December 18, 2004

Light Detection And Ranging (LIDAR) Requirements

SCOPE OF WORK FOR AIRPORT SURVEYING
UNDER THE
NOAA AERONAUTICAL SURVEY PROGRAM

REMOTE SENSING DIVISION
NATIONAL GEODETIC SURVEY
NATIONAL OCEAN SERVICE
NATIONAL OCEANIC & ATMOSPHERIC ADMINISTRATION
U.S. DEPARTMENT OF COMMERCE

LIDAR REQUIREMENTS

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1. GENERAL

The Aeronautical Survey Program (ASP) provides source data used by the Federal Aviation Administration (FAA) to develop instrument approach procedures, determine maximum takeoff weights for aircraft, update aeronautical publications, and perform other functions. The primary objective in an airport obstruction survey is to accurately geolocate objects that penetrate FAA Obstruction Identification Surfaces (OIS). Penetrating objects are termed "airport obstructions." Examples of typical types of obstructions include trees, buildings, towers, poles, antennas, and terrain, to name just a few. This Scope of Work defines requirements for lidar data acquisition and processing to support the ASP. Project Instructions will provide project-specific information. Additional requirements for airport obstruction surveys are contained in FAA No. 405, *Standards for Aeronautical Surveys and Related Products* (U.S. Dept. of Transportation, 1996).

Lidar data acquisition for airport obstruction surveying is very different than acquisition for other applications, such as floodplain mapping or bare-earth terrain mapping. For this reason, this document contains detailed information on collecting lidar data for obstruction survey purposes. The following list outlines some of the most important considerations in collecting lidar for airport obstruction surveys and references the corresponding sections of this document:

A. Dual-look capability. Using a combination of tilt (or "forward look") angles is advantageous in obstruction surveying in that it yields strong geometry (point density on vertical objects) and radiometry (return signal strength), while also assisting in distinguishing between real features and false returns. (See Sections 4.1A and 5.2.)

B. Horizontal point spacing. The density of laser points on the ground is a key factor in the ability to detect obstructions. The horizontal point spacing in both the along-track and across-track directions must, therefore, meet the specifications contained in this document. (See Section 5.1.)

C. Vertical point spacing. Because many obstructions are tall, small-diameter objects, such as poles, the vertical point spacing is also a key consideration. The vertical point spacing, defined as the vertical distance between points from consecutive scan lines on the face of a vertical surface, is only applicable to tilted systems. (See Section 5.2.)

D. Mission planning. The mission parameters used in obstruction surveying are different than those typically used for other applications, such as bare-earth terrain mapping. In addition to choosing parameters that will meet the required horizontal and vertical point spacing, radiometric considerations (i.e., those related to received signal strength) must be taken into account. To ensure that the received signal from small-diameter, low-reflectance obstructions, such as antennas or poles, will be above the receiver detection threshold, it is typically necessary to use a narrow beam divergence and fly as low as possible, taking into account eye-safety limits and other considerations. (See Sections 7.1 and 7.2.)

E. Radiometric performance. The radiometric performance of the lidar system is critical in obstruction detection in that the received signal from small diameter, low-reflectance obstructions must be above the receiver detection threshold for these objects to be detected and successfully mapped. Lidar systems to be used in obstruction surveying must pass the radiometric qualification test described in this document. (See Section 6.)

F. Processing. For airport obstruction surveys, it is critical that first return (or "first pulse") data be used, as the required survey point for an obstruction corresponds to the top of the object. Furthermore, it is important that no filtering/interpolation be performed on the data, as this could lead to data points on obstructions inadvertently being eliminated or smoothed. (See Section 13.)

G. Imagery. Aerial photography (digital or film) is important in that it assists in attributing obstructions and in distinguishing real features from false returns. (See Section 10.)

The following conventions have been adopted for this document. The term "shall" means that compliance is required. The term "should" implies that compliance is not required, but is strongly recommended. All times shall be recorded in Coordinated Universal Time (UTC).

2. GOVERNMENT

A. PROPERTY OF DATA – All original data, from the instant of acquisition, and other deliverables required through this contract, are and shall remain the property of the United States Government. This includes data collection outside the project area. These items include the Contractor-furnished materials.

B. The government will provide to the Contractor:

1. PROJECT INSTRUCTIONS – Project Instructions are a separate document providing specific project information, containing any unique project requirements, and may have the following attachments:
    - Maps showing the project area;
    - Obstruction Identification Surface (OIS) requirements
2. LIDAR ACQUISITION REQUIREMENTS (this document)
3. REJECTED DATA – If data are rejected by NGS, NGS will send sample data upon request showing the problem areas.

3. DELIVERY SCHEDULE AND DATA FLOW

3.1 REGULAR PRODUCTION

Any request to deviate from these standards shall be approved in advance in writing by NGS.

A. DATA ACQUISITION STANDARDS

1. PDOP/VDOP shall be <3.
2. Unless otherwise stated in the project instructions, horizontal along-track and across-track point spacing shall not exceed the limits specified in Table 5.1.
3. Unless otherwise stated in the project instructions, vertical point spacing shall not exceed the limits specified in Table 5.1.
4. Aircraft bank angle shall not exceed 15 degrees.

B. DATA PROCESSING

1. The format of the data shall be latitude, longitude in packed D-M-S (DDMMSS.SSS) and referenced to the North American Datum 1983 (NAD 83).
2. The vertical datum is the North American Vertical Datum of 1988 (NAVD 88). To conform with aeronautical conventions and FAA standards, elevation units are U.S. Survey Feet.
3. The geoid model to be used in converting from GPS-derived ellipsoid heights to NAVD 88 orthometric heights is GEOID03 or the most current version. For geoid information see: www.ngs.noaa.gov/GEOID.
4. No filtering or interpolation shall be performed on the mass points data (other than outlier removal as described in Section 13.2), as these types of processing can inadvertently remove data points on obstructions.
5. The Contractor shall ensure complete coverage of the OIS. There shall be no holidays in the data (no data gaps) anywhere within the OIS.
6. The Contractor shall record all processing steps and software used including version number.
7. The Contractor shall use either Rapid or Precise orbits (but not UltraRapid orbits) for GPS processing.

