their data is accurate. This allows them to obtain solid, independent data to prove the accuracy of their survey numbers to internal and external stakeholders.

Propeller already supports check points, so any checkpoints uploaded in during the processing flow are checked against the model automatically, and the results are published in the processing report generated after each map.

Claims

Propeller, DJI, and Trimble have worked together to deliver a fully integrated solution that reliably provides photogrammetric models accurate to 3cm (1/10 ft) from independent 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 survey flight to be at least 10 minutes or longer.
- Both image positions or resultant survey outputs available in geodetic, projected, or local coordinate systems.

  Propeller's processing solution is optimized for this workflow and is able to deliver model accuracy down to 1/10ft (3cm), even across large areas (checkpoints up to 1km from GCPs).

  DJI's optimized camera settings deliver unprecedented image quality, and, because the drone and camera rotate independently, sharp images are captured even during windy conditions.

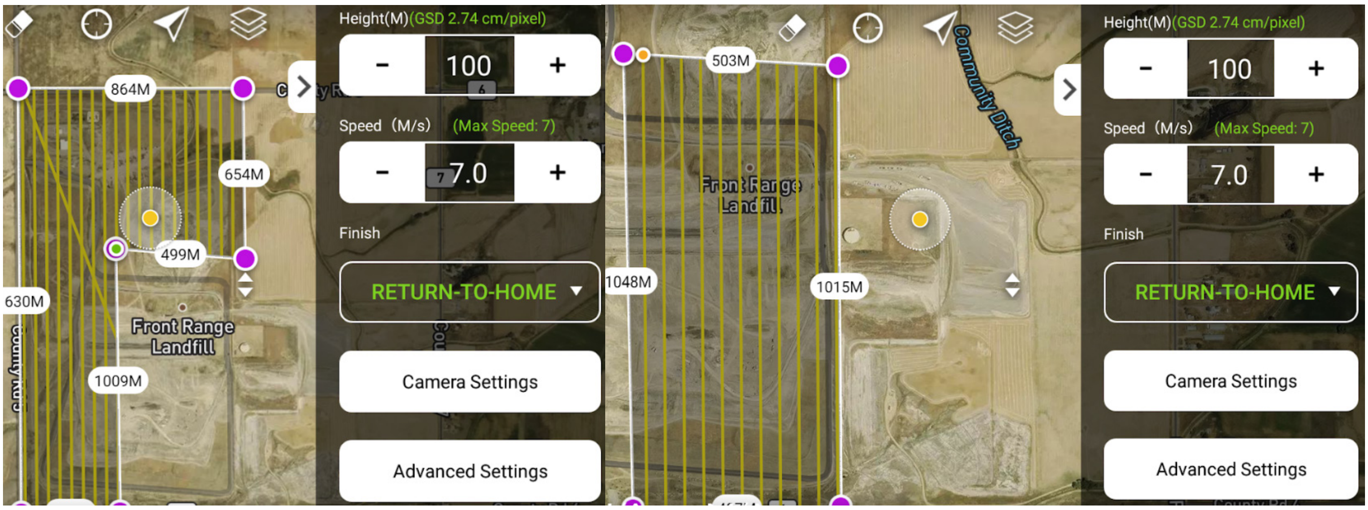
Equipment used

- 1x DJI Phantom 4 RTK
- 10x Propeller 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 and spray painted

Testing description

On September 23, 2018, a team from Trimble went out to a large (640 acre or 1 mi^2) landfill in Colorado to test the P4R PPK drone's accuracy in a workflow using an AeroPoint as a passive base.

Our test was designed to cover half the site: 1 x 0.5mi (about 360 acres). With a large pile located in the southeast half of this site, the flight plan was broken up into lower lying areas (left) and higher areas (right).



