ABSTRACT

TITLE OF THESIS: Transforming the National Geospatial-Intelligence Agency Vertical Obstruction Program

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The National Geospatial-Intelligence Agency (NGA) maintains a world-wide vertical obstruction (VO) dataset that contains all pertinent objects known to NGA that pose a hazard to the airborne activities of Department of Defense (DoD) customers. Customer requirements are generating an increase in the quantity and quality of the VO data. How can NGA meet the customer requirements for VO data? NGA is addressing these challenges in a multi-faceted effort to transform the VO program.

VO data attributes related to geodetic reference systems, horizontal and vertical datums, geoid models, and height measurements are analyzed for applicability to the Digital Vertical Obstruction File (DVOF) dataset. VO data acquisition, dissemination, attribution, format, documentation, and standardization will be improved to enhance interoperability with customers and providers,

The investigation of a Controlled Flight into Obstruction aircraft mishap serves an important role in acting as a catalyst for change to improve procedures and policies affecting aviation safety and the VO program. Mishap analysis generates proposed corrective actions that will enhance mishap prevention and strengthen the VO program.

The earth may be envisioned as a living entity, with VOs figuratively sprouting, morphing, and dying on a continuous basis. The ability to monitor or verify the status of six million plus VOs, and appropriately add, delete, or modify the dataset on a scheduled basis is a monumental task. The customer requirements for DVOF are decreasing the VO height threshold that will result in the growth of documented VOs. Also, more stringent data currency parameters will place additional requirements on VO data exchange, VO data mining and VO collection assets.

LIDAR offers capabilities to fulfill the increased VO collection requirements. Airborne LIDAR can collect VO data over large areas with the accuracy offered by differential GPS and co-registered imagery. The basic concepts of LIDAR operation are presented to illustrate the possibility of VO collection from an airborne vehicle at a 1000 meter altitude or a space-borne platform at a 400 kilometer low earth orbit. Assisted or automatic VO detection, localization, classification, and documentation are desired capabilities for meeting customer requirements.

The Richmond LIDAR collect is an example of the practical application of existing LIDAR technology used for collecting VO data. Both manually and semi-automatically LIDAR-derived VO data is compared with the Digital Vertical Obstruction File data to demonstrate the strengths and weaknesses of both data sources. The PC_VO tool program was used for assisted VO detection derived from the LIDAR data.

Space-borne LIDAR offers great potential to fulfill customer requirements for VO data. LIDAR transmission and receiver systems are gaining efficiencies that will enable a viable space-borne system for VO processing. With continued technological development, the goal of utilizing space-borne LIDAR for VO detection and data collection is feasible.

The solution to the transformation of the NGA VO program is a combination of hardware, software, personnel, inter-agency agreements, and plans.

[redacted]

(U) TRANSFORMING THE NATIONAL GEOSPATIAL-INTELLIGENCE AGENCY VERTICAL OBSTRUCTION PROGRAM

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CHAPTER 1

(U) Introduction and Overview of the Vertical Obstruction Program

(U) The Topic

(U) The National Geospatial-Intelligence Agency (NGA) provides geospatial-intelligence (GEOINT) to the Secretary of Defense, the Secretaries of the Military Departments, the Chairman of the Joint Chiefs of Staff, the Combatant Commanders (COCOMs), and other United States Government (USG) departments and agencies per Department of Defense (DoD) directive 5105.60 of July 29, 2009. Per Title 10 U.S. Code §467, the term GEOINT means the exploitation and analysis of imagery and geospatial information to describe, assess, and visually depict physical features and geographically referenced activities on the Earth. GEOINT consists of imagery, imagery intelligence, and geospatial information. A component of GEOINT that is related to the Safety of Navigation mission provided by the Aeronautical Analysis tradecraft is the Digital Vertical Obstruction File (DVOF). The NGA DVOF is a worldwide vertical obstruction (VO) data set.

(U) The organization, management, and maintenance of the VO program, in addition to the content of the VO data set, are affected by customer requirements. A goal of the DVOF is to document all pertinent point, line, and area features known by NGA that project above the Earth’s surface and constitute a hazard to the customer’s airborne activities. Customer requirement objectives affecting VO data quantity, quality, areas of coverage, minimum recorded height, and currency will necessitate an evolution of the

VO program. The NGA Vertical Obstructions Working Group (VOWG) and Vertical Obstructions Modernization Team (VOMT) are addressing the challenge to provide Safety of Navigation users and partners with VO data to mitigate risk and enhance mission completion.

(U) Light Detection and Ranging (LIDAR) offers great potential to fulfill VO data requirements. The geodetic accuracy and resolution attainable by LIDAR coupled with Global Navigation Satellite System (GNSS) capabilities offer customers increased levels of VO data quality that may enable increased VO data requirements. Airborne LIDAR collection provides expanded capabilities for VO source data. Additionally, new technology developments warrant further investigation of space-based LIDAR VO collection operations. Space-based LIDAR may offer expanded collection capabilities for coverage area, persistence, and timeliness not offered by current platforms.

(U) The Research Question

(U) How can NGA meet customer requirements for VO GEOINT? The DVOF is the current legacy dataset for storing, retrieving and managing worldwide VOs. The Aeronautical Obstruction Environment (AOE) software program acts as the portal manager and translator for the VO source ingest process that has limited potential for upgrade. A host of concerns addressing the ability of the DVOF and AOE to meet customer requirements within the context of now, next, and after next, demand a vision based on forward thinking policies, processes, and technologies. The VO program transformation must address VO data accessibility, accuracy, attribution, collection strategy, coverage area, currency, periodicity, precision, quality confidence levels, resolution, and validation within the framework of tasking, collection, processing, exploitation, and dissemination (TCPED). Customer requirements are driving changes that will incorporate research and development, operational, maintenance, and interoperability capabilities focused through the vision of the National System for Geospatial-Intelligence (NSG). A new VO program developed within the framework of international standards to promote global interoperability will strengthen NGA's ability to provide VO GEOINT to the NSG.

(U) The Hypothesis

(U) NGA can meet customer requirements for vertical obstruction data through a strategy encompassing the use of VO program requirements management, partnerships, source data fusion, and advanced technology.

(U) Key Questions

1. (U) What are the implications of using different coordinate reference systems based on different ellipsoids with disparate geoid models?
2. (U) How can the analysis of aircraft controlled-flight-into-obstruction (CFIO) mishaps be used to improve the VO program?
3. (U) What additional methods and sources are available for VO data collection?
4. (U) How can LIDAR be used to populate the DVOF?

(U) Review of the VO program transformation

(U) Chapter 2 covers basic concepts of VO documentation and the inherent geodetic challenges encountered with the current construct of multiple datums and coordinate reference systems used in VO documentation. Also, issues associated with vertical datums and the uses of the mean sea level metric for aviation related heights are addressed. Interoperability issues with VO source partners and customers necessitate development of a universal VO program schema. As a major steward for GEOINT within the NSG, NGA shapes the VO program for DoD customers. Additionally, potential sources for VO data are identified, that include the world-wide International Civil Aviation Organization (ICAO) Electronic Terrain and Obstacles Database (ETOD), Intelligence Community (IC), and foreign military datasets.

(U) In Chapter 3, several examples of aircraft mishaps are given that exemplify the importance of VO awareness and documentation. Each scenario illustrates different aspects of the VO challenge from the perspective of both the provider and the user. Through examination of these mishaps, corrective action can be identified that may need to be addressed in the development of the future VO program. Examples of innovative technology contributing to the safety of navigation for low-level flight are addressed through the Ron Brown Airfield Initiative (RBAI).

(U) Chapter 4 identifies U.S. military service requirements requesting the VO height threshold for DVOF inclusion be reduced as critical flight operations take place closer to the Earth’s surface. The increase of VOs in the DVOF will place an additional burden on data maintenance. Emergent tasking for specific areas of coverage to update

DVOF currency places increased demands on collection requirements. At the request of NGA, several studies have been conducted to examine the performance of the current VO program and to predict the scope of anticipated future requirements.

(U) Chapter 5 explores the realm of Light Detection and Ranging (LIDAR) as a source for VO data. An introduction of basic LIDAR principles of operation can assist in gaining insight into the potential advantages and disadvantages of LIDAR over other VO collection methods. Through the fusion of the accuracy and precision offered by LIDAR and Global Navigation Satellite Systems (GNSS) in an airborne collection system, the possibilities for rapid wide-area VO collection are realized. The potential for automatic or assisted VO feature extraction will be a key component in processing the anticipated increased number of VOs identified by LIDAR collection.

(U/~~/FOUO)~~ Chapter 6 illustrates the practical application of LIDAR collection technology and assisted VO extraction. The Jungle Airborne Under Dense Vegetation Imaging Technology (JAUDIT) system was used to perform a LIDAR collect of urban Richmond Virginia. The airborne collection vehicle used a lateral offset scanning method to illuminate targets to the side of the flight track. This capability demonstrated the ability to customize collection tracks to enhance LIDAR data of specified targets, such as pre-determined flight tracks or roads. The LIDAR collection VOs were compared with the DVOF data for a defined area. Manual mensuration and analysis of the two VO data sources revealed variance in horizontal and vertical attributes. Furthermore, a newly developed VO extraction program, the “PC_VO tool”, was used to identify VO data derived from the JAUDIT LIDAR collect in the same defined bounded area as provided by the DVOF. A comparison of the two datasets revealed an increase of VOs documented by the PC_VO tool program over the existing VOs present in the DVOF.

(U/~~/FOUO)~~ Chapter 7 explores the potential for spaced-based LIDAR. The increased requirements for VO data currency, denied area coverage, and coherent change detection capability all drive the development of space-based LIDAR. In addition to VO data collection, space-based LIDAR will benefit the production of Digital Surface Models (DSM), Digital Elevation Models (DEM), Digital Terrain Models (DTM), the identification of Helicopter Landing Zones (HLZ), Foliage Penetration, Littoral coastal zone/Harbor/River mapping, Mine/Submarine detection, and 3-D targeting datasets.

(U) The NGA VO program continues to transform its role as a data aggregator. Data mining incorporates existing VO data sources, and data exploration is seeking new VO data sources. As an active producer of VO data, NGA is developing new sources and methods for creating a comprehensive VO dataset. Both active and passive acquisition of VO data requires consideration for maintaining a current dataset.

CHAPTER 2

(U) Through the DVOF, NGA's VO program delivers a product that currently satisfies customer VO data needs. However, the increasing demands of customer requirements act as a catalyst to shape future VO program development. A fundamental review of the VO program and the basic elements that comprise VO data reveals the scope of the transformation necessary to ensure the relevancy of the DVOF. The bases of VO documentation are rooted in geodetic coordinate reference systems, vertical and horizontal datums, geoids, height measurement, and attribute coding. Data standardization is paramount to maximize the utility of the DVOF. Through VO data standardization, data acquisition and dissemination are facilitated. NGA seeks to maximize VO data mining, partnerships in data exchange, and VO data creation, through active collection techniques to meet future customer requirements.

(U) Functionality of the VO Program

(U) The main software component of the VO program for processing VO data is the Aeronautical Obstacle Environment (AOE) system. Through the AOE**,** VO data is entered into the DVOF. VO attributes are assigned within the context of NSG standards designed to maximize the utility of data.

(U) The legal mandates of Federal law, Title 10 U.S Code and DoD Directive 5105.60, require NGA to support the war-fighter with current and accurate VO data. The NGA Office of Global Navigation, Aeronautical Division Obstructions Branch (PVHC) is tasked to maintain a world-wide database of vertical obstructions. The database known as the DVOF comprises approximately six million man-made and natural features[1] that are known to NGA. The vertical obstructions are categorized as point, line, or area features which are sufficiently tall to pose a potential hazard to flight. Examples of such features include radio antennas, industrial plants, bridges, power pylons, cableways, storage tanks, windmills, and power lines. Geologic features, such as mountain peaks and rock pinnacles, are not entered into the DVOF, but are included in DEMs such as Digital Terrain Elevation Data (DTED) and Shuttle Radar Topography Mission (SRTM) databases.

(U) The classification of the individual data elements of the DVOF may range from UNCLASSIFIED to SECRET. Classification of a Web DVOF output file is dependent upon which requesting network is utilized to access the DVOF, the source of the requested data, the location of the VO, and the reported accuracy of the data.

(U) Aeronautical Obstacle Environment (AOE) System

(U) The AOE software program is utilized to support the VO data program. The DVOF database is populated through AOE. The VO data maintained in the AOE is available to customers though the NGA Gateway portal as a Web DVOF product, and is accessible on the Joint Worldwide Intelligence Communications System (JWICS), Secret Internet Protocol Router Network (SIPRnet), and Non-Secure Internet Protocol Router Network (NIPRnet). The Web DVOF is updated every 28 days. When extracting VO data from Web DVOF, the Additional Query Filters allow the customer to adjust a wide variety of parameters to refine VO searches for desired relevant data fields.

[1] (U) Trees may be included as natural point features for inclusion in the DVOF. This case is rare; less than two hundredths of one percent of DVOF vertical obstructions are classified as trees.

(U) Point Features

(U) A single point feature, such as a radio tower, is generally entered as a discrete point in the DVOF. However, there are exceptions to this general rule. Multiple point features in close proximity may be recorded as a single feature, as in the case of co-located radio masts or power pylons. The ability to refine multiple point features may be affected by limited available published source material for analysis. Additional sources to collect VO data to resolve the ambiguity of multiple point features include electro-optical (EO), LIDAR, and synthetic aperture radar (SAR) imagery. Each of these sources has strengths and weaknesses to support VO analysis. For example, EO and LIDAR VO collection may be limited in the equatorial cloud belt region, while SAR collection may be limited by VO composition and reflectivity characteristics.

(U) Due to constraints of the AOE program, the minimum distance recordable between two VOs, or spatial numerical resolution, is one-tenth of one arcsecond. In general terms, on an ellipsoidal surface at sea level as defined by World Geodetic System (WGS-84), one-tenth of one arcsecond latitude is approximately 10.17 feet at the Earth's poles, and 10.07 feet at the Earth's equator. Correspondingly, one-tenth of one arcsecond longitude is 10.07 feet at the equator and 0.03 feet at one-tenth of one arcsecond latitude displacement from the Earth's poles. The AOE program will only accept entry of a VO greater than one-tenth of one arcsecond in latitude or longitude in proximity to another VO coordinate data point. This horizontal resolution capability is coupled with (x,y) horizontal accuracy data and horizontal confidence level to define the attributes of VO data in the horizontal plane. Similar concerns for accuracy, resolution, and confidence level affect the integrity of the (z) vertical VO data elements. Current customer VO requirements can be addressed with the 0.01 arcsecond data recording capability of the AOE program.

(U) Line Features

(U) Electric power transmission lines, gondola aerial cables, bridges, or dams are examples of linear features in DVOF. A line feature may consist of single or multiple line segments stored in DVOF that are merged into one feature. The line feature may have a start point, turning points, and an end point. In the case of suspended cables, the known support structures for the linear feature are normally listed as point features in the DVOF. The highest segment height above mean sea level between support structures is recorded. For power transmission lines and bridges, the (z) height of the line feature is determined by the vertical distance from the underlying terrain or the surface of the body of water that the line feature spans between two point features.

(U) Area or Polygon Features

(U) An area or polygon feature is defined by geographical coordinates circumscribing an enclosed area, with the tallest VO above mean sea level (AMSL) within that area defining the height of the whole area. The tallest height VO above ground level (AGL) may not necessarily be the tallest VO AMSL that defines the area feature height. Examples of area features include amusement parks, solar panel farms, stadiums, buildings, or large metropolitan areas. Large built up infrastructure areas will supply a predominant feature height, and any significant deviations to this height are reported as point or line features.

(U) VO height

(U) In the DVOF for each VO entry, the height AGL value refers to the measured length of the VO in the vertical axis, or vertical extent, whereas the height AMSL value refers to the AMSL height of the top of the VO. Attributes for VO height information include Height AGL, Height AMSL, Location Elevation, Height AGL accuracy, Height AMSL accuracy, and Location Elevation accuracy. The geoid model from which the Height AMSL and Location Elevation values were determined is not identified in the DVOF metadata. Whether Earth Gravimetric Model (EGM) 96-referenced Digital Terrain Elevation Data (DTED) or Shuttle Radar Topography Mission (SRTM) data is used for terrain elevation values, the elevation must be referenced to a geoid model to derive a Mean Sea Level (MSL) value. Height AMSL and Location Elevation referencing values could be more fundamentally expressed as a Height above Ellipsoid (HaE) value.

(U) Defining the Obstruction

(U) Every point, line, or area obstruction in the DVOF is assigned a five character Feature and Attribute Coding Catalogue (FACC) alpha-numeric value as listed in Appendix A. These broad category codes describe feature attributes in generic terms. For example, the FACC for a generic building (AL015) has 56 different descriptions. To further refine what type of point feature building is identified, an obstruction Feature Type Code (FTC) is assigned.

(U) The three digit FTCs listed in Appendix A are solely applicable to point features. The FTC provides a more specific description of the VO than that provided by the FACC. The numeric FTC field range is from 000 – 999. A restructuring of the FTC format may allow more than the current maximum of 1000 discrete feature types to be attributed.

(U) The AOE program currently assigns an 11 character alpha-numeric field VO identifier, comprising the country code or U. S. state code, an 8 character obstruction number, and a producer code. In order to accommodate the growing number of VOs being added to the DVOF, a new system for VO identification has been incorporated. The Universal Unique Identifier (UUID) coding regimen will allow up to approximately 3×10^{38} unique 32-character hexadecimal digits to be applied to identify a VO. The new overarching Global Navigation Services - Aeronautical (GNS-A) program, which will include an improved AOE function, is slated to include the NGA-generated UUID. Future ingests of other VO database sources may have externally generated UUIDs assigned to VOs. The DVOF database should be able to process ingested external host source VO UUIDs in concert with NGA UUIDs.

(U) Defining NSG Standards

(U) Coordination of effort is required to minimize the complexity of the VO documentation solution. ICAO Guidelines for Electronic Terrain, Obstacle and Aerodrome Mapping Information (Document 9881) and ISO 19100 series offer a framework to harmonize data content across the aeronautical geospatial information arena. NGA should examine Document 9881 as a template to incorporate data interchange processes and formats in order to identify and standardize common vertical obstruction features and attributes. Promoting the accepted ICAO framework will enable a standardized interchange of world-wide information. VO dataset interchange between the data supplier (nation states) and the customer (NGA) will be enhanced by a common transfer format, such as Extensible Markup Language (XML) or Aeronautical Exchange Markup Language (AIXM), to enable real-time networked interoperability. Dataset interchange guidance is identified in the ISO 19100 series Data Product Specifications (DPS) for vertical obstructions. The DPS can be used as a basis for developing a VO dataset format within the construct of the new GNS-A program. As an example, DVOF should incorporate a point VO attribute for horizontal extent as it is present in the ETOD program. The horizontal extent is the footprint of or the area subtended by an obstruction. An obstruction area defined by tower guy wires or aerostat tether displacement cone should be documented in the DVOF. Assuring NGA's interoperability will strengthen its position as leader of the NSG in fulfilling the mission to provide GEOINT to DoD.

(U) Geodetic Reference Systems

(U) The location of a VO is found on the basis of a specified geodetic coordinate reference system, datum, and ellipsoid model. Various VO data sources are reported in different frames of reference, which complicate efforts to maintain the highest quality standards for precision and accuracy. The two datums in use by the U.S. government are NAD 83 and WGS 84. The DoD requires the use of WGS 84, while the FAA currently utilizes NAD 83.

(U) Locating the Vertical Obstruction

(U) For U.S. government geodetic purposes, latitude and longitude coordinates are expressed in the North American Datum of 1983 (NAD 83) or WGS 84 terrestrial reference systems. A review of various datum and terrestrial reference models will highlight the need for standardization to ensure the DoD and the NSG are provided with the best possible geospatial-intelligence. For precise GEOINT purposes, location is not simply defined by latitude/longitude coordinates and MSL height. A precise and accurate location can now be defined by a coordinate reference system realization/epoch, latitude, longitude, ellipsoid height, and velocity. The National Geodetic Survey (NGS) has developed the Horizontal Time Dependent Positioning (HTDP) program to incorporate motions of geophysical origin that account for the change in geodetic coordinates. Coordinates and height change over a period of time due to dynamic Earth geologic processes.

(U) Horizontal Datum

(U) The DVOF incorporates a mathematical ellipsoidal model of the Earth known as the WGS 1984 that is used to calculate the latitude and longitude of VOs. The majority of VO data supplied to DVOF is referenced to WGS 84. However, some of the VO data supplied by external sources is referenced to local datums. The coordinates for a VO on the Earth's surface in the WGS 84 Earth Reference Frame may not match the coordinates from another datum. The NGA-supplied datum software program Geographic Translator (GEOTRANS) is available online to convert geographic coordinates among a wide variety of coordinate systems, map projections, and datums.

GEOTRANS can transform candidate source VO coordinates from the major regional, operational, and local source datums to WGS 84 coordinates. GEOTRANS was designed for coordinate conversion generally at scales 1:50,000 or smaller.

If the local datum VO coordinates are not able to be converted to the WGS 84 Earth Reference Frame due to lack of documentation, the coordinates are recorded with reference to the original source datum in the remarks section data element of DVOF. Coordinate formats are recorded in the DVOF by decimal degrees (DD), degrees, minutes, and decimal minutes (DDM), or degrees minutes seconds (DMS). Web DVOF coordinate output options are available in various forms.

(U) Federal Agencies and DoD datum usage

(U) According to the Federal Aviation Administration (FAA), the North American Datum of 1983 (NAD 83), as promulgated by its geo-data steward authority, the NGS, is the official recognized horizontal datum utilized by the FAA and should be the default horizontal datum for all geospatial datasets of the United States. The first realization of NAD 83 was adopted in 1986, and multiple adjustments have been subsequently issued. NAD 83 was originally founded on the premise of a two-dimensional (x,y) coordinate reference system, and has been upgraded to a three dimensional reference system (x,y,z) with the advent of Global Positioning System (GPS). Each successive modernization effort to refine NAD 83 realizations has incorporated the overarching utility of the DoD-operated GPS GNSS.

(U) Another common coordinate reference system is WGS 84. WGS 84 is the official DoD positional reference system. DoD users will use WGS 84 coordinates and HaE unless the use of other positional reference systems is required. [2]

(U) The NAD 83-GRS 80 and WGS 84 ellipsoids have slightly different locations and orientations of their Cartesian axes. The Cartesian coordinate system is based on three mutually perpendicular axes intersecting at the Earth's geocenter. The center of mass axis origin that was adopted for NAD 83 is displaced about 2.2 meters from the Earth's true geocenter.[3] The NAD 83 ellipsoid alignment may have resulted in a good representation for the North American continent, but did not produce an overall best fit for the entire Earth. The WGS 84 ellipsoid is aligned with the Earth's rotational axis to produce a best overall global representation.

(U) The equator-bulging WGS 84 and NAD 83-GRS 80 ellipsoids share a common value for the semi-major equatorial axis (a) of 6,378,137 meters, but differ slightly in the semi-minor polar axis (b) value: WGS 84 at 6,356,752.3142 meters and NAD 83-GRS 80 at 6,356,752.3141 meters. Flattening (f), a unit-less value, is denoted as $f = (a-b) / a$. Overall, flattening is consequential to the Earth's geodetic and orbital characteristics. The WGS 84 ellipsoid Earth model is not as flattened as the NAD 83–GRS 80 model. The one ten-thousandths of a meter difference has no appreciable affect

[2] (U) Chairman of the Joint Chiefs of Staff, CJCSI 3900.01C, *Position (Point and Area) Reference Procedures*, 30 June 2007, 1, URL: <http://www.dtic.mil/cjcs_directives/cdata/unlimit/3900_01.pdf >, accessed 27 November 2010. Cited hereafter as "JCS."

[3] (U) Richard A. Snay and Tomás Soler, "Modern Terrestrial Reference Systems PART 2: The Evolution of NAD 83", *Professional Surveyor*, February 2000, 1, URL: <http://www.profsurv.com /magazine/article.aspx?i= 546>, accessed 10 October 2010. Cited hereafter as "Evolution of NAD 83."

on coordinate transformations from one reference system to the other.[4] What does have an effect on coordinate transformation differences are the location and orientation of the respective WGS 84 and NAD 83 Cartesian axes.

(U) NAD 83 and WGS 84 differences

(U) Variables in Earth's geophysical characteristics include a shifting center of mass, a changing rotation rate, and rotational axis movement. The rotational axis movement is measurable relative to the extra-terrestrial reference frame and is manifested as precession and nutation. The oblate spheroid shape of the Earth is one of the factors that contribute to precession. The gravitational forces of the sun and moon, acting on the Earth, cause the Earth's rotational axis to circumscribe a virtual cone relative to the ecliptic plane. Nutation is a nodding variation manifested on Earth's precessional cycle caused by tidal forces. Also, the movement of Earth's rotation axis relative to the crust is measured as polar motion. Points of the Earth's crust are moving relative to one another due to plate tectonics, earthquakes, volcanic/magmatic activity, post-glacial rebound, human extraction of underground fluids, solid Earth tides, ocean loading, and other geophysical activity. A fundamental difference among the various reference frames involves how they address the motion associated with plate tectonics.[5] WGS 84 accounts for plate tectonic movement on a global scale, while NAD 83 is predicated on a stationary North American plate. The WGS 84 datum is revised by establishing new

[4] (U) Craig M. Rollins and Thomas H. Meyer, "Effect of ΔЄ on XYZ Coordinates," preprint (2011), *Survey Review*, 3 January 2011.

[5] (U) Richard A. Snay and Tomás Soler, "Modern Terrestrial Reference Systems (Part 1)," *Professional Surveyor*, December 1999, 1, URL: <www.ngs.noaa.gov/CORS/Articles/Reference-Systems-Part-1.pdf>, accessed 11 September 2010.

realizations or adjustments to the location and orientation of the Cartesian axes of the ellipsoid, as improved positioning accuracy is derived from GPS ground control stations, Doppler Orbit determination and Radio-positioning Integrated on Satellite (DORIS), laser ranging, and advanced geodetic techniques. These updated realizations are used to update coordinate points as the Earth changes.

(U) The FAA primarily uses some form of NGS-generated NAD 83 based geo-data. As an exception, some survey coordinates in the FAA Aviation System Standards (AVN) database for airfields in Alaska, Hawaii, and the Pacific area incorporate the WGS 84 reference system. Horizontal accuracies come into question when addressing different terrestrial reference systems. As stated in the NGS United States Gravimetric Geoid Model 2003 readme file, coordinates in the WGS 84 (G873) system are very close to those of the NAD 83 system (with only 1-2 meters of horizontal shift.)[6] Additionally, the NGS reports that NAD 83 and WGS 84 are not the same if accuracy requirements are less than 3 meters.[7] The shift in horizontal location is significant because the accuracy of aeronautical data, to include runway endpoints and VOs, can be documented in the Aeronautical Digital Data Environment (ADDE) and DVOF to the hundredth of an arc second.

(U) The original WGS 84 reference system realization of 1987 essentially agreed with the NAD 83 reference system realization of 1986. However, due to refinement of GPS ephemeris data and the movement of the Earth's tectonic plates, new realizations

[6] (U) National Geodetic Survey, *USGG2003 README FILE*, URL: <http://www.ngs.noaa.gov/ GEOID/ USGG2003/s2003rme.txt>, accessed 22 October 2010.

[7] (U) Dave Doyle, NGS Chief Geodetic Surveyor, *Datums and Projections: Demystifying the Reference Frame*, 27, URL: <http://www.ngs.noaa.gov/corbin/class_description/Datums_Projections. shtml>, 27, accessed 24 October 2010.

have been generated. With an extensive network of terrestrial control points that utilize GPS tracking stations to monitor system performance, DoD established the WGS (G730) second realization. The letter G connotes "GPS" and 730 denotes the GPS week number (starting at 0h UTC, 2 January 1994) when NIMA started expressing derived GPS orbits in this frame.[8] The third realization of WGS 84 was (G873) and the fourth realization of WGS 84 is (G1150). Similarly, NAD 83 has experienced multiple realizations such as NAD 83 (1986), (HARN), (CORS93), (CORS94), and (CORS96).[9] As the Earth continuously changes, coordinates for VOs can be updated with each new realization of the terrestrial reference system. NGA will soon promulgate a new WGS 84 realization (G16xx) to maintain the highest standards for geospatial accuracy to achieve concordance with the latest International Earth Rotation and Reference Systems Service (IERS) International Terrestrial Reference Frame (ITRF) 2000 model.

(U) A Federal Register notice published on 14 June 1989 (FR25318) by the National Oceanic and Atmospheric Administration (NOAA) under the auspices of the Office of the NGS affirmed NAD 83 as the official horizontal datum for all future U.S. surveying and mapping activities performed or financed by the Federal Government. Furthermore, this notice said that to the extent practicable and feasible, all Federal agencies using coordinate information should provide for an orderly transition to NAD 83. Subsequently in 1995, NOAA issued further guidance in the Federal Register that recommended all maps and charts produced for North America, at scales of 1:5,000 or

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[8] (U) Richard A. Snay and Tomás Soler, "Modern Terrestrial Reference Systems PART 3: WGS 84 and ITRS," *Professional Surveyor*, March 2000, URL: <http://www.ngs.noaa.gov/CORS/Articles/Reference-Systems-Part-3.pdf>, accessed 11 September 2010.

[9] (U) "Evolution of NAD 83," 2.

smaller, that are based on either the NAD 83 or the WGS 84 should have the horizontal datum labeled as NAD 83/WGS 84.[10] Chairman of the JCS Instruction 3900.01C also states that at mapping scales of 1:5000 and smaller, NAD 83 and WGS 84 are considered equivalent.[11] Maps and charts depicting a scale of 1:5000 or smaller may be deemed as acceptable to interchange NAD 83/WGS 84, but digital geodetic latitude and longitude coordinates expressing arc second and smaller values should be reported as NAD 83 or WGS 84. The virtually identical reference systems of 1987 are no longer virtually identical. For the sake of accuracy, standardization, and safety of navigation, a universal application of the most up-to-date realization of the WGS 84 datum would be beneficial to the members of the NSG.