C. ACCURACY STANDARDS

Accuracy requirements for airport surveys are a function of the survey type, which is specified by the FAA and listed in the individual project instructions. Additional information on accuracy requirements can be found in FAA Order 8260.19, *Flight Procedures and Airspace* (U.S. Department of Transportation, 1993) and FAA No. 405, *Standards for Aeronautical Surveys and Related Products, Fourth Edition* (U.S. Department of Transportation, 1996).

To ensure high-quality data, the Contractor may be required to perform a standard accuracy assessment and/or obstruction detection analysis on the lidar data. The individual project instructions will list the specific requirements.

The standard accuracy assessment, if required, will be performed in accordance with the "ASPRS Lidar Guidelines – Vertical Accuracy Reporting for Lidar Data" (ASPRS, 2004) and the corresponding horizontal accuracy reporting guidelines (when available). Only the "fundamental" vertical accuracy, as defined by ASPRS, needs to be calculated and reported; "supplemental" vertical accuracies for various ground cover classes do not need to be reported. Accuracy shall be reported at the 95% confidence level. At least 30 checkpoints shall be used, and these shall be referenced to the National Spatial Reference System (NSRS) and, preferably, tied to the National Continuously Operating Reference Stations (CORS) network. In accordance with the ASPRS Guidelines, the checkpoints should be at least three times more accurate than the data being tested and should be well distributed throughout the dataset. The checkpoints should be located on open terrain of constant gradient for which the "first return" and "last return" elevations are equal. A final report shall be generated following this testing process and delivered to NGS. This report shall contain a table summarizing the results including the number of checkpoints, and the mean, median, mode, skewness, and standard deviation of the dataset, in addition to the $Accuracy_{(z)}$, as defined in the ASPRS Guidelines.

Obstruction detection analysis is performed by comparing the lidar data against an independent high-accuracy field-surveyed obstruction data set. The software used in the obstruction detection analysis compares the data sets and computes the percent detection, as well as the horizontal and vertical RMSE for obstruction data points in the lidar data set. If obstruction detection analysis is required, NGS will supply the analysis software and specifications, as well as the independent field-surveyed data set.

D. DATA FORMAT STANDARDS

1. Format of deliverables shall be:
    a. Mass points: Delimited ASCII text containing at the minimum the following columns: All recorded returns (i.e. first, last, and any intermediate returns), GPS time, intensity, latitude (NAD83, DDMMSS.SSS, longitude (NAD83, DDDMMSS.SSS), height (NAVD88, feet). <u>No interpolation or filtering</u> shall be performed on the mass points.
    b. Intensity: GEOTIFF.
    c. Imagery: GEOTIFF. 0.5-m resolution or better (see Section 10).
2. The media for deliverable shall be DVD. Contractor shall maintain a copy of the data until NGS acknowledges receipt.

3.2 DATA FLOW

A. Acquisition Contractor (AC) acquires data,

B. AC processes data to NGS specifications,

C. AC validates data versus checkpoints,

D. AC ships data to NGS,

E. NGS receives data, assumes responsibility, reviews data, notifies AC of review outcome.

F. If during the NGS review, the data are found to not meet the Scope of Work (SOW), the Contractor may be required to re-acquire the data.

3.3 COMPLETION DATE

All deliverables shall be received by NGS, as specified, no later than the date in the Project Instructions.

4. EQUIPMENT AND MATERIAL

4.1 LIDAR SYSTEM

A. DUAL-LOOK CAPABILITY - The lidar data must be collected using two look angles (nadir and 20º forward), *except when the lidar survey will be supplemented with a conventional field survey*. This requirement can be met either with a custom dual-look system (i.e., a lidar system designed specifically for obstruction surveying utilizing dual lasers, each with a different look angle) or by using a variable-tilt sensor mount (Figure 4.1) and flying the project area twice: once in each configuration. Using two different collection geometries is important for two reasons:

1. The nadir-pointing and tilted senors compliment each other in that the tilted sensor provides better geometry (laser points that "walk up" the face of a vertical object), while the nadir-pointing sensor yields higher return signal strength from small obstructions.

2. The dual-look approach assists in distinguishing between "false returns" (i.e., unwanted returns caused by atmospheric particles, birds, electronic noise, etc.) and real features (e.g., the top of a power pole) in that it is unlikely that the same false point would be registered with both geometries.

Figure 4.1. Example of variable-tilt sensor mount. One method of meeting the dual-look requirement is to fly the project area twice (once in each configuration) using a variable-tilt mount.

B. MAINTENANCE – Before commencing data acquisition, the Contractor shall supply certification to NGS before that preventive maintenance and factory calibration have been satisfactorily completed within the last year for the lidar sensor.

B. DATA COLLECTION

1. Carrier-phase L1 and L2 kinematic GPS shall be acquired and used in processing the trajectories. See Section 12 for further details.
2. The lidar system must acquire and output "intensity" data (i.e., data values proportional to the signal strength for each return).
3. The lidar system shall be capable of meeting the horizontal and vertical point spacing requirements specified in Section 5.

C. MALFUNCTIONS – All lidar system malfunctions shall be recorded, and NGS notified. A malfunction is defined as a failure anywhere in the lidar sensor that causes an interruption to the normal operation of the unit. Also, record and report any malfunctions of the GPS or IMU collection systems.

