ASPRS LIDAR GUIDELINES:

Horizontal Accuracy Reporting

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1. ABBREVIATIONS

ALS – Airborne Laser Scanning

DEM – Digital Elevation Model

DTM – Digital Terrain Model

IMU – Inertial Measurement Unit

INS – Inertial Navigation System

POS – Positioning System

FEMA – Federal Emergency Management Agency

NDEP – National Digital Elevation Program

NOAA – National Oceanic and Atmospheric Administration

USACE – U.S. Army Corps of Engineers

USGS – U.S. Geological Survey

FGDC – Federal Geographic Data Committee

NSDI – National Spatial Data Infrastructure

NSSDA – National Standard for Spatial Data Accuracy

2. TERMINOLOGY

Be aware that practitioners in the fields of surveying, mapping, and GIS are not always consistent in their use of these terms. Sometimes the terms are used almost interchangeably, and this should be avoided. Here the most commonly used terms will be presented and explained.

Quality Assurance (QA) is the process of evaluating overall project performance on a regular basis to provide confidence that the project will satisfy the relevant quality standards.

Quality Control (QC) is the process of monitoring specific project results to determine if they comply with relevant quality standards, and identifying means of eliminating causes of unsatisfactory performance.

It is important to distinguish between such terms as “accuracy” and “precision”.

Accuracy is the degree to which information on a map or in a digital database matches true or accepted values. Accuracy is an issue pertaining to the quality of data and the number of errors contained in a dataset or map. In discussing a GIS database, it is possible to consider horizontal and vertical accuracy with respect to geographic position, as well as attribute, conceptual, and logical accuracy.

The NSSDA uses root-mean-square error (RMSE) to estimate positional accuracy. RMSE is the square root of the average of the set of squared differences between dataset coordinate values and coordinate values from an independent source of higher accuracy for identical points. Accuracy is reported in ground distances at the 95% confidence level. Accuracy reported at the 95% confidence level means that 95% of the positions in the dataset will have an error with respect to true ground position that is equal to or smaller than the reported accuracy value. The reported accuracy value reflects all uncertainties, including those introduced by geodetic control coordinates, compilation, and final computation of ground coordinate values in the product.

Precision refers to the level of measurement and exactness of description in a dataset. Precise locational data may measure position to a fraction of a unit. Precise attribute information may specify the characteristics of features in great detail. It is important to realize, however, that precise data--no matter how carefully measured--may be inaccurate. Surveyors may make mistakes or data may be entered into the database incorrectly.

The level of precision required for particular applications varies greatly. Engineering projects such as road and utility construction require very precise information measured to the millimeter or tenth of an inch.

Highly precise data can be very difficult and costly to collect manually.

High precision does not indicate high accuracy nor does high accuracy imply high precision.

Boresight error - the angular misalignment between the laser sensor unit and IMU

Absolute offset – the measurement of location of a point of interest, which has known coordinates, throughout the lidar data, where it is visible

Relative offset – the measurement of discrepancies between tie-points in the overlap between two or more strips

3. INTRODUCTION

Lidar technology has became a very well-used remote sensing tool among land surveyors and the mapping community worldwide. It must be pointed out that a topographic airborne lidar is not intended to totally replace conventional surveying but rather serve to complement and increase the efficiency of existing remote sensing and mapping means. Such a tool can be efficiently employed in remote, inaccessible, and forested areas, in order to collect the bare-earth feature, and ground information. There is no doubt that the lidar data produces reliable data for height determination. The lidar datasets can be viewed as multi-phase data. For example, as the project progresses, the client may want to enhance lidar accuracy by adding additional breaklines. Combining data with a more limited ground survey serves to enhance accuracy, and save time and expenses.

Currently the common use of ALS is generating surface terrain models, which are DEMs and enhanced DTMs. Some typical applications are as follows:

- visibility analyses (i.e., power transmission lines, mining industry and urban planning)
- rectification of imagery in photogrammetry
- rectification of data from hyper-spectral and satellite sensors
- improving existing hydrological models
- feature detection (i.e., 3-D modeling of buildings, roads, rail roads, and river banks)
- biometric analyses (i.e., forestry, flood planning, and coastal monitoring)
- producing contours (a less detailed representation of the scene as compared to filtered laser data)

In some cases horizontal accuracy is considered as less important information than vertical accuracy. For example, the desired information for visibility analyses of power transmission lines or biometric analyses in forestry are not driven by positional accuracy information of the subjects. Rather the height information of trees or crown size, and profiles of wires are of importance.

However, there are certain applications, which already require the lidar dataset to meet expectations for horizontal accuracy. For instance, one such area of applications would be obstacle avoidance. An obstruction survey of an airport area differs dramatically from flood mapping or bare-earth terrain mapping.

4. THE TASKS OF THE GUIDELINES

The major tasks of these guidelines are the following:

- To provide any user, who employs a topographic airborne laser scanning system, with appropriate common guidelines and recommendations for acquiring accurate digital lidar elevation data.
- To assist companies and agencies in establishing standards for their organizations for a routing work.
- To help to reduce the overall time the customer needs for planning and acquiring the desired data as straight forwardly as possible.

These guidelines are designed to support the common customer demands for accuracy of the lidar dataset regardless of the type of the airborne laser scanning system, and regardless of a scan pattern on the ground surface.

5. THE PURPOSE OF QA/QC

The importance of quality assurance (QA) and quality control (QC) is an essential issue in processing and handling of the data set delivered by the laser scanning, especially, airborne. There are a number of studies, assessments and evaluations, which have been carried out by academic, governmental, and private organizations in the last decade.

In general, in the content of this paper, the purpose of the QA / QC procedures is to guarantee efficient and consistent validation of complex data set delivered by the laser sensor, INS, and GPS.

6. A BRIEF REVIEW OF EXISTING STANDARDS

A General Status of Current Work

There is work going on among different communities like remote sensing and mapping practitioners, land surveyors and GIS professionals. This work is focused on developing common guidelines for using topographic airborne lidar, which is becoming more and more popular, and processing laser data. A brief description of the work with respect to reporting horizontal accuracy will be given.

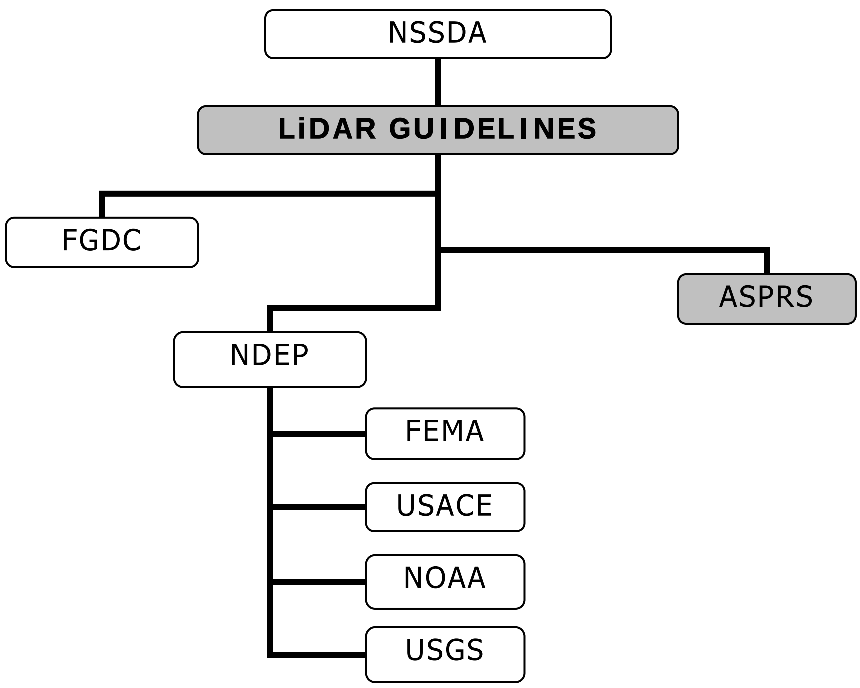


Figure 1. Flowchart showing the current involvement in developing of the lidar guidelines

There is an existing common standard NSSDA, which is widely used within the mapping, cartographic and remote sensing communities. It defines statistical and testing methodologies for estimating the positional accuracy of points on maps and in digital geospatial data, with respect to georeferenced ground positions of higher accuracy. The final digital maps and other deliverables of the ALS are expected to meet the accuracy requirements established in NSSDA too.