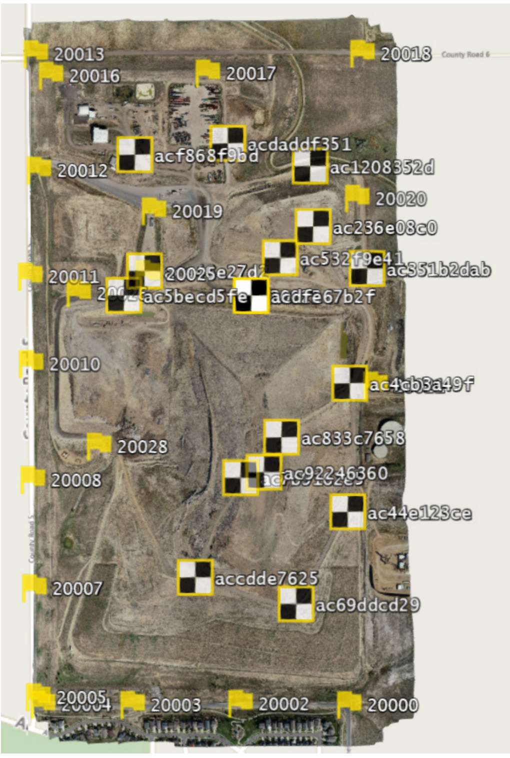
Flight settings

- 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, along with a Trimble SPS985 dual-frequency rover. The Trimble GNSS rover received corrections from a base station operating on the landfill and broadcasted over radio (photo on right).

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.



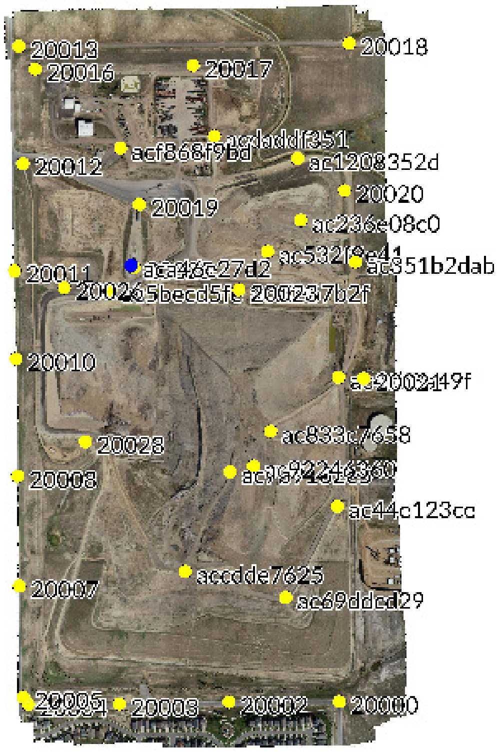
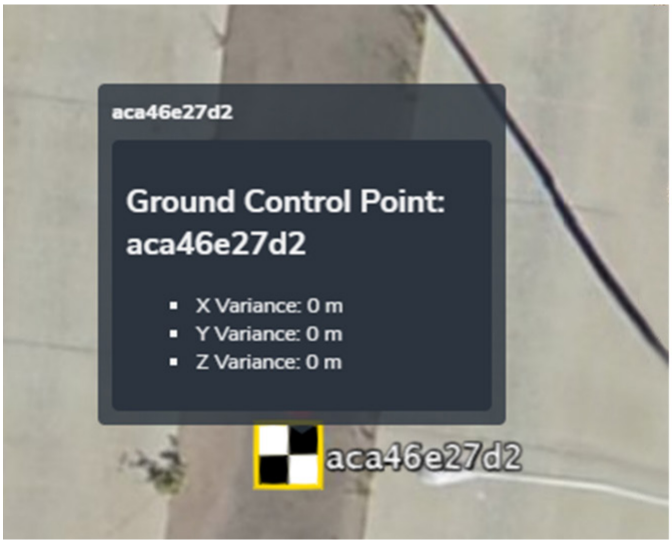
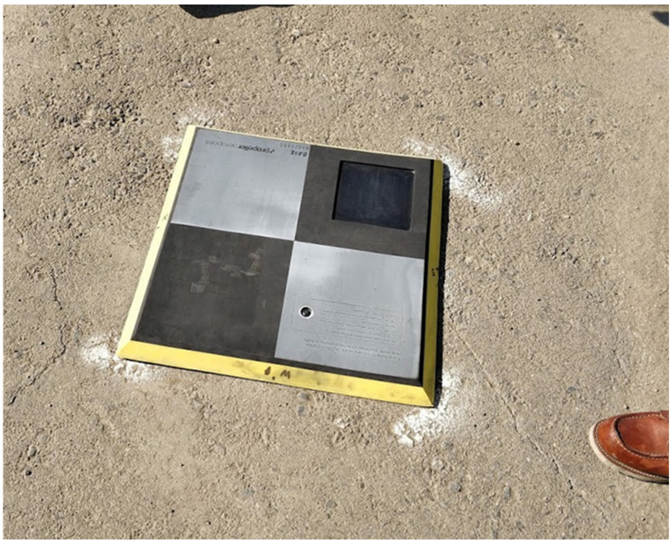