4.2 AIRCRAFT

A. PLATFORM TYPE – The type of aircraft and the aircraft tail number used shall be stated on the Lidar Flight Log (Appendix A) and all aircraft used in the performance of this Project shall be maintained and operated in accordance with all regulations required by the Federal Aviation Administration. Any inspections or maintenance of the aircraft for performance of this Project which results in missed data collection shall not be considered as an excusable cause for delay.

B. PORT OPENING – The design of the port opening(s) in the aircraft shall be such that the field of view is unobstructed when a sensor is mounted with all its parts. The field of view shall, so far as is practicable, be shielded from air turbulence and from any outward flows, such as exhaust gases, oil, etc. The port opening shall not contain any type of window (including optically-flat windows). The sensor shall have a clear view of the ground below, and no optics other than those internal to the lidar system and installed by the manufacturer shall be placed in the optical path of the laser beam. This requirement is due to the fact that some attenuation of the laser radiation will occur even with coated, optically-flat windows, which could lead to non-detection of obstructions.

5. POINT SPACING

The spacing of the lidar data points is a critical factor in the ability to detect obstructions. Both the horizontal and vertical point spacing (defined in Sections 5.1 and 5.2, respectively) shall meet the specifications contained in Table 5.1, unless otherwise stated in the project instructions.

5.1 HORIZONTAL POINT SPACING

Horizontal point spacing refers to the spacing of the lidar points on a flat surface. Horizontal point spacing is defined along two directions: along track (i.e., in the direction of flight) and across track (i.e., perpendicular to the direction of flight). The horizontal along-track point spacing, HPS_{along}, is given by

$$HPS_{along} = \frac{v}{2f_{sc}} \tag{5.1}$$

where v is the flying speed over ground and f_{sc} is the scan frequency. The horizontal across-track point spacing, HPS_{across}, is given by

$$HPS_{across} \approx \frac{\text{Swath Width}}{\text{Number of points per scan line}}$$

$$= \frac{2H\tan\left(\frac{S}{2}\right)}{\text{PRF}\left(\frac{\tau_{sc}}{2}\right)} \tag{5.2}$$

where H is the flying height, S is the full scan angle, PRF is the pulse repetition frequency, and τ_{sc} is the period of the scanner (i.e., the inverse of the scan frequency).

Unless otherwise stated in the project instructions, horizontal point spacing must meet the specifications contained in Table 5.1.

5.2 VERTICAL POINT SPACING

Vertical point spacing refers to the vertical distance between points from consecutive scan lines on the face of a vertical surface. Vertical point spacing is only applicable in the case of a tilted sensor. Vertical point spacing, *VPS*, is given by

$$VPS = v\tau_{sc}\cot(t) \tag{5.3}$$

where v is the flying speed over ground, τ_{sc} is the period of the scanner, and t is the tilt (or "forward look") angle.

Unless otherwise stated in the project instructions, the vertical point spacing must meet the specifications contained in Table 5.1.

	Maximum Across-Track Horizontal Point Spacing	Maximum Along-Track Horizontal Point Spacing	Maximum Vertical Point Spacing
Lidar survey supplemented with aerial photography (digital or film)	0.5 m	0.5 m	1.5 m
Lidar survey supplemented with aerial photography and field survey	0.8 m	0.8 m	N/A

Table 5.1. Point Spacing Specifications.

6. RADIOMETRIC QUALIFICATIONS TEST

The objective of the test procedures described here is to radiometrically qualify lidar systems for airport obstruction surveying. The radiometric performance of a lidar system is critical in obstruction detection. Small-diameter, low-reflectance obstructions, such as dark-colored poles and antennas, are not likely to be detected with systems that do not pass this test. The test procedures have been designed to meet the following requirements:

- Provide a common reference so that the results from different manufacturers' lidar systems will have the same meaning.
- Provide a method that specifically tests the ability of the lidar system to detect small-diameter obstructions, such as antennas and poles.
- Define a clearly-stated pass/fail criterion.
- Utilize a ground-based, controlled test environment.
- Ensure repeatability of the results.

The test will be carried out under the oversight of NOAA personnel at the NOAA Lidar Radiometric Calibration Center (LRCC) at Corbin, VA, unless written consent is granted by NOAA for the Contractor to perform the in-flight radiometric qualification test in lieu of the test described below. The test setup is illustrated in Figure 6.1. The test target consists of one-half inch wood doweling painted with Kodak White Reflectance Coating. This coating provides a standard reflectance of nearly 100% at 1064 nm with lambertian reflectance properties. The target is placed at a known distance of R_o = 100 m and positioned such that it intercepts the transmitted beam in the middle. The doweling must be long enough to cross the entire beam spot diameter.

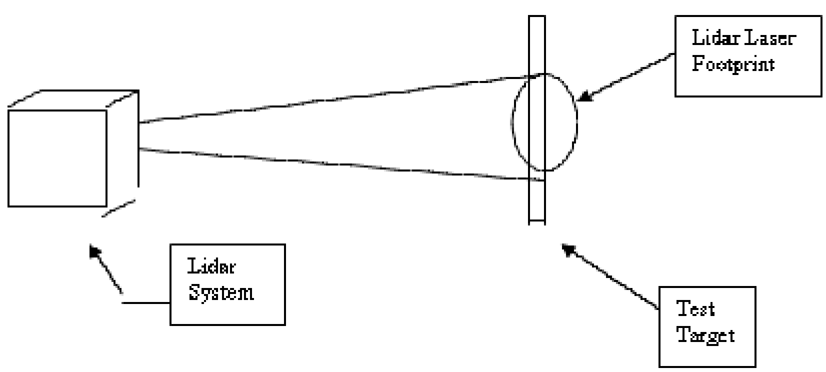

Figure 6.1. Setup for radiometric qualifications test to be performed at the NOAA Lidar Radiometric Calibration Center (LRCC) at Corbin, VA.