(U) Defining Height

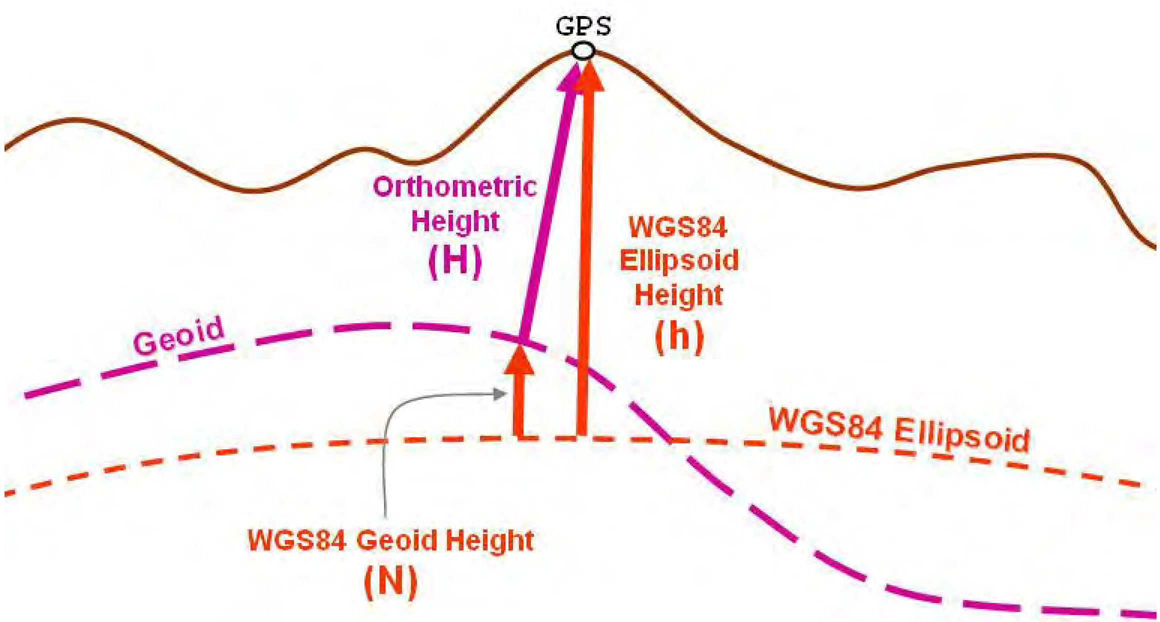
(U) The DVOF has been established primarily to support DoD airborne operations. The legacy altitude measurement reference for aviation activities is based on Mean Sea Level (MSL). Therefore, the height of a VO has traditionally been recorded with reference to MSL. However, with the increased demands for precision and accuracy, the weaknesses of the MSL paradigm become evident. The Height above Ellipsoid (HaE) value can more accurately define a point relative to the Earth reference frame.

[10] (U) National Oceanic and Atmospheric Administration, Docket No. 950728196—5196-011, "Use of NAD / WGS Datum Tag on Mapping Products", *Federal Register* / 60, no. 157 (15 August 1995). URL: <http://www.ngs.noaa.gov/PUBS_LIB/Fed Register/FRdoc95-19408.pdf>. Accessed 3 April 2011.

[11] (U) "JCS," 2.

(U) Vertical Datum

(U) GPS data points normally include latitude/longitude coordinates and an HaE value. The HaE and geoid height are used to derive an orthometric height. Orthometric height is simply defined as height above or below MSL. MSL is derived from the geoid model. The geoid shape is irregular, but considerably smoother than Earth's physical surface. Although the Himalaya mountain range rises over 8,800 meters Above Mean Sea Level (AMSL), the geoid vertical relief is only plus or minus 100 meters from the WGS 84 reference ellipsoid.



(U) Figure 2- 1. Orthometric-Ellipsoid-Geoid Height

(U) Source: Natural Resources Canada, Canadian Spatial Reference System, URL: <http://www.geod.nrcan.gc.ca/images/wgs84geoid_e.jpg>, accessed 28 October 2010.

(U) Orthometric height (H) is approximately equal to height above the ellipsoid (h) value minus the ellipsoid height of the geoid or geoid undulation (N) value, yielding

H ≈ h - N. The approximate nature of the formula is due in part to a discounting of the deflection of the vertical, as depicted by the local plumb line (vector H) in Figure 2-1. For DVOF, the orthometric height of a VO should be representative of a MSL height derived from a standard model, such as the WGS 84 ellipsoid and EGM 96 geoid heights. Calculating MSL height within the domain of the improved accuracies offered by GPS and advanced geoid modeling offers an evolving standard to define mean sea level.

(U) The geoid may be defined as the equipotential surface of the Earth's gravity field that nominally defines MSL.[12] If the Earth was a homogeneous non-rotating sphere, the geoid would be located a fixed distance from the Earth's center of gravity. However, this is not the case and the virtual geoid surface occurs at various distances from the Earth's center. The Earth Gravitational Model (EGM) geoid defines the nominal MSL surface by gravimetric studies and mathematical calculations. The geoid coincides with that surface to which the oceans would conform over the Earth if free to adjust to the combined effect of the Earth's mass attraction and the centrifugal force of the Earth's rotation, and continue through the continents at the same level of gravitational potential, while discounting other oceanographic forces such as El Niňo and other ocean currents.[13]

(U) Phenomena that may be considered for affecting the MSL values of the oceans include volumetric changes due to thermal expansion/contraction, salinity, and the size of glaciers and ice sheets on the continents. Other factors affecting vertical datum include tectonic plate motion, volcanic activity, crustal rebound caused by glacial

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[12] (U) Thomas H. Meyer and others, "What Does Height Really Mean?" Department of Natural Resources and the Environment, University of Connecticut, (1 June 2007): 25. URL: <http://digital commons.uconn .edu/nrme_monos/1/>, accessed 11 October 2010. Cited hereafter as "Height."

[13] (U) DMA Technical Report 80-004, "Geodesy for the Layman," Defense Mapping Agency, 16 March 1984, URL: <http://www1.nga.mil/ProductsServices/GeodesyGeophysics/Related Documents/ Geo4lay.pdf>, accessed 14 November 2008. Cited hereafter as "Geodesy for the Layman."

melting, and crustal subsidence caused by natural gas, oil, and water aquifer extraction. These variable factors complicate efforts to model the Earth accurately. Additionally, sea level does not exactly match the geoid.

(U) In summary, the geoid is often chosen to be the equipotential surface of the Earth's gravity field that best fits mean sea level in a least squares sense, and the geoid has thus become the fundamental vertical datum for mapping.[14] Due to these variable factors, mean sea level is becoming obsolete as a modern reference for orthometric height due to the accuracy provided by the WGS 84 ellipsoid, ever improving geoid models, and the GPS GNSS. One may question the need for such accuracy in a broad spectrum of aeronautical applications. DoD customer requirements and ETOD standards address these questions.

(U) MSL reference in aviation

(U) Because world-wide aviation activities are heavily vested in the MSL (geoid) vertical reference, it is important for geodesists continually to update an accurate Earth reference frame model, and for aviation standards authorities such as the International Civil Aviation Organization (ICAO), FAA, and DoD through the NSG to establish and maintain a standard framework for global application.

(U) Altitude is routinely referenced to MSL for take-off, landing, and en-route flight operations. The current legacy altitude measuring system is referenced to atmospheric pressure and its relationship to MSL. The term MSL is tied to orthometric height. Orthometric height is tied to the geoid.

[14] (U) "Height," 28.

(U) Pressure sensing instrumentation used for altimetry purposes has increased in reliability and accuracy. To achieve these improvements, altimeter system equipment and installation requirements have been improved. As an example, the original mechanical altimeter, consisting of cogs, levers, pulleys, and an aneroid capsule bellows, has been outfitted with an electrically powered vibrator to overcome friction within the sensing and indicating system. A benefit introduced by this improvement is the reduced vertical separation minimum (RVSM) program that has increased airspace capacity and fuel savings by allowing aircraft to fly with reduced separation at higher flight levels. In this instance, a QNE barometric altimeter setting of 29.92 inches of mercury, which is set at a specific transition altitude while ascending (notionally at 18,000' MSL), will display pressure altitude, or flight level. QNE transition altitudes/levels vary world-wide depending on local flight procedures. The different flight procedures for changing barometric altimeter settings vary across different flight information regions, and have the potential to cause vertical clearance problems with other aircraft or terrain.

(U) For flight operations below the transition level, a local QNH barometric altimeter setting is used to display altitude above MSL. This altitude information is important for takeoff and landing operations in reduced visibility and low ceiling meteorological conditions. A QNH altimeter setting must be entered in the altimeter instrument (notionally below 18,000') from a source within 100 nautical miles to ensure acceptable altitude reporting performance, as the QNH setting is referenced to local barometric pressure conditions.

(U) With these various concepts of utilizing barometric pressure for altitude measuring purposes, one must consider the effects of instrument calibration error, temperature error, and pressure error. Barometric altimeter accuracy is affected by pressure and temperature variations and is subject to calibration errors.

(U) Reliance on pressure sensing instruments that use electrical power for altitude measurements relative to mean sea level is a paradigm that embodies legacy concepts and equipment. New technology offers improvements in performance and safety. Examples of fundamental shifts in the application of aviation technology include the incorporation of fly-by-wire flight control systems to replace mechanical cables and pulleys, and the diminutive role of ground based radar for air traffic control in the Next Generation Air Transport System (NextGen): Automatic Dependent Surveillance – Broadcast (ADS-B) system. Additionally, ADS-B can provide air traffic control functions using GNSS inputs for x, y, z position. GNSS allows for altitude or z-height (HaE) to be addressed from a different perspective than the legacy pressure sensing altimeter based on the MSL paradigm.

(U) Mean sea level and equipotential gravimetric surface values have changed as new geoid models are developed. HaE is a standard that is much more stable and accurate than MSL. HaE is readily available through GNSS and offers the accuracy to precisely document VO positional attributes. HaE should be more fully integrated into aviation height measuring applications.

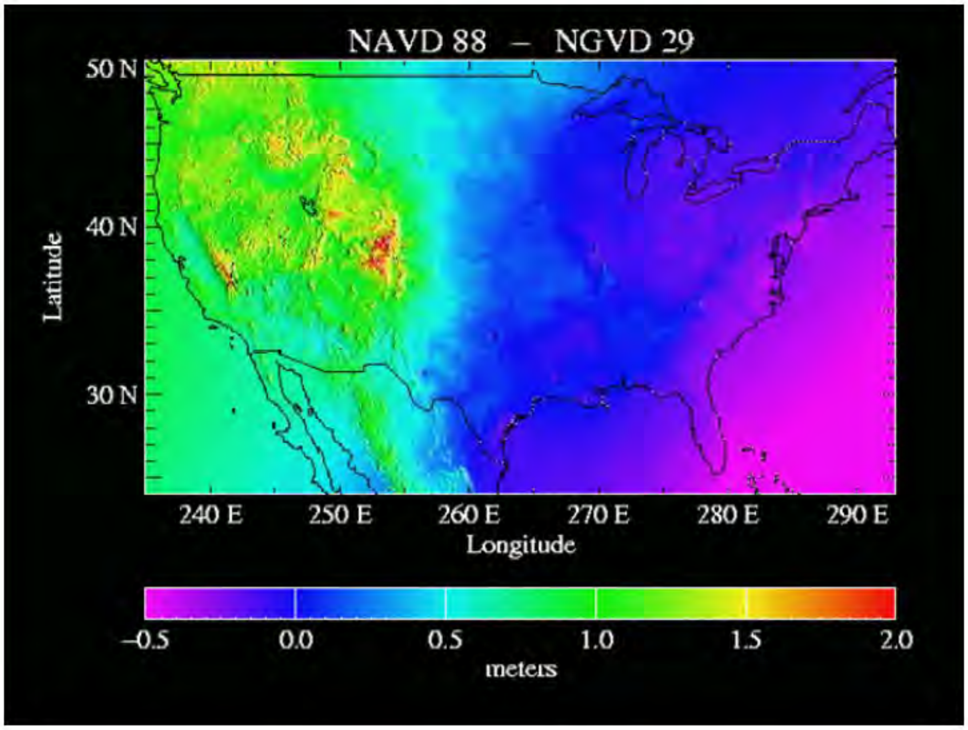
(U) Multiple geoid models and vertical datums

(U) With the availability of GNSS such as GPS, increased accuracy for geospatial data is achievable. The world geodetic reference system known as WGS 84 has established a reference ellipsoid that mathematically defines an approximation of the

Earth as an oblate spheroid. In conjunction with the ellipsoid model, an improved Earth Gravitational Model (EGM) 96 was applied to refine the geoid. This model has the same reference ellipsoid as WGS 84, but has a higher-fidelity geoid with 55 km resolution, versus 200 km for the geoid (EGM 84) associated with original WGS 84. The ICAO ETOD program currently adheres to the WGS 84 reference coordinate system incorporating the EGM 96 model or its later realizations.[15]

(U) Alternatively, in the past, some federal agencies have supported various vertical datum models such as National Geodetic Vertical Datum (NGVD) 29 applied to the NAD 27 coordinate reference system, and the North American Vertical Datum (NAVD) of 1988 applied to the NAD 83 coordinate reference system. Conversion of elevation values expressed in NGVD 29, which is used by the Federal Communications Commission (FCC), or NAVD 88, which is used by the FAA, can be accomplished with the NGS VERTCON tool program. VERTCON computes the difference in orthometric height for a given point between NGVD 29 and NAVD 88 models. See Figure 2-2 for a comparison of NAVD 88 and NGVD 29,

[15] (U) ICAO, *Guidelines for Electronic Terrain, Obstacle and Aerodrome Mapping Information*, Document 9881, 74, URL: <http://www2.icao.int/en/pbn/ICAODocumentation/ICAO Documentation/ Guidelines for Electronic Terrain, Obstacle and Aerodrome Mapping Information.pdf>, accessed 22 October 2010. Cited hereafter as “ETOD.”



(U) Figure 2-2. NAVD 88 – NGVD 29 Height Difference

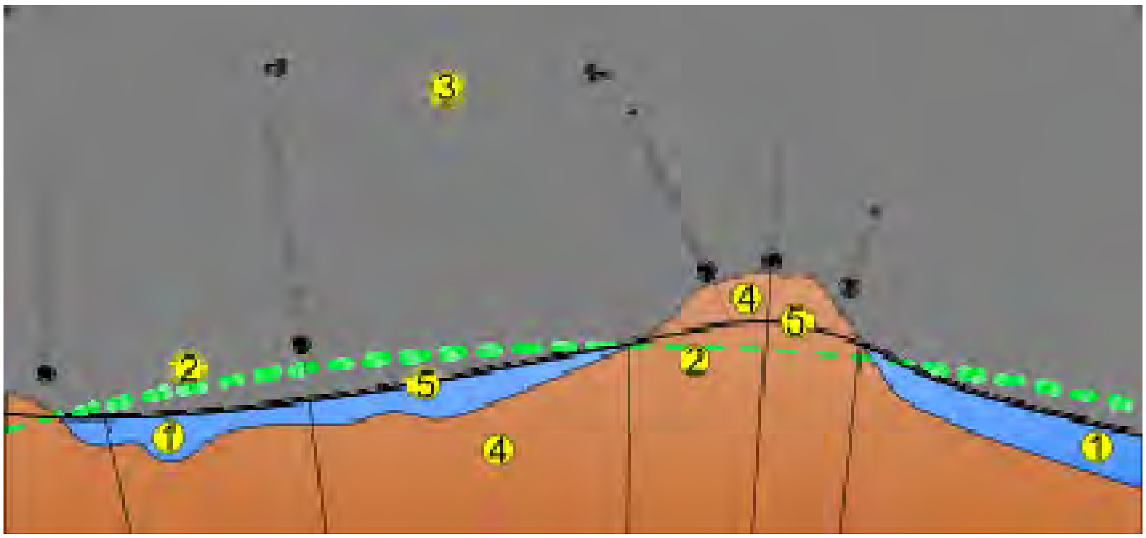
(U) Source: National Geological Survey, URL: <http://www.ngs.noaa. gov/heightmod/3NMGPSHts PrimerMay07.ppt>, accessed 4 December 2010.

(U) One must ensure the precision of elevation values during conversion of data units that are reported in integer, decimal tenths, or hundredths values. Exercising reciprocal conversions (backwards) of height data with rounded or truncated elevations could give a false impression of precision values.[16] Overall, the uniform application of a universal standard would increase safety and eliminate conversion/transformation equations.

[16] (U) Dane E. Ericksen, Hammett & Edison, Inc., *NAD 83: What it is and why you should care,* 1994 SBE National Convention and World Media Expo, Los Angeles, CA, 1, URL: <http:// www.h-e.com/pdfs /de_sbe94.pdf>, accessed 6 September 2010.

(U) Geoid variation and Earth Gravitational Model 96

(U) The geoid is by definition a surface to which the force of gravity is everywhere perpendicular. In Figure 2-3, note that the plumb bobs are displaced towards an area of high mass.



(U) Figure 2-3. Earth's surface model representations
1. Ocean 2. Ellipsoid 3. Local Plumb 4. Continent 5. Geoid

(U) Source: MesserWoland, Image:Geoida.svg, URL: <http://wapedia.mobi/en/Image:Geoida.svg>, accessed 14 November 2008.

(U) The WGS 84 reference ellipsoid is an approximate mathematical representation of the surface of the Earth. As a result of the uneven distribution of the Earth's mass, the geoid surface is irregular and, since the ellipsoid is a regular surface, the two will not coincide. The separations are referred to as geoid undulations. The deviations of the EGM 96 model of the geoid from the WGS 84 reference ellipsoid range from about minus 105 meters to about plus 85 meters.[17] Three frames of reference

[17] (U) "Geodesy for the Layman".

related to the location of a point include the physical Earth's topographic surface, or orthometric height, the WGS ellipsoid, and the EGM geoid. For the purposes of determining the AMSL value or Orthometric height (H) of a VO, one must subtract the geoid height (N) from the height above ellipsoid value (h). That means a WGS 84 derived ellipsoidal height may have different AMSL values depending on whether the EGM 96 or EGM 08 geoid model is used. Similarly, the NAD 83 GRS 80 ellipsoid model may determine different orthometric heights using the NGVD 29 derived from mean sea level tidal gauges or the NAVD 88 network of benchmarks.

(U) Additionally, it is important not to mix heighting systems. One must use a reference ellipsoid of a datum that matches the reference ellipsoid of the gravimetric model. Therefore, for example, GPS heighting should not be done with GEOID03 (associated with NAVD 88) and the WGS 84 datum.[18] With regard to horizontal geodetic coordinates, the FAA has converted all National Aeronautical Charting Office (NACO) Digital Obstacle File (DOF) data to the WGS 84 datum as of 19 November 2007. However, for vertical geodetic documentation, per the FAA, all VO data identified with a Julian data on or after the 71st day of 2001 is placed in the NAVD 88, and all other elevations in the NACO DOF are in NGVD 29.[19] The mixing of the reference ellipsoid of a datum (WGS 84), with the North American leveling network, or North American Vertical Datum (NAVD 88) or (NGVD 29) will introduce additional conversion adjustments to horizontal and vertical data.

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[18] (U) "Height," 53.

[19](U) Federal Aviation Administration, SPECIAL NOTICE, "Important Information on Horizontal and Vertical Datums," URL: <http://aeronav.faa.gov/content/aeronav/products/digital/DOF_ README .pdf>, accessed 12 December 2010.

(U) Earth Gravitational Model 08

(U) The EGM 96 global gravitational field model has been surpassed by the Earth Gravitational Model 2008 (EGM 08). EGM 08 provides an improvement in the accuracy and resolution of the global vertical reference model. EGM 96 supported a vertical accuracy of ±50 centimeters and a nominal resolution of 30 arc minutes. EGM 08 provides a vertical accuracy of ±15 centimeters and a horizontal resolution of 5 arc minutes. See Figure 2-4 for a comparison of EGM 96 and EGM 08. According to Dr. [redacted] of NGA, with the EGM 08 model, NGA is realizing more than three times higher accuracy at six times higher resolution, as compared to EGM 96.[20] This is significant because the EGM 08 model is used to perform geoid computations to determine AMSL heights. The differences in the geoid from the EGM 96 to the EGM 08 model vary from 1 to 2 meters in the contiguous United States of America, to greater than 3 meters in Iraq and Afghanistan.[21] The most recent airfield surveys conducted with the NGA derived EGM 08 vertical datum offer the greatest accuracy for AMSL values.

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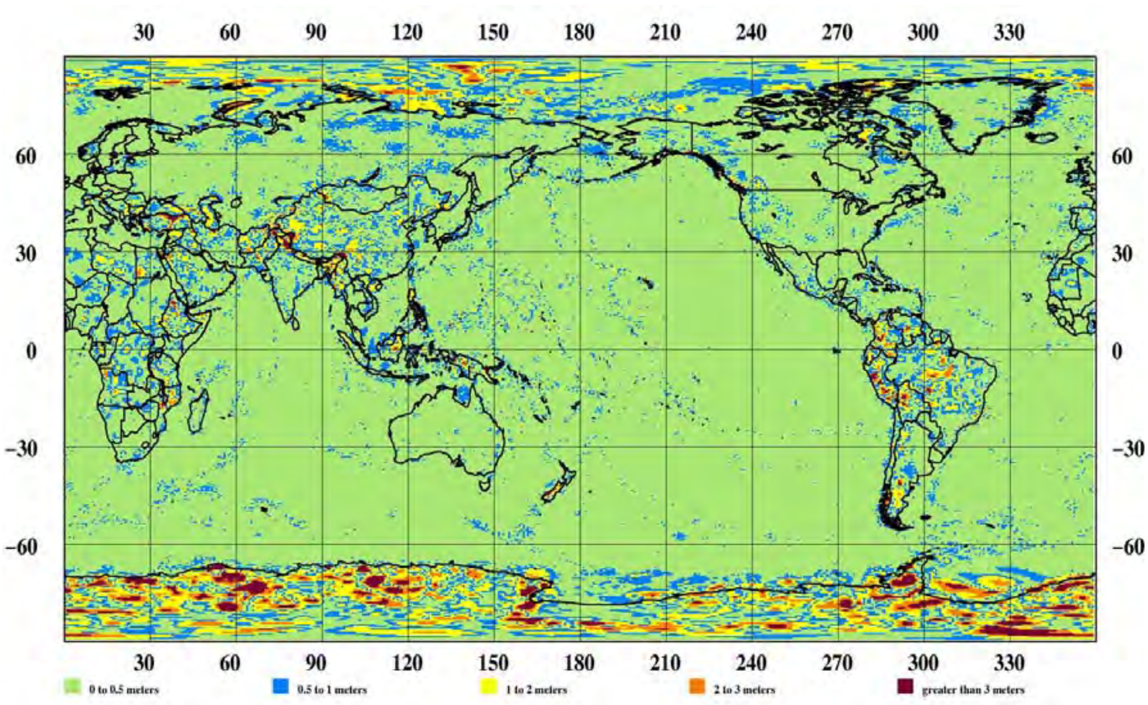
[20](U) [redacted], "Earth Gravitational Model Advances GEOINT Sciences," *Pathfinder*, November/December 2008, 11.

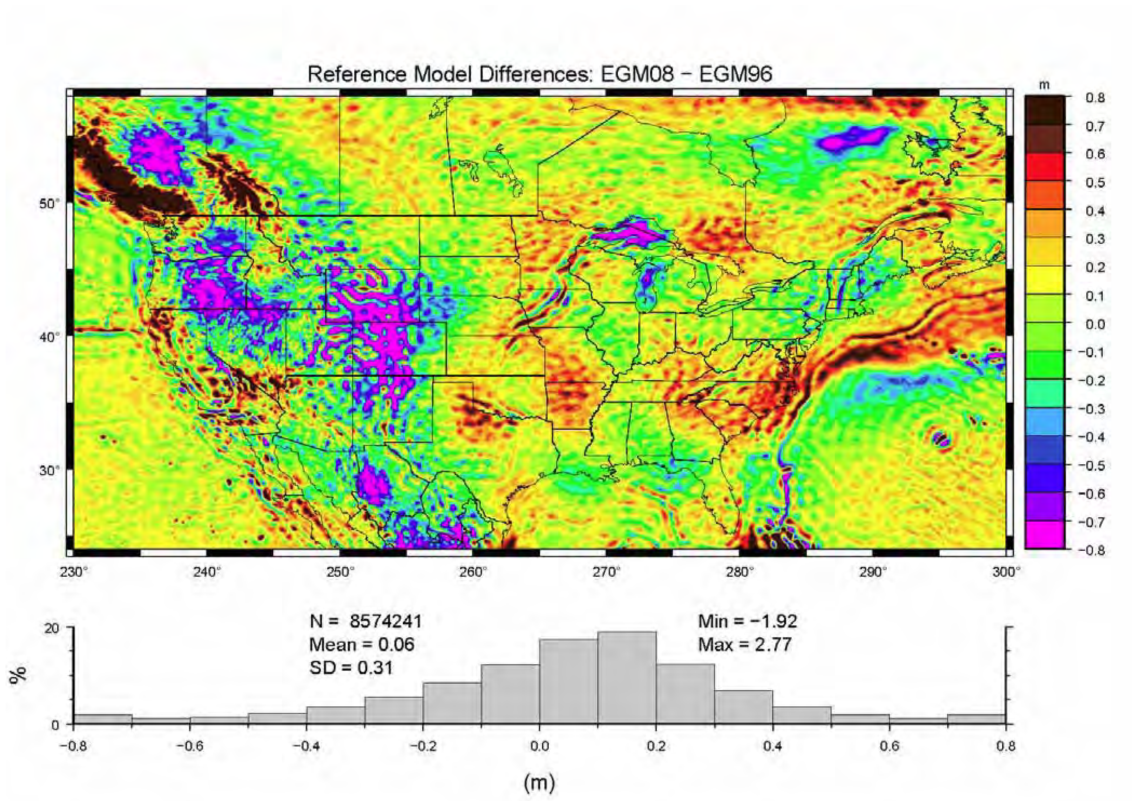
[21] (U) [redacted] NGA, Geodetic Scientist, St. Louis, MO, "Geoid Changes between EGM 08 and EGM 96," e-mail interview by author, 2 March 2009.



(U) Figure 2-4. Earth Gravitational Model (EGM) 96 and EGM 08 Comparison

(U) Source: (b)(3), (b)(6) [redacted]**, "Geoid Changes Between EGM 08 and EGM 96," NGA, ppt, 8 October 2008.**

(U) As depicted in Figure 2-5, NOAA's NGS has prepared another graphic that depicts the changes between NGA's EGM 96 and EGM 08 within the conterminous U.S.



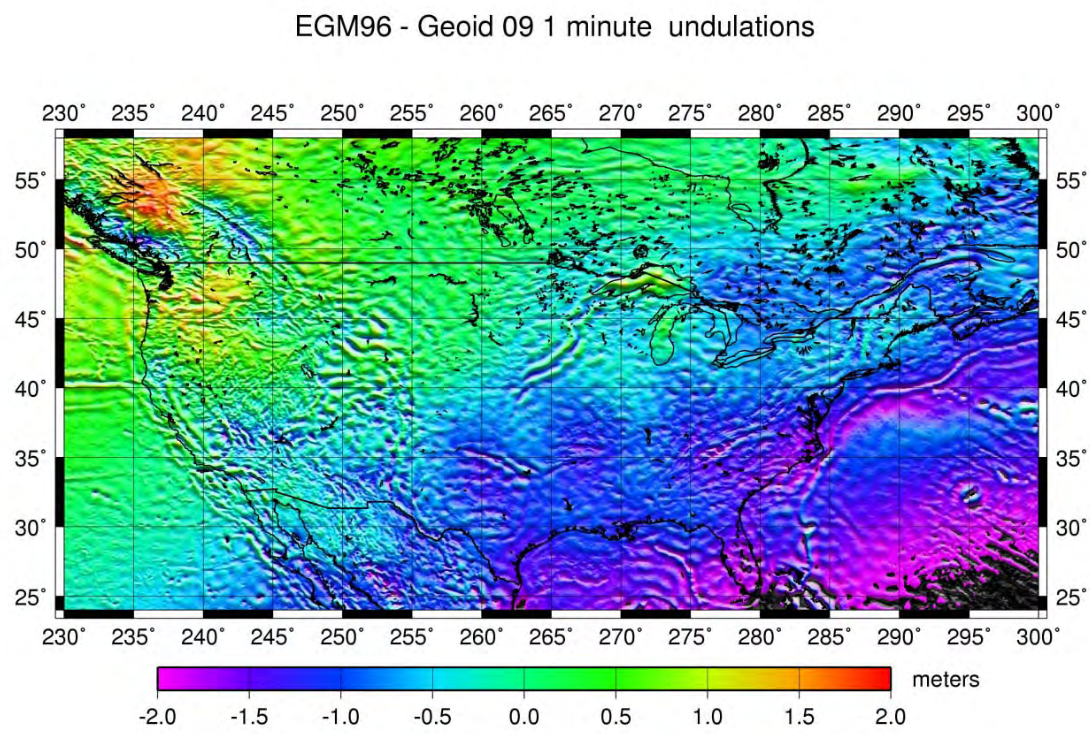
(U) Figure 2-5. EGM 08 – EGM 96 Differences in the U.S.

(U) Source: NOAA/NGS, "Difference in Reference Model," ACSM-MARLS-UCLS-WFPS Conference 2009, URL: <http://www.ngs.noaa.gov/GEOID/PRESENTATIONS/2009 _02_20 _ACSM/1_NGS_Roman_ USGG2009.pdf>, accessed 22 October 2010.

(U) NGS Geoid Models

(U) Similarly, the NGS has developed geoid models for application to the NAD 83 GRS 80 ellipsoid. The latest NGS Geoid 09 (USGG09) model further refines the past iterations of geoid models Geoid 96, 99, and 03. At a one minute sampling density, the EGM 96 geoid model differs from the NGS Geoid 09 model from -3.83 m to +2.13 m, with a mean difference of -0.48m, standard deviation (SD) = 0.75, root mean square

(RMS) = 0.92.[22] See Figure 2-6 for a graphic depiction of EGM 96 – Geoid 09 differences.



(U) Figure 2-6. Earth Gravitational Model (EGM) 96 and Geoid 09 Comparison

(U) Source: [redacted], "Geoid Changes Between EGM 08 and EGM 96," NGA, ppt, 22 October 2010.

(U) Crucial geoid relevance

(U) It is incumbent upon the NSG to promote the establishment of the most accurate geoid model to ensure the accurate documentation of VOs. To ensure the highest standards for accuracy and safety of navigation, VO documentation and aeronautical concerns must operate from a common geodetic frame of reference. EGM 08 currently offers the best vertical reference geoid model, and should be incorporated as

[22] (U) [redacted] NGA, Geodetic Scientist, St. Louis, MO, "Geoid Undulations Comparison," e-mail interview by author, 20 October 2010.

the standard for geospatial information in conjunction with the latest realization of WGS84. Continued development of geoid models is needed to establish the optimal geoid undulation model for the Earth. Global aeronautical issues are addressed by ICAO, and ICAO has adopted WGS 84 / EGM 96 (or its later realizations) as the standard terrestrial reference frame

(U)VO Data Standardization

(U) VO data standardization can be expressed in terms of quality attributes encompassing accuracy, precision, format, and integrity. A common VO data format will increase the ability of the DVOF to ingest candidate VO source data with minimal manipulation. Data sharing from trusted sources is a key component of expanding the scope of the DVOF.