Figure 3: Orthomosaic with Ground Control (Blue) and Check Point (Yellow) Locations

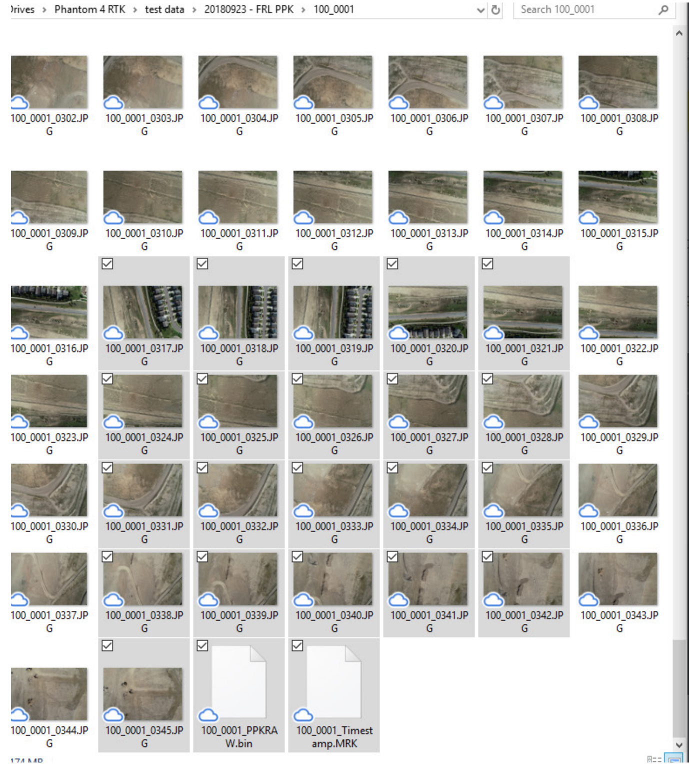
This AeroPoint acted as the sole GCP in the model, and was placed by laying the target on an AeroPoint stencil from a previously flown survey. The drone used five batteries to cover the whole site, and completed the flight in 90 minutes.