The laser is fired at the test target and the return signal strength is recorded. The return signal strength is then scaled to correspond to the actual planned flight parameters using Equation 6.1:

$$S_{R_{MAX}\rho_{MIN}} = S_{R_o\rho_o}\left(\frac{R_o}{R_{MAX}}\right)^3\left(\frac{\rho_{MIN}}{\rho_o}\right) \qquad (6.1)$$

where $S_{R_o\rho_o}$ is the measured signal, R_o is the test range (100 m), R_{MAX} is actual maximum range for the planned flight parameters, ρ_o is the reflectance of the standard target (100% with the Kodak White Reflectance Coating), and ρ_{MIN} is the "worst-case scenario" reflectance, which we take to be 5%. R_{MAX} is calculated from:

$$R_{MAX} = \frac{H}{\cos(t)\cos(s)} \qquad (6.2)$$

Where H is the flying height, t is the tilt ("forward look") angle, and s is the half scan angle from the flight plan. The pass/fail criterion is then defined by Equation 6.3

$$S_{cr} > f_{cr} \cdot f_a \cdot S_{thr} \qquad (6.3)$$

where f_{cr} is correction factor that accounts for the fact that the pass/fail criterion for the signal should be at least 10% above the system threshold, and f_a is a correction factor for atmospheric losses, which is obtained from the graph in Figure 6.2.

If Equation 6.3 is satisfied, the system passes the test; otherwise it fails. Figure 6.3 graphically illustrates a case in which the system passes the test.

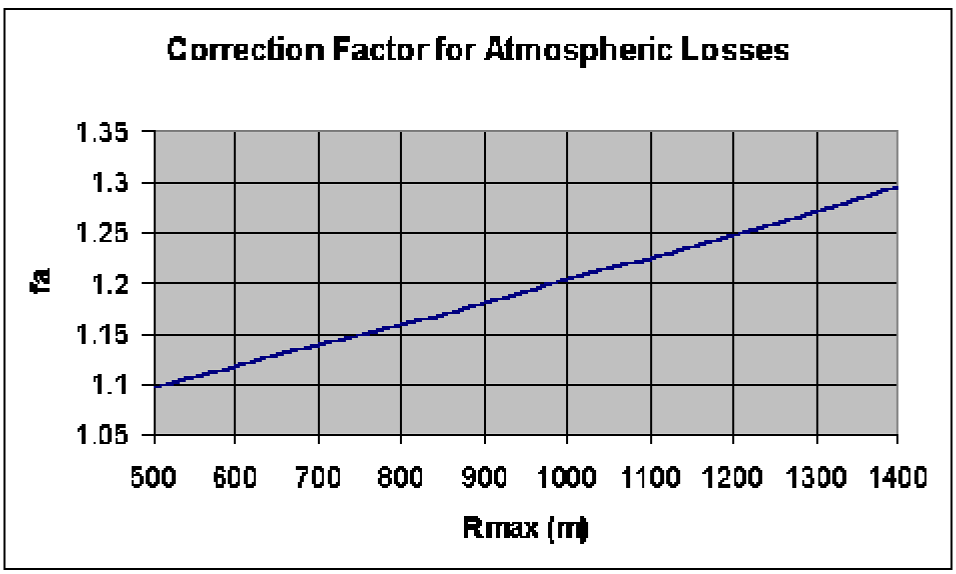

Figure 6.2. Atmospheric correction factor, f_a, as a function of the maximum range, R_{MAX}.

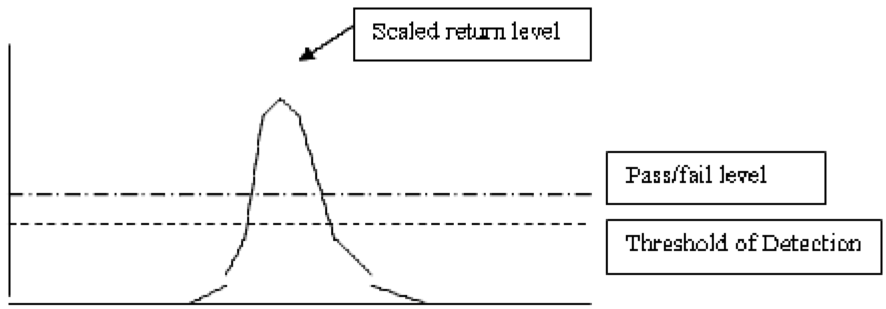

Figure 6.3. Graphical illustration of a case in which the system passes the radiometric qualifications test.

With written consent from NOAA, the Contractor may opt to perform the in-flight radiometric qualifications test in lieu of the test described above. In this scenario, NOAA and the Contractor will agree upon a test range, which the Contractor will fly using planned mission parameters for the airport survey work. At the time of overflight, NOAA personnel will position the Obstruction Testing In-situ System (OTIS) within the test range. OTIS consists of a base plate to which several antenna-like objects of different heights and reflectances at 1064 nm may be attached. NOAA personnel will conduct an accurate GPS survey of OTIS before or after the flight mission. After processing the lidar data, the Contractor will deliver to NOAA a mass points file for the test range, and NOAA will investigate the radiometric performance through a comparison of the mass points against the GPS reference data for OTIS.