The lidar guidelines, which are being developed and prepared by the ASPRS Lidar Committee, cover the recommended methods for measuring and reporting the accuracies of digital elevation data recorded by airborne lidar mapping instruments. In addition, the Guidelines cover determining what level of accuracy can be associated with a mapping product that is generated from a lidar dataset. They also include recommendations for the proper planning and implementation of appropriate ground checkpoints to support a lidar dataset, including how to handle different land cover classes across a project site. Furthermore, the lidar guidelines are in compilance with the relevant sections of the Guidelines for Digital Elevation Data released by the NDEP.

NDEP is a program, whose main purpose is to promote the exchange of accurate digital land elevation data among government, private and non-profit sectors, and the academic community, and to establish standards and guidance that will benefit all users. Such members of this program as FEMA, USACE, NOAA, and USGS have contributed their "best practice" concerns regarding lidar.

FGDC has already accepted a standard FGDC-STD-007.3-1998, which is called "Geospatial Positioning Accuracy Standards, Part 3: National Standard for Spatial Data Accuracy." It has been developed to provide a common reporting mechanism so that users can directly compare datasets for their applications. It was realized that map-dependent measures of accuracy, such as contour interval, can be not fully applicable when digital geospatial data can be readily manipulated and output to any scale or data format. Principal changes included requirements to report numeric accuracy values, for instance, a composite statistic for horizontal accuracy, instead of component *X, Y* accuracy. Additionally, this standard defines and describes requirements for ground truth and supporting GPS data collection.

These organizations have, in particular, prepared some recommendations for applying ALS, which are directed towards their particular needs in the most effective way:

- FEMA in 2000
- U.S. Army Corps of Engineers in 2002
- ASPRS Reporting Vertical Accuracy in 2004
- NOAA (updated Web-site, 20 February 2005)

Of course, there are a number of internal guidelines and instructions for lidar scanning, which are used by the operators of ALS. However, they are not being considered here, because those guidelines would not be fully applicable in general practice and are often very specific task-oriented.

Horizontal Accuracy in NSSDA and NMAS

Horizontal accuracy is strongly related by the requirements of vertical accuracy. When a high vertical accuracy is required, then it will be essential for the data producer to maintain high horizontal accuracy. This is because horizontal errors in elevation data normally, but not always, contribute significantly to the error detected in vertical accuracy tests.

Horizontal error is more difficult than vertical error to assess in lidar datasets. This is because the land surface often lacks well-defined topographic features, which are required for such tests, or because the resolution of the elevation data is too coarse for precisely locating distinct surface features.

There are minimum expectations of horizontal accuracy for elevation data acquired using lidar, which are recommended by ASPRS. They are summarized in the following Table 1, which shows the interrelationship between the NMAS and NSSDA extrapolated values. Typically, it is required that the lidar data producer applies an appropriate methodology for elevation data collection by lidar. It is also assumed that the horizontal control structure is well known.

NMAS *Map Scale*	**NMAS** *CMAS 90%*	**NSSDA** *RMSE(r)*	**NSSDA** *Accuracy(r) 95% confidence level*
1" = 100' or 1:1,200	3.33 ft	2.20 ft or 67.0 cm	3.80 ft or 1.159 m
1" = 200' or 1:2,400	6.67 ft	4.39 ft or 1.339 m	7.60 ft or 2.318 m
1" = 400' or 1:4,800	13.33 ft	8.79 ft or 2.678 m	15.21 ft or 4.635 m
1" = 500' or 1:6,000	16.67 ft	10.98 ft or 3.348 m	19.01 ft or 5.794 m
1" = 1000' or 1:12,000	33.33 ft	21.97 ft or 6.695 m	38.02 ft or 11.588 m
1" = 2000' or 1:24,000 *	40.00 ft	26.36 ft or 8.035 m	45.62 ft or 13.906 m

Table 1. Comparison of NMAS/NSSDA Horizontal Accuracy

* The 1:24,000- and 1:25,000-scales of USGS 7.5-minute quadrangles are smaller than 1:20,000; therefore, the NMAS horizontal accuracy test for well-defined test points is based on 1/50 inch, rather than 1/30 inch for maps with scales larger than 1:20,000

FEMA and ASPRS

The FEMA's guidelines recommend the following:

The 1/30-inch standard for large-scale maps is called the Circular Map Accuracy Standard (CMAS). The NMAS became obsolete for digital mapping products because computer software can easily change the scale of a map, and maps do not become more accurate just because the computer software and/or user may "zoom in" on the map to display it and/or produce it at a larger scale.

To prevent abuse of digital mapping data, the mapping industry operated during much of the 1990s under ASPRS 1990 Standards. The ASPRS 1990 Standards established limiting RMSEs for three classes of maps (Class 1, Class 2, Class 3), along with typical map scales associated with the limiting errors. Three times the "limiting RMSE" was essentially a 100-percent confidence level standard.

In 1998, the FGDC published the NSSDA, which superseded both the NMAS and the ASPRS 1990 Standards for digital mapping products. NSSDA implemented a statistical and testing methodology for estimating the positional accuracy of points on maps and in digital geospatial data, with respect to georeferenced ground positions of higher accuracy. Radial RMSE ($RMSE_r$) calculations were established, and radial accuracy ($Accuracy_r$) at the 95-percent confidence level was established as 1.7308 x $RMSE_r$. $Accuracy_r$ is defined as "the radius of a circle of uncertainty, such that the true or theoretical location of the point falls within that circle 95-percent of the time." NSSDA specifies horizontal errors at the 95-percent confidence level, whereas the NMAS specified horizontal errors at the 90-percent confidence level, and ASPRS 1990 specified horizontal errors at nearly the 100-percent confidence level. When assuming all horizontal errors have a normal distribution, the NSSDA/NMAS conversion factor is as follows:

$Accuracy_r$ = CMAS x 1.1406

With NSSDA, $RMSE_r$ is defined in terms of feet or meters at ground scale rather than in inches or millimeters at the target map scale. The $RMSE_r$ of a DFIRM panel is the cumulative result of all errors, including those introduced by mapping partners in performing ground surveys, aerial triangulation, map compilation, and digitization activities. The $RMSE_r$ and $Accuracy_r$ values shown in Table 2 are the maximum permissible values established by NSSDA for base maps compiled at 1"=500' and 1”=1000’ under NMAS. Table A-1 serves as a “crosswalk” between the NMAS, NSSDA, and The ASPRS 1990 horizontal accuracy standards.

$RMSE_r$ = sqrt($RMSE_x{}^2$ + $RMSE_y{}^2$).

NMAS Map Scale	**NMAS** CMAS 90% confidence level	**NSSDA** $Accuracy_r$ 95% confidence level	**NSSDA** $RMSE_r$	**ASPRS 1990** Class 1/2/3 Limiting $RMSE_r$
1” = 500’	16.7 feet	19.0 feet	11.0 feet	7.1 feet (Class 1) 14.1 feet (Class 2) 21.2 feet (Class 3)
1" = 1,000'	33.3 feet	38.0 feet	22.0 feet	14.1 feet (Class 1) 28.3 feet (Class 2) 42.4 feet (Class 3)
1” = 2,000’	40.0 feet	45.6 feet	26.3 feet	28.3 feet (Class 1) 56.5 feet (Class 2) 84.9 feet (Class 3)

Table 2. Comparison of Horizontal Accuracy Standards

Thus, when FEMA specifies a base map at 1" = 500', for example, this is the same as FEMA specifying that a digital base map should have a horizontal $RMSE_r$ of 11 feet or $Accuracy_r$ of 19 feet at the 95-percent confidence level, for consistency with the new NSSDA.