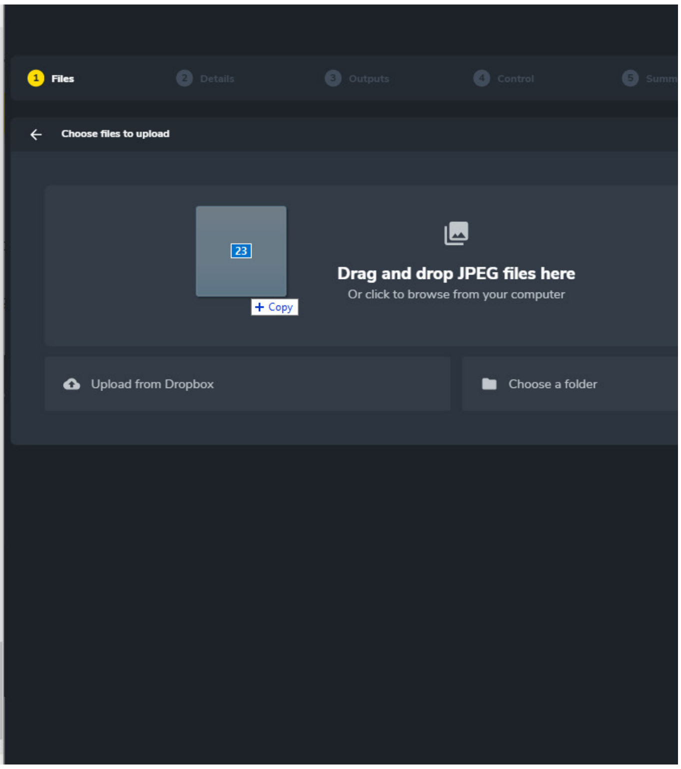




Note that the checkpoints along the left side of the site are actually outside of the drone's flight zone. We wanted to test nonoptimal surveying situations, and this layout makes the checkpoint data used here the worst-case scenario when it comes to placement.

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 the [Propeller Platform](https://www.propelleraero.com):