7. SYSTEM CALIBRATION

Inadequate calibration or incomplete calibration reports shall be cause for rejection of the data by NGS. Calibration reports for each lidar system used shall be supplied to NGS at the beginning and end of the project. The calibration reports shall cover each of the following types of calibration:

7.1 FACTORY CALIBRATION – Factory calibration of the lidar system shall address both radiometric and geometric performance and calibration. (Note: the factory radiometric calibration does not obviate the need for the radiometric qualification test for obstruction surveying described in the previous section). The following briefly describes the parameters to be tested according to test procedures defined by the manufacturer. Some of these procedures and parameters may be unique to a manufacturer since hardware varies from manufacturer to manufacturer.

1. Radiometric Calibration (sensor response):
    - Ensure that the output of the laser meets specifications for pulse energy, pulse width, rise time, frequency, and divergence for the lidar system being tested.
    - Measure the receiver response from a reference target to ensure that the response level of the receiver is within specification for the lidar system being tested.
    - Check the alignment between transmitter and receiver and certify that the alignment is optimized and within specification.
    - Measure T0 response of receiver (i.e., the response at the time the laser is fired) to ensure that the T0 level is within specification.

2. Geometric Calibration:
    - Range Calibration – Determine rangefinder calibrations including first/last range offsets, temperature dependence, and frequency offset of rangefinder electronics, range dependence on return signal strength. Provide updated calibration values.
    - Scanner Calibration – Verify that scanner passes accuracy and repeatability criteria. Provide updated scanner calibration values for scanner offset and scale.
    - Position Orientation System (POS)-Laser Alignment – Alignment check of output beam and POS. Also, provide updated POS misalignment angles.

    Overall, the system shall be tuned to meet the performance specifications for the model being calibrated. The contractor shall ensure that, for each lidar system used, factory calibration has been performed within the 24-month period preceding the data collection. Recalibration is required at intervals no greater than 24 months. Contractors who wish to apply for a waiver to this requirement must send a written request to NGS stating the date of the last factory calibration and a detailed justification for the waiver.

7.2 FIELD CALIBRATION – Field calibration is performed by the system operator through flights over a calibration site that has been accurately surveyed using GPS or conventional survey techniques. Typically, the calibration site may include a large, flat-roofed building whose corners have been accurately surveyed with GPS and a large, flat parking lot or runway. The calibration may include flights over the site in opposing directions, as well as cross flights. The field calibration is used to determine corrections to the roll, pitch, and scale calibration parameters. Field calibration must be performed for each project or every month, whichever is shorter.

7.3 LEVER ARMS – Determination of sensor-to-GPS-antenna offset vector ("lever arm") components: The offset vector shall be determined with an absolute accuracy (1σ) of 1.5

cm or better in each component. Measurements shall be referenced to the antenna phase center. The offset vector components shall be redetermined each time the sensor or aircraft GPS antenna is moved or repositioned in any way.

8. MISSION PLANNING AND CLEARANCES

8.1 MISSION PLANNING

A. COVERAGE AND PARAMETERS – The Contractor shall plan flight lines for the project area (described in the Project Instructions) and ensure complete coverage of the obstruction identification surfaces (OIS). The horizontal along-track point spacing, horizontal across-track point spacing, vertical point spacing, swath width, swath overlap, navigation, GPS, visibility, point density and radiometric considerations shall be taken into account in flight planning. NGS may supply recommendations and/or requirements for planning parameters in the Project Instructions.

B. OVERLAP – Adjacent swaths shall have a minimum overlap of no less than 50% of the mean swath width.

C. FLIGHT DIRECTION – Flight lines shall be flown in either direction, but adjacent, parallel lines should be flown in opposite directions to help identify systematic errors.

D. LIDAR SURVEY PLAN REPORT

1. PROPOSED FLIGHT LINES – Prior to data acquisition, the Contractor shall submit paper map(s) clearly showing all proposed flight lines, and include coverage, scale, proposed ground control, and OIS boundaries. Also included shall be information about scan angle, pulse repetition frequency (PRF), flying height, flying speed over ground, and horizontal and vertical point spacing.
2. ACTUAL LINES FLOWN – Similar map(s) showing the actual flight lines shall be included in the Final Report, see Section 13 U 3.

8.2 FLYING HEIGHT

Flying height is an important factor in obstruction detection in that the received power from small-diameter obstructions falls off as the 3^{rd} power of the flying height. Hence, to ensure a high-probability of obstruction detection, it is typically desirable to <u>fly as low as possible</u>, within the applicable eye-safety limits.

8.3 FLIGHT CLEARANCES

The Contractor shall comply with all required Federal Aviation Administration Regulations, including obtaining all required clearances.

9. EYE SAFETY

Because Lidar systems typically employ Class 4 lasers, safety is a paramount concern. ANSI standards for safety shall be followed. See ANSI Z136.1 Safe Use of Lasers and ANSI Z136.6 Safe Use of Lasers Outdoors. For further details regarding safety issues in Lidar data collection, refer to *Eye Safety Concerns in Airborne Lidar Mapping* (Flood, 2001, ASPRS Conference Proceedings). The contractor shall assume sole responsibility for adherence to all safety regulations and shall implement necessary internal controls to ensure the safety of all persons in the aircraft and in the survey area below.

10. IMAGERY

Stereo aerial photography is an important supplement to the lidar data in that it enables the following functions to be performed:

- Qaulity Assurance/Quality Control
- Feature Attribution
- Outlier Removal

The aerial photography may be obtained using a calibrated digital or film-based camera. The requirements for the aerial photography collected during a lidar project are less stringent than those enforced for conventional surveys in NGS' Aeronautical Survey Program. However, the aerial photography must meet the following minimum requirements:

- Spatial resolution of 0.5 m or better
- 60% or greater forward endlap
- 30% or greater sidelap
- Acquired within two weeks of the airborne lidar acquisition (but preferably simultaneously) and during leaf-on conditions
- Acquired with a minimum sun angle of 30º for film-based cameras and 20º for digital cameras

The project instructions will contain requirements for ground control and/or direct georeferencing of the imagery.