(U) Standardization Goals

(U) As functional manager of the NSG, NGA leads the effort to provide guidance to the NSG community. The NSG contains the combination of technology, policies, capabilities, doctrine, activities, data, and communities necessary to produce geospatial intelligence in an integrated multi-intelligence, multi-domain environment. The NSG community consists of Members and Partners. Members include the IC, Joint Staff, Military Departments (to include the Services), and COCOMs. Partners include Civil Applications Committee Members, comprising U.S. Army Corps of Engineers, Department of Agriculture, Department of the Interior, Department of Transportation, Environmental Protection Agency, National Aeronautics and Space Administration, National Science Foundation, and others. Also, NSG international partners include Australia, Canada, and Great Britain. Additionally, industry, academia, defense service providers, and civil community service providers participate in NSG activities.[23]

(U) Under the direction of the NSG, the GEOINT Standards Working Group (GWG) recommends standards to meet DoD requirements for a centralized database that maximizes GEOINT interoperability. The National Center for Geospatial Intelligence Standards (NCGIS) was developed to coordinate data standards within DoD, and among other intelligence agencies, private industry, and foreign partners. Through the collective efforts of the NSG, Eurocontrol, the United Kingdom's Defence Intelligence Joint Environment (DIJE), to include the Defense Geographic Centre and Number 1 Aeronautical Information Documents Unit (No1 AIDU), Australia's Defence Imagery and Geospatial Organization (DIGO), Canada's Directorate of Geospatial Intelligence (D Geo Int), ISO, Radio Technical Commission for Aeronautics (RTCA), and ICAO, geospatial-intelligence stewards should seek a common standard that is universally adopted for VO documentation, to include at a minimum horizontal and vertical datum, scale measurements, and VO identification schema.

(U) Accuracy

(U) VO data elements related to horizontal and vertical position, AGL height, thematic classification, temporality, completeness, and lineage documentation can be assigned accuracy values. A large portion of the DVOF is derived from downloaded files received from trusted foreign and domestic government sources. Each source file has its

[23] (U) National Geospatial-Intelligence Agency, National System for Geospatial-Intelligence, *Geospatial-Intelligence (GEOINT) Basic Doctrine*, Publication 1-0, September 2006, 29.

own minimum obstruction height and accuracy requirements. VOs are not denied entry into the DVOF for lack of accuracy data. Accuracy issues may arise from inadequate source material, lack of datum transformation, or other qualitative deficiencies. Regardless of the accuracy of the candidate VO, it is entered into the DVOF and its quality is appropriately documented with the associated validation code, accuracy figure, and deficiency code.

(U) Appendix A contains a list of DVOF validation codes. VO accuracy data is related to the collection process utilized to generate the data. Every VO feature in DVOF has a validation code attribute that indicates the method of data collection. Code 1 offers the highest degree of accuracy from NGA approved surveys, followed by Code 2 stereoscopic imagery. Respectively, Code 3 monoscopic imagery is less accurate. Code 4 accuracy is dependent on the accuracy of the cartographic maps and charts from which the VO feature was extracted. Code 5 is defined by the reported information supplied by host country Aeronautical Information Publications (AIP). Additionally, customer feedback reports and generic publications are included in this category, and accuracy may vary from trustworthy to less than reliable. Code 6 is applied to temporary VO features, such as construction cranes. Notice To Airmen (NOTAM) routinely report construction cranes as hazards to flight operations. If the crane is to remain in place for more than 6 months from the date of receipt for AOE processing, it is entered into the DVOF.

(U) Vertical Accuracy

(U) The vertical accuracy of any point feature in DVOF is recorded in three related elements. The first element is the Point Vertical Accuracy (PVA). PVA relates to the accuracy of the measurement of the MSL ground elevation from which the base of the VO is referenced. DTED or chart contour elevations are common sources for ground elevation. For chart derived ground elevations, the MSL accuracy is limited by the depicted contour interval. The PVA is synonymous with the Absolute Vertical Accuracy (AVA), and is defined in VO specifications as the difference between an assigned elevation and the true elevation at a specific point. Vertical accuracy is expressed in units of feet, at a 90 percent probability linear error as a proportion of the contour interval or photo-derived DTED post spacing.

(U) The second element is the Obstruction Height Accuracy (OHA). OHA relates to the accuracy of the obstruction height from the base surface to the top of the obstruction, or its vertical extent. The accuracy of this value varies with the system and method used for measurement. Examples of methods used to determine VO height include imagery mensuration, geodetic survey, LIDAR, or GNSS. Height accuracy is expressed in feet (linear error 90 percent probability).

(U) The third element is the Overall Vertical Accuracy (OVA) or AMSL accuracy. This is the accuracy of the obstruction height with reference to mean sea level expressed in feet. The OVA is determined by calculating the root sum square of the OHA and the PVA. Through the use of accuracy figures, the customer is furnished a metric to analyze the value of the VO data to meet mission requirements.

(U) DVOF data formats

(U) Once a VO is incorporated into the DVOF repository, the GEOINT is accessible for use by geospatial production systems. The height above ground level is a primary determining factor to classify an object as a vertical obstruction. The property of z-axis height is a major concern when DoD performs mission planning for flight operations close to the surface of the Earth. Contour, nap-of-the-earth, low-level, or terrain-following flight all rely on an exacting situational awareness of VOs and terrain elevation. The definition of "sufficiently tall so as to pose a potential hazard to flight" varies with customer requirements. The customers tailor their VO requirements per the mission requirements. The legal mandates of Federal law, Title 10 U.S Code and DoD Directive 5105.60, require NGA to support the war-fighter with current and accurate VO data. The USAF has requested VOs 150 feet AGL or greater be depicted on the Joint Operations Graphic – Air (JOG-A) charts, and had asked NGA to set a technical objective of 60 feet AGL or greater to support future mission requirements. The USAF also requested that NGA improve technical capabilities to provide a reasonable degree of confidence that 90 percent of the 150 feet VOs were captured.[24]

(U) Additionally, the USAF submitted a requirement for a VO standardized exchange format known as Vector Product Format (VPF) to support mission planning systems, flight management systems, digital terrain avoidance systems, Terminal Instrument Approach Procedures, and NGA feature foundation data. VO data in the VPF supports fighter aircraft components, such as the F-16 Digital Terrain Avoidance System.[25]

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[24] (U) National Geospatial-Intelligence Agency, "Vector Vertical Obstruction Data (VVOD) Production System," *FY05-09 Requirement Submissions*, FY05-09 032, NGA, 21 August 2002, URL: <http://needit.nga.ic.gov /pco/ri/needs/fy05/NeedsForm05A.asp?webid=41l>, accessed 13 October 2006.

[25] (U) National Geospatial-Intelligence Agency, "Aeronautical Obstruction Data Specification," *FY04-09 Requirement Submissions*, NGA, 19 September 2001, URL: <http://needit.nga.ic.gov/pco/ri/ needs/fy05/ NeedsForm04A.asp>, accessed 13 October 2006.

(U) The impetus initiated by the USAF requirements was further developed by the USN request for VPF data, known as Vertical Vector Obstruction Data (VVOD) to support U.S. Air Force, Navy, Army, Marine Corps, and Southern Command requirements. Per DoD MIL-PRF-89049/9A, the VVOD functions as a mission specific data set designed to support Geographic Information System (GIS) applications for DoD customers. The VVOD supports low-level day and night flight operations, obstacle avoidance systems, mission planning systems, flight management systems, terminal en route procedure development, special operations (SPECOPS), and search and rescue (SAR) missions.[26] The Navy also referenced the F/A-18 Strike Fighter command and control system requirements to bolster the need for VVOD. All these demanding requirements dictated accurate, near-real-time VO data.

(U) The VVOD is produced from the DVOF and comprises all point, line, and area VOs taller than 150 feet AGL. The VVOD has a 28-day update cycle that supports the Joint Mission Planning System (JMPS) and Tactical Moving Map Capability (TAMAC). The VVOD contains metadata consisting of VO validity code, type, location, datum, currency, and dimensions. Additional output formats for WebDVOF include Table Formatted Aeronautical Data Set (TFADS-O), consisting of tables and Structured Query Language (SQL) files, Environmental Systems Research Institute (ESRI) shapefiles, and Keyhole Markup Language (KML) files for use with Google Earth.

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[26] (U) National Geospatial-Intelligence Agency, "Joint Vector Vertical Obstruction Data (VVOD)" *FY05-09 Requirement Submissions*, FY05-09 030, NGA, 20 August 2002, URL: <http://needit. nga.ic.gov /pco/ri/needs/fy05/NeedsForm05A.asp?webid=410>, accessed 13 October 2006.

(U) VOs depicted on Aeronautical Charts

(U) The Global Navigation and Planning Chart (GNC) 1:5,000,000 scale and Jet Navigation Charts (JNC) 1:2,000,000 scale are used for high-altitude, long-range navigation and flight planning. Therefore, VOs are not depicted on these large scale charts.

(U) The standard height for depiction of VOs and the inclusion of individual VOs on NGA Flight Information Publication (FLIP) aeronautical charts varies with the scale of the product. The Operational Navigation Chart (ONC) 1: 1,000,000 scale is designed for medium altitude flight and contains cartographic data depicting VOs, airports, special use airspace, navigational aids, and Maximum Elevation Figures (MEFs). VOs 200 feet or taller are depicted. Because of scale and limitation of depiction in visually congested areas, per Mil-O-89200 (ONC), "Only the highest VO within each 3 minute by 3 minute cell, originating at full degree intersections, shall be shown in non built-up areas. The 3 minute by 3 minute cell is defined by the projection and projection ticks shown on the chart."[27] In conformance with the specification, only the highest VO within an approximately 9 square mile area is depicted.

(U) The Tactical Pilotage Chart (TPC) 1:500,000 scale is designed for low-altitude through medium-altitude visual and radar navigation. Only the tallest VO 200 feet or taller is depicted within a 1 minute by 1 minute (approximate one square mile area) cell.

(U) Joint Operational Graphic - (JOG-A) Air chart, 1:250,000 scale supports tactical low-level visual navigation. The JOG-A displays topographic data such as relief,

[27] (U) MIL-O-89200, Operational Navigation Chart Legend

drainage, vegetation, populated places, cultural features, coastal hydrographic features, aeronautical overprint depicting obstructions, aerodromes, special use airspace, navigational aids and related data.[28] According to MIL-J-89100, "All cultural features which extend 150 feet or more above the surrounding terrain are considered a hazard to flight and shall be shown and labeled, indicating the nature of the obstruction."[29] The incorporation of the 150 feet VO minimum height threshold for depiction is more stringent than the previously established 200 feet minimum. As of 1 October 2008, 610 out of 7002, or 8.7 percent of active JOG-A charts, depicted VOs at the 150 feet or taller threshold. NGA is continually striving to produce more JOG-A charts depicting the 150 feet VOs.

(U) Due to the proliferation of VO entries in the DVOF and the increased density of VOs within a defined area, there may not be sufficient space on a chart to plot its true position. Overlapping symbology can reduce the effectiveness of the chart. Ideally, the dot at the base of the tower symbol would be placed at the coordinates of the base of the tower on the chart. The cartographer may exercise cartographic license by placing the tower in the vicinity of its true location to enhance legibility. Another depiction strategy is to use leader lines emanating from the symbol and terminating at the positional coordinates of the VO. Coordinates of VOs should not be gleaned from chart sources for precision information purposes.

(U) To reduce chart clutter, multiple towers in close proximity are depicted with a multiple tower symbol. For a JOG-A chart and the TPC product, multiple VOs within a

[28] (U) "USAF Intelligence Targeting Guide," Air Force Pamphlet 14-210 *Intelligence*, 1 February 1998, URL: <http://www.e-publishing.af.mil/>, accessed 13 October 2008.

[29] (U) MIL-J-89100, Joint Operational Graphic – Aeronautical Chart Legend.

one nautical mile radius circle may be combined and depicted as a single multiple tower symbol. For ONC products, multiple VOs within a two nautical mile radius are combined and depicted as a multiple tower symbol. Providing only the most relevant visual details and the appropriate amount of texture ensures users do not become distracted with potential information masking or overload.

(U) VO Source data

(U) Acquisition of VO data from existing sources constitutes a major component of the DVOF dataset. NGA is constantly seeking to acquire new sources of VO data, and incorporate candidate VOs that meet DVOF requirements. Trusted sources of VO data include vetted foreign and domestic government sources, while other open source VO data requires additional processing.

(U) Sources of Domestic VO data

(U) Mapping, Charting, and Geodesy (MC&G) VO data from the Source (S) Key Component of NGA provides geographic area extraction of VO data. Within the NGA Aeronautical Domain, the Terminal Aeronautical GNSS Geodetic Survey (TAGGS) program provides airfield VO survey data for incorporation into DVOF. Stereo Airfield Collection (SAC) collects VOs from stereo overhead imagery.

(U) National Aeronautical Charting Office

(U) All domestic VOs are to be reported to the NACO through the U.S. Department of Transportation, FAA –Aeronautical Branch. The FAA's Aeronautical Information Branch analyzes and verifies aeronautical information used in the construction and maintenance of aeronautical charts, digital databases, and publications. It provides accurate aeronautical information to NACO charting branches, other FAA organizations, NGA, and the general aviation community.[30]

(U) NACO collects topographic and aeronautical data from numerous sources and uses this source data to compile and maintain aeronautical charts and products provided to military and civilian customers. In addition to documenting actual obstacles, FAA is involved in the proposed construction of VOs.

(U) Per the 14 *Code of Federal Regulation* (CFR), *Federal Aviation Regulations* (FAR) Part 77, in broadest terms, a sponsor who proposes construction of a structure greater than 200 feet in height, whether it contains an antenna or not, must submit a "Notice of Proposed Construction or Alteration" (FAA Form 7460-1) to the FAA. Additional limiting constraints on specific construction parameters in the vicinity of airports are listed in FAR §77.13 "Construction or Alteration Requiring Notice," as listed in Appendix F. The FAA must approve construction or alteration of structures that affect safety of air navigation.

(U) Obstacles submitted to the FAA with the FAA Form 7460-1 may be added to the NACO Digital Obstacle File (DOF). The NACO DOF describes all known obstacles of interest to aviation users in the U.S., with limited coverage of the Pacific, the

[30] (U) Federal Aviation Administration, *NACO Aeronautical Services*, URL: <http://www.naco.faa .gov/ index.asp?xml=naco/about>, accessed 22 January 2009.

Caribbean, Canada, and Mexico. The obstacles are assigned unique numerical identifiers, accuracy codes, and are listed in order of ascending latitude within each state or area by FAA Region. The NACO Downloadable Digital Obstacle File (DDOF) is available online and is updated every 56 days.[31]

(U) NACO Digital Obstacle File (DOF)

(U) The NACO DOF would gain additional VO data if it were to incorporate NGA's DVOF data within its area of responsibility. However, the FAA has an issue with DVOF accuracy, which limits ingestion of DVOF into the NACO DOF. According to the FAA, many of the DVOF VOs lack data regarding accuracy tolerance.

(U) The FAA is the primary federal agency that regulates all aspects of civil aviation for the U.S. As such, the FAA directly represents the U.S. as a member of the ICAO. Member states that participate in the ICAO ETOD program must adhere to strict accuracy requirements. According to an FAA Obstacle and Terrain Team administrator, "If DVOF were added to the DOF, the FAA would be required to find an alternative means to verify and upgrade many of the accuracy tolerance values DVOF provides and/or does not provide."[32] This problem has prevented the FAA from incorporating DVOF data into the NACO DOF. FAA Airport Obstruction Survey accuracy standards

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[31] (U) Digital Aeronautical Information CD (DAICD), URL: <http://www.avn.faa.gov/index. asp?xml =naco/catalog/charts/digital/chart_supp>, accessed 31 January 2009

[32] (U) (b)(6) [redacted] FAA, Obstacle and Terrain Team, Silver Spring, MD, "Vertical Obstruction Issues," e-mail interview by author, 17 June 2009.

mandate a 20-foot horizontal accuracy for VO location, and a 3 foot vertical accuracy for ellipsoidal and orthometric height values, all at a 95 percent confidence level.[33]

(U) DVOF receives source VO data from a variety of contributors in an effort to maintain the database with the highest possible accuracy. For U.S. territory, the Aeronautical Branch of the National Aeronautical Charting Office (NACO), in conjunction with the Federal Aviation Administration (FAA) Aviation System Standards Office, supplies VO digital databases harvested from United States Geological Survey (USGS). USGS topographic maps, state, local, and tribal government maps, private sector charts, railroad atlases, high tension line charts from electrical power transmission entities such as the Tennessee Valley Authority (TVA), and pylon databases from electric power providers such as Southern California Edison. All offer value for developing VO data. Additionally, as described by a Memorandum of Understanding between the FCC and NIMA dated 29 October 2003, the FCC furnishes VO data for radio transmission towers to NIMA that is directly integrated into the DVOF. The FCC obstacle data is also included in the NACO DOF. In complementary fashion, the FCC may also use the DVOF to populate a proposed database of tower sites or possible tower sites to assist FCC licensees in collocating their facilities.[34] However, the exchange of VO data must accommodate differences in datums, accuracy, format, and quality.

[33] (U) FAA, No. 405, "Standards for Aeronautical Surveys and Related Products," 1 September 1996, Fourth ed., A5.6, URL: <http://www.ngs.noaa.gov/AERO/aerospecs.htm>, accessed 17 December 2010. Cited hereafter as "FAA No. 405."

[34] (U) FCC News, *FCC and National Imagery and Mapping Agency Sign Inter-Agency MOU for Quarterly Sharing of Databases on Tower Locations,* 23 October 2003, URL: <http://fjallfoss.fcc.gov/edocs_public/attachmatch/DOC-240497A1.pdf>, accessed 31 August 2010.

(U) DOF Geodetic Reference Systems

(U) As noted on FAA Form 7460-1, coordinates for structures may be submitted using the North American Datum of 1983 (NAD 83) or North American Datum of 1927 (NAD 27). NAD 83 is an Earth-centered datum based on the Geodetic Reference System of 1980, which is based on measurements made by satellites and terrestrial instruments. The older NAD 27 is a datum based on the Clarke ellipsoid of 1866, and has its reference point located at Meades Ranch in Kansas. There are substantial differences in the two ellipsoids ranging from up to 90 meters in the western U.S. to 10 meters in the central and eastern U.S

(U) Congress passed Public Law 101-508, Section 9120, the *Aviation Safety and Capacity Expansion Act of 1990*, which mandated that the FAA convert all position data used in the National Airspace System to NAD 83. In compliance with this law, the FAA on 11 May 1992 issued a *Notice* in the *Federal Register* advising of the conversion to NAD 83 on 15 October 1992. This directly affected coordination between the FAA and FCC on all matters related to tower and antenna and aviation facility locations.[35] Data conversion programs to transform horizontal datum are available from NGA or National Oceanographic and Atmospheric Administration (NOAA) National Geodetic Survey. The NGA Web Geographic Translator (GEOTRANS) 2.4.1 is an online application program that allows the customer to convert geographic coordinates from a wide variety of coordinate systems, map projections, and datums.[36]

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[35] (U) Public Notice-*The Federal Communications Commission Continues to Require Applicants to Use Coordinates Based on the North American Datum of 1927*, Published at 57 Fed. Reg. 41938 (14 September 1992) and 7 FCC Rcd 6096, URL: <http://www.fcc.gov/mb/audio/decdoc/ letter/1992--09--01--pubnot.html>, accessed 1 February 2009.

[36] (U) “Geographic Translator,” NGA, URL: <http://geoengine.nga.mil/geospatial/SW_TOOLS /NIMAMUSE/webinter/geotrans.html>, accessed 3 February 2009.

(U) According to the latest FAA Form 7460-1, coordinates entered in block 11 may be based on NAD 83, NAD 27, or other datum as noted. The FAA Standard Instrument Approach Procedures and NACO aeronautical charts are based on the NAD 83 horizontal datum. For general purposes, within the contiguous U.S., the NAD 83 and WGS 84 horizontal datums are similar. However, as one examines global DVOF data exclusive of the North American tectonic plate, WGS 84 exhibits greater accuracy than NAD 83. Another component of the VO documentation concerns vertical data. The North American Vertical Datum of 1988 (NAVD 88) is the official vertical datum of the FAA and is used as a vertical datum for the NACO DOF in conjunction with National Geodetic Vertical Datum of 1929 (NGVD 29). However, DVOF and the ICAO ETOD database utilize EGM 96 for vertical datum.

(U) FCC Antenna Structure Monitoring

(U) The FCC Antenna Structure Registration Program (ASRP) establishes the process under which each antenna structure that requires FAA notification is registered with the FCC by its owner. Per Title 47 CFR Part 17, owners of antenna structures must register with the FCC any antenna structures taller than 200 feet, or located in the vicinity of an airport. The FCC specifically defines antenna structures as "the radiating and/or receive system, its supporting structures and any appurtenances mounted thereon."[37] Structures such as buildings, towers, bridges, windmills, and powerline pylons that do not have an attached antenna are not defined as antenna structures and are not to be registered

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[37] (U) Federal Communications Commission, *Antenna Structure Registration*, URL: <http://wireless. fcc.gov/antenna/index.htm?job=about>, accessed 24 January 2009. Cited hereafter as "*Antenna Structure Registration*."

under the FCC ASRP. VOs that do not contain antennas, regardless of their location or height, are not monitored by the FCC, and are solely monitored by the FAA if the structure meets qualifying criteria. In order to comply with the requirements of the ASRP, any new construction requires submission of a “Notice of Proposed Construction or Alteration” (FAA Form 7460-1) to the FAA. The proliferation of cell phone towers presents a VO documentation challenge to NACO. Through the ASRP, FAA receives data for VOs associated with electronic signal propagation or reception. These VOs are used to populate the NACO DOF.

(U) The majority of the ASRP pertains to antennas over 200 feet tall. VOs less than 200 feet present a concern that is not always addressed in the ASRP. ASRP requirements only apply to those antenna structures that may create a hazard to air navigation due to antenna height of 200 feet AGL or greater, or antennas less than 200 feet AGL in proximity to an airport. Therefore, the NACO DOF does not contain a comprehensive record of all antenna structures that do not meet ASRP reporting criteria. A 199 foot AGL antenna not in the vicinity of an airport may not be documented, based on the assertion that it poses no hazard to air navigation because it does not meet the 200 foot AGL requirement.

(U) Antenna Structure Registration does not replace the FAA notification requirement. Registration must be undertaken after an owner has requested a study of the site by the FAA and received a "final determination of no hazard," but before any licensing applications are filed with the FCC for the site.[38] The process minimizes the issuance of waivers or exemptions, loss of time or assets, and danger to safe navigation.

[38] (U) “*Antenna Structure Registration*”

(U) TowerMaps©, a commercial vendor of antenna data, claims to track over 98 percent of all commercially viable antenna sites. TowerMaps© website states that, based on a visual overlay of the two datasets, the completeness of FCC data is substantially less than that of TowerMaps©.[39] As a data harvester, TowerMaps© attempts to provide accurate information, but assumes no responsibility for, and makes no representations with respect to, the accuracy of the information.

(U) AntennaSearch© is a free online source for accessing databases that contain information on towers and antennas used for cellular, microwave, paging, and other commercial purposes. The service claims to access data for over 1.9 million antennas and towers within U. S. territory.[40] Users can check cell phone reception coverage areas and gather data on cell tower coordinates and height data. As an example, a local residence check revealed the site owners and heights of 44 towers located within a 4-mile search radius. The query also listed three new tower applications submitted to ASRP, and 155 antennae. The FCC-registered towers, and unregistered VOs documented in commercial databases such as TowerMaps© and AntennaSearch© , can serve as a cue for harvesting VO data.

(U) Other sources of potential VO data include NAVTEQ©, a leading provider of digital GIS maps, traffic, and location data, and the NGA Homeland Security Infrastructure Program (HSIP) Gold Dataset. The HSIP Gold Dataset comprises a compilation of vector data across all national infrastructure sectors. NGA assembled the

[39] (U) TowerMaps©, *Wireless Antenna Facility Location Data*, FCC (Antenna Structure Registration) and Tower Maps, URL: <http://www.towermaps.com/fcc.htm>, accessed 24 January 2009.

[40] (U) AntennaSearch©, *Start Your Search Now*, URL: <http://www.antennasearch.com/>, accessed 4 January 24 2009.

HSIP geospatial inventory by combining over 400 federal and commercial databases comprising domestic infrastructure and foundational map features.

(U) Homeland Security Infrastructure Program (HSIP)

(U) The continuously updated and annually distributed HSIP dataset is the best available infrastructure specific vector data, GIS shapefiles, attributes, and metadata that is furnished to support Homeland Security, Homeland Defense, and Emergency Preparedness/Recovery mission. Originally developed for federal use only due to licensing restrictions, permissions for use have been extended to state, local, and tribal governments when a federally declared disaster or state of emergency exists.[41] Efforts are underway to create a license-free HSIP Freedom database to allow timely universal access to accredited customers. NGA collaborates with other federal agencies and state GIS coordinators to acquire infrastructure data and develop a framework to manipulate the large breadth of public, commercial proprietary, and private data sources. Currently, a snapshot of the HSIP Gold database is produced annually and distributed via DVD. The HSIP Gold 2007 Version 1 DVD was disseminated in May 2007, and the HSIP Gold 2008 Version 2 DVD which contains over 300 datasets, began distribution in January 2008. The latest HSIP Gold version 2011 will contain over 400 data layers delivered to the customer in a two DVD set. Future plans include an enterprise solution that offers a service-oriented architecture that facilitates access to geospatial intelligence accessed online using Web services. Customers will benefit with real-time access to continuously updated foundational geospatial data.

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[41](U) Patrick Marshall, "Where GIS Gets Lost," *Government Computer News*, 2 May 2008, URL: <http://gcn.com/articles/2008/05/02/where-gis-gets-lost.aspx>, accessed 28 February 2009.

(U) The HSIP Gold Dataset serves as a potential source of VO data for inclusion in the DVOF and NACO DOF. Potential source for VO data include the geo-databases comprising:

Emergency Services - *Feature Class*: Atlas & Database of Air Medical Services (ADAMS), *Source*: ADAMS Base Helipads and Airports.

Communications – *Feature Class*: Antenna Structure Registrate, Cellular Towers, AM Antennas, FM Antennas, Microwave Towers, *Source*: Federal Communications Commission

Energy- *Feature Class*: Electric Transmission Lines, *Source*: Global Energy Decisions

Trans-Air- *Feature Class*: Aero-Obstructions, *Source*: Techni Graphic Systems Inc., NOAA

Trans-Ground- *Feature Class*: RRBRIDGES, BRIDGES, *Sources*: Department of Transportation (DOT), Federal Rail Administration, Techni Graphic Systems Inc.

Trans-Water- *Feature Class*: Nautical NAVAIDS, *Source*: Techni Graphic Systems Inc., NOAA

Water-Supply- *Feature Class*: Dams, *Source*: Dam Safety Program

(U) The HSIP Gold Database currently applies to U.S. territory. Similar HSIP-type infrastructure data may be leveraged from other world-wide sources to glean additional VOs for entry in the DVOF. This program could be patterned after the PVA Aeronautical Source Program. Through the Office of International Affairs and Policy (OIP) and PVA, NGA has established Memorandum of Understanding agreements with international partners to exchange FLIP aeronautical information. The exchange of VO data could similarly benefit both partners.

(U) Additional sources of VO data are available from ICAO. Under the auspices of ICAO Annex 15, the Aeronautical Information Service (AIS) program ensures the flow of information for the safety of international air navigation. According to ICAO Annex 15, each State is responsible for making available all information that is relevant to the operation of aircraft engaged in international civil aviation within its territory or air traffic control areas of responsibility. Within the AIS, the AIP documents contain VO data. The accuracy, resolution and integrity of the AIP VO data, and the VO data contained in the ETOD and the Aerodrome Mapping Data Base (AMDB) offer a rich source of VO data for inclusion in the DVOF.

(U) Sources of International DVOF data

(U) On an international scale, the Allied System for Geospatial-Intelligence (ASG), consisting of Australia, Canada, New Zealand, and the United Kingdom offer VO data for inclusion in DVOF. Germany is a trusted source of VO data used to populate DVOF. Other NATO or Southeast Asia allies offer potential opportunities for additional VO data. NOTAM information is a timely source to identify safety of flight hazards that include VO data for inclusion in the DVOF. Over 190 nations associated with ICAO publish AIP documents that list VOs for entry into DVOF. The intelligence community also maintains data that is used to populate the DVOF.

(U) Electronic Terrain and Obstacles Databases (ETOD)

(U) Under the auspices of the ICAO, concerns over the integrity, accuracy, and resolution of aeronautical information, to include ETOD, has resulted in the promulgation of Annex 15, Document 9881. The document establishes guidelines for Electronic Terrain, Obstacle and Aerodrome Mapping Information that were developed through consultation with the joint RTCA Special Committee 193 and the European Organization for Civil Aviation Electronics (EUROCAE) Working Group 44.[42] Document 9881 offers a framework for NGA to consider for the refinement of the Vertical Obstructions program.

(U) According to ICAO, member states' aviation authorities must establish a quality system and put in place quality management procedures at all stages (receiving and/or originating, collating or assembling, editing, formatting, publishing, storing, and distributing) of the aeronautical information/data process.[43] The quality system adopted by ICAO is a program registered through ISO19100 Geographic Information series standard. The ISO standards are voluntary, member-driven consensual principles established to foster collaboration. The ISO 19100 series of standards for Geographic Information is established as the reference data-modeling framework to lead toward a common methodology that will facilitate interoperability developments.

(U) The global relevance of ICAO is enhanced though the ISO program. In order for member states' aeronautical data to remain relevant, the data must be consistent with the ISO and ETOD standards. This reasoning could motivate the FAA and NGA to

[42] (U) ETOD, 2.

[43] (U) "Annex 15 to the Convention on International Civil Aviation" *Aeronautical Information Services*, URL: <http://www.icao.int/eshop/pub/anx_info/an15_info_en.pdf>, accessed 20 June 2009.

develop a VO data file structure within the overarching framework of the ICAO ETOD program.

(U) Other member states have encountered similar challenges to comply with the ICAO ETOD program, and have sought alternative solutions to gain acceptance within the framework of Amendment 33 to ICAO Annex 15. Amendment 33 addresses the data attribute requirements for member states to comply with the ETOD program. The South Africa Civil Aviation Authority (SACCA) has sought relief from the original technical content requirements of ETOD. SACCA documents forwarded to ICAO address problems associated with Electronic Obstacle Data (EOD) requirements.

> (U) Per the SACCA, "not all of EOD complies with the data integrity requirements, therefore South Africa will not fully comply with Chapter 10, ICAO Annex 15, and has filed differences (alternative method of compliance differences have been filed on 10.2.5, 10.4.2 and 10.5.6). The issue is that we are dealing with legacy data whose integrity cannot be guaranteed at present. Circular Error of Probabilities (CEPs) will be provided with all data whose positional integrity does not fully comply with Chapter 10, ICAO Annex 15."[44]

(U) The FAA could examine the possibility of filing differences, or an alternative method of compliance regarding specific program requirements, until the variance can be corrected. Domestic DVOF data may be totally ingested into the NACO DOF, or selectively culled to limit data ingestion to VOs meeting ETOD accuracy requirements.

(U) The scope of NGA's mission requirement to furnish the DVOF for its aeronautical GEOINT customers would be greatly expanded if the DVOF were modified to be a producer of obstacle data for inclusion into ETOD. Currently, NGA does not furnish VO data to any nation state for the expressed purpose of complying with ETOD

[44] (U) ICAO Information Paper, *Implementation of e-TOD and draft development of a policy for the management of national e-TOD programmes – South Africa*, URL: <http://www.icao.int/WACAF/APIRG/SG/2009/AIS_MAP_TF5/docs/e-TOD%20-%20IP-6.pdf>, accessed 20 June 2009.

program requirements. As an aggregator and producer of world-wide VO data, NGA could reconfigure the VO program and DVOF to become ETOD compliant. The non-U.S. data that NGA could include within the scope of the ETOD program would be a subset of the larger world-wide DVOF. Portions of the DVOF exceed the nominal attribute requirements of obstacles as defined in the ETOD program, while other portions are deficient relative to obstacle attributes. Among other topics, vertical obstacle collection methods, costs, dataset maintenance, and liability issues would need to be addressed if NGA exercised a greater role in the ETOD program.