When a base map is compiled at 1”=1,000’ and is published at a hardcopy map scale of 1”=500’, the horizontal accuracy remains that of the 1”=1,000’ map scale. Therefore, such a 1”=500’ map would be compiled to meet 38-foot horizontal accuracy at 95-percent confidence level, rather than 19-foot horizontal accuracy at 95-percent confidence level as is normally expected of maps published at a scale of 1”=500’. This is an example where “zooming in” on a map image does not make the map any more accurate.

Planimetric Accuracy Requirements Due to The ASPRS Classes

The data acquired by the means of ALS is also expected to meet requirements of planimetric accuracy, which are defined by the ASPRS. Accuracy Standards for Large-Scale Maps is shown in the following tables:

Class 1 Planimetric Accuracy, limiting RMSE (feet)	Map Scale
0.05	1:60
0.1	1:120
0.2	1:240
0.3	1:360
0.4	1:480
0.5	1:600
1.0	1:1,200
2.0	1:2,400
4.0	1:4,800
5.0	1:6,000
8.0	1:9,600
10.0	1:12,000
16.7	1:20,000

Table 3. ASPRS Accuracy Standards for Large-Scale Maps Class 1 horizontal (*X* or *Y*) limiting RMSE for various map scales at ground scale for *feet* units

Class 1 Planimetric Accuracy Limiting RMSE (meters)	Map Scale
0.0125	1:50
0.025	1:100
0.050	1:200
0.125	1:500
0.25	1:1,000
0.50	1:2,000
1.00	1:4,000
1.25	1:5,000
2.50	1:10,000
5.00	1:20,000

Table 4. ASPRS Accuracy Standards for Large-Scale Maps Class 1 horizontal (*X* or *Y*) limiting RMSE for various map scales at ground scale for *metric* units

Class 2 accuracy applies to maps compiled within limiting RMSE's twice those allowed for Class 1 maps. Similarly, Class 3 accuracy applies to maps compiled within limiting RMSE's three times those allowed for Class 1 mapping.

7. ERROR EFFECTS AND RECOMMENDATIONS

The level of readiness of ALS for very high resolution application has been numerously and thoroughly investigated and evaluated by authorized and competent organizations around the world since the middle of ‘90s. Mainly, these investigations were devoted to assessing vertical accuracy of the laser dataset and relative error sources.

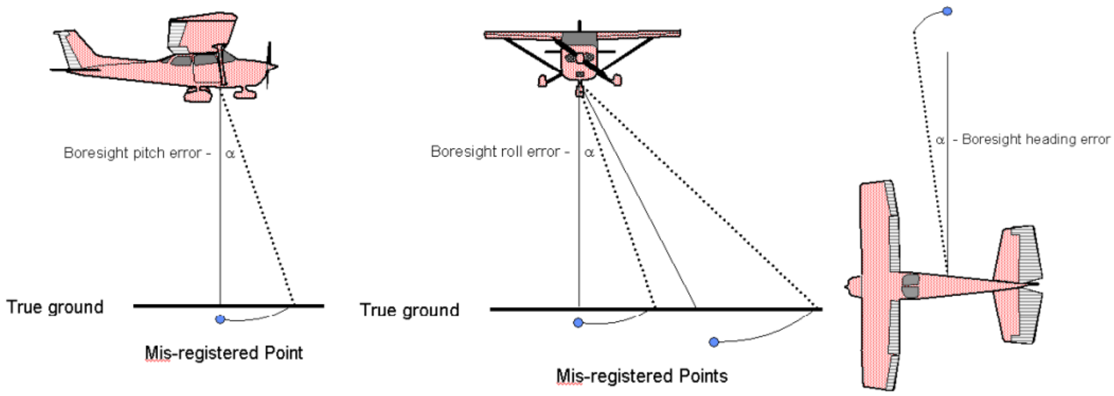
The important role of planimetric accuracy can be clearly visible, especially, when merging different datasets, for example, a laser point cloud and existing (digital) maps. Although all the necessary error filtering is done in the raw lidar data, it would be still possible that the control points are mismatched in a final product. The misalignments are often caused by careless or incomplete in-flight performances of a pilot, or a weak calibration, for example. Therefore, data fusion would be successful only, if the laser dataset and other data sources are spatially consistent.

Concerning horizontal accuracy, the major error sources in ALS are the following:

- Positioning of the carrying platform
- Orientation determination
- Offsets between the laser sensor, INS/POS equipment and an aircraft platform
- Errors in the electro-optical parts of the laser sensor
- Wrong laser and INS/POS data processing
- Careless integration and interpolation of the INS and GPS data (Pre-processing)
- Erroneous data from the reference ground GPS base stations
- Wrong data/coordinate transformation

Based on the currently used lidar data processing methods and algorithms, errors in ALS can be classified into four groups: error per block, error per strip, error per GPS observation, and error per point. The error from the IMU is of particular concern, as systematic differences on strips depend strongly on the error from the IMU. The IMU is one of the main causes of horizontal error in scanned data points, and errors very often increase or decrease with consistency in a flight's direction. This error consistency implies a linear relationship.

The **most critical error** in the ALS systems is the angular misalignment between the laser sensor and the navigational and positional systems (the boresight error). Errors, which are induced by the misalignment, are a function of flying height, scan angle and flying direction. For example, at a flying altitude of the ALS platform of 700 meters and an off-nadir scanning angle of 15 degrees, a misalignment of 0.1 degrees will result in a height error of 32 cm, and a planimetric error of 131 cm. It is obvious that the values of elevation and error are of different orders. These errors are readily apparent in overlapping ALS data. Comparing areas with elevation gradients (i.e., buildings with a clear structure) will reveal inconsistencies. The effects of roll, pitch, and heading on errors are illustrated in below figure.



(a) (b) (c)

Figure 2. Illustrations of the results of misalignments

The misalignment between the laser and the IMU causes each laser observation to be registered incorrectly. The dot in Figure 2 depicts a mis-registered laser observation. The pitch error (Figure 2a) results in a laser slant range to be recorded as nadir. As the slant range is longer, the entire strip tends to be pushed down. A roll error also causes a slant range to be incorrectly registered. The elevation differences tend to increase with a larger scan angle (Figure 2b). The heading error induces a skewing in each scan line (Figure 2c). Unlike a photographic image, a boresight error affects each observation and cannot be removed by applying a simple affine transformation to the entire strip. Instead the differences must be modeled by observing the induced errors in position of control points or common feature points.

Flight conditions

Typically, a pilot who is involved in remote sensing business is familiar and experienced with carrying out the traditional aerial photography. There such flight parameters as roll, pitch, and (heading (i.e., yaw) are not as critical as compared to the flights with the airborne laser scanning systems. Misunderstanding and/or ignoring the importance of these parameters for the accuracy of the laser data would easily lead to the gaps ("black holes") in the laser point clouds. In the worst case, the pilot would completely miss the target, because of the extreme values for roll, for example.