11. WEATHER AND TIME OF YEAR

11.1 WEATHER CONDITIONS

Lidar data acquisition missions shall be flown in favorable weather. Inclement weather conditions such as rain, snow, fog, mist, high winds, and low cloud cover shall be avoided. In addition, to ensure low atmospheric attenuation and high return signal strength, Visual Meteorological Conditions (VMC) and visibility of at least 8 miles are required. If clouds are present, data capture is only permitted if cloud coverage is above the height of the sensor and airborne platform. Lidar shall not be conducted when the ground is covered by water (flood), snow, or ice.

11.2 TIME OF DAY

Data acquisition operations may occur during either day or night. Unlike aerial photography, sun angle is not a factor in when a mission may be flown. However, time of day needs to be considered when supplemental imagery (e.g., video, digital imagery, or film photography) is acquired concurrently with the capture of lidar data to help assist in identifying features in post-processing production.

11.3 TIME OF YEAR

For obstruction detection, the contractor shall fly in leaf-on conditions, as this increases the probability of detecting the tops of trees. For most geographic locations, data acquisition must be completed before late fall. The project instructions will contains specific recommendations and/or requirements.

12. POSITIONING AND ORIENTATION FOR THE DATA

12.1 POSITIONING

A. GPS COLLECTION

1. All lidar data shall be georeferenced using integrated GPS/inertial systems employing dual frequency receivers.
2. All kinematic GPS (KGPS) solutions should use differential, ionosphere-free, carrier-phase combinations with phase ambiguities resolved to their integer values.
3. Aircraft trajectories shall be processed using carrier-phase GPS. Dual L1 and L2 frequency receivers and one-second collection shall be used.
4. All KGPS shall use at least two ground stations. The ground stations shall be accurately tied to the NSRS (stations in the NGS database); shall be positioned to 0.1 meter accuracy, or better; shall be within or near the project area; and shall be within 100 kilometers of the entire project area. Additional ground GPS stations may be required, and CORS (continually operating reference stations) can be used as ground stations. The ground stations should be positioned on opposite sides of the operating area. The ground stations shall be positioned, or the flight path arranged, so that during flight operations the aircraft will pass within 10 kilometers to each ground station at least once.
5. The maximum GPS baseline shall not exceed 100 kilometers at any time during flight. Regardless of aircraft flight time, GPS ground station data shall be collected for four hours.
6. Ground station data shall be submitted to OPUS (Online Positioning User

System – http://www.ngs.noaa.gov/OPUS/) for positioning in the NSRS, except where ground station is located over a known monument.

B. GPS SOLUTION PROCESSING

1. The Contractor shall collect, process, and submit the ground and airborne GPS data, both raw data and final processed data.
2. Differential KGPS solutions for the aircraft shall be obtained independently using each ground station.
3. These independent KGPS solutions shall be compared to display their differences in the north-south, east-west, and vertical components during the operational portions of the flights.
4. The RMS of these differences shall not exceed 5 cm in the horizontal and 10 cm in the vertical.
5. The KGPS solutions shall model the tropospheric delay using average surface meteorological values at the ground stations collected near the midpoint of operations.
6. The final KGPS solution will be an average of the separate ground station solutions.

C. ANTENNA

1. The GPS receivers should be equipped with antennas that have been calibrated by NGS. A choke-ring antenna to minimize multipath is preferred but not required.
2. The antenna height shall be accurately measured.

12.2 GROUND-BASED GPS RECEIVER

A. MARK – The ground-based receiver shall be set up over a known (or to-be-determined) marked base station and shall run continuously during the mission. If a known base station is used, it must be in the NGS database and hence part of the NSRS. If a new base station is used, it shall be marked permanently (to NGS specifications) or temporarily marked (such as a PK type nail or iron pin).

B. OBSERVATIONS – The position of an existing mark shall be checked by processing one GPS session and comparing the computed position with the NGS published position. A new mark shall be referenced to the NSRS by tying to one or more NGS Continuously Operating Reference Stations (CORS) by static GPS methods. If the distance to the nearest NGS CORS is less than 50 miles, use at least two independent sessions, each 2 hours long. If the distance to the nearest NGS CORS is greater than 50 miles, use at least two sessions, each 4 hours long. Make a separate tripod set-up and height measurement for each session. Take care in the accurate recording of the height of the antenna both before and after the flight. Record all heights, equipment serial numbers, etc. on the NGS forms: Visibility Obstruction

Diagram and GPS Observation Log. For a listing of these and other forms on the NGS website see: www.ngs.noaa.gov/PROJECTS/FBN/. Also, static observations may be processed using the NGS "On-Line User Positioning Service" (OPUS) found at: www.ngs.noaa.gov/OPUS/index.html. Observations to establish a new, permanent mark shall be submitted in NGS "Blue Book" format.

C. RECOVERY – For an existing NSRS station, write a digital recovery note using the online Mark Recovery Form: http://www.ngs.noaa.gov/FORMS_PROCESSING-cgi-bin/recvy_entry_www.prl For a new, permanent station write a digital station description in NGS format using WDDPROC. For a new, temporary mark write a brief description adequate to recover the station. Take three photographs of the base station (photographs of the CORS station are not required).