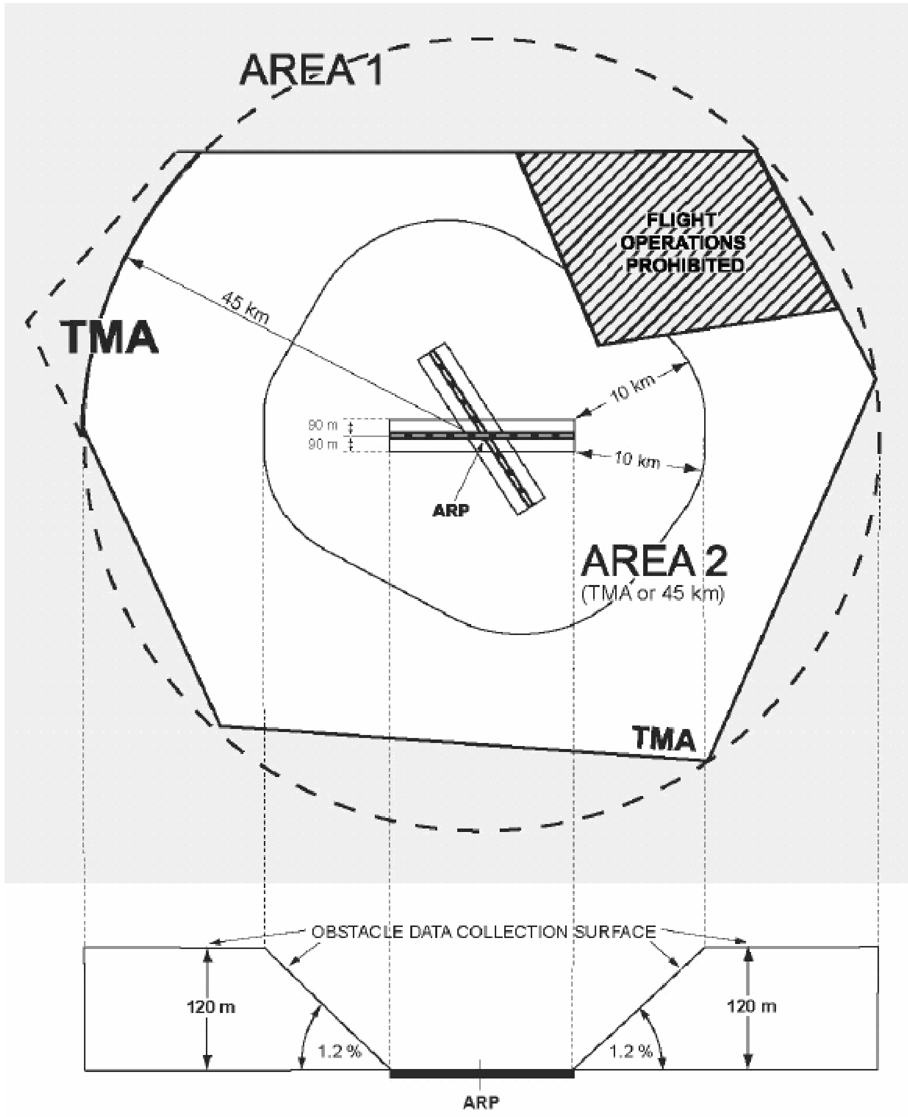
(U) ETOD Area categories

(U) ETOD terrain data and obstacle data are categorized into four areas:

- Area 1: Entire State territory, which comprises all the land mass of a member state
- Area 2: Aerodrome Terminal Area (TMA) as defined in the member state's AIP or, for airports without a defined TMA, an area not to exceed a 45 kilometer radius from the Airport Reference Point (ARP). See Figure 2-7.
- Area 3: Aerodrome/heliport area. See Figure 2-7.
- Area 4: Category II and III Instrument Approach Procedure operations area

(U) Area 1 requires collection and reporting of obstacles with a height equal to or greater than 100 meters.

(U) Area 2 requirements dictate collection and reporting any obstacles that penetrate a conical surface defined as a 1.2° slope emanating from the edges of a 180 meter wide rectangular area situated along a runway axis out to 120 meters height, which equates to a distance of approximately 10 kilometers from the airfield, continuing out to a 45 kilometer radius from the ARP or the Terminal Control Area boundary, whichever is smaller. This defined area is a simplified permutation of the NGA Stereo Airfield Collection Obstruction Identification Surface (OIS) zone.



(U) Figure 2-7. Obstacle data collection surfaces

(U) Source: International Civil Aviation Organization, *Guidelines for Electronic Terrain, Obstacle and Aerodrome Mapping Information Document 9881, 76*, URL: <http://www2.icao.int/en/pbn/ICAO Documentation/ICAO Documentation /Guidelines for Electronic Terrain, Obstacle and Aerodrome Mapping Information.pdf>.

(U) Area 3 collection and reporting applies to specified distances adjacent to aerodrome or heliport Surface Movement Areas (SMA). These areas are surfaces that are used for the take-off, landing, and taxiing of aircraft, which includes runways, taxiways, and apron areas. All vertical objects and terrain in the horizontal spatial extent region (50 meters for taxiway and apron SMAs and 90 meters for runway areas) that extend more than 0.5 meter above the horizontal plane passing through the nearest point on the aerodrome surface movement area may be hazardous for surface movement and must be surveyed.[45]

(U) Area 4 collection and reporting is only for those runways where precision approach Category II or III operations have been established. This 120-meter wide by 900-meter length box is centered on an extension of the runway centerline. This area applies only to terrain data mapping. Obstacle data within this area is collected according to Area 2 requirements. A summary of obstacle data quality requirements is provided, with the addition of the data maintenance periodicity adjusted to the ICAO AIP Aeronautical Information Regulation and Control (AIRAC) 28 day cycle schedule. However, the database may be updated more frequently than the standard AIRAC cycle schedule and information of changes that occur between AIRAC cycle updates may be provided by NOTAM, data link, or an equivalent method depending on the operational use of the data.[46] All of the quality attributes for VO data are crucial to safety of flight, which includes strict currency requirements applied to the maintenance period. If DVOF incorporates ETOD, currency updates must reflect ETOD changes as promulgated. See quality attributes as listed in Table 2-1.

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[45] (U) ETOD Forum 2008, International Civil Aviation Organization, *Guidelines for Electronic Terrain, Obstacle and Aerodrome Mapping Information Document 9881*, 132, URL: <http://ETODforum .com/last _year.htm>, accessed 26 June 2009.

[46] (U) ETOD, 123.

Quality Attributes	Area 1 The State	Area 2 Terminal Control Area	Area 3 Aerodrome/ Heliport Area
Horizontal Accuracy	50.0 m	5.0 m	0.5 m
Data Classification Integrity level	Routine (10^{-3})	Essential (10^{-5})	Essential (10^{-5})
Vertical Accuracy	30.0 m	3.0 m	0.5 m
Vertical Resolution	1.0 m	0.1 m	0.01 m
Confidence Level (1σ)	90%	90%	90%
Maintenance period	as required	as required	as required

(U) Table 2-1. Obstacle Data Quality Requirements

(U) Source: International Civil Aviation Organization, *Guidelines for Electronic Terrain, Obstacle and Aerodrome Mapping Information Document 9881*, 47, URL: <http://www2.icao.int/en/pbn/ICAO Documentation/ICAO Documentation /Guidelines for Electronic Terrain, Obstacle and Aerodrome Mapping Information.pdf>.

(U) ETOD Reference Systems

(U) The ICAO ETOD program uses the WGS 84 horizontal reference coordinate system. If the horizontal reference system is not WGS 84, the reference system and transformation parameters to WGS 84 must be specified.

(U) The vertical reference system is the datum to which the elevation values are referenced. MSL is the required vertical reference system. The EGM 96 must be used as the global gravity model. If a geoid model other than the EGM 96 is used, a description of the model used, including the parameters required for height transformation between the model and EGM 96 must be provided.[47]

(U) Pursuit of Ground Truth

(U) The variety of coordinate reference systems, datums, geoid models, and reference ellipsoids affect the recorded data for the position and height of a VO. The standards for data attributes recorded by DVOF should meet the requirements set by the DoD customer. Interoperability and conformance with FAA and ICAO VO data quality standards will enhance the value of DVOF. Whether VO data is used for instrument approach procedure design, penetration of the OIS, precise engagement, ETOD Area 1, or ETOD Area 3 documentation, the need for accuracy is paramount. Accuracy requirements are determined by utilization. Considering the variables affecting VO geodetic coordinates and height values, it is imperative the NSG establish a DoD standard for VO data. The most accurate point position is defined by using the most current WGS-84 reference system for geodetic coordinates in conjunction with a HaE value. As CJCSI 3900.01C states, "Forces navigating and operating off hard copy and digital maps based upon MSL will continue to use MSL for elevations unless HaE (based on WGS 84) is available. Only ellipsoidal heights from approved sources will be used to support precision targeting with coordinate seeking weapons."[48] The MSL height paradigm should be relegated to VO data usage that requires less accuracy, and HaE should be adopted as the standard for exacting requirements.

[47] (U) "ETOD," 129.

[48] (U) "JCS," 2.

(U) The FAA acknowledges that future aviation will be heavily dependent on satellite navigation systems, such as GPS. With GPS navigation, coordinates and geodetic datums become extremely important. According to the FAA, "Eventually, regional datums, such as the North American Datum of 1983 (NAD 83)…. will probably be replaced by a global system, such as ITRF."[49] WGS 84 continues to be adjusted to achieve concordance with ITRF.

[49] (U) "FAA No. 405," 1.2.

CHAPTER 3

(U) With a basic understanding of how the VO program operates, one may examine instances where lack of situational awareness resulted in aircraft mishaps. Identifying the failure points in the VO data stream may help prevent a reoccurrence of another mishap. In conjunction with mishap investigation, the aviation safety programs of the military services, FAA, and NTSB promote ongoing tools for mishap prevention. The practical application of VO data to enhance VO awareness should promote safety and increase mission completion rates.

(U)Flight into Terrain or Vertical Obstructions

(U)Each mishap review presents different aspects of VO awareness and the impact on the providers and customers of VO data. The following mishap reviews exemplify VO issues that require analysis and the identification of mitigation strategies.

(U) Cervino Cablecar Mishap 1998

(U) On 3 February 1998, an EA-6B Prowler jet aircraft from VMAQ-2 on a training mission originated from Aviano AB severed the cables of a ski gondola at Cermis recreational ski area near the town of Cavalese located in the Italian Dolomites area of the Alps mountain range. The aircraft, while flying at an altitude of 360 feet above ground level (AGL) and 540 knots, sliced through the cables supporting a cablecar, resulting in the deaths of 20 passengers onboard the cable-car. The aircraft sustained damage to the right wing, the upper part of the vertical stabilizer, and the jamming pod, which resulted in the termination of the mission and forced the crew to return to base. The crew executed a precautionary emergency approach and engaged the emergency aircraft arresting gear due to a suspected hydraulic malfunction.

(U) The United States Air Force (USAF) 31st Fighter Wing (FW) hosted the 1997 deployment of United States Marine Corps (USMC) Marine Tactical Electronic Warfare Squadron Two (VMAQ-2) to Aviano Air Base (AB) Italy in support of Operation Deliberate Guard. Between 22 August 1997 and 3 February 1998, the day of the mishap, VMAQ-2 had carried out a total of 254 sorties, including 164 operational missions, 69 squadron training flights and 21 post-maintenance functional check flights.[50] The Pilot in Command of the mishap aircraft, call sign EASY 01, was making his last flight in the EA-6B Prowler and was transferring to continental United States (CONUS) to join an F/A-18 Hornet squadron.

(U) United States aviation squadrons deployed to Aviano AB were expected to observe all U.S. military procedures, local operating procedures, and Italian regulations governing all facets of aviation operations, to include low-level flight training missions.[51] However, due to a lack of communication and coordination between the 31st FW and VMAQ-2, the aircrewmen of flight EASY 01 were not aware of all the available

[50](U) Camera Dei Deputati, *Parliamentary Committee of Inquiry into the Cermis Tragedy Final Report*, 8 February 2001, Doc. XXII-bis N.1, URL: <http://legxiv.camera.it/_dati/leg13/lavori/documenti parlamentari/indiceetesti/xxiibis/001i/d010.htm>, 9, accessed 30 August 2008. Cited hereafter as "Chamber of Deputies Inquiry, 2001."

[51] (U) "Chamber of Deputies Inquiry, 2001," 119.

resources to safely plan and execute the mission on training route AV047 BD. The lack of vertical obstruction awareness by the aircrew of EASY 01 contributed to the mishap.

(U) According to the Command Investigation Board (CIB), a U.S. military administrative inquiry conducted in accordance with the Judge Advocate General Manual (JAGMAN), the cables of the Cermis cable car were hit by the aircraft at approximately 15:13 local time, at a height of no more than 370 feet. The cables severed in the impact were the lowest in the cable car belt; the lower cable was 364 feet AGL. The Commanding Officer of VMAQ-2 stated that after the accident the mishap pilot had told him he knew he had hit the cable.[52]

(U) The Italian government established the Italian Parliamentary Committee of Inquiry into the Cermis Tragedy (IPCICT) to conduct an exhaustive inquiry to fully clarify the events, causes, and responsibilities at all levels concerning the mishap. The rules and regulations governing military training flights were examined by the IPCICT. The committee report stated that meteorological and environmental conditions were satisfactory over the entire route covered by the training flight. It also reported that a ban on flights below 2000 feet over Italian territory had been included in USAF Flight Crew Information File (FCIF) 97-16 of 29 August 1997, which was known by or made available to U.S. military personnel. Additionally, according to USMC Order 3500.14F, (Aviation Training and. Readiness Manual, Volume I), paragraph 5000.3, navigation training flights for non-Low Altitude Tactics (NOLAT) were limited to a minimum of 1000 feet AGL for aircraft not equipped with a Heads Up Display (HUD) device, as is

[52] (U) "Chamber of Deputies Inquiry, 2001," 109.

the case with the EA-6B.[53] The aeronautical charts onboard the mishap aircraft depicted 2000 feet as the minimum authorized altitude along the segment of the training flight near the mishap site. Additionally, the aircraft would have avoided all obstacles along the route if it had flown at a minimum altitude of 1000 feet AGL, as depicted on the smaller knee-board charts found in the mishap aircraft and per USMC Order 3500.14F.[54]

(U) The mishap aircraft carried aeronautical charts published by NGA, formerly known as U.S. National Imagery and Mapping Agency (NIMA), that did not depict the Cermis cableway. The IPCICT reported that according to the U.S. military judge involved in the Uniform Code of Military Justice (UCMJ) investigation, NGA was responsible for producing aeronautical charts of the mishap area that had used scales that did not contain information about VOs such as the gondola car suspension cables.[55] The reference to map scales in the IPCICT report regarding VOs is factually true. The Global Navigation and Planning Chart (GNC) 1:5,000,000 scale and Jet Navigation Chart (JNC) 1:2,000,000 scale are used for high-altitude, long-range navigation and flight planning. Therefore, VOs are not depicted on the GNC and JNC charts. These large scale charts were not relevant to the low-level mishap flight.

(U) Whether depicted on an Operational Navigation Chart (ONC) 1: 1,000,000 scale, a Tactical Pilotage Chart (TPC) 1:500,000 scale, or a Joint Operational Graphic (JOG)-1A chart (scale 1:250,000), VOs 200 feet or taller are included on NGA

[53] (U) "Chamber of Deputies Inquiry, 2001,"96.

[54] (U) "Chamber of Deputies Inquiry, 2001," 124.

[55] (U) "Chamber of Deputies Inquiry, 2001," 135.

aeronautical charts.[56] Due to the density of VOs within a defined area and the inability to clearly depict the VOs, the multiple towers symbol is used to avoid a cluttered, illegible display. Also, cartographer's license is granted to displace the VO location on the chart to retain overall legibility. The dot at the base of the tower symbol is not required to be placed on the chart at the coordinates of the tower. These anomalies affect the user's ability to rely on VO depiction on legacy edition charts for precision geospatial information purposes.

(U) U.S. military personnel were under no obligation to use only charts from NGA. Available planning resources were not utilized to access the most accurate data, which was provided by the Italian Aeronautical Cartographic Information Center (CIGA). CIGA had sent 8 copies of the Italian charts depicting the Cermis cableway to the 31st FW, the designated host command for U.S. aviation assets at Aviano AB.[57]

(U) However, VMAQ-2 and the 31st FW Standardization and Evaluation Section were not aware of the existence of the low-level Italian maps (scale 1:500,000, Sheet 1, Ed. 2) that described a horizontal obstacle within one nautical mile of the mishap area. The IPCICT reported that it was neither the policy nor practice of the United States to only use aeronautical products produced by NIMA or DoD when operating outside U.S. air space.[58]

(U) In this incident, U.S. military flight crews had not utilized the Italian aeronautical charts that were provided to the 31st FW. Although there was no specific

[56] (U) In the case of selected Joint Operational Graphic (JOG)-1A charts (scale 1:250,000), VOs that are 150 feet or taller are eligible for depiction. As of 1 October 2008, about 9 percent of the total active JOG charts (approximately 7000 charts) depicted VOs greater than 150 feet or taller.

[57] (U) "Chamber of Deputies Inquiry, 2001," 59.

[58] (U) "Chamber of Deputies Inquiry, 2001," 96.

obligation to exclusively use U.S. aeronautical charts, the mishap aircraft carried only U.S. charts that did not depict the Cermis cableway. If the U.S. flight planners had incorporated the data in the CIGA charts into the flight planning process, the flight crew would have been aware of the hazard to aerial navigation. The governing U.S. Navy instruction addressing the conduct of preflight planning stipulates that "before commencing a flight, the pilot in command shall be familiar with all available information appropriate to the intended operation….In addition, the pilot in command and mission commander (when there is one designated) shall conduct a risk assessment prior to the flight."[59]

(U) The investigation showed the aircrew had clearly broken the rules concerning flight path, altitude, and airspeed as set by their flight plan.[60] Had Easy 01 executed the flight plan within the prescribed lateral limits of the training route AV047 BD, the aircraft would have avoided the aerial cableway. If Easy 01 had flown at the prescribed altitude, it would have avoided the aerial cableway. If Easy 01 had flown at a slower airspeed, it could have allowed the pilot additional time to maneuver the aircraft to avoid the aerial cableway. The combination of flying off the prescribed route at below the authorized altitude at an excessive speed led to the mishap. The flight crew did not use all the mission planning resources that were available to increase their situational awareness. Even with the less than optimum pre-flight planning, the aircrew could have prevented the mishap had they properly executed the filed flight plan.

[59] (U) U.S. Navy, OPNAVINST 3710.7T, NATOPS General Flight and Operating Procedures, Department of the Navy, Office of the Chief of Naval Operations, 1 March 2004, 4-2.

[60] (U) "Chamber of Deputies Inquiry, 2001," 54.

(U) The professionalism exhibited by USMC VMAQ aircrews, and their conformity with existing flight regulations while deployed to Aviano, had been previously demonstrated by the actions of the Commanding Officer (CO) of VMAQ-3 on 3 April 1997. The pilot had performed and videotaped low-level aerobatic flight maneuvers on the same route where EASY 01 of VMAQ-2 severed the ski gondola cables. Three days subsequent to the Cermis mishap, the CO of VMAQ-3 was relieved of command.[61]

(U) The CIB recommended that NGA review all map sources from foreign countries to ensure that all host-provided obstructions to flight are accurately plotted.[62] NGA does incorporate geospatial data provided by a variety of sources in its aeronautical products. A summary of VO sources utilized to populate the DVOF follows:

- Foreign AIP from civil aviation authorities in conformance ICAO standards
- NACO Aeronautical Branch of the FAA
- USGS topographic maps
- State, local, and tribal government maps
- FCC radio towers
- Homeland Security Infrastructure Program
- MC&G Transnational Issues / Geo-technical Analysis Group of NGA
- Monoscopic and Stereoscopic imagery
- NGA List of Lights

[61] (U) Chamber of Deputies Inquiry, 2001, 230.

[62] (U) Chamber of Deputies Inquiry, 2001, 130.

- NOTAM
- Airfield survey reports
- Customer feedback forms located in FLIP products
- United Kingdom, Australia, and Germany trusted source reports
- Private sector charts, railroad atlases, TVA, and high tension electrical line charts from power-line companies

(U) All the listed sources furnish candidate VO information that is collected, analyzed, processed, ingested, and incorporated into the DVOF and published in NGA FLIP comprising the following products:

- High and Low altitude enroute charts
- ONC, TPC, and JOG aeronautical charts
- Enroute supplements
- Area planning books
- Terminal books to include Radar Instrument Approach Minimums, Standard Instrument Departure (SID), Instrument Approach Procedure (IAP), Airport Diagram
- Standard Terminal Arrival (STAR)
- Web DVOF
- Electronic Chart Updating Manual (ECHUM)
- Digital Flight Information File (DAFIF)

(U) A wide variety of applications utilize DVOF input for a broad spectrum of aviation analytical procedures and products. A sample of DVOF uses includes:

- Terminal ground proximity warning system with forward looking terrain avoidance function and minimum safe altitude warning (MSAW) system
- Determination of contingency procedures for use in the event of an emergency during a missed approach or take-off
- Instrument procedure design (including circling procedure)
- Determination of en-route “drift-down” procedure and en-route emergency landing location
- Aircraft operating limitations analysis
- Aeronautical chart production and on-board databases
- Flight simulator
- Synthetic vision
- Advanced surface movement guidance and control system (A-SMGCS)
- Aerodrome/heliport obstacle restriction and removal[63]

(U) The breadth of aeronautical data management involved in the production and utilization of DVOF is far reaching and has critical implications in aeronautical activities. This incident highlights issues concerning the collection, processing, and distribution of VO data and its incorporation into aeronautical products and services.

[63] (U) International Civil Aviation Organization, ETOD Forum 2008, *Guidelines for Electronic Terrain, Obstacle and Aerodrome Mapping Information Document 9881*, URL: <http://etodforum.com/last_year.htm>, accessed 26 June 2009.

(U) Dubrovnik, Croatia, Ron Brown Mishap 1996

(U) On 3 April 1996, a USAF T-43A, the military version of the Boeing B-737-200 aircraft, experienced a controlled-flight-into-terrain (CFIT) mishap. The jetliner was attempting a Non-Directional Beacon (NDB) Instrument Approach Procedure (IAP) to the Cilipi airport near Dubrovnik, Croatia. The IAP had not been approved for use by DoD aircrews. Passengers aboard the mishap aircraft included a Department of Commerce delegation headed by Secretary of Commerce Ron Brown. All 35 passengers and aircrew onboard the aircraft perished in the mishap. The Air Force Accident Investigation Board (AFAIB) found that the mishap was caused by a failure of command, aircrew error, and an improperly designed IAP. The AFAIB determined that the host country supplied IAP was not designed to DoD and internationally agreed upon technical specifications.[64] A finding from the investigation suggested that the IAP did not provide sufficient obstacle clearance in accordance with ICAO guidelines, and featured a minimum descent altitude that was too low.[65] Additionally, the U.S. National Transportation Safety Board (NTSB) claimed that if the IAP had been designed with standard vertical obstacle clearance limits, the aircraft would not have hit the ground.[66]

[64] (U) Department of Defense, *Air Force Details results of CT-43 Accident Investigation,* News Release No. 342-96, (7 June 1996), URL: http://www.defenselink.mil/releases/release.aspx?releaseid =926>, accessed 30 August 2008. Cited hereafter as "DoD, *CT-43 Accident Investigation*, June 1996."

[65] (U) Edward Phillips, "Multiple Errors Lead to Brown Crash," *Aviation Week and Space Technology*, 144, no. 25 (17 June 1996): 71, URL: <http://www.aviationnow.com>, accessed 10 June 2008.

[66] (U) Ramon Lopez, "USAF 'broke orders' on CT-43 disaster flight," *Flight International*, 19 June 1996, URL: <http://www.flightglobal.com/articles/1996/06/19/12659/usaf-broke-orders-on-ct-43-disaster-flight.html>, accessed 6 September 2008.

Maj Gen Charles H. Coolidge, USAF, head of the AFAIB, summarized the sequence of events that resulted in the mishap.

> (U) "Prior to 1994, non–DoD approaches were routinely flown by the Air Force. A change in the directive in 1994 required major commands to review non-DoD approaches such as the procedures for Dubrovnik [Cilipi Airport]. The 86th Airlift Wing[67] routinely went into many airfields in Eastern Europe that do not have DoD approved approaches. The Wing requested a waiver to continue flying non-DoD approaches at European airports without review. While awaiting a formal reply to the waiver request, U.S. Air Force Europe (USAFE) officials told wing leaders they could continue to fly the approaches. In January 1996, however, Headquarters, U.S. Air Force denied the waiver request, and USAFE withdrew their permission to fly the approaches. But the wing chose to continue using non-DoD approaches. Based on a history of using the approaches for years, the wing leaders erroneously believed the approach procedures to be safe. The day after the accident the wing rescinded the aircrew authorization to fly non-DoD approaches."[68]

(U) The aircrew should not have attempted to fly the IAP into the Cilipi airport because the IAP had not been approved for use by DoD aircrews. USAF directives require prior review of non-DoD approved IAPs. However, USAFE had not reviewed the IAP for conformance to U.S. DoD specifications for overall design safety, accuracy of navigation signals, and obstacle clearance. Although informed that the waiver request had been denied, wing commanders chose not to rescind aircrew authorization to fly the non-DoD IAP without prior review. Due to the ever evolving nature of military requirements, tasking of aviation assets, and availability of accredited and non-accredited IAPs, the military needed to enact a program to ensure that aircrews utilized properly reviewed IAPs. In response to this need, the USAF promulgated Air Force Instruction (AFI) 11-230 Instrument Procedures.

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[67] (U) Based at Ramstein Air Base, Germany.

[68](U) Linda D. Kozaryn, "Air Force Releases Brown Crash Investigation Report," *American Forces Information Service News Articles*, 13 June 1996, URL: <http://www.defenselink.mil/news/newsarticle.aspx?id=40796>, accessed 5 September 2008.

(U) AFI 11-230 addresses the USAF Foreign Terminal Instrument Procedures (FTIP) program, per Secretary of Defense (SECDEF) policy. The program grants the military services authority to establish a process that identifies, maintains, and reviews a list of nations and specific airports that meet instrument procedure criteria equivalent to US standards. This relieves USAF Terminal Procedures (TERPS) personnel from the responsibility of completing full manual or automated reviews of every host nation IAP prior to use by DoD aircrews. This special accreditation is applied when the USAF has very high confidence in the host country's flight inspection practices and IAP development and publication procedures. The Host Country Aeronautical Information Publication (AIP) Instrument Approach Chart - ICAO and the Jeppesen[69] IAP chart NDB Rwy 12 Approach (16-1) to Dubrovnik had not received this special accreditation status.

(U) Regardless of the USAF accreditation status of any of host country published IAPs, Jeppesen publishes the following note regarding its aeronautical products, stating that Jeppesen provides:

> (U) "No express of implied warranty, and disclaims any liability with respect to the design, adequacy, accuracy, reliability, safety, or conformance with government standards or regulations, of any flight procedure prescribed by a government authority, including, but not limited to, any express or implied warranty of merchantability of fitness for a particular purpose, accuracy, reliability, safety, or conformance with government standards or regulations, of any information depicted on its charts or maps, or otherwise contained in this manual which Jeppesen obtained from source material created, designed or published by others. Under no circumstances will Jeppesen be liable for incidental, consequential or other damages from alleged negligence, breach of warranty, strict liability, or any other theory, arising out any claim that any flight procedure or other outside source material is defective, inadequate, inaccurate, unreliable, unsafe, or fails to conform with any government standard or regulation."[70]

[69] (U) Jeppesen is one the premier world-wide providers of commercial aeronautical navigation charts and digital flight information.

[70] (U) Jeppesen Airway Manual, *Items Not Covered by Warranty*, AM-07

(U) The NDB Runway 12 approach at Dubrovnik did not provide sufficient obstacle clearance per ICAO guidelines, and featured a minimum descent altitude that was too low for a safe approach and landing.[71] At the time of the mishap, the Minimum Descent Altitude (MDA) for the IAP was 2,150 feet AMSL. As reported by University of Bielefeld Professor Peter Ladkin, PhD, the deficiency findings regarding the design of the IAP were disputed by Croatian aviation authorities.[72] However, subsequent to the mishap, Croatian authorities raised the MDA to 2,300 feet AMSL.[73] Due to the scrutiny brought about by the mishap, the authority responsible for terminal procedure, Hrvatska Kontrola Zračne Ploovidbe d.o.o. (Croatia Control Ltd.), is thought to have raised the MDA due to an increased awareness of the ICAO standards and a desire to bring the IAP into conformance.

(U) The mishap aircraft deviated by 9 degrees from the final approach course, and proceeded 1 mile beyond the missed approach point, which resulted in controlled flight into a mountainside.[74] Although the mishap causal factors were not directly attributed to a man-made vertical obstruction as defined by NGA, a portion of the accident investigation focused attention on NGA terminal IAP FLIP. The number of host nation IAPs published in FLIP was increased as additional USAF Terminal Procedures (TERPS)

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[71] (U) Edward H. Phillips, "Multiple Errors Linked to Brown Crash," *Aviation Week and Space Technology*, 144, no. 25 (17 June 1986): 71.

[72] (U) Peter Lakin, PhD, *The USAF T-43A Accident at Dubrovnik, Croatia on 3 April 1996*, 29 April 1996, University of Bielefeld Report, URL: <http://www.rvs.uni-bielefeld.de/publications/Incidents /DOCS/Com AndRep/Dubrovnik/summary-T43.html>, accessed 14 September 2008.

[73] (U) Dubrovnik/Čilipi, Croatia L RWY 12, *AIP Hrvatska AIRAC AMDT 2/20005*, 14 April 2005, LDDU AD2-33.1.

[74] (U) "DoD, *CT-43 Accident Investigation*, June 1996.

personnel were assigned to perform the required DoD review process prior to the IAP being transferred to NGA for publication. NGA will publish IAPs in FLIP at the request of the military services (Air Force, Army, Navy, and Coast Guard) Office of Primary Responsibility.

(U) As a result of the high-visibility Ron Brown accident, Secretary of Defense William Perry issued a directive to mandate the installation of specified safety equipment on passenger carrying transport category aircraft. The Air Force reprogrammed $264 million to upgrade or accelerate the installation of flight data recorders, cockpit voice recorders, and global positioning navigation systems on DoD passenger transport aircraft, similar to equipment that had been required of FAR Part 121 commercial airline aircraft for years.[75]

(U) The GPS equipment provided enhanced situational awareness to aircrews and improved enroute and terminal approach capabilities. With the advent of GPS systems onboard aircraft, accurate geospatial data for airfields became more critical for safety of navigation. In order for the military aircrews to exploit the capabilities of GNSS in the terminal approach environment, it was essential that accurate "ground truth" geospatial data be provided for airfields with DoD IAPs. In order to maximize the utility of the GNSS data, the user must reference equally accurate geospatial data. A major step in the pursuit of this goal was the ICAO incorporation of the WGS 84 Earth Reference Frame for GPS based navigation systems.