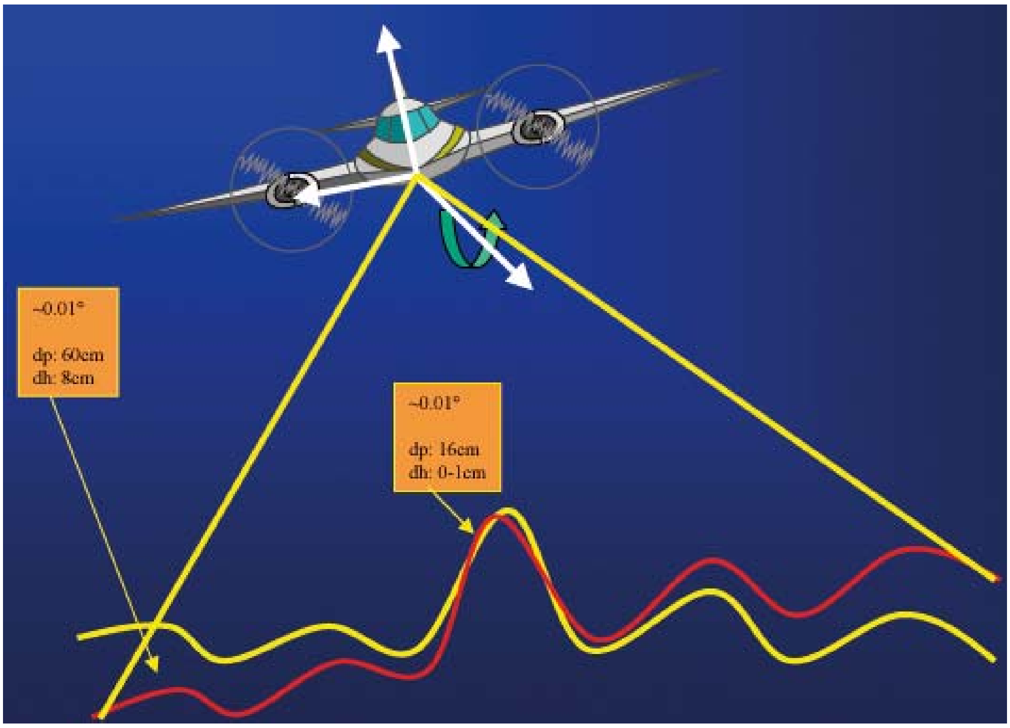


Figure 3. An influence of roll on the positions of the footprints of the laser shots on the ground

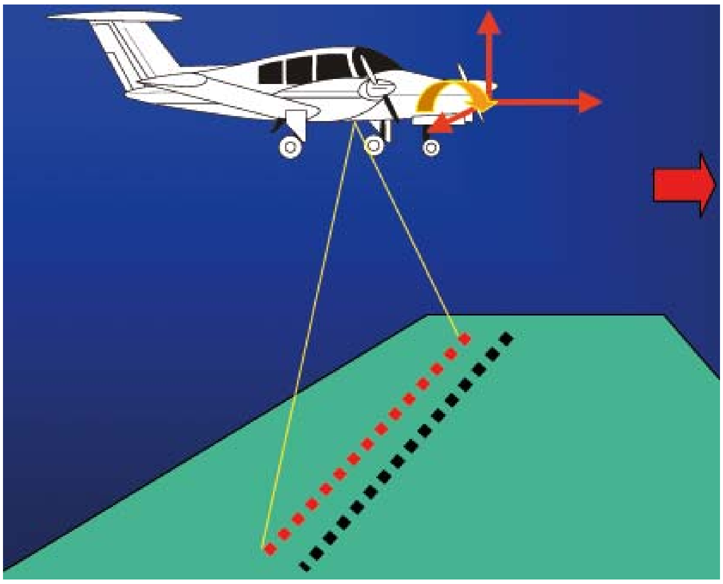


Figure 4. An influence of heading on the positions of the footprints of the laser shots on the ground

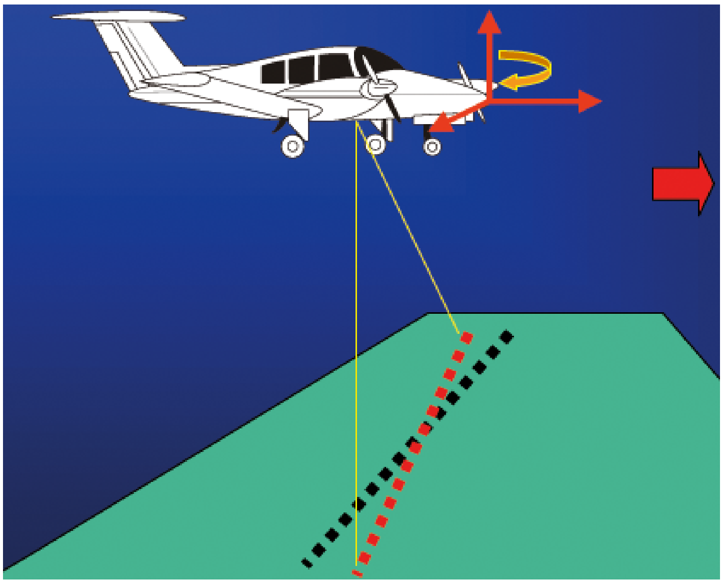


Figure 5. An influence of pitch on the positions of the footprints of the laser shots on the ground

Any changes in the angle of roll cause a dramatic displacement of the laser spots on the ground, which causes an error in height. The bigger an inclination, the greater an effect (error).

The changes in heading cause the displacement of the laser spots along the flight track. Typically, the error in height is not significant.

The movement about the *Z*-axis causes usually displacements of only few centimeters. The displacement between neighboring points at the edges of the scan path across the flight line is larger, than in the middle of the scan swath.

The below following table shows a few examples how the positioning error is dependant uppon the angular error (Figure 5):

flight altitude	**angular error**	**positioning error**
2000 m	0.005 °	0.17 m
4000 m	0.005 °	0.35 m
6000 m	0.005 °	0.52 m

Table 5. Examples of the values of positioning errors depending on the flight altitude and the angular error

OPERATIONAL GUIDELINES

- The pilot must be correctly instructed and, preferably, trained before taking off with the laser scanner on board:
  - No unnecessary (sudden) movements or deep inclinations (turns) when the laser sensor is switched on, so that: (a) to keep the onboard GPS successfully and continuously locked on with the required number of the GPS satellites, and (b) to not produce “black holes” or gaps in the laser dataset.
  - Stay on line all the time during the recording of the laser, navigation, and positioning data.
  - Maintain the constant flight ground speed in order to insure the planned laser point density.
  - Maintain the fixed flight altitude above ground, in order to insure (a) a secure flight, and (b) the planned laser point density.

- The banking angle must not exceed the angle of elevation of the locked satellites above the horizon (typically max 15°)

- No large banking angles, because the INS can be temporally suspended, because of the effect of gravity

- A typical INS system must meet the following flight limits:
  - ≤ 0.005 ° for roll
  - ≤ 0.005 ° for pitch
  - ≤ 0.008 ° for heading (i.e., yaw)

Ground GPS Network

A surveying mission, which involves an airborne laser scanning system, must be accomplished by a correct support from the GPS ground base stations. Without a ground GPS network, the whole laser scanning mission is not usable, because the laser dataset cannot be linked to 3D real world coordinates.

A proper planning of the ground GPS network must be performed before beginning a data collection mission. This GPS network must fulfill the following requirements, at a minimum:

- completely free of errors
- include six known control points for quality control purposes
- minimum two points, which will form a base of production of a flight trajectory, that are completely open to the sky, i.e., free from a multi-path effect of the GPS signal and cycle slip noise

As compared to photogrammetric measurements, erroneous ground control points have high residuals, which can be checked in aerial images and corrected. In the case of the lidar data, the laser, GPS and navigational data cannot be treated in the same way as it has been done earlier using the traditional triangulation method.

Additionally, three of six known control points must be fixed, in order to control the scale, orientation and position in the least square adjustment. The other three are used as additional check points.