For additional specification guidance on mark setting, GPS observations, data processing, and data submittal in NGS format, see the "General Specifications for Aeronautical Surveys, Volume I, Establishment of Geodetic Control on Airports" at:

- http://www.ngs.noaa.gov/AERO/Supinst.html
- http://www.ngs.noaa.gov/FGCS/BlueBook/
- http://www.ngs.noaa.gov/PROJECTS/FBN/

12.3 AIRCRAFT GPS RECEIVER

A. GPS OBSERVATIONS – The GPS receivers used on both the aircraft and ground station(s) shall be able to collect and record, at least once per second, carrier phase observations from a minimum of four satellites (five or more preferred). All data shall be collected with a Position Dilution of Precision (PDOP) of less than 3.

B. GPS LOCK – The aircraft shall maintain GPS satellite lock throughout the entire flight mission. If satellite lock is lost, on-the-fly ambiguity resolution methods may be used to recapture lock, while airborne. Report these instances, procedures used, and any other unusual occurrences.

12.4 AIRBORNE ORIENTATION

The lidar system shall utilize a high-quality integrated GPS/Inertial Measurement Unit (IMU) system. The IMU shall operate at a minimum of 50Hz.

12.5 AIRBORNE POSITIONING AND ORIENTATION REPORT

The Report shall include at least the following paragraphs:

– Introduction
– Positioning

– Data Collection
– Static Processing
– Kinematic Processing
– Data Sets
– Orientation
– Data Collection
– Data Processing
– Data Sets
– Final Results

A. INTRODUCTION – Provide an overview of the project and the final processed data sets and list the data sets in table form with the following columns: Dataset ID, Date of Acquisition, Projects covered by the data set, and Description/Flight Line(s) Identification.

B. POSITIONING – Discuss the methodology, the hardware and software used (including models, serial numbers, and versions), the PACS, SACS, and/or CORS station(s) used, a general description of the data sets, flight lines, dates and times of sessions, the processing (including the type of solution–float, fixed, ion–free, etc.), and the results (discussion of the coordinates and accuracy) . Submit a description of the data sets, and the raw and processed data. If the NGS OPUS website was used to process the static data, the Contractor shall provide a digital copy of the OPUS report. If a known station was used from the NGS database, the Contractor shall identify the station by name and permanent identifier (PID), and provide the published coordinates used in the kinematic position step. If multiple base stations were used, provide processing details, coordinates, and accuracy for all stations.

C. ORIENTATION – Discuss the factors listed above for Positioning.

D. FINAL RESULTS – Describe any unusual circumstances or rejected data, and comment on the quality of the data.

13. OIS ANALYSIS AND OUTLIER REMOVAL

13.1 OIS ANALYSIS

Obstruction Identification Surface (OIS) analysis entails analyzing each data point in the lidar mass points file against the FAA-specified OIS for the airport. The dimensions of the OIS are functions of the following factors: the length of the runway(s), the configuration of the runway(s), the type of survey (e.g., ANA vs. AOC), and the FAA designation for each runway approach. The OIS analysis must be performed using NGS supplied software contained in the NGS COM Surface Model software libraries. The output of the OIS analysis shall include all penetrating lidar points and all other required points. Each output point must contain a latitude, longitude, NAVD88 orthometric height, accuracy code (in accordance with *FAA Order 8260.19, Flight Procedures and Airspace*, U.S. Dept. of Transportation, 1993), and applicable zone information.

13.2 OUTLIER REMOVAL

Distinguishing between false returns (i.e., unwanted returns due to birds, atmospheric particles, electronic noise, etc.) and real features (e.g., the top of a pole) is currently one of the greatest challenges in extracting obstructions from lidar data. The individual project instructions will specify whether the outlier removal is to be performed by NGS or the Contractor. In general, outlier removal consists of two steps: automated sorting and manual analysis. Automated sorting uses algorithms to quickly sort the penetrating and other required mass points into three categories: 1) obstructions, 2) obvious outliers, and 3) possible outliers. Manual analysis is more time-consuming and involves a human analyst viewing each possible outlier overlaid on the stereo imagery (see Section 10).

14. DATA LABELING

All DVDs shall be labeled with the project name, collection date(s), Contractor name, and disk contents. Lidar data DVDs shall be able to be easily matched with the corresponding Lidar flight log(s).

15. DATA SHIPMENT AND PROCESSING

15.1 SHIPMENT

The Contractor shall ship final deliverables in NGS format (on DVD), directly to NGS, to arrive at NGS within ten working days from the date the data were processed. Copies of the Lidar Flight Log and the raw navigation files may be made and used by the Contractor to produce and check the final deliverables.

15.2 NGS NOTIFICATION

The same day as shipping, the Contractor shall notify NGS of the data shipment's contents and date of shipment by transmitting to NGS a paper or digital copy of the data transmittal letter via email or fax.

16. DELIVERABLES

A. LABOR, EQUIPMENT AND SUPPLIES – The Contractor shall provide all labor, equipment (including aircraft and lidar system), supplies and material to produce and deliver products as required under this document.

B. LIDAR SURVEY PLAN – Prior to data acquisition, submit a proposed Lidar

Survey Plan which specifies the data collection parameters to be used and contains a map of the flight lines and the project coverage area, including flying height and speed over ground, scan angle, PRF, and horizontal and vertical point spacing. NGS will review the proposed mission planning reports, normally within five business days, and will respond in writing with approval and/or comments. The Final Report shall contain map(s) showing the flight lines and boundaries of lidar data actually collected.

C. LIDAR TEST – The Contractor shall acquire and deliver an example dataset over an airport.

D. LIDAR RAW DATA – Submit the completed data collection raw output.

E. LIDAR PRODUCTS – Required products may include: mass points files, intensity images, and imagery. The Project Instructions will specify which additional products, if any, are required. See 3.1 D.

