ELEVATED DATA | GROUNDED TRUTH

Positional Accuracy Report

ASPRS Positional Accuracy Standards, Edition 2, Version 2 (2024)
Test date November 18, 2026 · Revised November 21, 2026 · Job 26-230

NOVAK GS GEOSPATIAL SOLUTIONS

Summary

Novak Geospatial Solutions™ tested the positional accuracy of a drone-derived orthomosaic and digital surface model (DSM) against independently surveyed checkpoints, following the ASPRS Positional Accuracy Standards for Digital Geospatial Data, Edition 2, Version 2 (2024). Both results are below the RMSE of the accuracy classes tested. Two findings that bear on how the results are used are summarized below and documented in sections 4 and 6.

HORIZONTAL ACCURACY ($RMSE_H$)

0.10 ft

3.0 cm · class tested: 0.16 ft (5.0 cm) · met

VERTICAL ACCURACY, NON-VEGETATED ($RMSE_V$)

0.09 ft

2.6 cm · class tested: 0.20 ft (6.0 cm) · below class RMSE

Accuracy statements

Horizontal. This data set was tested to meet ASPRS Positional Accuracy Standards for Digital Geospatial Data, Edition 2, Version 2 (2024) for a 5.0 cm (0.164 ft) $RMSE_H$ horizontal positional accuracy class. The tested horizontal positional accuracy was found to be $RMSE_H$ = 3.0 cm (0.099 ft).

Vertical. The non-vegetated vertical accuracy (NVA) measured in this test was $RMSE_V$ = 2.6 cm (0.085 ft), below the RMSE of the 6.0 cm (0.197 ft) vertical accuracy class of the ASPRS Positional Accuracy Standards for Digital Geospatial Data, Edition 2, Version 2 (2024). A “tested to meet” statement is not made for vertical accuracy, because the elevation check on NGS mark DH5092 read 0.04 to 0.16 ft low and is unresolved (section 6).

Findings to read with the results

- **Vertical reference check.** The check on the NGS mark does not establish a correction for the test site. Until it is resolved, it limits what the vertical result establishes about absolute NAVD88 elevations (section 6).
- **Horizontal mean error.** The mean horizontal error is 0.056 ft to the northwest (east -0.042 ft, north +0.037 ft). The east component is at the level where ASPRS section 7.2 recommends investigation (25% of the class RMSE, 0.041 ft). The review is in section 4. No correction was applied, and the mean error is included in the RMSE.

Site	Yahara Materials, Schadler Pit · 6053 WI-78, Mazomanie, Dane County, Wisconsin
Area and products	34.4 acres of pit floor (page 2); results apply to open, bare ground within it. Orthomosaic with 0.64 in (1.6 cm) pixels and digital surface model with 1.28 in (3.3 cm) cells, as delivered
Checkpoints	34 checkpoints were set and surveyed, and 33 were used in the assessment (ASPRS requires at least 30). One target was folded over by wind and excluded. All were withheld from processing. 5 ground control points (GCPs) controlled the model
How it was computed	Checkpoint survey uncertainty is combined with the checkpoint residual RMSE in quadrature. Horizontal: $\sqrt{(0.089^2 + 0.043^2)} = 0.099$ ft. Vertical: $\sqrt{(0.074^2 + 0.042^2)} = 0.085$ ft

1 · Test Site and Point Layout

The test area is the working floor of an aggregate pit: open, bare sand and gravel with stockpiles, haul roads and a pond. Ground control points and checkpoints were placed on flat, firm ground across the floor and on the access ramp along the northeast rim, covering an elevation range of 769.7 to 813.0 ft.



Orthomosaic from the tested flight. Orange line: validation area. Coordinates of every point are listed in section 5.

Validation area	34.4 acres, bounded by the pit floor edge. All 5 GCPs and all 33 checkpoints lie inside it
Checkpoint distribution	Checkpoints fall in all four quadrants about their centroid (NE 7, NW 10, SW 8, SE 8; each more than 20% of the total). Closest pair is 107 ft apart; no checkpoint is closer than 97 ft to a GCP
Ground conditions	Bare, non-vegetated ground at every checkpoint. No checkpoint is on a stockpile face, in vegetation or near water
Targets	2 ft black-and-white quartered targets, pinned flat, surveyed at the center
Coordinate system	NAD83(2011) / WISCRS Dane County, US survey feet (EPSG:7599), with NAVD88 (GEOID18) heights. ASPRS defines class values in centimeters; feet are shown for convenience