[75] (U) DoD *CT-43 Accident Investigation*, June 1996."

(U) The Ron Brown Airfield Initiative

(U) The requirement for geospatial accuracy was met through a NGA program known as the Airfield Initiative (AI) or Ron Brown Airfield Initiative (RBAI).[76] The RBAI initially identified all military and civilian airports with instrument approach procedures to which the U.S. DoD planned to conduct passenger aircraft operations three or more times per year.[77] As a first step, the program involved the collection of geospatial information to support IAPs for approximately 1000 airfields worldwide. To achieve the increased accuracy requirements for the RBAI, NGA was tasked to develop a database of these airfields containing photogrametrically collected obstruction and airfield features, site survey data (when available), airfield feature data from the Automated Airfield Flight Information File (AAFIF), VOs from the DVOF, and an Airfield Elevation Model (AEM) derived from a reflective surface DEM such as the SRTM data residing in the NGA DTED at a one arc second resolution. This DTED 2 data provides elevation values at approximately 30 meter post spacing. The AEM coverage is provided within a 7 nautical mile radius from the runway ends. With the advent of this improved geospatial data, it would be possible to monitor and review existing IAPs and offer a tool for development of new IAPs to any airfield by exploiting Global Navigation Satellite System/Global Positioning System technology. The RBAI program was undertaken by NGA's SAC team.

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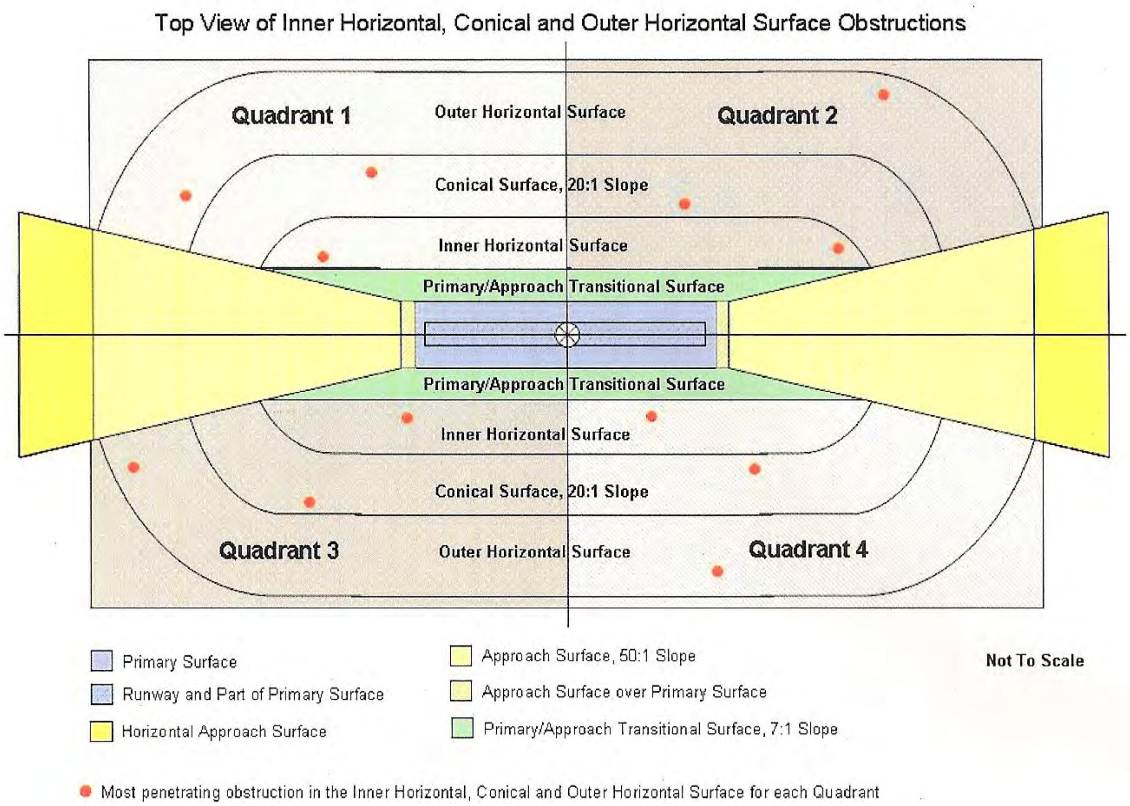
[76] (U) Fred Henstridge, "Emerging Technology: Geodesy in Aviation," *Professional Surveyor*, February 2001, URL: <http://www.profsurv.com/archive.php?issue=50&article=705>, accessed 21 September 2008.

[77] (U) British Aerospace Engineering (BAE) Systems BAE SYSTEMS developed ClearFlite in response to NGA's Ron Brown Airfield Initiative (RBAI), URL: <http://www.socetgxp.com/content /products/product-modules /clearflite/why-did-bae-systems-develop-clearflite-airfield-obstruction-identification-software>, accessed 3 May 2009.

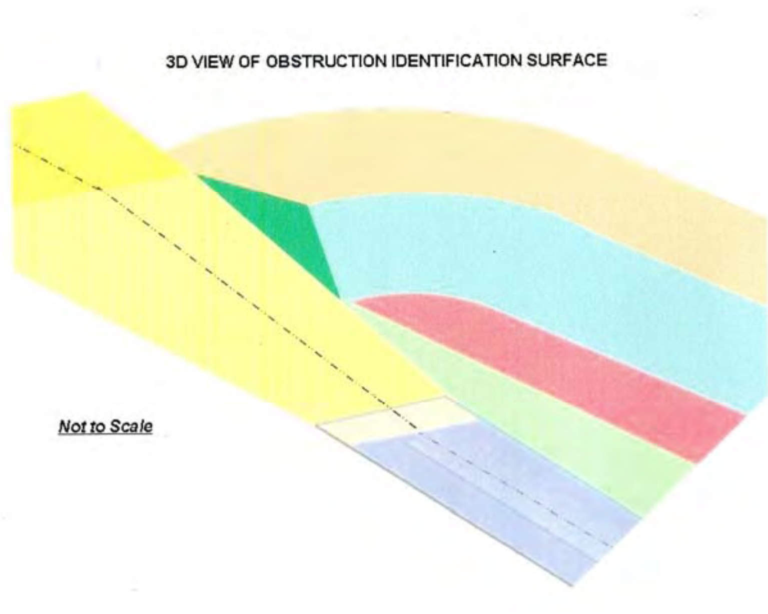
(U) To aid geospatial analysts in the search for VOs, stereo pairs of airfield electro-optical imagery are viewed using the BAE ClearFlite product. Clearflite has the ability to identify VOs by overlaying an Obstruction Identification Surface (OIS) over the airfield environs. The OIS is an imaginary three dimensional surface that is superimposed over the airfield area as seen in Figures 3-1 and 3-2. The OIS is established around an airfield to include the published instrument approach procedures and the surrounding terrain. The OIS may be roughly envisioned as a 3-D shapefile resembling a football stadium or an inverted flattened wedding cake placed over the airfield and elongated along the runway axis. OIS VOs are those features that intrude into a flight path, excluding vegetation. Temporary construction equipment, batch plants, or debris piles that are located on airport property and controlled by the airport authority are not to be included. Frangible structures, such as airport signage, moving target indicator reflectors, windsocks, and some approach lights are not included in the OIS survey.[78]

[78] (b) (3) [redacted]



(U) Figure 3-1. OIS Horizontal Surfaces

(U) Source: (b) (3) [redacted]



(U) Figure 3-2. 3-D View of OIS

(U) Source: (b) (3) [redacted]

(U) Summary

(U) The SAC program epitomizes the concept of layered geospatial intelligence for aeronautical data. The program provides foundational geospatial-aeronautical data that produces high fidelity aeronautical information and precise, comprehensive GEOINT for airfields throughout the world. Runways, aprons, taxiways, navaids, electronic aids, visual aids, and obstructions are collected for feature extraction. Airfield buildings are collected in 2½ dimension[79] shapefile formats for use in GIS applications, for NSG member organizations and partners. The program supports aeronautical products that include DoD FLIP Terminal IAPs, SIDs, STARs, Radar Minimums, Take-off/Alternate

[79] (U) For an area or polygon feature, the maximum vertical height, or Z axis height value is applied throughout the defined horizontal boundaries of the feature. For example, a ground truth peaked roof building would be depicted as a flat roof building, (with the flat roof appearing at the peak height). This measurement approximates the highest realistic extent of the building roof structure above the surrounding terrain.

requirements, and Navigation Planning (NAVPLAN) charts. SAC data is utilized to populate the AAFIF, DAFIF, ECHUM, and the DVOF. Additional products supported include Man Portable Air Defense Systems threat analysis, Force Protection, Unmanned Combat Aerial Vehicles, and USTRANSCOM Critical Infrastructure Program. Although initial collection of the geospatial-intelligence data is accomplished using stereo imagery, subsequent data maintenance will be completed with monoscopic imagery. The SAC program benefits the NSG members and partners, and has a broad application potential to help fulfill the requirements of the FAA to comply with the developing ICAO ETOD program.

(U) Austin Powerline Mishap 2007

(U) On 7 May 2007 at 2125 PDT, a U.S. Navy SH-60F Seahawk helicopter struck the catenaries of two power line static discharge wires suspended above the electrical transmission lines between two 80 foot tall power line pylons.[80] The night low-level Combat Search and Rescue (CSAR) flight was being flown in support of Carrier Air Wing Three (CVW-3) pre-deployment operations at NAS Fallon, Nevada. The Naval Strike and Air Warfare Center (NSAWC), based at the remote Nevada site, was conducting a "SEAWOLF" Seahawk Weapons and Tactics Instructor (SWTI) training course for visiting Air Wing helicopter squadrons. The SWTI courses provided strike planning and execution training opportunities in a dynamic, scenario-driven simulated wartime environment. The remote high-desert restricted flight areas provided the

[80] (U) The smaller diameter top wires act as a lightning rod by attracting lighting strikes and prevent direct hits on the high voltage electrical lines that are strung below the static discharge wires.

opportunity for realistic CSAR tactical maneuver training at minimum altitudes. CSAR missions involve high speed, low-level flight conducted under the cover of darkness to minimize the risk of detection and to increase the probability of mission success. Numerous emerging technology products are available for military use. State-of-the-art equipment such as the AN/AVS-9 aviator night vision image intensifiers, forward looking infrared thermal imaging (FLIR) sensors, or imaging millimeter wave radar systems permit low level flight in reduced visibility conditions. The Helicopter Autonomous Landing System that uses millimeter wave radar provides the aircrew the ability to see outside the cockpit in zero visibility conditions to conduct take-off, landing, and enroute operations while avoiding wires, cables, and terrain.[81] Similarly, the Obscurant Penetrating Autosynchronous LiDAR (OPAL) system uses LIDAR, an IR camera and a terrain database to provide the pilot a synthetic vision system designed to operate in an obscured helicopter landing zone.[82] Ball Aerospace Tactical Airborne Laser Remote Sensing applications include an integrated 3-D flash LIDAR unit, a Medium Wave Infra-Red sensor, and a visible light system. These active and passive devices exploit a broad swath of the electromagnetic spectrum to allow flight operations during low-visible light or no-visible light conditions. The availability and use of these systems should be maximized.

[81] (U) Sierra Nevada Corporation, *SNC Demonstrates Three-Dimensional 94 GHz Imaging Radar for Helicopter Operations in Brownout*, 29 April 2008, URL: <http: www.sncorp.com/news/press/ snc_ 2008 _hals_0408.shtml>, accessed 31 May 2009.

[82] (U) Maureen Campbell, “Case study: LiDAR system provides helicopter pilots a clear line of sight in brownouts,” Military Embedded Systems, June 2008, URL: <http://www.mil-embedded.com/ articles /id/?3368>, accessed 15 October 2010.

(U) The ability of flight crews to detect, acquire, and avoid obstructions within a safe sight distance remains a daunting task. A "safe sight distance" relies on the ability of the pilot to see, react, and avoid obstacles. Factors that affect a safe sight distance include visibility, VO conspicuity, detection ability, aircraft speed, altitude, thrust, maneuvering G-load limits, and pilot and aircraft control system input/output response time.

(U) Preflight Planning

(U) An important task of preflight planning is to identify known VOs along the planned flight path. The Sierra Pacific Power Company powerlines that the helicopter struck were depicted on NGA NAVPLAN aeronautical charts used for mission planning. The mishap crew had a preflight briefing package that was prepared by the training department.[83] Because of its ease of use and ability to layer information onto charts, helicopter pilots at SWITI routinely used Falcon View mission planning software and navigation tool. NGA provides the GEOINT that customers use in GIS applications for mission planning. Customers can access GEOINT through online resources, DVDs, or CDs. Although still required to carry legacy NAVPLAN paper charts for navigation, squadrons increasingly rely on client customized layered geospatial-intelligence navigation charts crafted to meet mission requirements. These charts can be printed locally using a commercially available plotter for large charts or a smaller desk-top printer for knee board-sized strip charts.

[83] (U) Lieutenant Colonel (b)(6) [redacted], USMC, Marine Liaison/Rotary Wing Branch Head, Naval Safety Center, 112, Norfolk, VA, "Navigation Charts/Vertical Obstructions," e-mail interview by author, 14 November 2008.

(U) Combat Flight Planning Software (CFPS) is the mission planning application within the Portable Flight Planning Software (PFPS) in which Falcon View is the mapping/visualization tool. Many aircrews, including helicopter flight crews, use the PFPS applications for mission planning.[84] CSAR missions can be planned and plotted with a high degree of precision, to include the production of a DD-175 Flight Plan and jet logs depicting flight segment heading, course, speed, time, and fuel burn information. CFPS has the ability to interface with a memory storage device known as a brick, which enables geospatial information to be downloaded directly into the SH-60F navigation computer.

(U) The only land based navigational aid available for use on the mishap SH-60F was a tactical air navigation (TACAN) unit. Due to terrain masking, radial and distance measuring equipment (DME) TACAN information was not available at low altitudes in mountainous terrain. Although the helicopter had an internal GPS receiver, the system was not rated for navigation.[85] The aircraft had no passive advanced Inertial Navigation System (INS), but did have a Doppler radar navigation system to complement the GPS. The aircraft did not have the capability to upload aeronautical charts into the helicopter navigation system multi-function display (MFD) in the cockpit. However, through the PFPS, a file containing symbols and flight plan data could be uploaded into the helicopter navigation computer.[86]

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[84] (U) Lieutenant [redacted], USN, Rotary Wing Weapons School, Naval Strike and Air Warfare Center, Fallon, NV, "Mission Planning for Airwing Helicopter Operations at NSAWC," e-mail interview by author, 25 February 2008.

[85] (U) Lieutenant [redacted], USN, Rotary Wing Weapons School, Naval Strike and Air Warfare Center, Fallon, NV, "SH-60F Navigation Systems," e-mail interview by author, 27 May 2008.

[86] (U) [redacted], e-mail interview, 27 May 2008.

(U) Taking into account the resources available to the flight crew, the challenge of maintaining navigational situational awareness during the night low-level training mission was considerable. The harmonization of aircrew coordination, training, planning, and advanced mission tools are prerequisites for the demanding CSAR environment. To support flight crew navigation planning GEOINT requirements, NGA has the capability to produce precise, high quality, three dimensional imagery fly-through scenes for low-level flight. For example, to support NATO's combat operations in Yugoslavia, NGA used satellite imagery and maps to create geospatial products to guide U.S. Army AH-64 Apache helicopters along low level routes through the mountains from Albania to Kosovo. NGA was able to produce the 3-D imagery quickly because it had been working on a project to chart low-level obstructions around the globe.[87]

(U) The basic foundational and layered datasets required to construct customized three dimensional fly-through scenes are available; however, the quality of the product can be improved with higher quality DTED, DVOF, and cartographic GEOINT. Falcon View offers a virtual fly-through simulation consisting of an aeronautical chart draped over DTED layered with VO shapefiles. Google Earth offers a similar capability.

(U) The incorporation of advanced navigation tools that are currently available would increase mission effectiveness and enhance flight safety. Hardware and software upgrades to allow advanced navigation displays in a Night Vision Goggle (NVG) compatible glass cockpit would enhance mission effectiveness. Integration of a fully rated GPS suite, INS, Terrain Contour Matching (TERCOM), TERCOM Aided Inertial Navigation System (TAINS), DAFIF, DTED, and DVOF data into the flight mission

[87] (U) Vernon Loeb, "Accidents expose map agency's vulnerability," *Washington Post*, 18 July 1999, A10.

computers would be beneficial to support low-level flight in the demanding CSAR environment. Use of active navigation systems requiring transmission of energy throughout the electromagnetic spectrum is limited by emission control measures to enhance survivability.

(U) Chart Maintenance

(U) A lack of situational awareness was a contributing factor in the aircrew failure to avoid the powerline. Vertical obstructions are depicted on ONC, TPC, and JOG navigation planning charts. The original edition NAVPLAN charts are printed on an infrequent basis, and the current edition of the chart may be several years old. For example, the latest JOG-A chart relevant to the mishap site was Series 1501 AIR, Sheet NJ 11-2, Edition 3. The depicted map information was current as of 1993, per the chart legend. The Air Information was current through 6 March 1998. Included in the marginalia template was a caution note stating, "Vertical Obstructions, including powerlines, have been extracted from the most reliable sources available. However, there is no assurance that all are shown, or that their locations or heights are exact." This note is also present in the Chart Updating Manual (CHUM). Additionally, another caution on the JOG-A chart states, "Consult NOTAMS and Flight Information Publications for the latest information; the DoD Aeronautical Chart Updating Manual or MOD (U.K.) Aeronautical Chart Amendment document, for other chart revision information."

(U) In order to keep the VO data on the charts current, NGA produces the ECHUM. The ECHUM files can be downloaded from the NGA portal on JWICS, SIPRnet, or NIPRnet and are displayed using GIS such as Falcon View or ArcGIS products. The ECHUM enables the user to update the chart with the most recent data as listed in Appendix C. The ECHUM update files are applied to NAVPLAN charts, special aeronautical charts, such as military range and training area charts, and FAA Visual Flight Rules (VFR) terminal area and sectional charts. It is important to note that Topographic Line Maps (TLM) 1:50,000 and 1:100,000 scales are not updated in the CHUM. The high level of detail provided by these low scale TLMs are useful for helicopter flight, which is routinely conducted at lower altitudes than fixed-wing flight. Without CHUM updates, the TLMs display outdated information and increase the probability of low level controlled flight into wires, towers, and pylons. Customers using TLMs for low-level flight must understand that the charts are not subject to CHUM updates.

(U) The CHUM is produced every six months in a three volume book form that is presently only available on-line as an Adobe Acrobat portable document format (.pdf) file. The last paper CHUM was printed in March 2004. This manual is used to update paper charts with pen and ink changes. An interim monthly CHUM Supplement is also available on-line to enable users to maintain the accuracy of the paper charts until the next CHUM edition is released. Additionally, Digital (D) CHUM Compressed ARC Digitized Raster Graphic (CADRG) Supplement Disc (CSD) compact discs are issued on a monthly basis to present permanent VO annotations on CADRG charts. These contractor modified CADRG charts have the updated ECHUM data applied to permanently change the pixels on the raster graphics. The DCHUM NAVPLAN charts are also available via NGA websites for use in mission planning software and can be printed to provide a hard copy product more up-to-date than an original issue edition paper chart.

(U) Regarding the CHUM General Information Chart Discrepancies table shown in Appendix C,[88] as of the October 2006 CHUM Supplement, Airfield data is no longer presented in the CHUM. Airfield data comprises over 600 airfield specific data descriptors. The most up-to-date airfield information is available in the latest version of the DAFIF, which is disseminated every 28 days. NGA's distribution of the all encompassing DAFIF is intended to eliminate duplication among a variety of sources.

(U) Reporting Vertical Obstructions

(U) NGA has a leading role in the management of the world-wide vertical obstruction database. When customers discover a VO that does not appear in the DVOF, they notify NGA of the undocumented VO. Users are instructed to include as much information as possible in the e-mail, and NGA then refines the DVOF attributes using other sources and sensors.

> (U) "If an aircrew observes an obstruction that is not shown on the chart, he should estimate the latitude, longitude and height of the obstruction (AGL) by the best means available. In foreign areas, information on obstructions should be submitted directly to NGA, ATTN: PVHC, Mail Stop J-27, 3838 Vogel Road, Arnold, MO 63010-6238 using the [Quality Feedback Card] or other convenient media. In domestic areas, information on obstructions should be submitted through appropriate channels to the Military Regional Representative (MRR) for the FAA Region where the obstruction was observed. The MRR will forward this data to the appropriate Regional Airspace Branch for verification, documentation and dissemination through the National Flight Data Digest which is distributed to all government charting agencies."[89]

[88] (U) CHUM, National Geospatial-Intelligence Agency, General Information, Chart Discrepancies, January 2009, 5.

[89] (U) CHUM, National Geospatial-Intelligence Agency, January 2009, 2.

(U) A postage pre-paid NGA Quality Feedback Card that is located in the DOD FLIP Enroute Supplement may be used to submit candidate VO information. See Appendix D for the NGA Quality Feedback Form.[90] In order to maintain the most comprehensive DVOF possible, NGA will accept candidate VOs via telephone, e-mail, or postage card. Additionally, the sample DVOF Input Form proposed to the VOWG, as shown in Appendix E, enables one to submit VOs to NGA for inclusion in the DVOF.

(U) Other Agencies VO Report Forms

(U) The Royal Australian Air Force (RAAF) has a similar program that parallels the NGA VO report program. As stated in the RAAF Aeronautical Information Package Catalogue, instructions for reporting uncharted VOs are addressed with the following remark: "If an aircrew member observes a vertical obstruction that is not shown on the chart, he/she should estimate the latitude, longitude, and height (AGL) of the obstruction by the best means available and inform RAAF Aeronautical Information Service (AIS) immediately. An Obstruction Report Form is available from either the Defence Intranet (defweb.cbr.defence.gov.au /raafais/) or Internet (www.raafais.gov.au)."[91] The RAAF Vertical Obstruction Report Form is contained in Appendix F.[92]

(U) For the civil aviation sector, the Australian Government Civil Aviation (AGCA) Safety Authority has issued Advisory Circular AC 139-08(0) April 2005 Reporting of Tall Structures. The Advisory Circular provides guidance to those

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[90] (U) Quality Feedback Card (NGA Form 8560-1), Aug 2004.

[91] (U) RAAF Aeronautical Information Package Catalogue, 4 September 2003, URL: <http://www.raafais. gov.au/Pdf/cat_040903/cat_0409031.pdf>, accessed 31 December 2008.

[92] (U) RAAF Vertical Obstruction Report Form, URL: <http://www.raafais.gov.au/frame .htm?obstr _form2. htm>, accessed 31 December 2008.

authorities and persons involved in the planning, approval, erection, extension or dismantling of tall structures to that they may understand the vital nature of the information they provide. This document and the associated Tall Structures report form may be found in Appendix G.[93]

(U) For VOs within the FAA areas of responsibility, NACO currently did not have a specific form for reporting existing VOs. Although the FAA Form 7460-1 is utilized to report notice of proposed construction or alteration of any construction of more than 200 feet in height above the ground based at its site, pre-existing VOs not identified on a chart are not submitted via a standardized form. The FAA Sectional Aeronautical Chart contains a template box that states, “Reporting chart errors- You are requested to inform us of chart errors and/or additions that come to your attention while using this chart. Telephone toll free at 1-800-626-3677, or email us at 9-AMC-Aerochart@faa.gov. Where delineation of data is required such information should be depicted clearly and accurately on a current chart, a replacement chart will be returned.”[94] In order to provide additional examples of notification for customers to report VOs for inclusion in the DOF, NACO representatives were e-mailed copies of the Australian military and civilian VO reporting forms for analysis and further consideration for inclusion into future NACO obstacle reporting program requirements. The Australian civil and military forms offer examples for developing an indigenous FAA/NACO form.

[93] (U) AGCA Safety Authority, *AC 139-08(0) April 2005 Reporting of Tall Structures*, URL: <http: //www.casa.gov.au/rules/1998casr/139/139c08.pdf>, accessed 31 December 2008.

[94] FAA, *San Antonio Sectional Aeronautical Chart*, NSN 7641014100168, 8 May 2008.

(U) Documentation of legacy VOs

(U) Accurate depiction of VOs on aeronautical charts is essential to minimize the risk of controlled flight into terrain/obstructions. In the SH-60F mishap, the aircrew's foreknowledge of the VO hazard did not prevent the helicopter from striking the span wires between the pylons. The JOG–A chart depicted the powerlines struck by the mishap aircraft, while the DVOF did not contain the powerlines or pylons. Powerlines that appeared on the hard copy aeronautical chart had not been transferred to DVOF. Due to the lack of documentation, some VOs are not registered in DVOF. This lack of documentation in the NACO DOF may be attributable to protection of commercial proprietary data, absence of reporting requirements, lack of oversight responsibility, or legacy VOs that have been depicted on charts for many years, but have not been included in the DOF. Likewise, domestic VOs may be documented in the DVOF, but do not meet the reporting requirements for NACO DOF. NGA's increased scrutiny of low-level high speed Visual Flight Rules Military Training Route (VR) and Instrument Flight Rules Military Training Route (IR) corridors and Military Operating Areas (MOA) should document VOs at the 60 foot level.

(U) Following the incident, upon the author's recommendation, the Sierra Pacific powerlines involved in the mishap have been entered into DVOF as appropriate point and line features. With the ever increasing reliance on softcopy products and the diminishing emphasis on legacy hard copy paper products, it is imperative that DVOF contain all VOs. As the responsible producer for the DVOF, NGA must exploit all VO sources and collaborate with mission partners to ensure a complete DVOF product.

(U) Exchange of VO data

(U) The obstacle data processed by FAA and Federal Communication Commission (FCC) populates the NACO DOF. The DOF contains all reported obstacles of interest to aviation users in the U.S., with limited coverage of the Pacific, the Caribbean, Canada, and Mexico. The obstacles are assigned unique numerical identifiers and accuracy codes. The NACO assigned accuracies for the DOF are ingested and integrated into the DVOF. As a trusted source of VO information, NGA accepts the accuracy of the NACO DOF. The FAA/NACO Downloadable Digital Obstacle File (DDOF) is updated every 56 days and is available online. NGA ingests the DOF weekly, and it is made available to customers in the monthly update of Web DVOF.

(U) Web DVOF contains world-wide vertical obstructions and is accessible on the NGA website using NIPRnet, SIPRnet, or JWICS. DVOF data can be recovered in preformatted customer defined areas and filtered based on VO attributes. The defined results can be downloaded in various formats that are tailored for specific use, such as building instrument approach procedures or layering shapefiles and attributes using GIS products.

(U) Similarly, when new VOs are documented in U.S. territory by NGA for inclusion into the DVOF, the FAA should seek inclusion of these VOs that fall within the specifications as defined in FAR Part 77 §77.13 into the DOF. VOs must be entered in the DOF in compliance with stringent accuracy requirements, in order to conform to airport and runway imaginary slope clearance standards and terminal instrument approach procedures requirements. NGA maintains a world-wide database from a variety of sources having varying degrees of accuracy. The FAA has identified data format compatibility issues with DVOF data that limit the ability of NACO to ingest DVOF data into the DOF. Also, accuracy requirements have been identified by FAA personnel as a limiting issue for considering the feasibility of including DVOF data into the DOF.

(U) However, related VO issues have been identified by the Kansas Department of Transportation Aviation Division (KDOTAD) regarding the accuracy of the DOF, which would seem to cloud the accuracy issue. KDOTAD has proposed the use of LIDAR for the development of high quality DEMs. The DEMs would be used for safety inspections and site surveys to aid in the identification of VOs that penetrate the approach surfaces to existing and proposed runways. In conjunction with the site survey, KDOTAD conducts a review of the DOF to correlate observed VOs with reported VOs. Two problems are identified in the KDOTAD report. The first issue is that DOF currently does not contain all natural VOs that can constitute a threat to low flying aircraft in the terminal environment. The second issue is that the DOF contains phantom obstructions that were placed in the file using estimated coordinates.[95] The accuracy of these estimated coordinates is not absolute, and the accuracy depends on the data source. The magnitude of the error does not preclude the use of these data, provided it is identified and accounted for.[96] Estimated phantom coordinates of the DOF and purported lax coordinate accuracy values of the DVOF both affect the integrity of the DOF. LIDAR would verify existing VOs and assist in the removal of phantom obstructions in the DOF. Per the State of Kansas GIS Business Plan, LIDAR provides a great deal of

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[95] (U) State of Kansas Geographic Information Systems Business Plan, *Improved Elevation Data for Statewide Applications*, May 2009, 8, URL: <http://www.da.ks.gov/gis/documents/KS_Improved Elevation Data_BusinessPlan .pdf>, accessed 28 March 2009.

[96] (U) U.S. Department of Transportation, FAA, National Policy, Flight Procedures and Airspace, 8260.19D, 11 July 2008, 2-28.

accuracy to the Terminal Procedure (TERPS) evaluation process, and provides a very powerful tool for aviation safety.[97] The accuracy requirements of the DOF and the incorporation of DVOF data present a challenge to the conflation of the two databases. An exchange of data is vital to maintaining accurate, viable VO databases. These concerns are being addressed by the appropriate VO authorities at NGA and the FAA.

(U) Kern River Powerline Civilian Mishap 1995

(U) On 29 August 1995, a Bell 206 L-1 Jet Ranger helicopter struck Southern California Edison (SCE) powerlines while conducting aerial filming along the Kern River near the National Forest Service Limestone Campground south of the Sherman Pass Road intersection on California Mountain Highway 99.[98] The three No. 2 copper stranded electrical transmission lines were not depicted on applicable charts,[99] nor documented in ECHUM or DVOF. SCE officials estimated the span of the powerlines over the river at 1500 to 2000 feet in length.[100] Although NGA's standard was to plot obstacles that reach 200 feet or higher, military officials have requested that NGA provide information on hazards as low as 50 feet.[101] The span wires were not equipped with high visibility

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[97] (U) *Improved Elevation Data for Statewide Applications*, 8.

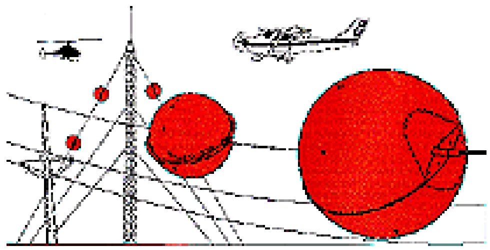
[98] (U) National Transportation Safety Board (NTSB), Mishap Report LAX95FA313, URL: <http:// www.ntsb. gov/ntsb/brief.asp?ev_id=20001207X04274&key=1>, 27 February 1996, accessed 16 December 2008.

[99] (U) NGA NAVPLAN Series 1501 AIR, Sheet NI 11-1 Edition 4, JOG-A chart, United States Geological Survey (USGS) ISBN: 978-0-607-10756-2, Fairview 1:24,000 scale topographic quadrangle chart., Topographic Line Map (TLM) 23554, Edition 1, 1 January 1984.