F. FLIGHT REPORTS – Submit the completed, original Lidar Flight Logs with the data, and a copy directly to NGS.

G. GLOBAL POSITIONING SYSTEM (GPS)/INERTIAL MEASUREMENT UNIT (IMU) FILES – The Contractor shall submit the original, raw data files and processed trajectory files directly to NGS, to arrive at NGS along with the raw data points and final products. See sections 12.1 and 12.4.

H. AIRBORNE POSITIONING AND ORIENTATION REPORT – Submit raw GPS and IMU data (in the manufacturer's format) along with the final processed GPS trajectory and postprocessed IMU data. Also submit a report covering the positioning and orientation of the Lidar. See Section 12.5.

I. RANGE AND SCANNER ANGLE FILES – The Contractor shall submit the original, raw data files directly to NGS, to arrive at NGS along with the raw data points and final products.

J. GPS CHECK POINTS – Submit an organized list of all GPS points used for the project as base stations and check points. Indicate which GPS points are existing ground control and which stations are new and positioned relative to the NSRS. See Project Instructions and sections 3.1 C and 12.2.

K. NGS SURVEY FORMS – The Contractor shall prepare and submit the following NGS forms for each GPS check point and the GPS base station(s): Visibility Obstruction Diagram, GPS Observation Log, Recovery Note or Station Description. See Section 12.2.

L. CALIBRATION REPORTS – There is no standard format for the calibration reports. However, the calibration reports shall contain, at a minimum, the following information:

a. The date the calibration was performed.

b. The name of the person, company, or organization responsible for performing the calibration.

c. The methods used to perform the calibration.

d. The final calibration parameters or corrections determined through the calibration procedures.

M. SENSOR MAINTENANCE – Provide maintenance history directly to NGS of the sensor to be used for acquiring Lidar. See Section 4.1.

N. DATA SHIPMENT – See Sections 3 and 15 for instructions.

O. DATA SHIPMENT REPORTING – The Contractor shall notify NGS of each data shipment's contents and date of shipment by transmitting to NGS a paper or digital copy of the Lidar Flight Log (marked "copy" at the top) and a copy of the data transmittal letter via email or facsimile. This shall be done the same day the data is shipped to the data processing contractor. See Section 15.

P. UNUSUAL CIRCUMSTANCES – The Contractor shall also notify NGS of any unusual circumstances that occur during the performance of this project which might affect the deliverables or their quality and especially of any deviation from this project. This may be included in the weekly email required below, unless urgent.

Q. DEVIATIONS FROM SCOPE OF WORK – Requests to exceed or deviate from the Project Instructions will be considered if written justification is provided to NGS in advance. No deviation is permitted until written approval is received from NGS.

R. STATUS REPORTS – The Contractor shall submit project status reports via email to the Contractor Officer's Technical Representative (COTR) contacts in Section 14 every week, until the work is complete. **These reports are due at NGS by 2:00 p.m. EST each Monday.** These reports shall include a summary of completed data acquisition, with dates completed; data shipped, and dates; and any unusual circumstances, equipment malfunctions, and/or any disturbance of the sensor. **A weekly status report is required even if no progress has been made.**

S. FINAL REPORT
The Contractor shall supply to NGS a Final Report incorporating all of the information in this Deliverables section including, at least, the sections suggested

below:

1. Work performed under this contract, discuss each deliverable including: the maximum range from the base station, the minimum swath overlap, percent of good laser returns (if available), standard deviation and residuals in GPS trajectories, and an explanation of the DVD labeling;
2. Equipment used to perform this work, including hardware models and serial numbers, calibration reports, and software names and versions (include aircraft and lidar info);
3. Flight line map(s), and project coverage area;
4. Discussion of data quality including quality assurance (QA)/quality control (QC) procedures;
5. Ground Control Report, including a station list in table format;
6. Aircraft Navigation;
7 Airborne kinematic GPS Report, including ground stations;
8. Weather, solar altitude, and time of year;
10. Any unusual circumstances or problems, including equipment malfunctions (including those already reported);
11. Any deviations from this Lidar SOW, including those already reported;
12. Any recommendations for changes in the Lidar SOW for future work.

T. PROPERTY OF DATA – All original data, from the instant of acquisition, and other deliverables required through this contract including raw data and final products, are and shall remain the property of the United States Government. This includes data collection outside the project area.

17. REVIEW

Data and other deliverables not meeting these specifications may be rejected.

18. POINTS OF CONTACT:

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19. REFERENCES

ASPRS, 2004. ASPRS Lidar Guidelines – Vertical Accuracy Reporting for Lidar Data V1.0. American Society for Photogrammetry and Remote Sensing, Bethesda, Maryland.

Flood, M., 2001. *Eye Safety Concerns in Airborne Lidar Mapping*. Proceedings of the ASPRS 2001 Annual Convention, 23-27 April, St. Louis, Missouri (American Society for Photogrammetry and Remote Sensing, Bethesda, Maryland), unpaginated CD-ROM.

Parrish, C.E., G.H. Tuell, W.E. Carter, and R.L. Shrestha, 2005. Configuring an airborne laser scanner for detecting airport obstructions. *Photogrammetric Engineering & Remote Sensing*, Vol. 71, No. 1.

Parrish, C., J. Woolard, B. Kearse, and N. Case, 2004. Airborne LIDAR Technology for Airspace Obstruction Mapping. *Earth Observation Magazine (EOM)*, Vol. 13, No. 4.

U.S. Department of Transportation, 1993. *FAA Order 8260.19, Flight Procedures and Airspace*. Federal Aviation Administration, Washington, DC.

U.S. Department of Transportation, 1996. *FAA No. 405, Standards for Aeronautical Surveys and Related Products, Fourth Edition*. Federal Aviation Administration, Washington, DC.