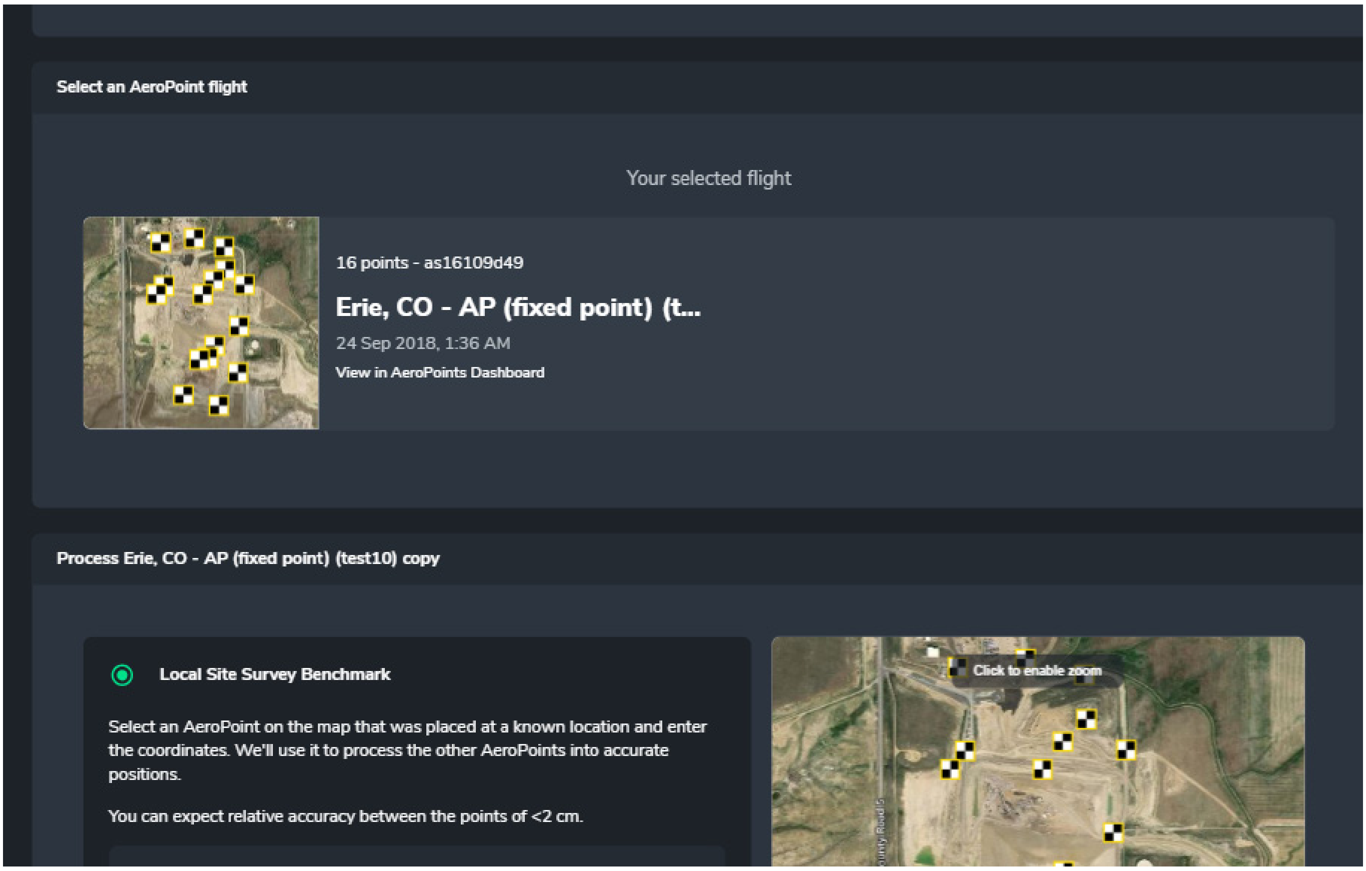


Propeller automatically checked the dataset integrity

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

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

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

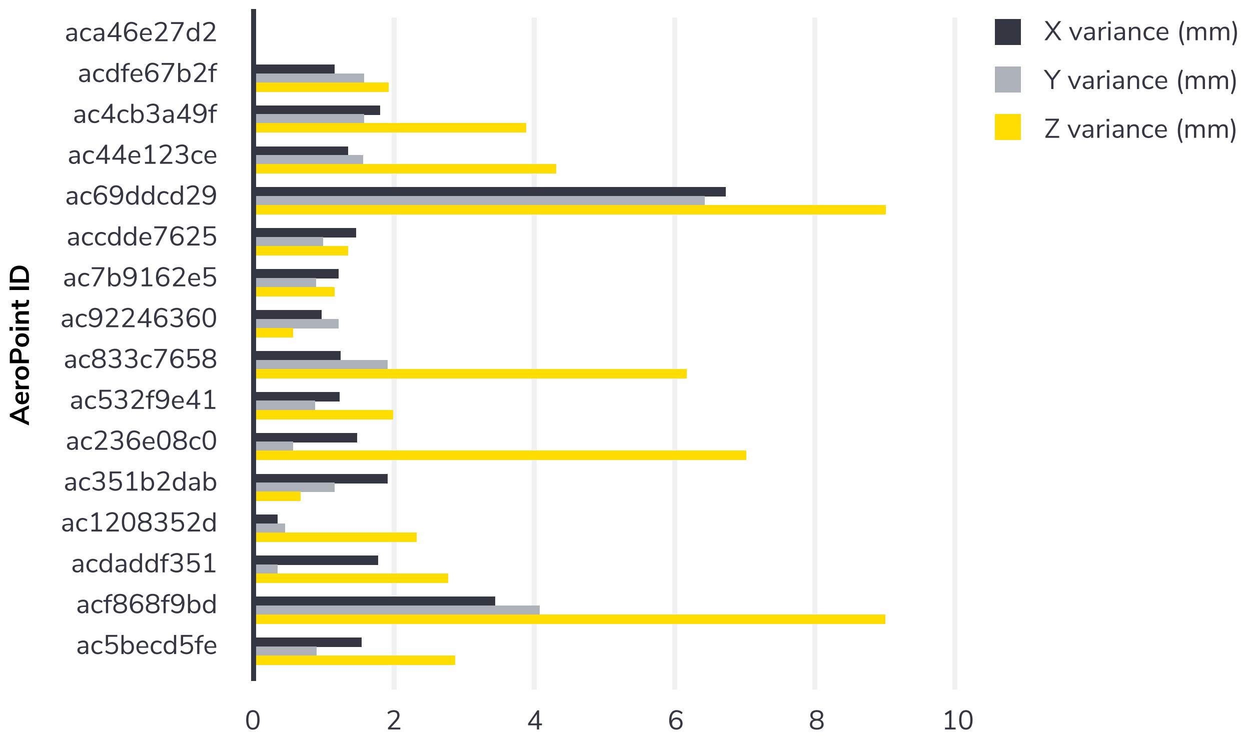


Users then follow the prompts and hit upload. Both the drone images and the PPK data are uploaded.