[100] (U) NTSB Mishap Report LAX95FA313, 27 February 1996.

[101] (U) Lisa Getter, "Federal agency's faulty maps have played part in recent accidents: Lack of current data, cuts in personnel blamed for mapping problems," *Milwaukee Journal Sentinel*, 23 May 1999,

spherical ball markers to increase conspicuity as seen in Figure 3-3. After the 1995 mishap, SCE decided not to mark or reroute the wires.[102]



(U) Figure 3-3. Tana Wire Marker

(U) Source: http://www.tanawiremarker.com/faa.htm

(U) Marking Vertical Obstructions

(U) FAA Advisory Circular (AC 70/7460-1K), "Obstruction Marking and Lighting," provides extensive recommendations for increasing the conspicuity of obstacles. In the Advisory Circular, the degree of compliance to the recommendations are expressed in terms of "should" or "may" for recommended measures, and "shall" or "must" for measures requiring strict compliance.

(U) Per the FAA, requests for modification or deviation from the standards outlined in the Advisory Circular must be submitted to the Obstruction Evaluation Service. The registering sponsor is responsible for adhering to approved marking and/or lighting limitations, and/or recommendations given, and should notify the FAA prior to

URL: <http://proquest.umi.com/pdqweb?did=41860543&sid=3&Fmt=3&client1d=7647&RQT&VName =PDQ>, accessed 26 February 2008.

[102] (U) John Pitchford, "Know Your Local Flying Area," *Approach*, 44,no. 3(March 1999), URL: <http: //www.proquest.com>, accessed 10 February 2008. Cited hereafter as "Local Flying Area."

removal of marking and/or lighting.[103] Per AC 70/7460-1K regarding a specific obstacle, "The [obstacle] may be so…removed from the general flow of air traffic…that marking or lighting would serve no useful purpose."[104] Such a determination would allow the canyon spanning powerlines to remain unmarked. However, in light of the mishap occurrence, marking the powerlines that span the Kern River at a height of 209 feet [105] would be an alternative option to increase safety.

(U) Markers are used to highlight structures when it is impractical to make them conspicuous by painting. Spherical markers are used to identify overhead wires. The diameter of the markers used on extensive catenaries across canyons, lakes, and rivers should be not less than 36 inches (91cm). Smaller 20-inch (51cm) spheres are permitted on less extensive power lines.[106] Lighted markers are available for increased night conspicuity of high-voltage (69KV or greater) transmission line catenaries. These markers should be used on transmission line catenaries near airports, heliports, across rivers, canyons, and lakes.[107] The Southern California Edison powerlines involved in the mishap were estimated to be less than 69KV; therefore there was no requirement to illuminate the VO. Experience has shown that even a transmission powerline of less than 69KV constitutes a genuine hazard to aircraft, as evidenced by the helicopter mishap.

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[103] (U) Federal Aviation Administration (FAA), *Advisory Circular (AC 70/7460-1K)Chg2*,1 February 2007, 1. Cited hereafter as "FAA, *Advisory Circular (AC 70/7460-1K.*"

[104] (U) "FAA, *Advisory Circular (AC 70/7460-1K*, 1."

[105] (U) "Local Flying Area."

[106] (U) "FAA, *Advisory Circular (AC 70/7460-1K*," 7.

[107] (U) "FAA, *Advisory Circular (AC 70/7460-1K*", 10.

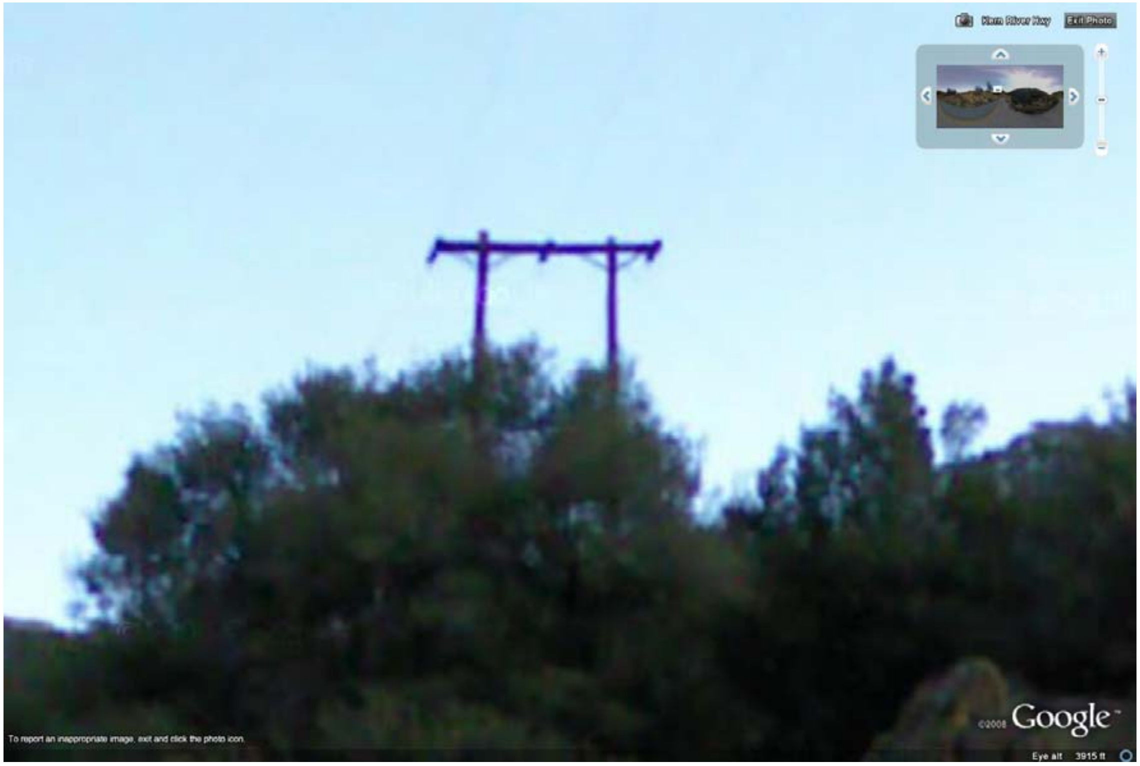
(U) Google Earth Street View

(U) A review of the mishap site in January 2009 using Google Earth "Street View" imagery along California Mountain Highway 99 confirms the existence of the powerline pylons and wires in the vicinity of the mishap site. Located approximately 16 miles north of Kernville, California, the transmission powerlines are visible on the east bank of the Kern River along California Mountain Highway 99 from Fairview Dam to the Forest Service Limestone Campground. Figure 3-4 reveals a pair of two pole pylons, approximately 30 feet tall, south of California Forest Route 22S05, also known as the Sherman Pass Road. The powerline path continues northwest to a saddle on the south side of Kern River Canyon. The wires appear to span the Kern River Canyon approximately 450 feet north of the Johnsondale Bridge. Figure 3-5 depicts the first pylon north of the Kern River, which supports the canyon-traversing span of the powerline. The span nadir height is estimated to be several hundred feet above the Kern River.

(U) This study has the potential to be more than just an academic exercise. To this end, the NACO point of contact responsible for documenting obstacles located in California was informed via telephone conversations and e-mail of the need to document the power lines in the DOF. NACO has contacted Southern California Edison in an effort to access data on the alleged wires traversing the Kern River. If the wires are confirmed by the proper authorities and accurate coordinates and height data can be collected, one would expect the VO to be entered into NACO DOF. Once entered in the NACO DOF, the data will be ingested for inclusion into the DVOF.

(U) Figure 3-4. Powerline Pylons South of Johnsondale Bridge On Kern River (East Bank side)

(U) Source: Google Earth Street View (North)
Icon position 35° 58′ 06.16″N 118° 28′ 54.46″W



(U) Figure 3-5. Powerline Pylon North of Johnsondale Bridge On Kern River (West Bank side)

(U) Source: Google Earth Street View (North)
Icon position 35° 58′ 16.42″N 118° 29′ 16.54″W

(U) Kern River Powerline Military Mishap 1998

Naval Air Weapons Station (NAWS) China Lake helicopter crews routinely conduct SAR training missions in the Sierra Nevada mountain range of California. On 18 February 1998, during daylight hours in visual meteorological conditions, a U.S. Navy UH-1N helicopter from NAWS China Lake impacted power lines spanning the Kern River gorge near the National Forest Service Limestone campground south of the Sherman Pass Road intersection on California Mountain Highway 99 in the Sequoia

National Forest while conducting a SAR training flight. The mishap that produced five fatalities occurred in the same area as the 29 August 1995 Jet Ranger helicopter crash. Several features of this incident reveal the importance of the requirement for NGA to provide the customer with accurate heights and locations of VOs.

(U) The mishap occurred despite the fact that the Navy helicopter pilot had recently flown SAR training missions and was familiar with the operating area. The pilot was aware of the powerlines that traversed the Kern River gorge and the previous civilian helicopter wirestrike mishap that resulted in two fatalities.[108] Despite this knowledge, the Navy helicopter struck the same powerlines at the same location as the civilian Bell Jet Ranger helicopter did less than 3 years earlier. A military investigator determined that the electrical wires should have appeared on the maps, noting that a crash involving the same power lines had killed two people three years earlier.[109] The electrical wires have not yet appeared on NAVPLAN or FAA sectional charts, nor have the wires been equipped with high visibility spherical ball markers as of March 2009.

(U) Vertical Obstruction Documentation

(U) Regarding aerial cables and powerlines, DVOF should contain the highest segment AMSL height between pylons. In the case of powerlines spanning a canyon, the cable height may be calculated by a straight line drawn between the pylons either side of the canyon, and dropping a vertical measurement to the lowest point of the underlying surface, whether it be ground or water. This measurement method gives the greatest VO

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[108] (U) "Local Flying Area."

[109] (U) Molly Trudeau, "Communication Breakdown," *Geo Info Systems*, June 1999, 10.

height value, and affords the greatest clearance if one intends to avoid the cable by flying over it. Another measurement method may include measuring the distance from the cable catenary nadir height to the lowest surface beneath the line segment feature. Cable stretch affecting span height will vary according to line load factors and temperature. VO line feature data varies according to accuracy and resolution of horizontal and vertical datum, and the method employed for segment measurement.

(U) Potential solutions to the VO challenge are being sought. For example, in the post mishap lessons learned recommendation from the Naval Safety Center (NAVSAFCEN), the Aircraft Operations Division helicopter analyst recommended that the best way to foster VO awareness was to build a master hazard chart in the flight briefing ready room with every man-made VO highlighted. In addition, every pilot and observer on the aircraft should carry copies of the chart. When uncharted hazards are discovered, aviators should mark them on the master hazard map.[110] These recommendations are incomplete.

(U) It is not sufficient to simply notify flight crews within one's local community regarding VO hazards. Crewmembers need to report uncharted VOs to the Military Regional Representative for the FAA region where the obstruction was observed by utilizing the NGA Quality Feedback Form or by sending an e-mail to NGA at chum@nga.mil to ensure VOs are included in the DVOF.

(U) To improve safety awareness, Aviation Safety Officers can research civil and military mishaps that have occurred in their local flying area.[111] It is the policy of NGA

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[110] (U) "Local Flying Area."

[111] (U) "Local Flying Area."

to investigate the role of FLIP products in mishaps involving DoD aircraft when news reports indicate that the cause may be due to a navigation issue not caused by equipment failure, weather, or pilot error. Additionally, a review of FLIP is to be initiated when an official accident report is received implying that an NGA product or information may be involved or that the accident is of a suspicious nature involving high-level officials or dignitaries.[112] Any airborne incident involving a civilian or military manned or unmanned vehicle's controlled flight into an obstruction should trigger an investigation by NGA to determine the role of DVOF. If such a procedure were in place after the first mishap on 29 August 1995, the subsequent investigation may have resulted in the powerline pylons and wires being entered into the DVOF. Efforts applied to VO detection, compilation, and dissemination contributes to mishap prevention and helps accomplish NGA's Safety of Navigation mission.

(U) FAA Resources

(U) The FAA and NTSB have dedicated resources to address aviation mishaps that involve controlled flight into terrain or vertical obstacles. The initiatives and programs offered by FAA and NTSB represent a series of efforts across a spectrum of issues to promote aviation safety.

[112] (U) National Geospatial-Intelligence Agency, Aeronautical Services, *Geographical Analyst Guide Version 1.2*, 6 January 2009, 6-25.

(U) CFIO Mishap Investigation Resources

(U) Several resources that are available include the Aviation Safety Information Analysis and Sharing System (ASIAS). Established by the FAA, the ASAIS site allows users to execute multiple searches across eight FAA and NTSB aviation safety related databases, and display results in various formats. Additionally, through an agreement with Airclaims Ltd., the public can also access mishap information contained in the World Aircraft Accident Summary database.[113]

(U) As this unfortunate series of aircraft mishaps demonstrates, there are serious disconnects with the current system of VO tracking. If the mishap report from the first mishap had been reviewed and corrective action taken, it may have been sufficient to prevent the second. Southern California Edison could have relocated the power lines or installed marker balls. Either one of these actions may have been enough to prevent a second mishap.

(U) NGA, as the designated authority responsible for maintaining the world-wide DVOF database, should receive all aviation mishap reports for accidents with causal factors related to VOs. It seems a reasonable approach that, as mishaps occur, changes would be made to VO data presentation, procedures, and even the obstructions themselves in order to prevent further damage and loss of life.

[113] (U) FAA, *Aviation Safety Information Analysis and Sharing System*, URL: <http://www.asias .faa. gov/portal/ page?_pageid=56,398034,56_398041&_dad=portal &_schema =PORTAL>, accessed 14 February 2009.

(U) FAA *Safer Skies* Initiative

(U) In 1998, the FAA established the General Aviation CFIT Joint Safety Analysis Team (JSAT) and Joint Safety Implementation Team (JSIT) as part of the *Safer Skies* program to reduce fatal accidents. General Aviation contains the largest segment of aviation activity, with the other areas being military aviation and commercial air carrier service. Per FAA definition, a CFIT accident occurs when an airworthy aircraft, under the control of a pilot, is flown into terrain (water or obstacles) with inadequate awareness on the part of the pilot of the impending disaster.[114] Through a comprehensive review of mishap causal factors, the teams sought to develop and implement intervention strategies to foster safe aviation operations. The JSAT CFIT study specifically analyzed wire and tower strikes. The wire and tower strike incidents that occurred from 1996-2007 could serve as sources of VO data for inclusion into DVOF. Unfortunately, the Jet Ranger helicopter mishap of August 1995 was not part of the CFIT study. JSAT recommendations focused on human factors, such as improved pilot training, briefing, safety awareness, and decision making. Additional efforts addressed equipment and hardware fixes, such as terrain clearance and obstacle detection devices, obstacle painting and lighting, and visibility enhancement strategies. These efforts emphasize the "see and avoid" doctrine that provide the basis for VFR operations.

(U) A primary concern for the elimination of CFIT or CFIO should be the documentation of VOs. Reliance on visual cues alone for VO awareness does not take advantage of the multiple resources available to assist in obstacle avoidance. Obstacle

[114] (U) FAA, *Safer Skies: A Focused Safety Agenda*, 29 February 2000, 4, URL: <http://www.faa.gov/safety/programs_initiatives/pilot_safety/safer_skies/gajsc/gajsc_documents/media/cfit.pdf>, accessed 14 February 2009. Cited hereafter as "*Safer Skies.*"

avoidance begins with geospatial awareness. Accurate navigation and situational awareness supported by an accurate VO database (GEOINT) are foundational requirements for safe low-level flight operations. One of the JSIT Implementation Plans recommended a publicly available federal government produced Digital Terrain Elevation and Obstacles Database.[115] This recommendation is currently fulfilled by the NACO Downloadable Digital Obstacle File (DDOF) and NGA DTED databases.

(U) Another recommendation is to develop a comprehensive obstacle database of wires, towers, support structures and other similar obstacles that stand 100 feet or higher, that are updated on a regular schedule and available for both preflight planning and for graphical display in the cockpit.[116] This goal represents a very substantial challenge for NACO and NGA, and is not achievable under the current framework of DOF and DVOF programs. Although the DOF and DVOF are updated on a monthly basis, VOs are not verified on a scheduled basis. The Earth may be envisioned as a living entity, with VOs figuratively sprouting, morphing, and dying on a continuous basis. The ability to monitor or verify the status of all six million plus VOs, and appropriately add, delete, or modify the database on a scheduled basis is a monumental task. However, specific customer requests for verified VO data within a defined area can be furnished.

(U) Based on the assumption of a complete, current, and accurate VO database, the JSAT CFIT study recommended the development of technologies that will enhance

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[115] (U) "*Safer Skies,*" *7.*

[116] (U) "*Safer Skies,*" *9.*

passive and active visual and electronic sensor VO detection systems supported by a cockpit display of wires, towers, support structures, and other similar obstacles.[117]

(U) Mishap Review

(U) Each reviewed mishap offers examples of various challenges facing NGA and the DVOF. The lessons learned from mishap investigations provide an opportunity for analysis of causal factors and offer the potential to develop corrective action. A posteriori analysis of the mishaps is not the best method of providing Safety of Navigation guidance. One cannot discount the value of learning from these mishaps and applying corrective action.

(U) Cervino

(U) In the Cervino mishap, the NAVPLAN charts onboard the aircraft did not depict the cable car VO. However, this does not mean that the crew was not aware of the VO or the intent of the pilot. The cockpit hand held video tape of the “rite of passage” low level flight was erased.[118] The mishap pilot was completing his final flight prior to his transfer back to the United States of America. The deviation from the flight plan was not in accordance with all applicable rules and regulations. Disregard for the safe conduct of the flight was not affected by the depiction of a VO on a chart. Even if all VOs are properly documented, it still does not overcome a pilot’s lack of judgment or disregard of regulations. The mishap did reinforce the NGA policy of continuously

[117] (U) “*Safer Skies",” 9.*

[118] (U) “Chamber of Deputies Inquiry, 2001,” 234.

seeking to harvest all VO sources and products for inclusion into the DVOF. NGA is pursuing additional new technologies to expand VO collection, processing, and distribution of VO data and its incorporation into aeronautical products.

(U) Dubrovnik

(U) As a consequence of the Dbrovnik mishap, the RBAI was established. The integration of GNSS advanced capabilities, GPS technology, WGS Earth Reference System data, EGM data, DTED, Stereoscopic Imagery, and GIS software are crucial elements used by the NGA SAC team to meet DoD requirements. This program produces accurate geospatial data, to include shapefiles, and metadata attributes for airfield features. The RBAI identifies VOs that penetrate the OIS. VO documentation was enhanced within the terminal flight area of selected airfields. VO detection procedures and skills developed under the RBAI were also applied to collect VOs in other than the terminal flight environment that resulted in enhanced worldwide VO collection.

(U) Austin

(U) The Austin Powerline mishap illustrates the challenges facing the users and provider of geospatial data. The customer had access to the NAVPLAN charts that depicted the VOs involved in the wirestrike. Mission planning included review of legacy paper charts and included CADRG charts used in Falconview PFPS. The aircraft did not have a moving map display with layered GEOINT depicted along the route of flight. Although capable of producing three dimensional fly-through routes for low-level helicopter flight, the foundational datasets such as DTED and DVOF are not always available at the desired accuracy and resolution. Prior to this mishap, DVOF did not contain the mishap powerlines. Even if the powerlines had been incorporated into DVOF, the mishap aircraft's navigation computer rudimentary capabilities were a limiting factor to support the aircrew's situational awareness. NGA continues to expand its collection efforts and diversify sources of VO data. Likewise, VO customers continue to acquire innovative products to utilize advanced GEOINT.

(U) Kern River

(U) The Kern River mishaps illustrate the result of lack of situational awareness in two aircraft mishaps at the same location. In both instances, the pilots were aware of the VO hazard, but due to a lack of due diligence, flew into wires spanning the Kern River. The power pylons in the area are less than 80 feet tall, and are not depicted on NAVPLAN charts. However, the unmarked wires spanning the Kern River are estimated to be in excess of 200 feet above the river surface. This condition would warrant inclusion of the power line wires in DVOF.

(U) More stringent FAA requirements to mark VOs to increase conspicuity may help prevent wirestrikes. After the first fatal civilian helicopter mishap, a determination was made that the wires spanning the Kern River were so removed from the general flow of air traffic that marking or lighting the obstruction would serve no useful purpose. This determination was shown to be faulty by the occurrence of the second fatal military helicopter mishap. The wires remained unmarked after the second wirestrike. Evidently seven fatalities and two aircraft losses did not adequately serve as a useful argument for marking the wires to help prevent an aircraft mishap.

CHAPTER 4

(U) The DoD military service components have specified VO data requirements that are based on mission capabilities. NGA meets current service requirements, and will need additional capability to fulfill future objective requirements. In order to optimize NGA's ability to fulfill DoD customer requirements, it would be advantageous to accommodate the standards of other sources of VO data; such as ICAO's ETOD, and allied nations VO datasets.

(U) Military Service VO Data Requirements

(U) NGA's core customers define the VO program requirements. Each military service has tailored VO data needs to fulfill the required operational capability and projected operating environment requirements.

(U) U.S. Army

(U) The U. S. Army has identified the need to refine VO data requirements for specific mission datasets to benefit the war fighter and assure mission success. Vertical obstruction data comprises one of the essential elements of geospatial data required to fulfill Army requirements to support Intelligence Preparation of the Battlefield (IPB). These VO requirements as defined by the Army consist of VOs greater than 50 meters AGL in tactical operations areas, and 25 meters AGL in some areas, depending on the unit's mission and tactical situation as defined by the combatant commander.[119] Additionally, the Army Digital Topographic Data Requirements identified the need to access VOs over 46 meters AGL in the Vector Product Format (.vpf) file format.[120] DVOF supports the .vpf format requirement, known as Vector Vertical Obstruction Data (VVOD), and can also provide data in various other formats.

(U) DVOF comprises permanent man-made and natural VOs. Man-made VOs in place for less than six months, such as mobile construction cranes, are not included in DVOF. Natural VOs, such as trees, present additional challenges due to the temporal changes in VO attributes and the periodicity of VO collection. The DVOF includes trees located in the vicinity of airports that are specifically requested by DoD customers and controlling obstacles as defined by the FAA that affect flight operations in the vicinity of aircraft take-off and landing areas. Additionally, the Army routinely conducts low level flight operations below 500 feet to employ terrain and obstacle masking tactics. This flight regime requires accurate VO documentation and strict VO awareness.

(U) To foster increased VO awareness for Army helicopter pilots, CWO3 Jon Sturnick proposed that aviation units set up a working relationship with all cell phone, power, and construction companies in the local flying area to harvest VO information. Per Army Regulation 385-095, the Aviation Unit Operations Officer should ensure a detailed hazard location chart is current, accurate, available for review, and shared with

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[119] (U) Major General Randall R. Castro, USA, "Refinement of Army Geospatial Information and Services (GI&S) Requirements-2005," Department of the Army, United States Army Engineer School Fort Leonard Wood, 4 January 2005. Cited hereafter as "Army Requirements."

[120] (U) Major General Robert G. Flowers, USA, "Refinement of Army Digital Topographic Data (DTD)," Enclosure 1, Department of the Army, U.S. Army Maneuver Support Center and Fort Leonard Wood, 14 June 2000.

interested parties.[121] The Army has promoted the concept to support GEOINT by furnishing NGA and the FAA with VO data collected at the local unit level. NGA can ingest, conflate, and disseminate through WebDVOF the VO data it receives from the Army.

(U) The Army has constructed an extensive VO database known as Aviation Vertical Obstruction Identification Database (AVOID) that documents VOs within a unit's flight operations area of responsibility (AOR).[122] For example, the Fort Rucker flying area AVOID contains approximately 700 VOs. In March 2009, the AVOID was shared with NGA to be considered for inclusion into DVOF. The VO data exchange between NGA and the Army will continue to offer additional input as the AVOID program is expanded within Army aviation units. Efforts are underway to incorporate the AVOID program at Fort Campbell and Fort Benning. As stated by Major General (b) (6) [redacted], "We look forward to sharing data products produced by Army units in the field for value adding and archiving at NGA." [123] The Army has personnel, aircraft, and vehicles in the field equipped with GPS receivers that can serve as potential collection sources for VO data. Accordingly, a helicopter hovering over a radio tower can obtain coordinates and height information from GPS and radar altimeter instruments.

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[121] (U) Chief Warrant Officer Three Jon Sturnick, USA, ASO/IP, C Co, 1-14th AVN REGT, Fort Rucker, AL, "Did You See that Tower," *Flight Fax*, URL: <https://safety.army.mil/Portals/multimedia /MULTIMEDIA ARCHIVE/Magazines/2001FlightfaxIssues/tabid/452/Default.aspx>, accessed 31 July 2009.

[122] (U) Chief Warrant Officer Four (b)(6) [redacted], USA, AMPS Action Officer, Concepts and Requirements Directorate (CRD) U.S. Army Aviation Center of Excellence (USAACE), Fort Rucker, AL, "Army Vertical Obstructions (VO) Program," e-mail interview by author, 07 July 2009.

[123] "Army Requirements."

(U) Another source of VO data is the Buckeye LIDAR program. The Buckeye LIDAR system has collected thousands of square kilometers of LIDAR elevation data in Iraq and Afghanistan, and has more recently been used to collect LIDAR data in domestic flight training areas. Depending on LIDAR collection parameters, VO information may be extracted from the collection data and included in a VO database.

(U) The various VO data collection schemes generate varying data quality. These concerns over data quality, attributes, accuracy, resolution, and documentation will be addressed by NGA and the Army to ensure appropriate ingest and attribution of candidate VO data into the DVOF. Validation of VO data remains a core element for the integrity the DVOF, and this requirement is ultimately supported by the responsible supplier of the VO data.

(U) U. S. Navy

(U) The Navy has submitted requirements for an obstruction database to be used for cruise missile mission planning. These weapon systems provide land attack capability and over-the-horizon defense against surface threats and may be employed globally in littoral areas. Other USN and USMC manned and unmanned air vehicles also benefit from world-wide VO data. Littoral areas are routinely populated with buoys, lights, transponders, radar reflectors, tethered balloons, drilling platforms, rocks, and islands not included in the World Vector Shoreline database. Initial areas of maritime interest include the Persian Gulf, Korean Peninsula, and the Malacca and Taiwan Straits.

(U) The current over-water obstruction database is obtained by filtering the obstructions contained in the Digital Nautical Charts (DNC) database. NGA utilizes foreign country source, National Ocean Service (NOS) data, Naval Oceanographic Office Surveys, Notice to Mariners, List of Lights, Radio Aids, and Fog Signals, and imagery for obstructions that may be entered into DNC cultural, navigation, or obstruction thematic layers.

(U) Due to mission requirements, the pilot of a low flying aircraft must maintain keen situational awareness to avoid a variety of obstructions. Unmanned airborne systems also rely on terrain and VO data for pre-programmed and reactive flight paths by using active and passive measures to see and avoid obstacles. To improve mission success rates in coastal areas, littoral VOs must be documented in the DVOF. The lack of VO data requires higher flight altitudes, which increases the flight vehicle's vulnerability to detection and engagement.

(U) The Harpoon missile weapon system has a need for DVOF data.[124] The Tomahawk missile also has requirements for DVOF to support Mission/Strike planning and route generation. The multi-faceted mission planning and route generation processes require accurate information from a wide range of GEOINT products, to include DTED and DVOF input. DVOF provides critical data for obstacles that must be avoided when determining the flight path for a low flying missile.

(U) To fulfill mission planning requirements for the Harpoon missile in FY 05, the Navy originally requested a threshold requirement for a VO database that contained at

[124] (U) Commander (b) (6) [redacted], USN, PMA201-SH, "Vertical Obstructions Over Water," Requirement ID 765, (b) (3) [redacted] accessed on 13 October 2006. Cited hereafter as "Navy Requirements."

least 90 percent of the actual, existing over-water obstructions with a minimum height of 30 feet at mean low tide. The request also included a more encompassing objective requirement to document VOs with a minimum height of 10 feet.[125]

(U) However, due to weapons systems developments and a relaxing of these stringent VO requirements, a subsequent FY 07 submittal for VO data was modified to increase the minimum recorded VO height from 30 feet to 30 meters.[126] This three-fold increase in minimum VO height will change notional collection strategies to fulfill the requirement. The Navy also pursued a threshold requirement to update the VO data at least every six months. A more restrictive objective requirement stated that the VO data should be updated at least every month. The most demanding situation is in predefined areas of interest or tactical significance, where real time updates would be the objective. These data currency requirements present substantial challenges for the VO collection strategy.

(U) Another Navy mission with a VO data requirement is the monitoring of seaborne Mobile Offshore Drilling Units (MODU). A MODU is a floating drill-rig barge with support legs that can be extended or retracted. Due to the design of mobile sea platforms, the above water and below water components of Jack-up, Semi-submersible, and Submersible rigs pose a threat to airborne, surface, and sub-surface vehicles. Depending on the type and operational status of the MODU rig, the leg stanchions may extend hundreds of feet above or below the water surface.

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[125] (U) "Navy Requirements."

[126] (U) Commander [redacted], USN, PMA201 SH, "Vertical Obstructions Over Water," Requirement ID 765, [redacted] accessed 31 July 2009.

(U) By virtue of the platform's mobility, frequent updates of the MODU's position are required. In areas of tactical significance, a MODU's position is required within five hours of the request.[127] NGA maintains a MODU database populated from U.S., foreign agency, and commercial industry sources to track rig name and location. The VO height of the MODU is not maintained in the database.

(U) The global scope of these requirements presents substantial challenges to NGA. The Tasking, Collection, Processing, Exploitation, and Dissemination (TCPED) process to generate an improved DVOF is challenged when additional data for minimum height AGL VOs is required at an increased sampling frequency. A combination of technologies, comprising mono and stereo SAR, Electro-Optical imagery, and LIDAR should be further developed to increase the quantity and quality of VO data that will supplement existing domestic and foreign VO databases. The increased challenges of the stringent VO data requirements proposed by the services may be mitigated by improved technology and alternative collection methods. Emergent requests for verified, current, high quality VO data for a limited specified area can be provided depending on the availability and quality of VO databases, the capabilities of VO collection assets, VO data attribute requirements, and available time. One must determine the value of a documented 10 foot tall VO to the customer, and the ability of NGA to provide the VO data. An analysis of the cost/benefit ratio fluctuates with each scenario.

[127] (U) Lieutenant Commander (b) (6) [redacted], USN, COMSUBFOR, "Seaborne Mobil Oil Drilling Unit," Requirement ID 905, (b) (3) [redacted] accessed 31 July 2009.

(U) U. S. Air Force

(U) The Air Force has validated the current requirement to depict 150 foot VOs on the Joint Operations Graphic (JOG) 1:250,000 scale Navigation Planning charts. The requirement also mandates that the DVOF database shall have at least a 90 percent degree of confidence to capture all VOs 150 feet AGL or taller. Additionally, the Air Force requests NGA continue to work toward meeting a technical objective to capture 60 feet AGL VOs in support of future mission requirements. The U.S. Marine Corps has adopted the Air Force VO requirements.