2 · Method

Ground survey

- All 39 points (5 GCPs, 34 checkpoints) were surveyed on November 18, 2026 between 8:48 AM and 12:12 PM with an Emlid Reach RX2 on a 2.00 m pole with bipod, using network RTK corrections from the Wisconsin WISCORS network (mountpoint RTCM34).
- Every observation was a fixed (FIX) solution averaged for 30 seconds. Receiver-reported precision was 0.016 to 0.018 ft horizontal and 0.010 to 0.018 ft vertical on every point.
- The rover was checked on National Geodetic Survey mark DH5092 (ROXBURY W GPS) before and after fieldwork (section 6).
- Seven points were re-observed 4.0 to 5.6 hours later on a new fixed solution. The survey accuracy used in this report comes from those repeat pairs (section 6).

Flight

Aircraft and camera	DJI Matrice 4E, wide camera (4/3 CMOS, 20 MP, mechanical shutter), network RTK on the same WISCORS mountpoint as the rover
Mission	Area route over a 54.4-acre boundary, 175 ft above ground, 85% forward and 80% side overlap, nadir plus 45° oblique images, ground speed about 6.5 to 8.3 mph (2.9 to 3.7 m/s) from photo metadata
Images	8,317 images. 8,180 (98.4%) carried a fixed RTK position; 137 (1.6%) did not (corrections were briefly interrupted near the 65% mark). All 8,317 were aligned
Conditions	Midday, partly cloudy and breezy. One checkpoint target was displaced by wind during the flight (section 5)

Processing

Software	DJI Terra 5.3.5, aerotriangulation followed by 2D map, point cloud, DSM and contour reconstruction
Control	GCP1 to GCP5 used as control. CP01 to CP34 entered as check points, never used in the adjustment
Target marking	Marks were placed by the software's target detection and then reviewed. Six check points whose automatic marks fell on the target edge were re-marked on the target center before the final adjustment
Aerotriangulation	1 connected block, 1.3 million tie points, reprojection error 1.21 px. GCP residuals after adjustment: 0.026 to 0.062 ft horizontal, −0.038 to +0.020 ft vertical
Outputs	Orthomosaic and DSM as GeoTIFF in NAD83(2011) / WISCRS Dane (ftUS) with NAVD88 (GEOID18) heights

Accuracy testing

- **Horizontal:** the center of each checkpoint target was located in the delivered orthomosaic and compared with its surveyed easting and northing. Centers were located by image analysis of the four-quadrant pattern and each one was confirmed by eye.
- **Vertical:** the delivered DSM was sampled at each checkpoint's surveyed easting and northing by bilinear interpolation and compared with the surveyed elevation.
- **Aerotriangulation residuals are not the result.** They are reported in section 7 for reference only.
- **No checkpoint was removed for a large residual.** Every valid checkpoint is included.

2 · Method (continued): Field Survey Photos

Each point was surveyed with the rover on the same 2.00 m pole, held plumb by a bipod with the pole tip on the center of the target. The photos below were taken at the time of each survey observation on November 18, 2026. Six of the 39 points are shown. Each target has a black-and-white four-quadrant pattern and a number for identification.