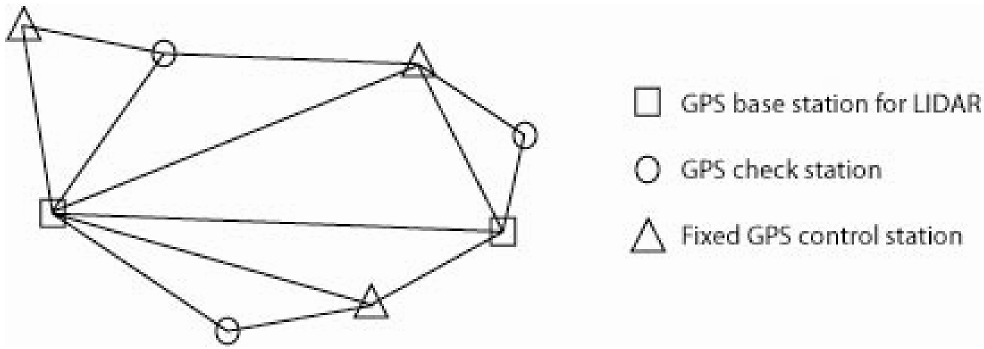


Figure 6. A general view of a GPS ground control network

GPS GUIDELINES

- The GPS ground control survey should be performed by a licensed surveying subcontractor, in order to minimize the risk of getting erroneous results.

- It is strongly suggested to deploy eight known points in the ground GPS control framework, at a minimum.

- The two open GPS control points are better set on the roofs of two suitably located, stable buildings.

- The distance between the ground reference GPS base stations and the GPS receiver(s) onboard the flying carrying platform is suggested 30 km to 50 km in a flat and obstacle-free area. In hilly and forested areas, this distance is smaller, typically, 15 km to 20 km.

- Especially for a large area projects, it is necessary to include the settings of the atmospheric conditions in calculations of a GPS trajectory.

Onboard Positioning System

Nowadays, the use of differential carrier phase global positioning system (DGPS) in kinematic mode has become widely used.

Satellite geometry has a major role in GPS positioning reliability. It is quantified by Positional Dilution Of Precision (PDOP). Poor satellite geometry or, in other words, a high PDOP, generates inaccurate GPS coordinates.

DGPS GUIDELINES

- A minimum of four visible satellites is required to position a GPS receiver using the DGPS system. Having six visible satellites is desirable.
- The survey time must be planned and optimized so that there is at least one visible satellite in each of the four quadrants.
- At least PDOP < 3 in rough or vegetated area;
  PDOP < 4 typically
- Observing longer GPS baselines, it is necessary to be aware of inaccurate orbit parameters (if available), which might introduce significant errors, and apply the necessary corrections in post-processing.
- Typically, GPS measurements are most reliable using dual frequency, 2 Hz GPS receivers.
- Onboard an aircraft the GPS receivers must be placed on fuselage, wings and tail, if possible (typically, if a helicopter is used).
- The offsets and misalignments between GPS, INS and the laser sensor must be known/measured on the ground before the flight which is accomplished with a validation flight.

In terms of data/coordinate transformation, ASPRS recommends to follow established requirements, which are stated in the NDEP Elevation Guidelines, and which says the following:

"The North American Datum of 1983 (NAD 83) should be the default horizontal datum for all geospatial datasets of the United States. NAD 83 is based on the Geodetic Reference System of 1980 (GRS 80) ellipsoid. However, it is necessary to remember that NAD 83 is nongeocentric by about 2.25 meters, while the latest version of WGS 84 is geocentric to a few centimeters. The official horizontal datum for military applications uses the WGS 84 ellipsoid.

The North American Vertical Datum of 1988 (NAVD 88) should be the default vertical datum for all elevation datasets of the United States.

To accurately convert elevations from GPS surveys into traditional orthometric heights, it is necessary to apply geoid height corrections as depicted in the latest geoid model of the area of interest. It is important that the latest geoid model be used for all surveys that involve GPS, and it is also important that the metadata for any digital elevation dataset include the geoid model that was used. For example, now that GEOID03 is available, it is important to know whether GEOID03, GEOID99, or GEOID96 corrections were applied to an existing dataset to improve the accuracy of an old survey. However, it is critical to remember that overlapping geoid models (such as GEOID99 for the USA and GSD95 for Canada) generally disagree with one another, causing step-functions in any DEM that crosses the border. The military uses the WGS 84 geoid for all applications globally. Therefore, this system has no discontinuities at country borders or boundaries.

In the most common coordinate systems, the 3-D coordinates of any point are defined by a pair of horizontal coordinates plus a z-value that normally equates to its orthometric height. It is important that the horizontal coordinate system be specified clearly to avoid confusion. It is suggested to apply the most widely used coordinate systems.

Universal Transverse Mercator (UTM) coordinates are normally preferred by (Federal) agencies responsible for large mapping programs nationwide. UTM is a planar coordinate system based on a uniform (and universal) Transverse Mercator grid that is the same for 60 UTM zones, each 6 degrees in longitude, worldwide. UTM coordinates are metric. Units should always be specified to include the number of decimal places used for meters. It is possible to specify UTM coordinates in meters and elevations in feet. X-coordinates are called "eastings" and Y-coordinates are called "northings." UTM scale factor errors are between 0.9996 and 1.0004, i.e., four parts in 10,000. Scale factor errors are inevitable when warping a nearly spherical surface to map it on a gridded piece of paper configured as a plane, cylinder or cone.

Each state has a unique State Plane Coordinate System (SPCS) that is tailored to the size and shape of the State so that scale factor errors are no larger than 1 part in 10,000, i.e., scale factor errors are between 0.9999 and 1.0001. States longer in the north-south direction utilize one or more Transverse Mercator grid zones for their States. States longer in the east-west direction utilize one or more Lambert Conformal Conic grid zones. Some States (for example, Florida and New York) use both Transverse Mercator and Lambert Conformal Conic zones, and Alaska also uses an oblique projection for one zone. Some States (e.g., Montana) chose to use only a single SPCS zone for convenience purposes, accepting scale factor errors larger than 1 part in 10,000. State plane coordinates are often expressed in U.S. survey feet, although some states use metric units. Units should always be specified, to include the number of decimal places used for either feet or meters. As with UTM, State Plane X-coordinates are called "eastings" and Y-coordinates are called "northings." Horizontal coordinates can always be specified in terms of geographic coordinates, i.e., longitude and latitude instead of eastings and northings. There are no scale factor errors associated with geographic coordinates.

DEMs may be produced with a uniform grid spacing ($\Delta x = \Delta y$) of 30 meters, 10 meters, or 5 meters, for example, where easting and northing coordinates of DEM posts are typically specified by uniform x/y grid spacing based on a SPCS grid, a UTM grid, or an Albers equal area grid. Because such DEM points are equally spaced in x and y directions (eastings and northings), they can present edge-join difficulties at tile boundaries where convergence of the meridians cause rows to shorten in length at higher latitudes.

DEMs may be produced with a consistent grid spacing of 1-arc-second (approximately 30 meters at the Equator), 1/3-arc-second (approximately 10 meters at the Equator), or 1/9-arc-second (approximately 3.3 meters at the Equator), for example, where Δx and Δy spacings between DEM posts are specified by consistent incremental changes in longitude and latitude. Because of convergence of the meridians, such DEM points will gradually come closer together at higher latitudes and physical, on-the-ground, post spacing in the east-west direction will be different than physical, on-the-ground post spacing in the north-south direction. A major advantage of the arc-second structure is that DEM tile edge-join difficulties are minimized or even eliminated.”

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9. APPENDIX A: Horizontal accuracy assessment and the NSSDA standard

3.2 Testing Methodology And Reporting Requirements

3.2.1 Spatial Accuracy

The NSSDA uses root-mean-square error (RMSE) to estimate positional accuracy. RMSE is the square root of the average of the set of squared differences between dataset coordinate values and coordinate values from an independent source of higher accuracy for identical points[1].

Accuracy is reported in ground distances at the 95% confidence level. Accuracy reported at the 95% confidence level means that 95% of the positions in the dataset will have an error with respect to true ground position that is equal to or smaller than the reported accuracy value. The reported accuracy value reflects all uncertainties, including those introduced by geodetic control coordinates, compilation, and final computation of ground coordinate values in the product.

