March 19, 2004

Light Detection And Ranging (LIDAR) Requirements

SCOPE OF WORK FOR SHORELINE MAPPING
UNDER THE
NOAA COASTAL MAPPING 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 Coastal Mapping Program (CMP) works to provide a regularly-updated and consistent national shoreline to define America's marine territorial limits and manage coastal resources. This shoreline is present on National Oceanic and Atmospheric Administration (NOAA) nautical charts and is considered authoritative when determining the official shoreline for the United States. The CMP is administered by the National Geodetic Survey (NGS), National Ocean Service (NOS), NOAA. This Scope of Work defines requirements for LIDAR data acquisition and processing to support the CMP. Project Instructions will provide project-specific information.

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 and imagery, from the instant of acquisition, and other deliverables required through this contract including final images, are and shall remain the property of the United States Government. This includes image 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:
2. Small scale maps showing the coastline and/or coastal ports to be acquired;
3. Tide coordination time windows for data acquisition, see Section 8.
4. LIDAR ACQUISITION REQUIREMENTS (this document)
5. 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. Mass point spacing shall not exceed limits defined in separate Project Instructions.
3. Digital Elevation Model (DEM)/Digital Surface Model (DSM) point

spacing shall not exceed limits defined in separate Project Instructions. The Digital Surface Model is defined as the bare earth ground surface.

4. Aircraft bank angle shall not exceed 15 degrees.

B. DATA PROCESSING

1. The data shall be projected in Universal Transverse Mercator (UTM) and referenced to the North American Datum 1983 (NAD 83). Only one UTM zone shall be used, even if the project area splits zones.
2. The vertical datum is the North American Vertical Datum of 1988 (NAVD 88).
3. The geoid model to be used in converting from GPS-derived ellipsoid heights to NAVD 88 orthometric heights is Geoid 99 or the most current version. For GEOID information see: www.ngs.noaa.gov/GEOID/GEOID99/geoid99.html.
4. Contractor shall remove outliers in raw data prior to interpolation. Outliers include obvious abnormalities in the data such as returns off of a bird, however be careful to not remove real outliers such as offshore rocks. Contractor shall supply NGS with both sets of raw points and an Outlier Removal File (ORF) indicating number of points removed. Interpolation shall be completed with industry standard software to facilitate validation of DSM. Contractor shall provide details of interpolation process (software and method).
5. There shall be no holidays in the data (no data gaps) unless unavoidable in which case other mapping methods may be used if approved by NGS. Interpolation across or smoothing over holidays is unacceptable and may result in rejection of the data by NGS. Any holidays shall be filled with additional data collection unless approved by NGS.
6. Contractor shall record all process steps and software used including version number.
7. Contractor shall use either the rapid or precise ephemeris for GPS processing.

C. ACCURACY STANDARDS

1. Accuracy reporting, i.e. $RMSE_{X,Y,Z}$, shall follow methods set forth by the Federal Geographic Data Committee at:
   - www.fgdc.gov/standards/documents/standards/chapter1.pdf, and
   - www.fgdc.gov/standards/documents/standards/chapter2.pdf, and
   - www.fgdc.gov/standards/documents/standards/chapter3.pdf

2. Accuracy shall be determined by the following methods:
   a. Contractor shall obtain a minimum of 30 validation check points using geodetic quality derived measurements at evenly-spaced intervals along the entirety of the project area. Using 30 checkpoints allows for a statistically significant error analysis. The

X, Y, and Z components shall all be referenced to the NSRS (National Spatial Reference System) and in the same coordinate system and datums used in the rest of the project. As a rule of thumb, the check points should be ten times better than the data they are checking.

b. The contractor should, if possible, acquire at least one flight line across a repeatable and verifiable surface (road, parking lot, tarmac) in order to compare the overlapping swaths to identify any systematic errors.

c. The offsets between both the mass point cloud and the derived DSM from that of the validation check points shall be used to calculate both $RMSE_{X,Y}$ and $RMSE_Z$.

d. The requirements for $RMSE_{X,Y}$ and $RMSE_Z$ will be specified in separate Project Instructions.

e. Contractor shall verify internal consistency of range measurements in areas of overlap among swaths that shall agree with the accepted instrument's error.

f. All validation data shall be submitted to the NGS, as well as an accuracy report that includes a statistical summary of the data quality. This shall include presentation of the $RMSE_{X,Y}$ and $RMSE_Z$, a table summarizing the overall statistics of both the $RMSE_{X,Y}$ and $RMSE_Z$ consisting of: number of points, mean, median, mode, skewness, standard deviation, minimum, and maximum representative of each RMSE calculation, as well as a table and separate histogram that illustrate the derived delta between each validation checkpoint and that of both the LIDAR mass point cloud and the derived DSM.