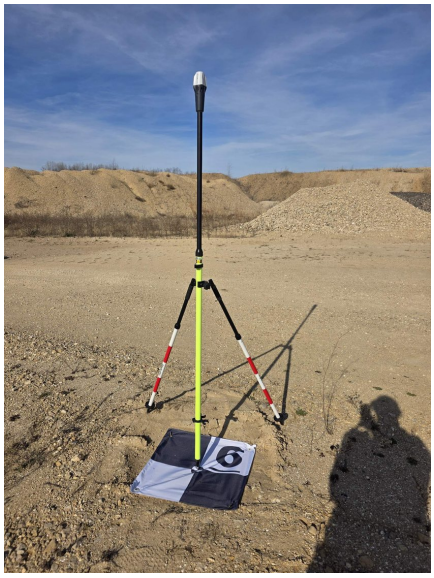
GCP5 · Ground control point · 11:48 AM



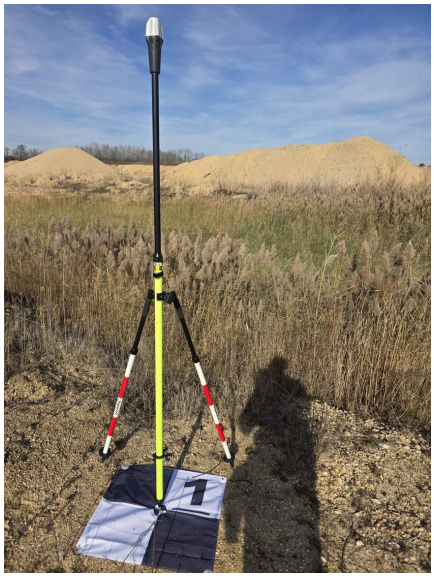
CP27 · Checkpoint · 11:40 AM



CP29 · Checkpoint · 12:02 PM



CP26 · Checkpoint · 11:31 AM



CP21 · Checkpoint · 11:04 AM



CP18 · Checkpoint · 11:10 AM

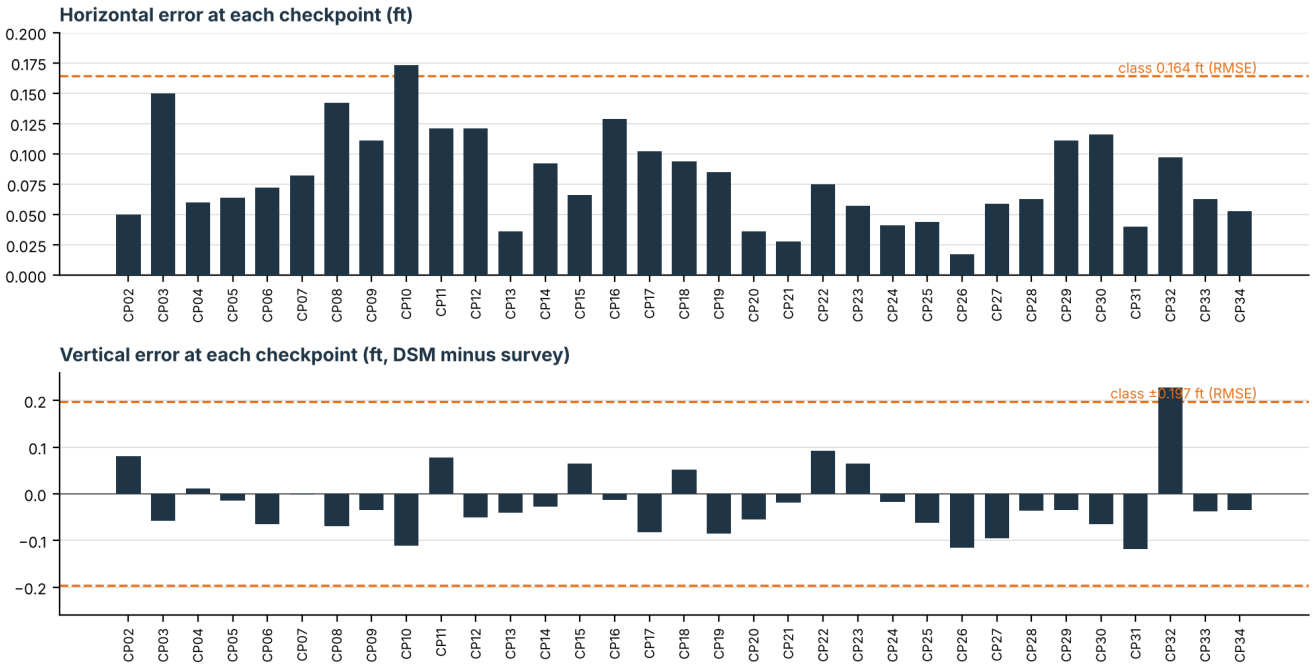
Field photos of other points are kept on file. The target-center images used to measure horizontal error in the orthomosaic are in section 4.

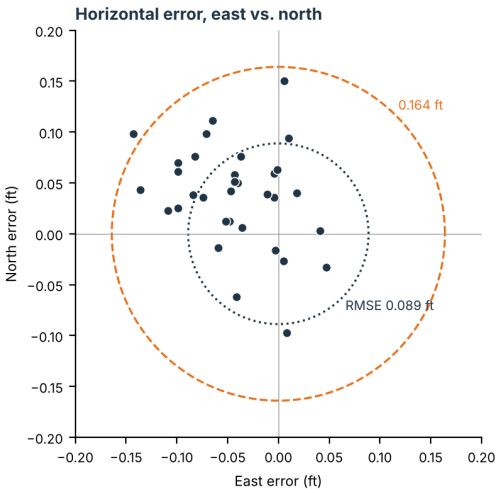
3 · Results

Error component (ft)	n	Mean	Median	Std. dev.	Min	Max	RMSE
East (ortho – survey)	33	-0.042	-0.043	0.048	-0.143	+0.047	0.064
North (ortho – survey)	33	+0.037	+0.040	0.050	-0.097	+0.150	0.062
Horizontal, radial	33	0.080	0.072	0.038	0.017	0.173	0.089
Vertical (DSM – survey)	33	-0.021	-0.035	0.073	-0.119	+0.227	0.074