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 a single AeroPoint is placed on a marked position with known coordinates and that acts as a base station for the other AeroPoints. All height variance fell below 1cm, as shown in the graph above.

Image Position Accuracy

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

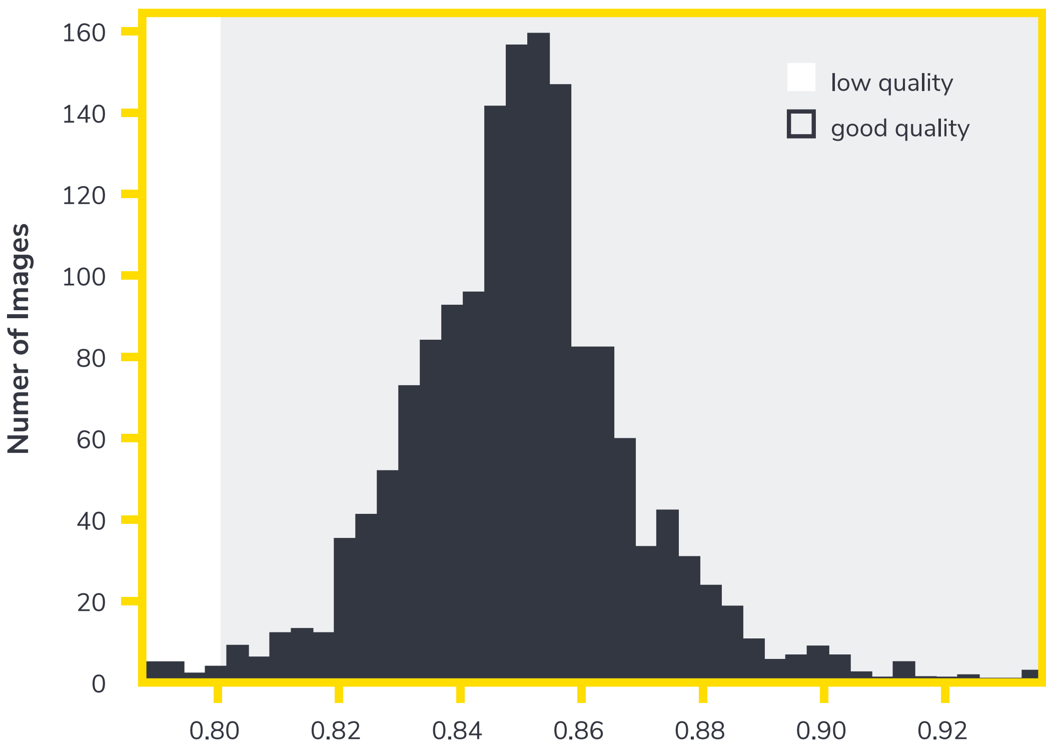
Aligned Cameras	X error (usft)	Y error (usft)	X/Y error (usft)	Z error (usft)	Total (usft)
1539	0.03	0.03	0.04	0.07	0.1

We also computed the accuracy of each image's geotagged position. The errors above indicate how far Propeller's 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), both quantities well below the survey-grade standard of 1/10ft.