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, X, Y, Z for points used to generate the DSM.
   b. Digital surface model (DSM): GEOTIFF.
   c. Shoreline vectors: shape file and/or ASCII nodes.
   d. Intensity: GEOTIFF.
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 check points,

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 INERTIAL MEASUREMENT UNIT

The Inertial Measurement Unit (IMU) employed in the LIDAR system shall meet or exceed the following performance specifications:

- Accuracy in roll and pitch (RMS): 0.015°
- Accuracy in heading (RMS): 0.050°

4.2 LIDAR SENSOR

A. MAINTENANCE – The Contractor shall supply certification to NGS before the project is commenced that preventive maintenance and factory calibration have been satisfactorily completed within the last two years 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 9 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 record the "true" last pulse. For example, in a system that collects three returns, the third return must correspond to the last detectable pulse within the return waveform to maximize the probability of getting the true (or closest to true) terrain measurement below the vegetation; it is not acceptable to simply record the first three events.

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.

4.3 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. The Contractor shall ensure that the aircraft has a proven service ceiling, with operating load (fuel, crew, sensor, and other required equipment), of not less than the highest altitude required to acquire the data.

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 above the outer structure. 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.

C. OPTICAL FLAT – NGS recommends that an optical flat not be used. If an optical flat is used, the physical characteristics of the window (such as size, thickness, smoothness, flatness, parallelism, glass quality, and optical transmissivity) shall be reported to NGS prior to use. The optical flat shall meet the following specifications:
   1. High transmittance at the laser wavelength;
   2. Mounted in material eliminating mechanical stress to the window;
   3. Free of blemishes, dirt, significant scratches, etc.;
   4. Not degrade the accuracy of the range measurements.

5. 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:

A. FACTORY CALIBRATION – Factory calibration of the LIDAR system shall address both radiometric and geometric performance and calibration. 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 model of LIDAR being tested.
- Measure the receiver response from a reference target to ensure that the response level of the receiver is within specification for the model of 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.

B. 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 such as triangulation or spirit leveling. 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.

C. DETERMINATION of sensor-to-GPS-antenna offset vector components ("lever arm"): The offset vector shall be determined with an absolute accuracy (1σ) of

1.0 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.

6. MISSION PLANNING AND CLEARANCES

6.1 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 project area. The mission planning parameters of: mass point spacing, swath width, swath overlap, navigation, GPS, visibility, tide-coordination, and point density shall be considered in planning. NGS may supply recommendations and/or requirements for planning parameters in the Project Instructions. The separate Project Instructions may define the point density of the mass points, Digital Surface Model (DSM), and other requirements.

B. OVERLAP – Adjacent swaths shall have a minimum overlap of no less than 25% 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, tide stage, proposed ground control, and project area boundaries. Also included shall be information about scan angle, pulse repetition frequency (PRF), flying height, and flying speed over ground. Prepare a separate, one-sheet map for each stage of the tide. The base map shall be the largest scale nautical chart covering the entire project area, if possible.
2. ACTUAL LINES FLOWN – Similar map(s) showing the actual flight lines shall be included in the Final Report, see Section 13 U 3.

6.2 FLYING HEIGHT

Sensor shall not be flown at an altitude that exceeds that given in the manufacturer's specifications or that results in a significant number of "drop-outs" (i.e., pulses for which no return is received.)

6.3 FLIGHT CLEARANCES

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

7. WEATHER AND TIME OF YEAR

7.1 WEATHER CONDITIONS

LIDAR data acquisition missions shall be flown in generally favorable weather. Inclement weather conditions such as rain, snow, fog, mist, high winds, and low cloud cover shall be avoided. Such weather conditions have been known to affect or degrade the accuracy of the LIDAR data. 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, and shall not be conducted when the land-water interface is obscured by snow, ice, etc. Storm systems and events (e.g. hurricanes, northeasters, and frontal boundaries) that may cause an increase in water levels, tidal heights, and wave activity shall be avoided.

7.2 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) is acquired concurrently with the capture of LIDAR data to help assist in identifying features in post-processing production. Video and digital imagery should only be acquired simultaneously with LIDAR during the day, while LIDAR intensity returns can be gathered either day or night.

7.3 TIME OF YEAR

Consideration of the season should be taken into account when trying to depict the ground surface under vegetation. Vegetation should be leaf-off to help maximize the possibility of receiving a LIDAR return from the ground surface. Also, seasonal fluctuations in sandy beach dynamics should be considered. Beach profiles and morphology can significantly vary in response from the energy presented upon the system in relation to the sequencing and fluctuations of weather events and patterns.

8. TIDE COORDINATION

8.1 DATA COLLECTION TIDE CONDITIONS

All data collection shall be at a tide stage below MLLW. Data shall not be collected during strong onshore winds, high waves or other anomalous weather conditions. Contractor shall acquire and submit an offshore buoy report for the project area during time of data acquisition (www.ndbc.noaa.gov).