	Fit to checkpoints	Survey accuracy	Product accuracy (RMSE)	ASPRS class tested	Result
Horizontal	0.089 ft	0.043 ft	0.099 ft (3.0 cm)	0.164 ft (5.0 cm)	Met
Vertical (NVA)	0.074 ft	0.042 ft	0.085 ft (2.6 cm)	0.197 ft (6.0 cm)	Below*

Product accuracy = √(fit² + survey²). Horizontal RMSE is $\sqrt{(RMSE_E^2 + RMSE_N^2)}$. ASPRS Edition 2 also requires the checkpoint survey to be at least twice as accurate as the class tested: 0.082 ft (2.5 cm) horizontal and 0.098 ft (3.0 cm) vertical. The repeatability estimates are below the checkpoint-survey limits for both classes. *The vertical result is below the class RMSE, but no "tested to meet" statement is made for vertical because the NGS mark check is unresolved (section 6).



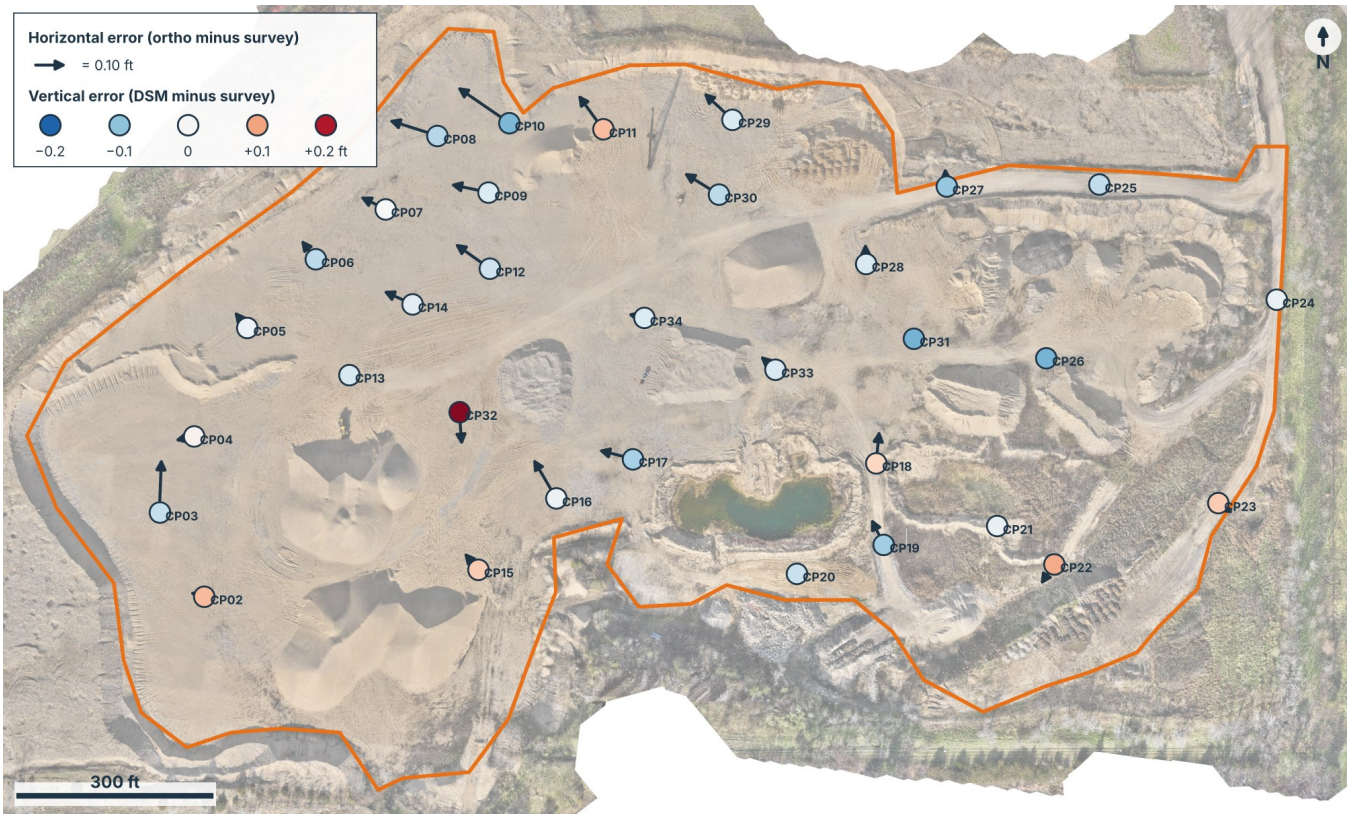


Reading the results

- The orthomosaic sits on average 0.056 ft (1.7 cm) northwest of the survey (mean east -0.042 ft, mean north +0.037 ft). This offset is included in the RMSE.
- The DSM sits on average 0.021 ft (0.6 cm) below the survey. The largest vertical difference is CP32 at +0.227 ft.
- The largest horizontal difference is CP10 at 0.173 ft.
- Class limits apply to the RMSE of the whole set, not to individual points. They are drawn on the charts for scale.

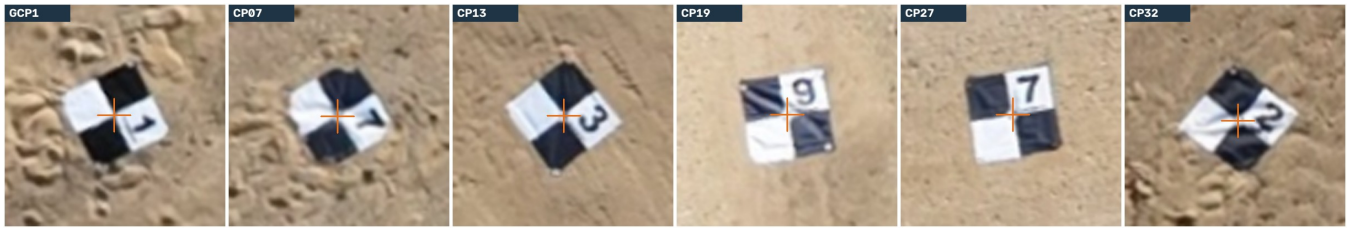
4 · Error Map

Each arrow shows the direction and size of the horizontal difference at a checkpoint, greatly enlarged. The color of each circle shows the vertical difference. A map of errors by location shows whether they are random or follow a pattern across the site.