3.2.2 Accuracy Test Guidelines

According to the Spatial Data Transfer Standard (SDTS) (ANSI-NCITS, 1998), accuracy testing by an independent source of higher accuracy is the preferred test for positional accuracy. Consequently, the NSSDA presents guidelines for accuracy testing by an independent source of higher accuracy. The independent source of higher accuracy shall the highest accuracy feasible and practicable to evaluate the accuracy of the dataset.[2]

The data producer shall determine the geographic extent of testing. Horizontal accuracy shall be tested by comparing the planimetric coordinates of well-defined points[3] in the dataset with coordinates of the same points from an independent source of higher accuracy. Vertical accuracy shall be tested by comparing the elevations in the dataset with elevations of the same points as determined from an independent source of higher accuracy.

Errors in recording or processing data, such as reversing signs or inconsistencies between the dataset and independent source of higher accuracy in coordinate reference system definition, must be corrected before computing the accuracy value.

A minimum of 20 check points shall be tested, distributed to reflect the geographic area of interest and the distribution of error in the dataset.[4] When 20 points are tested, the 95% confidence level allows one point to fail the threshold given in product specifications.

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[1] see Appendix 3-A

[2] see Appendix 3-C, section 2

[3] see Appendix 3-C, section 1

[4] see Appendix 3-C, section 3

If fewer than twenty points can be identified for testing, use an alternative means to evaluate the accuracy of the dataset. SDTS (ANSI-NCITS, 1998) identifies these alternative methods for determining positional accuracy:

- Deductive Estimate
- Internal Evidence
- Comparison to Source

3.2.3 Accuracy Reporting

Spatial data may be compiled to comply with one accuracy value for the vertical component and another for the horizontal component. If a dataset does not contain elevation data, label for horizontal accuracy only. Conversely, when a dataset, e.g. a gridded digital elevation dataset or elevation contour dataset, does not contain well-defined points, label for vertical accuracy only.

A dataset may contain themes or geographic areas that have different accuracies. Below are guidelines for reporting accuracy of a composite dataset:

- If data of varying accuracies can be identified separately in a dataset, compute and report separate accuracy values.
- If data of varying accuracies are composited and cannot be separately identified AND the dataset is tested, report the accuracy value for the composited data.
- If a composited dataset is not tested, report the accuracy value for the least accurate dataset component.

Positional accuracy values shall be reported in ground distances. Metric units shall be used when the dataset coordinates are in meters. Feet shall be used when the dataset coordinates are in feet. The number of significant places for the accuracy value shall be equal to the number of significant places for the dataset point coordinates.

Accuracy reporting in ground distances allows users to directly compare datasets of differing scales or resolutions. A simple statement of conformance (or omission, when a map or dataset is non-conforming) is not adequate in itself. Measures based on map characteristics, such as publication scale or contour interval, are not longer adequate when data can be readily manipulated and output to any scale or to different data formats.

Report accuracy at the 95% confidence level for data *tested* for both horizontal and vertical accuracy as:

Tested ____ (meters, feet) horizontal accuracy at 95% confidence level
____ (meters, feet) vertical accuracy at 95% confidence level

Use the "compiled to meet" statement below when the above guidelines for testing by an independent source of higher accuracy cannot be followed and an alternative means is used to evaluate accuracy. Report accuracy at the 95% confidence level for data *produced according to procedures that have been demonstrated to produce data with particular horizontal and vertical accuracy values* as:

Compiled to meet ____ (meters, feet) horizontal accuracy at 95% confidence level
____ (meters, feet) vertical accuracy at 95% confidence level

Report accuracy for data *tested* for horizontal accuracy and *produced according to procedures that have been demonstrated to comply with a particular vertical accuracy value* as:

Tested ____ (meters, feet) horizontal accuracy at 95% confidence level
Compiled to meet ____ (meters, feet) vertical accuracy at 95% confidence level

Show similar labels when data are *tested* for vertical accuracy and *produced according to procedures that have been demonstrated to produce data with a particular horizontal accuracy value*.

For digital geospatial data, report the accuracy value in digital geospatial metadata (Federal Geographic Data Committee, 1998, Section 2), as appropriate to dataset spatial characteristics:

(Data_Quality_Information/Positional_Accuracy/Horizontal_Positional_Accuracy/Horizontal_Positional_Accuracy_Assessment/Horizontal_Positional_Accuracy_Value)
and/or
(Data_Quality_Information/Positional_Accuracy/Vertical_Positional_Accuracy/Vertical_Positional_Accuracy_Assessment/Vertical_Positional_Accuracy_Value)

Enter the text "National Standard for Spatial Data Accuracy" for these metadata elements (Federal Geographic Data Committee, 1998, Section 2), as appropriate to dataset spatial characteristics:

(Data_Quality_Information/Positional_Accuracy/Horizontal_Positional_Accuracy/Horizontal_Positional_Accuracy_Assessment/Horizontal_Positional_Accuracy_Explanation)
and/or
(Data_Quality_Information/Positional_Accuracy/Vertical_Positional_Accuracy/Vertical_Positional_Accuracy_Assessment/Vertical_Positional_Accuracy_Explanation)

Regardless of whether the data was tested by a independent source of higher accuracy or evaluated for accuracy by alternative means, provide a complete description on how the values were determined in metadata, as appropriate to dataset spatial characteristics (Federal Geographic Data Committee, 1998, Section 2):

(Data_Quality_Information/Positional_Accuracy/Horizontal_Positional_Accuracy/Horizontal_Positional_Accuracy_Report)
and/or
(Data_Quality_Information/Positional_Accuracy/Vertical_Positional_Accuracy/Vertical_Positional_Accuracy_Report)

3.3 NSSDA and Other Map Accuracy Standards

Accuracy of new or revised spatial data will be reported according to the NSSDA. Accuracy of existing or legacy spatial data and maps may be reported, as specified, according to the NSSDA or the accuracy standard by which they were evaluated. Appendix 3-D describes root mean square error (RMSE) as applied to individual x-, y- components, former NMAS, and ASPRS Accuracy Standards for Large-Scale Maps. These standards, their relationships to NSSDA, and accuracy labeling are described to ensure that users have some means to assess positional accuracy of spatial data or maps for their applications.

If accuracy reporting cannot be provided using NSSDA or other recognized standards, provide information to enable users to evaluate how the data fit their applications requirements. This information may include descriptions of the source material from which the data were compiled, accuracy of ground surveys associated with compilation, digitizing procedures, equipment, and quality control procedures used in production.

No matter what method is used to evaluate positional accuracy, explain the accuracy of coordinate measurements and describe the tests in digital geospatial metadata (Federal Geographic Data Committee, 1998, Section 2) , as appropriate to dataset spatial characteristics:

(Data_Quality_Information/Positional_Accuracy/Horizontal_Positional_Accuracy/Horizontal_Positional_Accuracy_Report)
and/or

(Data_Quality_Information/Positional_Accuracy/Vertical_Positional_Accuracy/Vertical_Positional_Accuracy_Report)

Provide information about the source data and processes used to produce the dataset in data elements of digital geospatial metadata (Federal Geographic Data Committee, 1998, Section 2) under (Data_Quality_Information/Lineage).