8.2 NGS SUPPLIED WINDOWS

The government will supply data acquisition time/tide windows for each coastal area to be mapped. These “windows” cover an extended range of possible flying dates. These time/tide windows will be determined by NGS initially to help ensure that all data meet

the NGS tolerances for tide–coordinated data acquisition. If tide windows for additional dates are required, contact NGS.

8.3 CONTRACTOR-DETERMINED WINDOWS

If required by the Project Instructions, the Contractor shall determine predicted or actual acquisition time/tide windows (data acquisition times for tide coordination) for MHW and/or MLLW. Note, MHW is the mean of 19 years of high water and is not the high water level for any given day, except by coincidence. The same holds true for MLLW time/tide windows. The Project Instructions may also require the Contractor to install and/or monitor tide gages in the project areas for either real–time or post–flight tidal height comparisons.

8.4 REQUIREMENTS

The Contractor shall acquire all data within the given time/tide windows and shall produce a table showing the times of the time/tide windows and the times of the data acquisition. Be sure to take into account time zones, daylight savings time, and to use UTC time.

9. POSITIONING AND ORIENTATION FOR THE DATA

9.1 POSITIONING

A. GPS COLLECTION

1. All LIDAR data shall be positioned using kinematic GPS using dual frequency receivers and oriented with an inertial navigation system.
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 5cm in the horizontal and 10cm 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.

9.2 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 WWW site 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 in NGS format using NGS software WDDPROC. 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:

- www.ngs.noaa.gov/AERO/Supinst.html, and
- www.ngs.noaa.gov/FGCS/BlueBook/, and
- www.ngs.noaa.gov/PROJECTS/FBN/.

9.3 AIRCRAFT GPS RECEIVER

A. GPS OBSERVATIONS – The aircraft's GPS receiver shall be able to collect carrier phase observations and record, at least, once per second, from a minimum of four satellites (five or more preferred) at both the aircraft and the ground GPS receivers, for off-line processing. All data shall be collected with a Position Dilution of Precision (PDOP) of less than 3. After the post–processing, the GPS observation and ephemeris files are used to determine a flight path trajectory.

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.

9.4 AIRBORNE ORIENTATION

An Inertial Measurement Unit (IMU) shall be incorporated into the LIDAR unit. The IMU system shall be capable of determining the absolute orientation (roll, pitch, and yaw) at a minimum of 50Hz. See Section 4.1.

9.5 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 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 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.

10. 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.

11. 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).

12. DATA SHIPMENT AND PROCESSING

12.1 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.

12.2 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.

13. 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 contain a map of the flight lines and the project coverage area, including flying height and speed over ground, scan angle, and PRF. The separate Project Instructions supplied by NGS will define the project area(s) and may define the point density of the mass points, Digital Surface Model (DSM), and other requirements. See Section 6. 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 a section of coastline and/or coastal ports which are similar to the contract work (see separate Project Instructions). Tide coordination and Ellipsoid/Tidal relationship support may be required. If VDatum is available in the project area, it may be used instead of developing a Ellipsoid/Tidal relationship. VDatum is a

software tool that converts elevation data (heights and soundings) among 28 different vertical datums (see Milbert and Hess, 2001 or the NGS website).

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

E. LIDAR PRODUCTS – Required products may include: contour maps, Digital Elevation Models (DEM), Triangulated Irregular Networks (TINS), and intensity images. 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. For a sample flight log see Appendix A.

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 9.1 and 9.4.

H. AIRBORNE POSITIONING AND ORIENTATION REPORT – Submit raw GPS and IMU data 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 9.5.

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 2 and 9.2 A and B.

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 9.2.

L. TIDE COORDINATION TABLE – Supply table(s) showing the actual times of acquisition flights and the tide coordination time "windows." See Section 8. Explain any discrepancies.

M. 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.

N. SENSOR MAINTENANCE – Provide maintenance history directly to NGS of the sensor to be used for acquiring LIDAR. See Section 4.2 A.

O. SENSOR PORT WINDOW – Report the physical characteristics of any port window used to NGS. See Section 4.3 B.

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

Q. 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.

R. 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.

S. 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.

T. 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.**

U. 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;
9. Tide Coordination Report and Table;
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.

V. 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.

14. REVIEW

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

15. POINTS OF CONTACT:

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16. REFERENCES

Flood, M. *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, 2001.

Milbert, D. G., and K. Hess. *Combination of Topography and Bathymetry through Application of Calibrated Vertical Datum Transformation in the Tampa Bay Region*. Proceedings of the 2nd Biennial Coastal GeoTools Conference, Charleston, SC, January 8-11, 2001.