- **Horizontal:** arrows in the western half of the floor point consistently to the northwest, by up to 0.17 ft. Arrows in the eastern half are shorter and vary in direction. This pattern is reviewed on the next page.
- **Vertical:** differences are mixed in sign across the site with no trend by location. CP32 stands apart at +0.227 ft; its target marks and survey record were reviewed and no physical cause was found, so it remains in the result.

Target detection in the orthomosaic



Six of the 38 targets as they appear in the delivered orthomosaic (each tile is about 5.3 ft across). The orange cross is the located target center used for the horizontal comparison.

4 · Error Map (continued): Horizontal Mean Error Review

ASPRS Edition 2, section 7.2, recommends that the mean error be less than 25% of the target RMSE, and that a larger mean error be investigated and the findings reported. For the 0.164 ft horizontal class that level is 0.041 ft. The mean east error is -0.042 ft and the mean north error is +0.037 ft, so the east component is at that level and the pattern was reviewed. The vertical mean error (-0.021 ft) is well under its corresponding level of 0.049 ft.

What was checked

Checkpoints by time of first survey	n	Ortho: mean ΔE	Ortho: mean ΔN	Aerotri.: mean ΔE	Aerotri.: mean ΔN
8:48 to 9:30 AM	5	-0.037	+0.051	-0.034	+0.071
9:30 to 10:15 AM	8	-0.090	+0.055	-0.041	+0.048
10:15 to 11:05 AM	7	-0.038	+0.021	-0.013	+0.005
11:05 AM to 12:15 PM	13	-0.017	+0.029	+0.007	-0.005

Mean differences in feet, product minus survey. Aerotriangulation values are DJI Terra's check point residuals for the same points.