Photo Quality

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

(Image quality is an arbitrary scale of 0–1, where Propeller 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

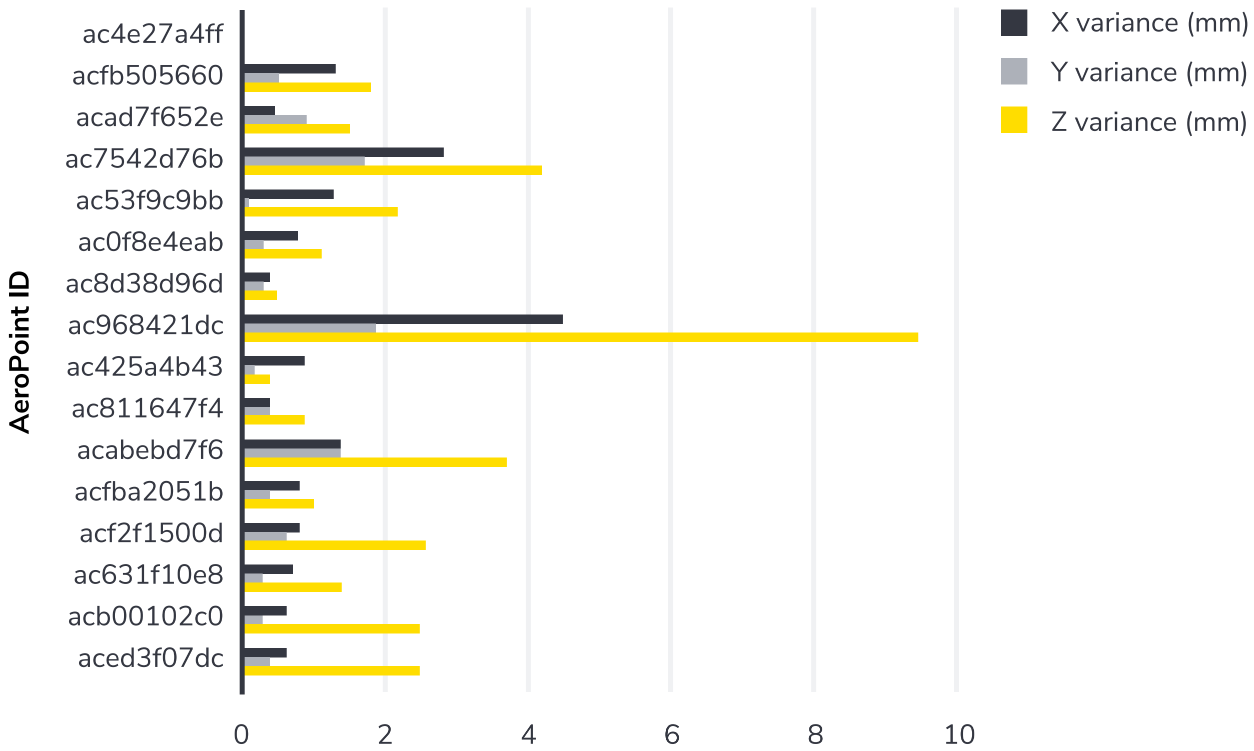
	US feet	Meters
RMS	0.100	0.031
Avg. of absolute value of error	0.076	0.023

Once the data was processed, we calculated the RMS error against checkpoints placed around the site. As shown in the above table, it was at about 1/10ft (3cm), with the average of absolute error values going below that at less than 1/10ft (2cm). These values are the best on the market and the ideal for survey-grade accuracy.