Federal Geographic Data Committee FGDC-STD-007.3-1998
Geospatial Positioning Accuracy Standards
Part 3: National Standard for Spatial Data Accuracy
Appendix 3-A (normative): Accuracy Statistics

EXPLANATORY COMMENTS

1. Horizontal Accuracy

Let:

$RMSE_x = sqrt[\sum(x_{data, i} - x_{check, i})^2/n]$
$RMSE_y = sqrt[\sum(y_{data, i} - y_{check, i})^2/n]$

where:
$x_{data, i}$, $y_{data, i}$ are the coordinates of the i th check point in the dataset
$x_{check, i}$, $y_{check, i}$ are the coordinates of the i th check point in the independent source of higher accuracy
n is the number of check points tested
i is an integer ranging from 1 to n

Horizontal error at point i is defined as $sqrt[(x_{data, i} - x_{check, i})^2 + (y_{data, i} - y_{check, i})^2]$. Horizontal RMSE is:

$$RMSE_r = sqrt[\sum((x_{data, i} - x_{check, i})^2 + (y_{data, i} - y_{check, i})^2)/n]$$
$$= sqrt[RMSE_x^2 + RMSE_y^2]$$

Case 1: Computing Accuracy According to the NSSDA when $RMSE_x = RMSE_y$

If $RMSE_x = RMSE_y$,
$$RMSE_r = sqrt(2*RMSE_x^2) = sqrt(2*RMSE_y^2)$$
$$= 1.4142*RMSE_x = 1.4142*RMSE_y$$

It is assumed that systematic errors have been eliminated as best as possible. If error is normally distributed and independent in each the x- and y-component and error, the factor 2.4477 is used to compute horizontal accuracy at the 95% confidence level (Greenwalt and Schultz, 1968). When the preceding conditions apply, $Accuracy_r$, the accuracy value according to NSSDA, shall be computed by the formula:

$$Accuracy_r = 2.4477 * RMSE_x = 2.4477 * RMSE_y$$
$$= 2.4477 * RMSE_r /1.4142$$
$$Accuracy_r = 1.7308 * RMSE_r$$

Case 2: Approximating circular standard error when $RMSE_x \neq RMSE_y$

If $RMSE_{min}/RMSE_{max}$ is between 0.6 and 1.0 (where $RMSE_{min}$ is the smaller value between $RMSE_x$ and $RMSE_y$ and $RMSE_{max}$ is the larger value), circular standard error (at 39.35% confidence) may be approximated as $0.5*(RMSE_x + RMSE_y)$ (Greenwalt and Schultz, 1968). If error is normally distributed and independent in each the x- and y-component and error, the accuracy value according to NSSDA may be approximated according to the following formula:

$$Accuracy_r \sim 2.4477 * 0.5 * (RMSE_x + RMSE_y)$$

2. Vertical Accuracy

Let:

$RMSE_z = sqrt[\sum(z_{data\ i} - z_{check\ i})^2/n]$

where

$z_{data\ i}$ is the vertical coordinate of the i th check point in the dataset.
$z_{check\ i}$ is the vertical coordinate of the i th check point in the independent source of higher accuracy
n = the number of points being checked
i is an integer from 1 to n

It is assumed that systematic errors have been eliminated as best as possible. If vertical error is normally distributed, the factor 1.9600 is applied to compute linear error at the 95% confidence level (Greenwalt and Schultz, 1968). Therefore, vertical accuracy, $Accuracy_z$, reported according to the NSSDA shall be computed by the following formula:

$$Accuracy_z = 1.9600 * RMSE_z.$$

Appendix 3-C.
Testing guidelines
(informative)

1. Well-Defined Points

A well-defined point represents a feature for which the horizontal position is known to a high degree of accuracy and position with respect to the geodetic datum. For the purpose of accuracy testing, well-defined points must be easily visible or recoverable on the ground, on the independent source of higher accuracy, and on the product itself. Graphic contour data and digital hypsographic data may not contain well-defined points.

The selected points will differ depending on the type of dataset and output scale of the dataset. For graphic maps and vector data, suitable well-defined points represent right-angle intersections of roads, railroads, or other linear mapped features, such as canals, ditches, trails, fence lines, and pipelines. For orthoimagery, suitable well-defined points may represent features such as small isolated shrubs or bushes, in addition to right-angle intersections of linear features. For map products at scales of 1:5,000 or larger, such as engineering plats or property maps, suitable well-defined points may represent additional features such as utility access covers and intersections of sidewalks, curbs, or gutters.

2. Data acquisition for the independent source of higher accuracy

The independent source of higher accuracy shall be acquired separately from data used in the aerotriangulation solution or other production procedures. The independent source of higher accuracy shall be of the highest accuracy feasible and practicable to evaluate the accuracy of the dataset.

Although guidelines given here are for geodetic ground surveys, the geodetic survey is only one of many possible ways to acquire data for the independent source of higher accuracy. Geodetic control surveys are designed and executed using field specifications for geodetic control surveys (Federal Geodetic Control Committee, 1984). Accuracy of geodetic control surveys is evaluated using Part 2, Standards for Geodetic Networks (Federal Geographic Data Committee, 1998). To evaluate if the accuracy of geodetic survey is sufficiently greater than the positional accuracy value given in the product specification, compare the FGCS **network accuracy** reported for the geodetic survey with the accuracy value given by the product specification for the dataset.

Other possible sources for higher accuracy information are Global Positioning System (GPS) ground surveys, photogrammetric methods, and data bases of high accuracy point coordinates.

3. Check Point Location

Due to the diversity of user requirements for digital geospatial data and maps, it is not realistic to include statements in this standard that specify the spatial distribution of check points. Data and/or map producers must determine check point locations. This section provides guidelines for distributing the check point locations.

Check points may be distributed more densely in the vicinity of important features and more sparsely in areas that are of little or no interest. When data exist for only a portion of the dataset, confine test points to that area. When the distribution of error is likely to be nonrandom, it may be desirable to locate check points to correspond to the error distribution.

For a dataset covering a rectangular area that is believed to have uniform positional accuracy, check points may be distributed so that points are spaced at intervals of at least 10 percent of the diagonal distance across the dataset *and* at least 20 percent of the points are located in each quadrant of the dataset.

Appendix 3-D.
Other Accuracy Standards
(informative)

1. Root-Mean-Square Error (RMSE) Component Accuracy

1.1 Relationship between NSSDA (horizontal) and RMSE (x or y)

From Appendix 3-A, Section 1, assuming $RMSE_x = RMSE_y$ and error is normally distributed and independent in each the x- and y-component, $RMSE_x$ and $RMSE_y$ can be estimated from $RMSE_r$ using:

$$RMSE_x = RMSE_y = RMSE_r /1.4142$$

Using the same assumptions, $RMSE_x$ and $RMSE_y$ can also be computed from $Accuracy_r$, the accuracy value according to NSSDA:

$$RMSE_x = RMSE_y = Accuracy_r/2.4477$$

1.2 Relationship between NSSDA (vertical) and RMSE (vertical)

From Appendix 3-A, Section 2, if vertical error is normally distributed, $RMSE_z$ can be determined from $Accuracy_z$, vertical accuracy reported according to the NSSDA:

$$RMSE_z = Accuracy_z/1.9600$$

1.3 RMSE Accuracy Reporting

Label data or maps as described in Section 3.2.3, "Accuracy Reporting," but substitute "RMSE" for "accuracy at 95% confidence level." For horizontal accuracy, provide separate statements for each RMSE component.

For digital geospatial metadata, follow the guidelines for preparing metadata in Section 3.2.3, "Accuracy Reporting," but substitute “Root-Mean-Square Error” for “National Standard for Spatial Data Accuracy” for these metadata elements (Federal Geographic Data Committee, 1998, Section 2), as appropriate to dataset spatial characteristics:

(Data_Quality_Information/Positional_Accuracy/Horizontal_Positional_Accuracy/Horizontal_Positional_Accuracy_Assessment/Horizontal_Positional_Accuracy_Explanation)
and/or
(Data_Quality_Information/Positional_Accuracy/Vertical_Positional_Accuracy/Vertical_Positional_Accuracy_Assessment/Vertical_Positional_Accuracy_Explanation)

2. Former National Map Accuracy Standards (NMAS)

2.1 Relationship between NSSDA and NMAS (horizontal)

NMAS (U.S. Bureau of the Budget, 1947) specifies that 90% of the well-defined points that are tested must fall within a specified tolerance:

- For map scales larger than 1:20,000, the NMAS horizontal tolerance is 1/30 inch, measured at publication scale.
- For map scales of 1:20,000 or smaller, the NMAS horizontal tolerance is 1/50 inch, measured at publication scale.