- **The pattern follows the order of the survey.** Points were surveyed from the west side of the floor to the east. The mean error is largest for checkpoints surveyed before 10:15 AM and smallest for those surveyed after 11:05 AM (table above). Because location and time of survey changed together, the two cannot be separated from this data.
- **It is present before the orthomosaic is built.** The same trend appears in the aerotriangulation check point residuals, so it does not come from orthorectification or from how target centers were measured in the orthomosaic.
- **Repeat observations point the same way.** The three valid repeat pairs on the west side (GCP2, CP02, CP03) each placed the afternoon position west of the morning position, by 0.023 to 0.038 ft. The four pairs on the east side show no consistent direction (mean +0.003 ft east). This is consistent with a small offset in the early-morning survey positions, but three pairs are not enough to establish it.
- **The target-center measurement was tested for bias.** The method was run on 60 simulated targets with known centers at random sub-pixel positions and rotations. Mean target-center error was under 0.001 ft in the simulation.
- **A mean difference remains between the orthomosaic and the aerotriangulation.** Across all 33 checkpoints the orthomosaic positions differ from the aerotriangulation positions by a mean of -0.027 ft east and +0.016 ft north. The difference is not uniform: by survey-time group, the east difference ranges from -0.049 to -0.002 ft. The mean east value equals half an orthomosaic pixel (0.027 ft), so a half-pixel registration difference in the exported image is a hypothesis. It has not been confirmed.

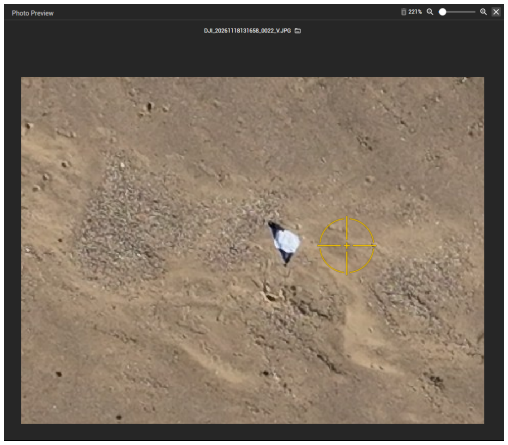
Finding

The cause of the horizontal mean error is not established. The evidence is most consistent with a small offset, on the order of 0.03 to 0.06 ft, in the ground survey positions observed early in the morning, together with a possible half-pixel registration difference in the exported orthomosaic. No correction was applied to the survey, the model or the results. The mean error is included in the reported RMSE, which remains below the RMSE of the class tested.

5 · Checkpoint Residuals

Surveyed coordinates are NAD83(2011) / WISCRS Dane (ftUS) and NAVD88 (GEOID18) ftUS. Differences are product minus survey, in feet. This table, with survey times and precisions, is available as a CSV file at novakgs.com/accuracy.