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

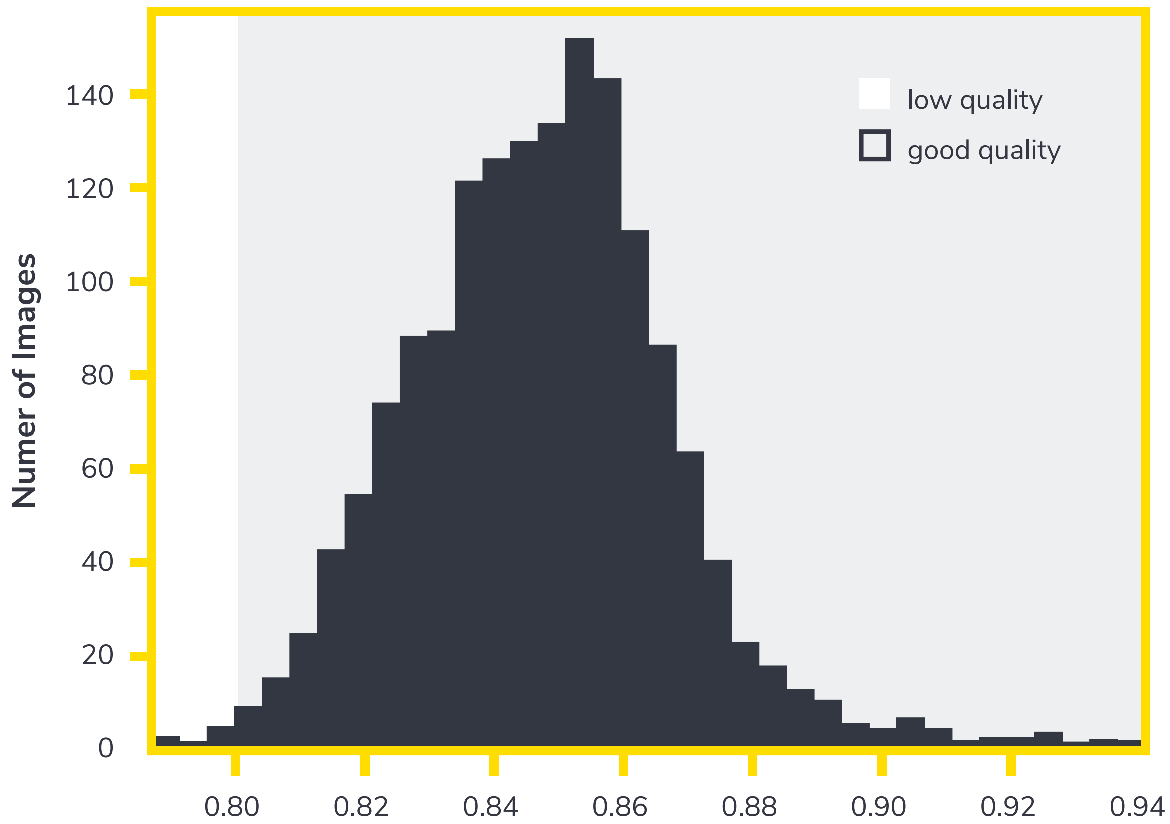
Total Number of Images:	1595	Usable Images:	1595
Average Altitude AGL:	328 usft	Ground Resolution:	1.07 in/pixel

Aligned Cameras	X error (usft)	Y error (usft)	X/Y error (usft)	Z error (usft)	Total (usft)
1595	0.03	0.03	0.04	0.03	0.07

As with the first flight, image position accuracy was very high. The errors shown in the above table show how much the Propeller Platform 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

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

We checked the RMS error against the checkpoints for this second flight in the table above. 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). These values are the gold standard for survey accuracy.

Conclusion

After repeated testing, the Propeller PPK solution consistently delivers accuracy down to or below 1/10ft (3cm) across the entire survey with the use of a single AeroPoint serving as a base station.

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

Moreover, the simple workflow of the Propeller PPK solution—place anAeroPoint, fly the Phantom 4 RTK drone, upload GCP data and drone images—is unique to the current market.

The Phantom 4 RTK and AeroPoints also solve the issue of working in local site coordinates because they have the ability to capture the data accurately and transform between coordinate systems easily by placing an AeroPoint on a local known point.

Appendix

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

	USft	Meters
RMS	0.100	0.031
Average of Absolute error values	0.076	0.023

Raw Results: September 23

Base/GCP Position 5277.61

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

	USft	Meters
RMS	0.102	0.031
Average of Absolute error values	0.091	0.028