If error is normally distributed in each the x- and y-component and error for the x-component is equal to and independent of error for the y-component, the factor 2.146 is applied to compute circular error at the 90% confidence level (Greenwalt and Schultz, 1968). The circular map accuracy standard (CMAS) based on NMAS is:

$$\begin{aligned} CMAS &= 2.1460 * RMSE_x = 2.1460 * RMSE_y \\ &= 2.1460 * RMSE_r /1.4142 \\ &= 1.5175 * RMSE_r \end{aligned}$$

The CMAS can be converted to accuracy reported according to NSSDA, $Accuracy_r$, using equations from Appendix 3-A, Section 1:

$$Accuracy_r = 2.4477/2.1460 * CMAS = 1.1406 * CMAS.$$

Therefore, NMAS horizontal accuracy reported according to the NSSDA is:

1.1406* [S * (1/30")/12"] feet, or 0.0032 * S, for map scales larger than 1:20,000
1.1406* [S * (1/50")/12"] feet, or 0.0019 * S, for map scales of 1:20,000 or smaller

where S is the map scale denominator.

2.2 Relationship between NSSDA and NMAS (vertical)

NMAS (U.S. Bureau of the Budget, 1947) specifies the maximum allowable *vertical* tolerance to be one half the contour interval, at all contour intervals. If vertical error is normally distributed, the factor 1.6449 is applied to compute vertical accuracy at the 90% confidence level (Greenwalt and Schultz, 1968). Therefore, the Vertical Map Accuracy Standard (VMAS) based on NMAS is estimated by the following formula:

$$VMAS = 1.6449 * RMSEz$$

The VMAS can be converted to $Accuracy_z$, accuracy reported according to the NSSDA using equations from Appendix 3-A, Section 2:

$$Accuracy_z = 1.9600/1.6449 * VMAS = 1.1916 * VMAS.$$

Therefore, vertical accuracy reported according to the NSSDA is (1.1916)/2 * CI = 0.5958 * CI, where CI is the contour interval.

2.3 NMAS Reporting

Map labels provide a statement of conformance with NMAS, rather than reporting the accuracy value. Label maps, as appropriate to dataset spatial characteristics:

> This map complies with National Map Accuracy Standards of 1947 for horizontal accuracy
> OR
> This map complies with National Map Accuracy Standards of 1947 for vertical accuracy
> OR
> This map complies with National Map Accuracy Standards of 1947 for horizontal and vertical accuracy

For digital geospatial data evaluated by the NMAS, follow the guidelines for preparing metadata in Section 3.2.3, "Accuracy Reporting," but substitute “U.S. National Map Accuracy Standards of 1947" for “National Standard for Spatial Data Accuracy” for these metadata elements (Federal Geographic Data Committee, 1998, Section 2), as appropriate to dataset spatial characteristics:

(Data_Quality_Information/Positional_Accuracy/Horizontal_Positional_Accuracy/Horizontal_Positional_Accuracy_Assessment/Horizontal_Positional_Accuracy_Explanation)
and/or
(Data_Quality_Information/Positional_Accuracy/Vertical_Positional_Accuracy/Vertical_Positional_Accuracy_Assessment/Vertical_Positional_Accuracy_Explanation)

3. American Society for Photogrammetry and Remote Sensing (ASPRS) Accuracy Standards for Large-Scale Maps

3.1 Explanation of ASPRS Accuracy Standards for Large-Scale Maps

ASPRS Accuracy Standards for Large-Scale Maps (ASPRS Specifications and Standards Committee, 1990) provide accuracy tolerances for maps at 1:20,000-scale or larger “prepared for special purposes or engineering applications.” RMSE is the statistic used by the ASPRS standards. Accuracy is reported as Class 1, Class 2, or Class 3. Class 1 accuracy for horizontal and vertical components is discussed below. Class 2 accuracy applies to maps compiled within limiting RMSE’s twice those allowed for Class 1 maps. Similarly, Class 3 accuracy applies to

3.4 ASPRS Accuracy Standards for Large-Scale Maps Reporting

Maps evaluated according to ASPRS Accuracy Standards for Large-Scale Maps are labeled by a conformance statement, rather than a numeric accuracy value.

Label maps produced according to this standard:

THIS MAP WAS COMPILED TO MEET THE ASPRS
STANDARD FOR CLASS (1., 2., 3.) MAP ACCURACY

Label maps checked and found to confirm to this standard:

THIS MAP WAS CHECKED AND FOUND TO CONFORM
TO THE ASPRS
STANDARD FOR CLASS (1., 2., 3.) MAP ACCURACY

NDEP Guidelines for Digital Elevation Data
Part 1 Content

Table 1 User Requirements Menu

General Surface Description (choose one or more) **Elevation Surface** (1.2.1): ☐ Digital surface model (first reflective surface) ☐ Digital terrain model (bare earth) ☐ Bathymetric surface ☐ Point cloud ☐ Mixed surface **Elevation Type** (choose one) (1.2.2): ☐ Orthometric height ☐ Ellipsoid height ☐ Other ________________
Model Types (1.3) (choose one or more) * Designate either feet or meters ☐ Mass points ☐ Grid (post spacing = ___ feet/meters) * ☐ Contour interval = _____ft /m * ☐ Breaklines ☐ Grid (post spacing = ____ arc-seconds) ☐ Cross Sections ☐ TIN (average point spacing = ___ feet/meters) * ☐ Other (For example, concurrent image capture)
Source (1.4) (choose one) ☐ Cartographic ☐ Photographic ☐ IFSAR ☐ LIDAR ☐ Sonar If Multi-return system: ☐ First return ☐ Last return ☐ All returns
Vertical Accuracy (1.5.1.1) (choose one) ☐ Fundamental Vertical Accuracy$_z$ = __ (ft or meters) at 95 percent confidence level in open terrain = RMSE$_z$ x 1.9600 ☐ Supplemental Vertical Accuracy$_z$ = __ (ft or meters) = 95th percentile in other specified land cover categories ☐ Consolidated Vertical Accuracy$_z$ = __ (ft or meters) = 95th percentile in all land cover categories combined
Horizontal Accuracy (1.5.1.2) (choose one) ☐ Accuracy$_r$ = ___ ft or meters Horizontal accuracy at the 95 percent confidence level (Accuracy$_r$) = RMSE$_r$ x 1.7308
Surface Treatment Factors (1.5.4) (optional – refer to the text) Hydrography; Man-made structures; Special earthen surfaces; Artifacts; Special Surfaces
Horizontal Datum (1.6.1) (choose one): ☐ NAD 83 (default) ☐ WGS 84 **Vertical Datum** (1.6.2) (choose one): ☐ NAVD 88 (default) ☐ MSL ☐ MLLW ☐ Other _____
Geoid Model (1.6.3) (choose one): ☐ GEOID03 ☐ Other _____
Coordinate System (1.7) (choose one): ☐ UTM zone ______ ☐ State Plane zone ______ ☐ Geographic ☐ Other _____
Units (1.7) Note: For feet and meters, vertical (V) units may differ from horizontal (H) units ☐ Feet to ___ decimal places ☐ V ☐ H ☐ Decimal degrees to ___ decimal places ☐ Meters to ___ decimal places ☐ V ☐ H ☐ DDDMMSS to ___ decimal places Feet are assumed to be U.S. Survey Feet unless specified to the contrary
Data Format (1.8) (Specify desired format(s) for each Product Type. See text for examples.) Product 1 ____________ Formats ____________ Product 2 ____________ Formats ____________ Product 3 ____________ Formats ____________
File size (1.9) (specify acceptable range) __________ Mb / Gb / Other _________ **File Extent** Boundary: Rectangular: x-dimension _____ m / ft. / degrees / other ___; y-dimension _____ m / ft. / degrees / other ___ NonRectangular: Bndry name ____________; Coordinate source ____________ Over-edge buffer width: ________________
Metadata compliant to the "Content Standards for Digital Geospatial Metadata" is highly recommended.

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