Point	Easting	Northing	Elevation	ΔE	ΔN	ΔH	DSM elev.	ΔZ
CP01	719168.364	523382.128	770.002			excluded		
CP02	719342.411	523134.178	769.698	-0.048	+0.012	0.050	769.778	+0.080
CP03	719272.163	523264.780	771.588	+0.006	+0.150	0.150	771.530	-0.058
CP04	719326.042	523383.618	771.698	-0.059	-0.014	0.060	771.709	+0.011
CP05	719409.567	523552.561	782.328	-0.040	+0.050	0.064	782.314	-0.014
CP06	719515.918	523659.602	779.564	-0.043	+0.058	0.072	779.499	-0.065
CP07	719624.990	523737.726	778.759	-0.074	+0.036	0.082	778.758	-0.001
CP08	719706.793	523851.824	779.889	-0.136	+0.043	0.142	779.820	-0.069
CP09	719786.604	523763.352	779.935	-0.109	+0.023	0.111	779.900	-0.035
CP10	719818.477	523872.108	783.219	-0.143	+0.098	0.173	783.107	-0.112
CP11	719965.619	523861.812	785.547	-0.071	+0.098	0.121	785.624	+0.077
CP12	719788.403	523644.986	779.989	-0.099	+0.070	0.121	779.938	-0.051
CP13	719568.743	523479.393	776.912	-0.004	+0.036	0.036	776.872	-0.040
CP14	719666.984	523589.585	778.306	-0.084	+0.038	0.092	778.279	-0.027
CP15	719770.236	523176.248	773.257	-0.043	+0.051	0.066	773.321	+0.064
CP16	719892.380	523286.918	778.287	-0.065	+0.111	0.129	778.274	-0.013
CP17	720012.058	523348.411	778.199	-0.099	+0.025	0.102	778.117	-0.082
CP18	720392.325	523342.089	778.484	+0.010	+0.094	0.094	778.535	+0.051
CP19	720404.198	523214.885	777.991	-0.037	+0.076	0.085	777.905	-0.086
CP20	720268.310	523169.843	775.182	-0.036	+0.006	0.036	775.127	-0.055
CP21	720581.237	523243.764	776.962	+0.005	-0.027	0.028	776.943	-0.019
CP22	720670.750	523184.420	781.095	-0.041	-0.062	0.075	781.187	+0.092
CP23	720926.967	523279.407	808.289	+0.047	-0.033	0.057	808.353	+0.064
CP24	721018.114	523596.641	812.956	+0.041	+0.003	0.041	812.939	-0.017
CP25	720740.414	523775.780	801.115	+0.018	+0.040	0.044	801.053	-0.062
CP26	720658.146	523505.915	777.835	-0.003	-0.016	0.017	777.719	-0.116
CP27	720502.244	523772.617	792.755	-0.004	+0.059	0.059	792.660	-0.095
CP28	720376.263	523652.612	778.362	-0.001	+0.063	0.063	778.326	-0.036
CP29	720167.565	523877.140	784.927	-0.082	+0.076	0.111	784.892	-0.035
CP30	720146.128	523760.406	783.586	-0.099	+0.061	0.116	783.521	-0.065
CP31	720451.008	523535.892	777.798	-0.011	+0.039	0.040	777.679	-0.119
CP32	719740.835	523421.419	775.591	+0.008	-0.097	0.097	775.818	+0.227
CP33	720234.892	523487.610	776.553	-0.047	+0.042	0.063	776.515	-0.038
CP34	720029.552	523568.096	776.459	-0.052	+0.012	0.053	776.424	-0.035
RMSE (n = 33)				**0.064**	**0.062**	**0.089**		**0.074**



Excluded checkpoint: CP01

The CP01 target was folded over by wind during the flight, leaving no visible center (image DJI_20261118131658_0022_V.JPG, 1:16 PM, shown at left). The point was excluded before any results were computed, for that physical cause alone. ASPRS allows exclusion for a documented physical cause and does not allow removal for a large residual.

With CP01 excluded, 33 checkpoints remain, above the 30 required for a full assessment.

6 · Ground Survey Record

Survey accuracy from repeat observations

Seven points were observed a second time during target recovery, each on a new fixed solution, 4.0 to 5.6 hours after the first observation. The difference between two independent observations of the same point reflects the error of both, so the accuracy of a single observation is the RMS of the differences divided by √2.

Point	First	Repeat	ΔE (ft)	ΔN (ft)	ΔH (ft)	ΔZ (ft)
GCP2	8:50 AM	2:27 PM	-0.023	+0.043	0.049	+0.003
CP02	9:00 AM	2:35 PM	-0.038	-0.042	0.057	+0.104
CP03	9:07 AM	2:38 PM	-0.032	+0.053	0.062	-0.079
CP27	11:40 AM	3:50 PM	+0.020	-0.040	0.045	-0.034
CP25	11:44 AM	3:52 PM	+0.012	-0.063	0.064	+0.013
GCP5	11:48 AM	3:55 PM	-0.031	-0.074	0.080	+0.068
CP24	11:54 AM	3:57 PM	+0.009	-0.064	0.065	+0.037
RMS of differences (7 pairs)					0.061	0.059
Survey accuracy (RMS ÷ √2)					**0.043**	**0.042**

Survey accuracy used in this report: **0.043 ft (1.3 cm) horizontal and 0.042 ft (1.3 cm) vertical.** This is based on 7 repeat pairs (2 GCPs and 5 checkpoints). Repeat observations taken at the remaining points during recovery were not retained in the project file, so the estimate rests on this sample.

CP01 repeat not used. CP01 was also re-observed at recovery, but its target was still folded over by wind and the second observation was taken at the midpoint of the fold crease, not on the original target center. The two observations are not of the same point, so the pair is left out for that physical cause. Its differences were 0.064 ft horizontal and -0.147 ft vertical. For reference, including it would give a survey accuracy of 0.043 ft horizontal and 0.054 ft vertical, and product results of 0.099 ft horizontal and 0.092 ft vertical. Both results are below the class RMSE either way.