(U) Requirements to produce newly derived VO data for a specified area within assigned time constraints present challenges that can be met with improved technology. NGA is investigating various types of auto-detection and feature recognition programs, and continues to explore innovative methods for increasing the speed, quantity, and quality of VO data acquisition.

(U) Future Requirements and Customer Interaction

(U) The scope of the DVOF will be strengthened by exploiting existing VO datasets. Incorporating universal data standards will facilitate data exchange.

(U) VO data attributes, such as horizontal and vertical positional accuracy, are to be collected at the 90 percent confidence level to fulfill the Guidelines for Electronic Terrain, Obstacle and Aerodrome Mapping Information, Document 9881. This document was established by ICAO for standardization of aeronautical data collection by data originators, for implementation by system designers, and for use by the aviation community in aeronautical information and aeronautical charts services, air transport operators, air traffic services, aerodrome operators, approach and departure designers.[128]

(U) NGA aggregates world-wide VO data from numerous sources with various degrees of accuracy. NGA can attain the 90 percent degree of confidence goal at specified accuracies within certain geographical areas. World-wide VO data coverage is limited by many factors. Accessibility to the collection area, capabilities of available collection platforms, time constraints, and VO data processing capabilities are some of the factors affecting emergent collection requirements. The availability of high-quality pre-existing VO data will affect the necessity for additional collection efforts. Furthermore, NGA continues to work toward meeting a technical objective of 60 feet in support of future mission requirements. The Air Force requirement recommends NGA enact a capability to locate, document, and disseminate VOs using automated means.[129] NGA has investigated various types of auto-detection schema and continues to explore innovative methods for increasing the speed, quantity, and quality of VO data collection and ingestion into the DVOF.

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[128](U) ETOD, 2.

[129] (U) [redacted], AF/A2ZY, "Vertical Vector Obstruction Data (VVOD) Production System," Requirement ID: FY05-09 032, [redacted] accessed 31 July 2009.

(U) Summary

(U) VOs are a critical safety of navigation risk that must be mitigated. All the military services have requested the VO height threshold be reduced as critical flight operations take place closer to the Earth's surface.

(U) To coordinate the military services' VO requirements, NGA established the Vertical Obstructions Working Group (VOWG), comprising military and NGA personnel. The VOWG provides a central forum for the establishment of consolidated VO requirements, and formulates the transition to a digital environment based on a data-centric, customer demand web-based product

(U) The war fighter's mission specific datasets demand the highest standards for VO and digital elevation model data that are applicable to the Intelligence Preparation of the Battlefield (IPB), weapon system platforms, mapping and charting production, terminal flight information procedures, and combatant commander specified areas. The Air Force technical objective VO height requirement of 60 feet AGL presents a challenge to NGA. As documented by a contractor supplied report to NGA, for the LIDAR study area, an exponential increase in VOs is realized as the threshold for collection is lowered from 150 feet to 100 feet. [130] Also, the Boeing Statistical Analysis of DVOF Final Report states, "Changing the height standard from 150 feet to 100 feet would increase the number of non-pylon features by 238 percent (slightly over twice as many features.)"[131] Changing the height standard for pylon features from 150 feet to 100 feet would also increase the overall VO count. Overall, the percentage of VOs documented by the AOE

[130] (U) Todd Jamison, "LIDAR VO Evaluation, Final Study Brief to NGA/PV," Observera Report to NGA/Acquisition Engineering-NSG System Engineering Division, 21 May 2009, 94.

[131](U) Boeing Company, "Pilot Program Final Report from the Statistical Analysis of the NGA Vertical Obstacle File (DVOF)," 27 September 2010, 24. Cited hereafter as "Boeing Analysis."

program (which supports the DVOF) was estimated to be 22.5 percent of all ground truth VO features.[132] The Boeing analysis calculated that on a world-wide basis, 77.5 percent of the ground truth VOs were not documented in the DVOF. At current collection height requirements, this calculation results in a world-wide VO count of over 26 million. Another estimate for total world-wide VO count based on a default or first measured pylon method statistical counting and measuring technique results in over 42 million VOs.[133] The DVOF currently contains over 6 million VOs, and one could expect that figure to grow substantially as collection requirements and capabilities are redefined. New technology and assets are needed to address the requirements. NGA continually strives to discover additional methods and sources to collect and maintain VO data through data exchange, data mining, and additional sensor collection opportunities. LIDAR is a promising technology that offers potential to improve the collection of VOs for populating DVOF.

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[132] (U) “Boeing Analysis,” 5.

[133](U) “Boeing Analysis,” 21.

CHAPTER 5

(U) Light Detection and Ranging (LIDAR) systems offer the capability to detect, locate, and provide quantifiable data for the documentation of VOs. Continuing advances in LIDAR and GNSS technology are improving the performance of airborne LIDAR sensors to scan larger areas in less time with increased data quality. The increasing quantity and quality of LIDAR data attributes has led to an evolving LIDAR data file format. A standardized LIDAR format will improve the utility of the data across the processing spectrum. Additionally, the proliferation of LIDAR data attributes increases the potential for error factors to affect LIDAR data processing.

(U) A basic review of LIDAR operating principles will familiarize the reader with factors effecting performance of an airborne LIDAR unit. After the LIDAR collection is complete, the analysis and extraction of VOs is performed to populate the DVOF.

(U) Light Detection and Ranging (LIDAR)

(U) LIDAR is an active illumination technique that uses backscatter laser light to gather information on the distance, topography, and surface properties of a target. For detecting VOs, the LIDAR system uses a collimated beam of coherent laser light to illuminate a target area. The LIDAR system generates the best data in an optically transparent atmosphere that is free of contamination. LIDAR can remotely detect objects and determine their position, velocity, or other characteristics by analysis of the reflected laser light. Post-collection processing of laser pulse reflections, comprising highly accurate positional data, is used to generate point cloud data. A LIDAR image can be constructed from millions of laser shots and reflected backscatter returns. Because the exact range and location of each laser backscatter return is known, one can produce a three dimensional image or a cloud of points known as Point Cloud Data. A point cloud is a set of three dimensional points describing the outlines or surface features of an object. A point cloud is best imagined as a collection of dots of light hanging in space indicating the spot where each reflection originated.[134]

(U) LIDAR has been used for flood-plain mapping, forestry management, and high-resolution terrain elevation products. Additionally, LIDAR enables the production of high resolution Digital Surface Models (DSM) that can be used to locate and classify VOs. Also, bare Earth Digital Terrain Models (DTM) or Digital Elevation Models (DEM) may be derived from LAS files. The analysis of highly processed geo-registered EO imagery and LIDAR point cloud data to permit the automated classification of VOs will greatly aid the effort to improve the DVOF.

(U) As a testament to the potential for LIDAR to fulfill GEOINT/GIS requirements, sixty LIDAR companies attended the International LIDAR Mapping Forum event held at Denver, Colorado in February 2010. LIDAR related services and products featured at forums include LIDAR hardware and complementary sensor manufacturers, survey service companies, data processing, GIS and management specialists, and LIDAR mapping vehicles.[135] Vendors are now offering LIDAR bathymetric and topographic mapping services.

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[134] (U/~~FOUO)~~ American Society for Photogrammetry and Remote Sensing, *LAS Data Exchange Format*, (b)(3) [redacted], accessed 6 January 2010.

[135] (U) International LIDAR Mapping Forum, Intelligent Exhibitions Ltd, Gloucestershire, UK, URL: <http://www.lidarmap.org/ILMF.aspx>, accessed 15 January 2011.

(U) LIDAR data is becoming more prevalent for use in a broad spectrum of GIS applications. For example, both Google and Microsoft have been utilizing ground vehicles with LIDAR sensors throughout most major cities in North America and Europe with the eventual goal of acquiring a high-resolution 3D model of the entire world. [136] Incorporating the LIDAR data would expand Google Earth's capabilities beyond the current 3-D Buildings and Street View features.

(U) Two types of laser ranging methodologies are predominantly used for topographic purposes: the timed pulse method and the phase comparison method.

(U) Phase Comparison LIDAR

(U) A carrier wave, consisting of continuous laser light that is amplitude modulated to produce sinusoidal measuring waves at specific frequencies, is transmitted to illuminate the target. The reflected signal returns to the receiver sensor and is analyzed for wavelength phase shift. A combination of low and high frequency modulated lasing produces high precision ranging.

(U) Due to the achievable signal-to-noise ratio, frequency instability, operational range, and characteristics of the continuous wave (CW) laser that is utilized for the phase comparison method, it is used primarily for non-aerial purposes and short ranges.[137] The high power requirements for the CW phase comparison method to obtain long range

[136] (U) Aleksey Golovinskiy and others, "Shape-based Recognition of 3D Point Clouds in Urban Environments," 1, URL: <http:www.cs.princeton.edu/~funk/iccv09.pdf>, accessed 30 January 2010. Cited hereafter as "Feature Extraction."

[137] (U) Ravil R. Agishev, "Analytic comparison of some features of pulse-lidar and CW-FM-ladar remote sensing," Kazan State Technical University, *SPIE- The International Society for Optical Engineering*, 5086**,** no. 305, (2003), doi:10.1117/12.512031 Online Publication Date: 18 September 2003, URL: <http://spie.org/x648.html?product_id=512031>, accessed 15 January 2011.

distance measurements render it impractical for airborne remote sensing. Current CW LIDAR systems power and thermal efficiencies will not meet space-based LIDAR requirements.

(U) Timed Pulse LIDAR

(U) A timed pulse system utilizes a laser pulse of light transmitted for a very short period of time. Similar to radar operating principles, the laser sensor determines the distance to an object by measuring the elapsed time from the laser light pulse transmission to the receipt of the reflected pulse or pulses at the receiver sensor. This pulse-echo system is based on precise time measurement that results in highly accurate distance measurements. Additional target information is derived from the intensity of the reflected pulse, and the number of reflected pulses received. For a laser ranging unit, distance (d) from the transmitter to the target equals time (t) of flight of the laser pulse from transmission to receipt of the reflected pulse multiplied by the speed of light (c) divided by two ($d = t \cdot c / 2$).

(U) With the velocity of light at approximately 3×10^8 meters per second, a 10 nanosecond[138] laser pulse will travel 3 meters. In order to obtain a distance accuracy, or resolution of 1 meter, the timing mechanism must have an accuracy of approximately 3 nanoseconds. A timing mechanism capable of measuring 3×10^{-11} second is capable of producing a 1 centimeter range resolution, while a 1 millimeter resolution is attainable with a timing device capable of measuring a 3 picoseconds (3×10^{-12}) interval. A timing device based on a quartz crystal-stabilized oscillator enables the accuracy to measure both the duration of the laser pulse and the elapsed time of flight for the laser pulse. The

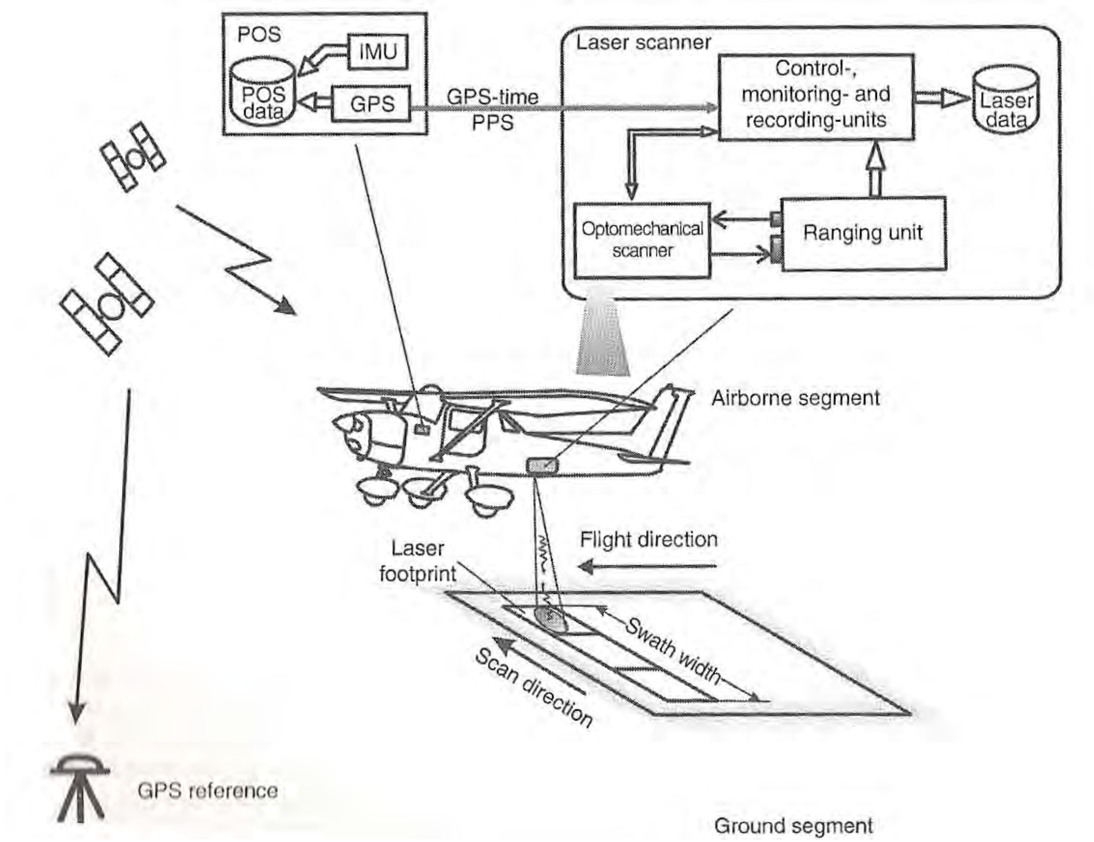
[138] (U) A nanosecond is one billionth (1×10^{-9}) of a second.

ability of the timer to measure extremely short time intervals is a major factor that defines the achievable accuracy of the laser range finding system. The most advanced timers available for use in laser ranging units today are capable of measuring single integer picosecond intervals.

(U) Airborne LIDAR

(U) LIDAR collection operations are predicated on the synergy of two major systems; the airborne LIDAR collection platform and the supporting navigation information system.

(U) An airborne platform equipped with three components-- a topographic Laser Scanner Unit (LSU) for range information, coupled with a Global Navigation Satellite System (GNSS), such as the U.S. Global Positioning System (GPS) or Russian Global Navigation Satellite System (GLONASS) to furnish position information, and an advanced Inertial Measurement Unit (IMU) for attitude information-- comprise the elements of an airborne system capable of collecting VO data. Ideally, the integrated LSU, GNSS, and IMU systems are co-located on the collection platform to reduce alignment and calibration errors. These combined components form a system known as airborne Light Detection and Ranging (LIDAR) as depicted in Figure 5-1.



(U) Figure 5-1. Airborne LIDAR System

(U) Source: Jie Shan and Charles K. Toth, *Topographic Laser Ranging and Scanning: Principles and Processing.* (New York: CRC Press, 2009), 131.

(U) Global Navigation Satellite System (GNSS) Performance

(U) The precise positional information required for airborne LIDAR is primarily obtained by using augmented Navigation System for Timing and Ranging (NAVSTAR) Global Positioning System (GPS) signals. Two other types of systems, the Ground Based Augmentation System (GBAS) and the Satellite Based Augmentation System (SBAS) are also available to enhance GPS navigational performance through the use of precisely located base station receivers that calculate its position based on satellite signals and compares this location to the known location. The Differential GPS (DGPS) correction signals are then transmitted to the LIDAR collection vehicle or are available for post-collection processing.

(U) A type of SBAS known as the Wide Area Augmentation System (WAAS) consists of approximately 38 terrestrial Wide Area Reference Stations (WRS) located in the contiguous United States, Alaska, Hawaii, Canada, Mexico, and Puerto Rico. The WRS stations monitor the GPS satellite fleet signals and forward the data to three Wide Area Master Stations (WMS). The WMS generate position and clock error correction signals that are transmitted to geostationary satellites positioned over the Americas through ground uplink stations and provide WAAS service predominantly to North America. The WAAS geostationary satellites transmit ionosphere and troposphere anomaly data, clock drift, and satellite ephemeris correction data for the GPS signals to optimize system accuracy for GPS users. WAAS typically provides better than 1 meter lateral and 1.5 meter vertical accuracy throughout the United States.[139]

(U) The more precise GBAS known as Local Area Augmentation System (LAAS) uses precisely surveyed local reference receiver ground stations placed in the vicinity of the area of operations to monitor GPS satellite signals. The ground stations transmit GPS data to a central location where the data is conflated, processed, and re-transmitted to GPS users. The operational area is nominally within a 25 kilometer radius[140] of the local receiver ground stations, and may extend from 25 to 30 miles from the collection area.[141]

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[139] (U) Federal Aviation Administration, "Wide Area Augmentation System," URL: <http://www. faa. gov/air_traffic/technology/waas/>, accessed 10 November 2009.

[140] (U) Federal Aviation Administration, "Local Area Augmentation System," URL: <http://www. faa.gov/about/office_org/headquarters_offices/ato/service_units/techops/ navservices/gnss/laas/>, accessed 8 November 2009.

[141] (U) Jie Shan and Charles K. Toth, *Topographic Laser Ranging and Scanning: Principles and Processing* (New York: CRC Press, 2009), 151. Cited hereafter as "*Laser Ranging*."

The LAAS correction data is applicable to a local area and offers greater accuracy than that provided by WAAS.

(U) Real Time Kinematics (RTK)

(U) The FAA's LAAS and WAAS provide near instantaneous navigation signals for aircraft through Real Time Kinematics (RTK). RTK is a process where GPS signal corrections are transmitted in real time from a geo-referenced receiver to a suitably equipped aircraft. The real-time processing of the GPS carrier phase signal compensates for atmospheric delay, orbital errors, and other variables in GPS geometry to increase positional accuracy within centimeters. Aircraft utilizing LAAS through a VHF data link are able to conduct instrument approaches and landings to suitably equipped airports during reduced ceiling and visibility meteorological conditions.

(U) While conducting airborne LIDAR collection operations, it is not necessary for the LIDAR platform to receive the transmitted GPS correction signal. The RTK GPS correction data recorded at the time of collection can be applied in post collection processing to produce airborne platform positional accuracy within ten centimeters and attitude data accurate within one hundredth of a degree.[142]

(U) National Continuously Operating Reference Stations (CORS)

(U) The National Geodetic Survey (NGS), an office of NOAA's National Ocean Service, manages a network of Continuously Operating Reference Stations (CORS). The CORS provide ancillary Global Navigation Satellite System (GNSS) data consisting of

[142] (U) "*Laser Ranging*," 152.

carrier phase and code range measurements in support of three dimensional positioning, meteorology, space weather, and geophysical applications throughout the United States, its territories, and a few foreign countries.[143]

(U) In order to further expand improved GPS accuracy areas, the CORS provide corrective data for GPS and GLONASS carrier phase and code range signals by comparing the received GNSS derived coordinates of the base station with the known highly accurate surveyed coordinates of the base station. A corrective signal is then produced to enhance the accuracy of the GNSS to within centimeters.

(U) NOAA has registered over 100 organizations that have joined the CORS network to share data from their permanent GPS base stations that meet stringent qualifying criteria. By registering permanent reference base stations, the coverage area, data quality, reliability, and functionality of the CORS network is assured. As of June 2010, the National CORS network contained approximately 1450 operational GPS base stations and continues to grow at a rate of about 7 stations per month.[144] CORS stations exist predominantly in the United States, with additional stations located in Iraq, Afghanistan, Liberia, Ethiopia, Guam, Pago Pago, Saipan, Suriname, Brazil, Cuba, and other countries near the equator. The Panga Community of Central Washington University (224 sites) and the U.S. Coast Guard (173 sites) are the largest operators of CORS network.

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[143] (U) National Geodetic Survey, NOAA, *Continuously Operating Reference Station*, URL: <http:// www.ngs.noaa.gov/CORS/>, accessed 12 June 2010.

[144] (U) Tomas Soler and Richard A. Snay, "Transforming Positions and Velocities between the International Terrestrial Reference Frame of 2000 and North American Datum of 1983," URL: <http:// www.ngs.noaa.gov/CORS/Articles/SolerSnayASCE.pdf>, accessed 17 December 2010.

(U) Independently operated DGPS systems also exist world-wide. The NAVCOM StarFire™ global satellite-based augmentation system provides decimeter positioning accuracy on a worldwide basis. Utilizing a network of more than 60 GPS reference stations around the world to compute GPS satellite orbit and clock corrections, Starfire™ claims to provide real-time accuracy typically better than 10 cm horizontal (1σ) and 15 cm vertical. The DGPS corrections are broadcast via three INMARSAT geostationary satellites that provide worldwide coverage and enable precise real-time navigation without the need for local ground base stations.[145]

(U) Optimizing GNSS data

(U) GPS plays an integral role in enabling the use of airborne LIDAR by providing precise positional information. By selectively scheduling LIDAR collection times, GPS Position Dilution of Precision (PDOP) affects can be minimized by viewing the maximum number of satellites possible with the greatest angular spread for favorable satellite geometry. When a minimum of at least four satellites are in view with ideal triangulation geometry, highly accurate position and time measurements are possible. Onboard multi-channel (12 or more) receivers can monitor GNSS data that is processed by the LIDAR Position and Orientation System (POS) computer system to calculate accurate temporal and positional data. A GNSS receiver capable of processing the European Space Agency (ESA)/European Union (EU) Galileo Positioning System or the Russian Global Navigation Satellite System (GLONASS) signal in addition to

[145] (U) StarFire™ Network, NAVCOM Technology, URL: <http://www.navcomtech.com/StarFire/>, accessed 27 December 2009.

NAVSTAR GPS signals can offer greater accuracy than a NAVSTAR GPS-only receiver system.

(U) The GPS signals received on the airborne platform are sent to the POS computer system for processing the WGS 84 latitude (x), longitude (y), and ellipsoid height (z), along with positional and timing data in the control, monitoring, and recording units. GPS signals enhanced with ground based augmentation systems further refine positional/trajectory data that the POS computer integrates to achieve previously unattainable positional accuracy. The positional and temporal accuracies attained through the GNSS enable LIDAR systems to be excellent VO data collectors.

(U) Inertial Measurement Unit (IMU) performance

(U) An IMU is a computer system that can detect changes in geographic position, velocity, or orientation through sensors. It does this by measuring the linear and angular displacement applied to the IMU system through gyroscopes and accelerometers. Gyroscopes are mounted in the IMU to sense angular positional displacement of the airborne platform. As a testament to the versatility of the laser, ring laser gyroscopes are utilized in current IMU designs to offer increased reliability and accuracy as compared to previous electro-mechanical designs. Similarly, accelerometers are motion sensors mounted in the IMU used to measure linear acceleration. The IMU computes attitude data through input received from six degrees of freedom pitch, roll, and yaw sensors for rotational and translational displacement. The IMU mounted in the airborne platform continually monitors the position and attitude of the airborne LSU and sends the information to the POS.

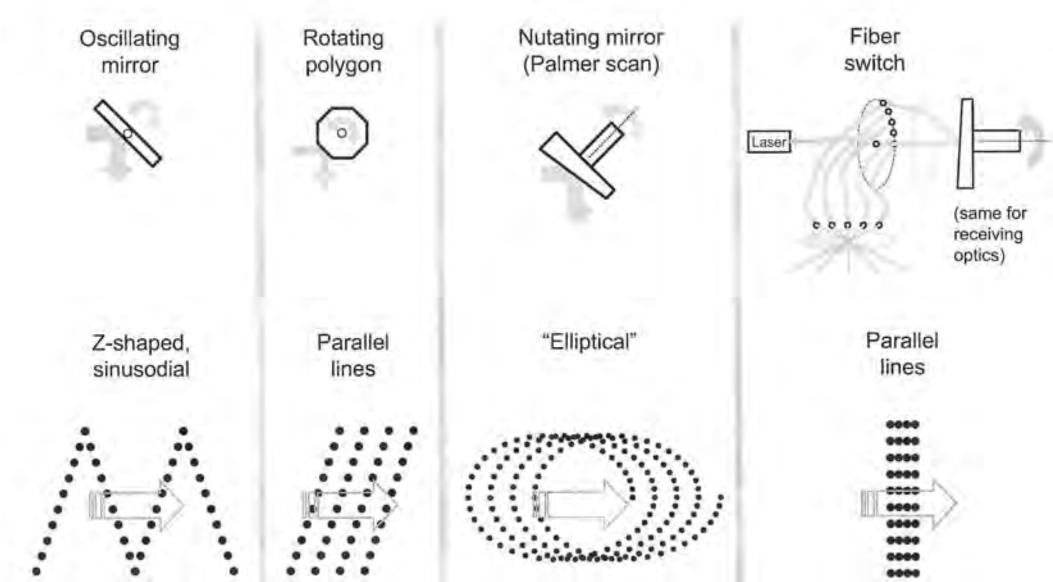
(U) The IMU should be mounted adjacent to or integral to the laser scanner to reduce systematic calibration errors. Additionally, displacement between the IMU and GPS antenna must be accounted for in post collection processing to accurately reflect the survey data point of origin. Mathematical lever arms, synonymous with offset vector components, are calculated to maintain positional integrity for IMU and GPS input to the POS used for LSU calibration, control, monitoring, and LIDAR data recording.

(U) Laser Scanner Unit (LSU) Performance

(U) A mono-static LSU contains an optical mechanical unit that directs laser light from the laser transmitter to the target and receives reflected laser light into a co-aligned optical receiver. A bi-static laser system has the transmitter and receiver optics spatially separated, which means the illumination and viewing angles are divergent. The lens used for the illuminating laser transmitter is different from the lens used to collect the backscatter photons for the receiver unit. Although the angle between the transmitter and the receiver optics varies depending on the range to the illuminated surface, this effect is minimized when operating space-based LIDAR from Earth orbit as compared to a terrestrial based LIDAR system.

(U) A slant range is determined by measuring the time of flight for the laser pulse. Each reflected pulse that is detected by the receiving sensor has an associated scan angle and intensity value that is needed for analysis to construct LIDAR data. Other LSU components include optical lenses, mirrors, filters, fibers, beam splitters, focal plane array image sensors, and accurate timing, control, monitoring, and recording devices.

(U) The LIDAR platform transmits a pulsed laser beam at defined intervals to figuratively paint a swath of target coverage across the flight path. The laser beam scan pattern is typically steered with oscillating or spinning scanner mirrors or prisms. Various sinusoidal, saw-tooth, parallel, or elliptical scan patterns are achieved with different configurations of oscillating, rotating, or nutating mirrors, as seen in Figure 5-2. Along-track and cross-track laser footprint pattern spacing on the target surface can be modified to meet collection requirements.



(U) Figure 5-2. Scan Mechanisms and Ground Patterns

(U) Source: Claus Brenner, *Aerial Laser Scanning*, International Society for Photogrametry and Remote Sensing (ISPRS), URL: <http://www. photogrammetry.ethz.ch/summerschool /pdf/08_Brenner_aerial_scanner.pdf>, accessed 15 January 2011.

(U) The basic components consisting of the LSU, GNSS, and IMU are integral for a functional mobile LIDAR system conducting terrestrial, airborne, or space-borne

LIDAR collection operations. Various modifications and improvements have been introduced that expand the capabilities of LIDAR.

(U//~~FOUO~~) Jungle Airborne Under Dense Vegetation Imaging Technology (JAUDIT)

(U//~~FOUO~~) The LIDAR Jungle Airborne Under Dense Vegetation Imaging Technology (JAUDIT) system was developed by Johns Hopkins University Applied Physics Laboratory (JHUAPL) under the sponsorship of NGA in order to adapt the Optech Airborne Laser Terrain Mapper (ALTM) 3100 with a gimbaled LSU mount for the purpose of achieving a very-high resolution step-stare mode foliage penetration.[146]

(U//~~FOUO~~) To offer further LIDAR collection versatility, the gimbal-mounted LSU can slew up to a ±20° longitudinal or lateral scan angle during a collection pass. This capability allows multiple scan angles or view aspects of a target on a single pass. Increased sampling densities on target specific areas can enhance VO detection capabilities. When the collection platform field of regard approaches the target collection area, the LSU is angled forward of nadir to scan the area of interest. As the collection platform continues along the flight track, the LSU rotates aft to illuminate the target area through nadir until the area of interest passes aft through the field of regard. The multiple look angles equate to additional energy on the target and generate enhanced point cloud data. Also, lateral offset LIDAR scanning to the side of the flight track is accomplished through LSU roll-axis excursions. The gimbaled LSU allows flexibility in flight planning and offers tailored scan capabilities to meet collection requirements.

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[146] (U) (b) (6) [redacted] and others, (U//~~FOUO~~) "*JAUDIT*," *High-Resolution Foliage Penetration with Gimbaled LIDAR*, The Johns Hopkins University Applied Physics Laboratory, (b)(3) [redacted]>, accessed 19 November 2009. Cited hereafter as "*JAUDIT*."

(U//~~FOUO~~) In order to more fully exploit the increased capabilities of the advanced gimbaled LSU, the IMU was mounted on the gimbaled assembly to obtain more precise measurements for the POS. By mounting the IMU on the gimbaled LSU, increased power drive requirements, inertial forces, vibration, and mechanical loads were placed on the pitch and roll mounts. To address these engineering challenges, alternating current brush-less servo actuators, integrated with harmonic drive gear reducers and other advanced components, were combined to produce an innovative gimbaled LSU.[147] Calibration alignment of the IMU reference frame and the gimbaled LSU reference frame conducted by JHUAPL scientists resulted in lever arm corrections that reduced geo-location data errors to ≤ ± 20 cm. The versatility of the JAUDIT allows it to direct the LSU in a pre-determined (programmable) track in the vicinity of the collection vehicle flight path. The higher ground resolution and multi-graze angle capability exhibited by JAUDIT can be applied to the concepts of VO collection performance goals stipulated in the National Geodetic Survey *Light Detection and Ranging Requirement* that promote multiple look angles, dense horizontal and vertical point spacing, and superior radiometric performance.[148] The LIDAR collection scan track or tile can be tailored to follow a desired path to maximize efficiencies for area of coverage, footprint density, collection duration, and LAS file size. The LAS file contains the raw point cloud data.

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[147] (U//~~FOUO~~) "*JAUDIT.*"

[148] (U) The ability to detect small diameter objects with low reflectance requires superior radiometric performance.

(U) LIDAR Data Format

(U) Once the LIDAR data has been collected, it must be packaged in a form that maximizes its usefulness. Changing capabilities, requirements, and customers contribute to the evolving state of LIDAR data format.

(U) LASer (LAS) File Exchange Format

(U) The American Society for Photogrammetry and Remote Sensing (ASPRS) has established the Laser File Exchange Format (LAS) format to be used as an industry standard for the processing, analysis, storage, and exchange of LIDAR data. The binary file LAS format accommodates data capture, processing, and archiving. At a basic level, raw point cloud data is stored in files comprising (x, y, z) coordinates, intensity value, and a time tag. Additional attributes include the number of returns per pulse, the sequence tag of the pulse, the pulse scanner mirror angle, the surface classification, such as ground or vegetation, and a unique point source identifier. In the early stages of LIDAR development, various sensor vendors designed their own proprietary laser data file formats for their products. Initially, interoperability was not the primary design goal for commercial applications. However, through the coordinated efforts of commercial vendors and the ASPRS, the standardized LAS v1.0 was established in May 2003 to allow a commercially viable data exchange format. As LIDAR potentialities were advanced, shortcomings in LAS v1.x format were addressed.