Datum check on NGS mark DH5092

The rover was set on National Geodetic Survey mark DH5092 (ROXBURY W GPS), about 5 miles northeast of the site, before and after fieldwork. Published position: latitude 43.2496307056, longitude −89.7082159917, ellipsoid height 224.398 m (736.212 ft), NAD83(2011); NGS condition: good. The vertical comparison is made in ellipsoid height, which keeps the geoid model out of the check.

Observation	Time	ΔE (ft)	ΔN (ft)	Horizontal (ft)	Δ ellipsoid height (ft)
Check-in 1 (60 s)	8:10 AM	+0.043	+0.020	0.047	−0.157
Check-in 2, new fix (60 s)	8:15 AM	−0.027	−0.037	0.046	−0.042
Check-out 1 (60 s)	4:10 PM	+0.046	+0.002	0.046	−0.103
Check-out 2, new fix (60 s)	4:12 PM	+0.048	−0.023	0.053	−0.101

- **Horizontal:** all four observations agree with the published position within 0.053 ft.
- **Ellipsoid height:** every observation read low, by 0.04 to 0.16 ft. The first check-in was re-observed on a new connection five minutes later and read 0.042 ft low; the two check-outs agree with each other within 0.002 ft at 0.10 ft low.
- **What this means for the vertical result:** GCPs and checkpoints were surveyed together through the same network, so a height offset common to both would not appear in the checkpoint residuals or in the repeat observations. The vertical result therefore shows how closely the surface model reproduces the ground survey. The mark check is the only independent evidence on the survey's agreement with the published vertical reference, and it is unresolved.
- **Sensitivity:** if the mark differences were a true offset making all survey heights too low, the DSM would carry it through the GCPs. Subtracting it from each residual and adding the survey accuracy gives a vertical product RMSE of 0.104 ft at 0.042 ft, 0.149 ft at 0.103 ft and 0.196 ft at 0.157 ft, the last just below the 0.197 ft class RMSE. At 0.103 ft and above, the survey itself would also exceed the 0.098 ft that ASPRS requires of a checkpoint survey for this class. A single mark about 5 miles from the site does not establish that such an offset applies at the site.
- **Planned follow-up:** the rover will be checked on additional NGS marks that have both a leveled NAVD88 height and a precise ellipsoid height, using repeat occupations with a fresh fix and a second correction source. The results will show whether the difference follows the equipment or is specific to the mark. They will be reported in a revision of this document, including any effect on the vertical accuracy statement.

7 · Reference Information

Ground control point fit in the delivered products

Point	Easting	Northing	Elevation	ΔE	ΔN	ΔH	DSM elev.	ΔZ
GCP1	719384.461	523646.541	783.710	-0.045	+0.046	0.065	783.728	+0.018
GCP2	719305.185	522956.341	769.827	+0.028	+0.086	0.090	769.840	+0.013
GCP3	719911.690	523712.921	782.046	-0.085	+0.057	0.103	782.003	-0.043
GCP4	720461.203	523104.439	778.972	-0.013	-0.012	0.018	778.948	-0.024
GCP5	720927.647	523765.726	808.536	-0.023	+0.018	0.029	808.535	-0.001

GCPs were used to build the model, so their fit is not a measure of accuracy. It is shown to confirm the control held through reconstruction.

Aerotriangulation check point residuals (DJI Terra, for reference)

Horizontal RMSE	0.080 ft (2.4 cm), 33 check points
Vertical RMSE	0.077 ft (2.4 cm), 33 check points
Note	These are internal to the software's adjustment and are not the reported result. The delivered-product figures in section 3 are slightly larger in the horizontal and similar in the vertical

8 · Scope and Limitations

- The results apply to the orthomosaic and DSM tested, on open, bare ground inside the 34.4-acre validation area, flown and processed as described.
- They do not establish accuracy on stockpile faces, steep slopes, vegetation or water, on the remainder of the 54.4-acre flight area, or for stockpile volumes and cut/fill quantities.
- They do not guarantee the accuracy of other projects. Site conditions, flight height, satellite reception and GCP layout all affect what is achievable. Accuracy on a given project is checked with independent checkpoints on that site.
- Survey accuracy is estimated from 7 repeat pairs. The unresolved NGS mark discrepancy (section 6) limits what this test establishes about absolute elevations.
- The checkpoints share the survey method and correction network of the GCPs. The test therefore measures how faithfully the products reproduce the ground survey, with the survey's own accuracy added in as Edition 2 requires.
- This test is repeated at least once a year and whenever primary equipment or processing software changes.

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