(U) LAS v2.0

(U) LAS v2.0 is envisioned to expand the capabilities of LAS v1.x, and provide an open format that allows different hardware and software tool vendors to use a standardize point cloud data exchange format. LAS files must be able to accommodate additional data to permit the capture, processing, and analysis of linear-mode, multi-return, full waveform, and Geiger mode returns. Additionally, multi-sensor LIDAR units using concurrent electro-optical imagery input, such as panchromatic, red, green, blue, and/or infrared values associated with a point cloud data, should be incorporated within the LAS 2.0 specification. The profusion of diverse LIDAR data coupled with vendor-unique capabilities presents a challenge to ASPRS LAS standardization.[149]

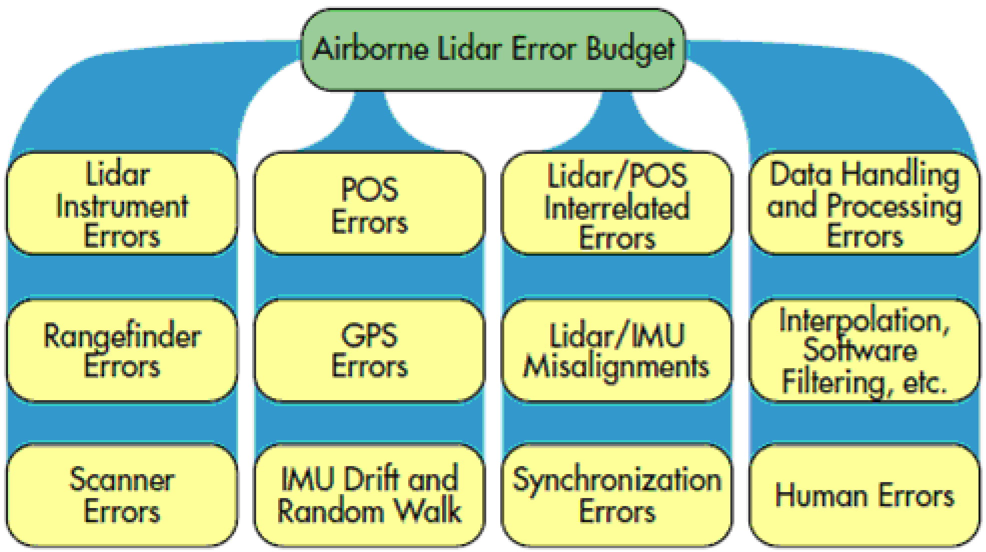
(U) LIDAR Error Factors

(U) The complexity of the airborne LIDAR system presents challenges to integrate the components of the system while maintaining data integrity. Error management seeks to optimize data quality while mitigating the error budget.

(U) The integration of the IMU, GPS, POS, and LSU components of the airborne LIDAR system results in quantitative spatial and temporal errors that must be identified and minimized. Factors contributing to the overall positional accuracy and precision of the post-processed point cloud data include the cumulative effect of errors identified in the Airborne LIDAR Error Budget. Each of the twelve input components identified in the Airborne LIDAR Error Budget (Figure 5-3) contributes a discreet error that is

[149] (U) (b)(6) [redacted], U.S. Army Corps of Engineers, Cold Regions Research & Engineering Lab, Hanover, NH, telephone interview by the author, 6 January 2010.

compounded by further processing of the data stream for collection, detection, processing, exploitation, and dissemination of the LIDAR data. Error mitigation is addressed through coordinated efforts across the spectrum of LIDAR procedures, software processes, and hardware configurations.



(U) Figure 5-3. Error Budget for Airborne LIDAR Systems

(U) Source: R. Valerie Ussyshkin, *Performance Analysis of ALTM 3100EA: Instrument Specifications and Accuracy of LIDAR Data,* ISPRS Proceedings, URL: <http://www.isprs .org/proceedings/XXXVI /part1/Papers/PS2-28.pdf>, accessed 18 April 2010.

(U) In generalized terms, measurement errors may be classified as systematic or random. Systematic error relates to the accuracy of data in comparison to a known truth or standard. For (x, y, z) point cloud data, accuracy is measured through comparison to the ground truth. Accuracy can be illustrated by placing a group of shots equidistant around a target bulls-eye. The systematic errors observed during data collection procedures are calculable and predictable, allowing accountable accuracy to be defined in terms of standard deviation.

(U) Random error relates to the precision of the data in which one determines how well a result has been determined. The precision of data is related to its reproducibility and is not related to its comparison with the known ground truth or standard. If one conducted multiple LIDAR collects under the same conditions and generated different results each time, random error would be expressed. If the same results are obtained each time, random error is minimized. Precision can be demonstrated by producing a tight group pattern of shots, but not necessarily on the bulls-eye. Ideally, random and systematic errors are considered minimized when a tight group of shots falls on the bulls-eye to exhibit both accuracy and precision.

(U) Evaluating the z-height accuracy of LIDAR point cloud data for VOs may be difficult, because the ground truth measurement has to be of a higher precision than that of the LSU itself. For example, to determine the height of an approximate 1,200 feet tall radio mast, a modern hypsometer incorporating a laser rangefinder and a clinometer may have been used to determine VO ground truth height.[150] Another measurement effort may involve a survey measurement derived from an installed GPS receiver on the tower apex. The veracity of this known ground truth is increasingly being called into question as the centimeter-measuring capabilities of LIDAR allow it to be elevated as the standard for determining VO z-value ground truth.

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[150] (U) A hypsometer is an instrument to measure height. A clinometer is an optical device that measures angles or slope.

(U) LIDAR Operating Principles

(U) An understanding of basic LIDAR operating principles will allow the reader to proffer innovative adaptations of LIDAR. A review of LIDAR operating parameters reveals the capability of current applications and by extrapolation, the potential uses of LIDAR.

(U) Pulse Repetition Frequency

(U) The ability of a legacy LSU to pulse at defined intervals is defined by the maximum operational slant range. Considering that the time (t) of flight for the transmitted and reflected laser pulse equals two times the height (h) of the LSU divided by the speed of light (c), or t = 2h/c, the time of flight for a laser pulse shot from an altitude of 1000 meters equals 6.7 microseconds.[151] The maximum Pulse Repetition Frequency (PRF) is equal to the inverse of the time of flight (t), or PRF = 1/ t. This simplified scenario equation does not take into account the pulse duration time of a few nanoseconds and it also assumes no transmit/receive overlap. Accordingly, from the height of 1000 meters, the maximum PRF is 150 kHz. Extrapolating out to a nominal Earth orbit of 400 kilometers, the maximum PRF would be 37.5 kHz when operating in a single pulse transmit-receive linear mode. In general, a higher PRF can yield a greater area coverage or footprint density per unit area, or both.

(U) Advancing beyond the concept of no transmit/receive overlap that is used in basic legacy LIDAR systems, recent developments offer expanded capabilities to achieve

[151] (U) One microsecond equals 1 x 10^{-6} second.

high pulse repetition frequencies by applying new techniques that involve multiple laser pulses simultaneously transiting to the target and back. This allows the LSU to emit new pulses without waiting for the reflection from the previous pulse being received. The latest Optech ALTM Gemini model can achieve PRF rates of 167 kHz using multi-pulse technology.[152] This capability allows more pulses on target in a shorter time interval to achieve greater resolution. However, at a fixed power input, an increase in PRF will result in a decrease in pulse energy and a less favorable signal-to-noise ratio (SNR) from the reflected pulse. In conventional terms, for laser ranging it is desirable to transmit at a high pulse repetition frequency with high power to obtain precise LIDAR data. The LIDAR unit should balance peak output power, PRF, noise mitigation, and receiver sensitivity to obtain optimum results.

(U) Swath Width

(U) The collection platform altitude above the ground affects swath width. With a LSU angular field of view (FOV) of theta (θ), the swath width (SW) equals two times the height above ground level (H) times the tangent of θ/2, or SW = 2·H· (θ/2). As the height of the LSU increases, the swath width increases. The FOV should accommodate the swath width to match the focal plane array pixels ground sample distance at the LSU optical diffraction limit to obtain the optimum resolution for the collection tasking.

(U) Scan Rate

The LSU scan rate addresses the ability of the LSU to perform scans transiting the swath width. An Opech 3100AE ALTM achieves a 70 Hz bi-directional saw-tooth

[152] (U) “Laser Ranging,” 50.

pattern with an oscillating plane mirror. The Riegl LMS-Q560 terrestrial scanner supports a uni-directional 160 Hz sinusoidal scan rate by utilizing a rotating polygonal mirror. A greater scan rate will produce more footprint points per unit time in the cross-track dimension. Along-track footprint point spacing is also affected by platform velocity. The gimbaled-LSU of the JAUDIT program may affect both lateral and longitudinal footprint spacing. LIDAR collection parameters, such as altitude, platform speed, swath width, angular field of view, cross-track and along-track point spacing as related to LSU scan pattern, power output, focal plane array sample rate, and SNR are some of the variables for consideration when seeking an optimum scan rate for VO detection. These factors are relevant for LIDAR operations from a helicopter at 1000 feet AGL or a space vehicle in a 400 kilometer low Earth orbit (LEO).

(U) Laser Beam Divergence and Footprint Size

(U) The parallel beams of coherent collimated laser light are subject to beam divergence. The minimum theoretical beam divergence angle (γ) due to diffraction is equal to 2.44 times the laser energy wavelength (λ) divided by the diameter (d) of the transmitting aperture, or $\gamma = 2.44\ \lambda / d$. A large aperture laser output mirror produces less beam spreading than a small aperture. For a Nd:YAG laser transmitting at 1064 nanometers using a 10 centimeter laser aperture, the minimum theoretical beam divergence is 0.026 milliradian (mrad).

(U) The minimum size of the ground footprint (D) is approximately equal to the value of beam divergence angle (γ) multiplied by the height (H) above ground level, or $D \approx \gamma \cdot H$. The theoretical limits of performance and the practical limits of real application affect the obtainable footprint size. The Optech ALTM 3100 exhibits a beam divergence of 0.3 mrad that produces a 30 cm footprint at 1000 m collection height.[153] Footprint diameter is one of the factors that affect spatial resolution for LIDAR. Table 5-1 lists minimum theoretical footprint size based solely on beam divergence effects. To obtain a footprint size of approximately 0.5 m from a 400 km LEO would require a 2 m aperture laser. This is noteworthy due to the consideration that a 1 m optical system LSU receiver-sensor produces a diffraction limited resolution of 0.5 m. This capability would match the performance offered by a beam footprint size of 0.5 m.

Notional Collection Platform Height	B-200 King Air Turboprop @2000 m	RQ-4 Global Hawk Jet @20,000 m	Satellite Space Vehicle Low Earth Orbit @400,000 m
Minimum Theoretical Footprint diameter w/ 10 cm aperture	5.2 cm	52 cm	10.4 m
Minimum Theoretical Footprint diameter w/ 1 m aperture	.52 cm	5.2 cm	1.04 m

(U) Table 5-1. Altitude and Footprint Beam Diameter comparison

(U) Source: Author's Analysis

[153] "Laser Ranging," 22.

(U) Beam Propagation

(U) Interaction of the laser beam with the atmosphere affects beam quality. Beam propagation quality for different laser wavelengths varies with atmospheric composition. Refraction, reflection, and absorption of the laser energy occur as the beam transits the atmosphere. Atmospheric attenuation and scattering caused by obscurants, particulates, dust, aerosols, gaseous molecular components, turbulence, thermal blooming, water droplets, fog, and meteorological phenomena affect laser propagation. LIDAR collection is severely hampered when the beam transits rain, mist, haze, or clouds, to the point that LIDAR collection is not possible through a solid overcast cloud layer. Regarding near-infrared (NIR) at 1064 nm as compared to visible light at ≈ 532 nm, the 1064 nm NIR exhibits superior atmospheric transmission characteristics and a better differentiation from solar background noise.[154]

(U) 1064 nm Laser Safety

(U) Exposures of the cornea, pupillary area, lens, or retina to the laser beam at less than the eye safety Nominal Ocular Hazard Distance (NOHD) will likely cause eye damage. In addition to direct illumination, exposure to reflected laser light at short distances may be hazardous. Thermal skin burns are possible at short ranges.

(U) The eye is vulnerable to laser radiation and may suffer damage from a direct or reflected beam. Laser wavelengths less than 400 nm (ultraviolet) or greater than 1400 nm (short wave infrared) can cause burning or cataracts on the cornea and lens. Water

[154] (U) David J. Harding, *Swath Imaging Multi-Polarization Photon-Counting Lidar,* NASA Goddard Spaceflight Center, URL: <http://www.grss-ieee.org/wp-content/uploads/lectures/Harding_Wed_IGAR _presentation_08/Presentation_Files/index.html>, accessed 15 October 2010.

absorption in eye tissue and the intraocular fluid blocks light at wavelengths longer than 1400 nm from reaching the retina, the part of the eye most vulnerable to laser damage.[155] However, laser wavelengths from 400 nm to 1400 nm can penetrate the eyeball and cause burns on the retina. Infrared lasers are particularly hazardous, since the body's "blink reflex" response is triggered only by visible light. Personnel exposed to a high power Nd:YAG laser emitting invisible 1064 nm radiation may not feel pain or notice immediate damage to their eyesight. A pop or click noise emanating from the eyeball may be the only indication that retinal damage has occurred, i.e. the retina was heated to over 100° C resulting in localized explosive boiling accompanied by the immediate creation of a permanent blind spot.[156] The extent of ocular damage is determined by laser wavelength, power, incidence angle, pulse repetition rate, and exposure duration. Space-based LIDAR operations do not pose a danger to personnel in the laser beam footprint on the Earth's surface. However, airborne LIDAR operations may pose a threat to personnel exposed to laser light. The eye-safe altitudes for airborne LIDAR operations are dependent on laser scanning angle, beam power, scan rate, pulse repetition rate, beam divergence, and atmospheric transmissivity.

[155] (U) Jeff Hecht, "Retina-Safe Wavelengths Benefit Open-Air Applications," *Laser Focus World* (March 2008), 89, URL: <http://www.optoiq.com/index/photonics-technologies-applications/lfw-display/lfw-article-display/322036/articles/laser-focus-world/volume-44/issue-3/features/photonic-frontiers-eye-safe-lasers-retina-safe-wavelengths-benefit-open-air-applications.html>, accessed 15 January 2011.

[156] (U) Lan Hsin Chuang, "A Traumatic Macular Hole Secondary to a High Energy Nd:YAG Laser," *Opthalmic Surgery and Lasers* 32, 73(2001), URL: <http://www.biomedexperts.com/Abstract.bme/11195748/A_traumatic_macular_hole_secondary_to_a_high-energy_Nd_YAG_laser>, accessed 28 November 2009.

(U) Target Reflectivity and Atmospheric Effects

(U) Reflectivity is defined as the ratio of the transmitted incident laser energy as compared to the reflected laser energy received from the target surface. Reflectivity varies with the incident laser wavelength and target composition. The target must exhibit sufficient reflectance to return a detectable signal to the receiver sensor. Factors affecting the strength of the reflected signal at the detecting sensor include the power of the laser pulse transmission, the transmissive affects of the atmosphere on the outgoing laser pulse, the reflectance of the target, and the transmissive affects of the atmosphere on the weaker reflected laser pulse on the return trip to the sensor. Using a 900 nm wavelength laser, reflectivity value of snow may be 80-90 percent, while a black rubber tire wall may reflect only 2 percent of the incident energy.[157] The power level of the reflected signal at the detector may be many orders of magnitude less than the original transmitted signal strength. The echo or backscatter detector must be able to register the faint reflected signal and discriminate it from background noise. The capability to detect the backscatter return signal is a critical factor for space-based LIDAR.

(U) The Nd:YAG laser notionally transmits a near-infrared 1064 nm beam, and the LSU receiver sensor is optimized to detect the same reflected signal. Diffraction grating or filters screen incoming energy to allow the laser transmitter frequency energy to reach the detector elements. However, undesired anomalous backscatter noise is present in solar radiation. The return signal, or backscatter reflection, passes through a UV sunlight filter that decreases the amount of near-infrared energy introduced by the

[157] (U) Claus Brenner, *Aerial Laser Scanning*, International Society for Photogrammetry and Remote Sensing (ISPRS), URL: <http://www.photogrammetry.ethz.ch/summerschool/pdf/08_Brenner_ aerial_ scanner.pdf>, accessed 27 November 2009.

sun. This simple noise mitigation filter is a method to reduce dark current. The unwanted solar noise would otherwise raise the noise floor, degrade the signal-to-noise ratio, and decrease the overall performance of the LIDAR detector system.

(U) Small amounts of background noise may be introduced by moonshine, or even by the action of high energy protons and electrons in the solar wind reacting with the mesosphere and thermosphere. Due to the effects of the Earth's magnetosphere, interaction of the solar wind and the ionosphere is funneled near the Earth's poles, as evidenced by Aurora Borealis and Aurora Australis. Nitrogen, oxygen, and krypton emissive spectra lines are present at 1063.955 nm, 1064.137 nm, 1064.398 nm, and 1064.472 nm.[158] The frequency of the emitted photons depends on a specific atmospheric gas and its electrical state, and on the energy of the particle that hits the atmospheric gas. Depending on the performance of sensor narrowband filters that are installed to reduce or eliminate sunlight or other sources of optical noise, the spurious energy could possibly add to background noise. Operators using single photon Geiger-mode avalanche photodiodes for space-based LIDAR operations should consider orbital kinematics and satellite ephemeris data to account for sun illumination and solar activity to reduce the effects of undesirable background noise at the baseline detector sensor frequency.

(U) Collection Geometry

(U) For an airborne LSU, a direct nadir shot may optimize returns for digital surface models, but the strategy for VO detection is supported by off-nadir shots with a

[158] (U) National Institute of Standards and Technology, NIST Atomic Spectra Database Lines Form, URL: <http://physics.nist.gov/PhysRefData/ASD/lines_form.html>, accessed 7 January 2010.

graze angle. LIDAR test collection data for VO detection performed by University of Florida and Optech, Inc. revealed that a 20° tilt, or forward look angle produced the best results for specular and lambertian[159] reflectance from VOs.[160]

Also, the National Oceanic and Atmospheric Administration (NOAA) Scope of Work (SOW) for Airport Surveying identifies procedures for collecting LIDAR data in support of airport obstruction surveys. The NOAA SOW states that LIDAR data acquisition should consider utilizing multiple look angles (nadir and 20° forward) or different viewing geometries to achieve a high probability of VO detection. A forward look angle yields stronger geometry by producing a higher point density on vertical objects and increases the return signal strength by illuminating more reflective surface of a VO. These phenomena increase the probability of VO detection and reduce false alarms.[161]

(U) For optimum VO detection, LIDAR collection parameters should have sufficient point density to ensure uniform coverage. The horizontal footprint spacing or density of laser points on the target area of interest will affect the probability of detection. The NOAA SOW collection parameters mandate that horizontal point spacing, both across track and along track, must not exceed 0.18 meters. When considering z-axis

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[159] (U) Specular reflectance produces a mirror-like reflection when incident angle ray equals reflected ray angle. Lambertian reflectance refers to the apparent brightness or luminosity of a surface that is equal (isotropic) from all viewing angles.

[160] (U) Christopher Parrish, and others, “Airbone LiDAR Technology for Airspace Obstruction Mapping,” *Earth Observation Magazine*, June/July 2004, URL: <http://web.archive.org/web/ 20061 110114926/www.eomonline.com/Common/Archives/2004junlul/04junjul_Airborne.html>, accessed 16 November 2009.

[161] (U) Department of Commerce, Remote Sensing Division, *Light Detection and Ranging (LIDAR) Requirements*, Scope of Work For Airport Surveying under the NOAA Aeronautical Survey Program, 7, URL: <www.ngs.noaa.gov/RSD/AirportSOW.pdf>, accessed 16 November 2009. Cited hereafter as “NOAA, *Lidar*.”

parameters, for scan angles other than nadir, the vertical point spacing must not exceed 0.5 meter. Additionally, SOW standards require ≥30 points per square meter.[162] To achieve such point densities, multiple parallel and cross perpendicular collection passes may be needed. This point density requirement could conceivably be attained by the JAUDIT system in one pass, which would increase accuracy and decrease costs. Adapting the JAUDIT gimbaled LSU to fulfill SOW requirements offers a potential solution to collect VOs with greater efficiency. To attain such point densities from LEO presents challenges when considering satellite ground track velocity, LSU scanning and pointing capabilities, laser pulse characteristics, and foot print size.

(U) Assisted VO Feature Extraction

(U) The analysis of LIDAR data in conjunction with co-registered EO imagery presents a synergistic dataset for conducting VO extraction. Pixel analysis is used to identify shapes to create VO artifacts. The developing assisted-VO-feature-extraction software programs are the initial step towards the goal of automatic feature extraction.

(U) Imagery diversity

(U) LIDAR offers advantages over the exclusive use of conventional Electro-Optical (EO) and Synthetic Aperture Radar (SAR) photogrammetry for the detection of VOs. Airborne LIDAR systems that can utilize co-registered, geo-referenced imagery for collection operations can take advantage of the complementary characteristics of the EO,

[162] (U) “NOAA, *Lidar*,”.11.

SAR, and LIDAR imagery spatial data. LIDAR exhibits superior vertical z-value data, while photogrammetric mensuration is superior for determining planimetric, or two dimensional (no relief), attributes. LIDAR data has been described as "Weak in positional information; difficult to extract semantic information" by Dr. Ayman Habib.[163] However, the Quick Terrain Modeler™ (QTM) LIDAR program offers exploitation tools for enhanced point cloud analysis and depiction that include user-defined input for point size variability, altitude coloration, ambient and direct lighting control, temporal variable shadow display, line of sight analysis, slope analysis, and contour line depiction. In comparison with basic LIDAR imagery, EO imagery is relatively rich in degrees of scale for attributes such as contrast, chromatic saturation, hue, color, graininess, and resolution. However, the advanced features of QTM allow LIDAR to be displayed with these EO imagery attributes

(U) VO feature identification is enhanced by using LIDAR point cloud data in conjunction with geo-referenced imagery to verify features in all datasets. Through this multi-sensor fusion, applying hybrid photogrammetric techniques to imagery and LIDAR data can improve VO detection and classification capability, and provide increased accuracy and resolution for VO data.

(U) Point Cloud Analysis

(U) By comparing adjacent pixel's z-values for LIDAR data and intensities within a nominal 3 x 3 kernel, edges can be defined along discontinuities. By comparing the center pixel with the surrounding pixels, an edge value can be assigned. The gradient based comparison values that exceed a set threshold are classified as an edge. This edge

[163] (U) "Laser Ranging," 373.

detection can be used to compose shapes that define edges, faces, and vertices. From these basic shapes, further processing is used for feature extraction and object segmentation. These derived shapes are then compared to topographic and geometric values contained in a VO feature extraction library, to be used for assisted or automatic feature extraction.

(U) Software tools are available to process LIDAR point cloud data to automatically identify the location and height of potential VOs. The refined data can be imported into the Quick Terrain Modeler™ 3D point cloud and terrain visualization software package.

(U) Princeton University scientists are developing algorithms that may be adopted to locate, segment, extract, and classify VOs.[164] By utilizing a multi-axis view of potential VOs, one can extract and compare the segmented item of interest with a feature model library for classification.

(U) Defense Advanced Research Projects Agency (DARPA) scientists are conducting efforts to develop automatic feature extraction algorithms that ingest and analyze LIDAR point cloud data. VOs can broadly be defined as exhibiting a specified height to area ratio.[165] Through the examination of VO size, shape, texture, shadow, spectral qualities, and geometric and topological elements, algorithms seek to label classes of objects such as buildings, bridges, cranes, power lines, towers, and pylons. Geometric elements for analysis include perimeter, area, intersecting angles, orientation,

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[164] (U) "Feature Extraction," 3.

[165] (U) David Opitz and others, "Automated 3-D Feature Extraction From Terrestrial and Airborne LIDAR," Visual Learning Systems, Inc, 5, URL: http://www.isprs.org/proceedings/XXXVI/4-C42/Papers /12_Object-based approach generic issues 0ICI/OBIA2006_Opitz_Rao_Blundell.pdf, accessed 3 March 2010.

and location. Topological elements are analyzed for sets of relationships that indicate how faces, edges, and vertices are interconnected.[166]

(U) URGENT program

(U) Efforts for automated feature extraction are also being addressed by the DARPA Information Processing Techniques Office through the Urban Reasoning and Geospatial Exploitation Technology (URGENT) program.[167] URGENT seeks to use co-registered LIDAR and EO imagery to document the locations, shapes, and classifications of objects. Traditional pattern recognition systems, biologically inspired computer vision technology, and machine learning algorithms are among the approaches of interest to the URGENT program.[168] Analyzing a feature-rich urban area is a time-consuming, labor intensive process. URGENT seeks to first enact an assisted feature extraction and eventually develop automatic feature extraction. Current testing involves selecting a region of interest to extract, such as a building, to serve as an example for the desired feature. The object-finding function of URGENT identifies additional extracted features similar in nature to the example, and the analyst provides positive or negative feedback on those extracted features. The analyst's feedback is used to teach the program to adjust the object recognition parameters for extraction. The further development of the assisted feature recognition capability will lead to automatic feature recognition. The mature

[166] (U) "Laser Ranging," 486.

[167] (U) Todd Hughes, DARPA, *Urban Reasoning and Geospatial Exploitation Technology*, URL: <http://www.darpa.mil/ipto/solicit/baa/BAA-07-13_PIP.pdf>, accessed 31 January 2010. Cited hereafter as "*URGENT*."

[168] (U) "*URGENT*," 5.

URGENT program is planned to be assimilated by NGA for the production of timely, accurate, and relevant GEOINT.

(U) Manual VO detection and feature extraction currently performed by a limited number of analysts will not meet future customer requirements for DVOF currency, quantity, and quality. The automatic processing of LIDAR data for detection, localization, and classification of VOs must be developed and exploited to meet future requirements for the DVOF. As the DVOF minimum AGL height reporting requirements continue to shrink from 150 feet to 60 feet, the increasing volume of LIDAR and EO data will require the use of some form of assisted or automated analytic tools to support the exponential rise in reported VOs. The rise in reportable VOs will also require additional collection capability to accommodate more stringent data currency requirements.

(U) Exploiting LIDAR

(U) Higher vertical and horizontal accuracies are achievable with increased resolution due to denser footprint spacing, shorter wavelength of illuminating energy, and the ability to fully exploit the latest LAS format dataset. The accuracy of older DEM datasets is not even close to the typical LIDAR accuracy.[169] LIDAR has been used for airborne digital elevation mapping to derive digital elevation models, bare Earth and reflective surface models, topographic features, and hydrographic and bathymetric data. The adaptability of LIDAR allows the user to adjust the performance characteristics of the system to optimize desired collection parameters. LIDAR characterization features that are available for exploitation not only include the measurement of time, phase,

[169] (U) "Laser Ranging," 248.

frequency, and amplitude, but also light polarization. The de-polarization of the reflected laser energy is a function of the amount of topical surface scattering versus penetrating volume scattering that occurs during reflection of plane-polarized laser light. The Airborne Laser Polarization Sensor and the Swath Imaging Multi-polarization Photon-counting Lidar (SIMPL) developed by NASA demonstrated the ability to differentiate needle-leaf and broad-leaf tree species based on 532 nm and 1064 nm de-polarization.[170] This capability would be useful for detection and possible classification of VOs based on analysis of de-polarized backscatter returns.

(U) Airborne LIDAR Backscatter Characteristics and Analysis

(U) The full waveform analysis technique has been used to extract maximum information from a conventional LIDAR collect. An important development for waveform analysis is the digitization of the analog backscatter return. This technique will be exploited in advanced LIDAR systems.

(U) Full Waveform Analysis

(U) The combination of range information from the LSU, orientation data from the IMU, and position data from the DGPS produce a coordinate frame of reference that results in a vector to define the (x, y, z) location of the reflected target. Using an IMU

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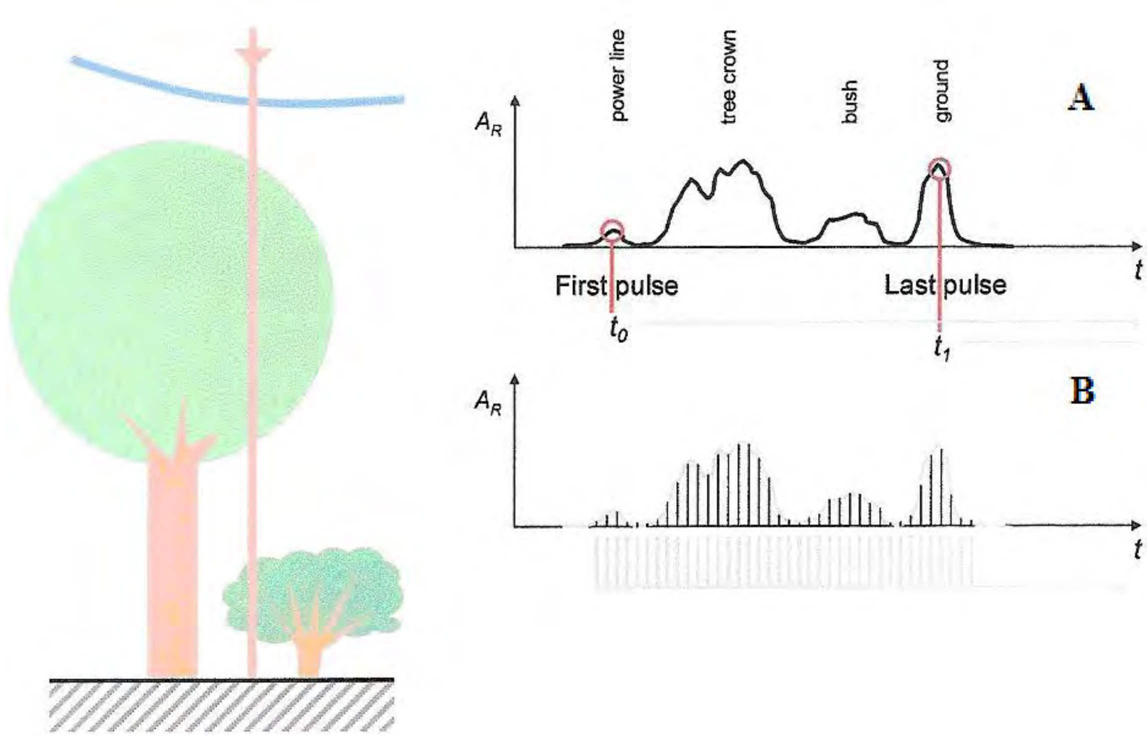
[170] (U) David Harding and others, *The Swath Imaging Multi-polarization Photon-counting Lidar(SIMPL): A Spaceflight Prototype*, NASA Goddard Space Flight Center, Greenbelt, MD, URL: <http://www.igarss08.org/Abstracts/pdfs/2378.pdf>, accessed 15 January 2011.

and a scan angle measurement, the pitch, roll, and yaw of the LSU mounted on the airborne platform is determined. The LSU position for each individual laser pulse is recorded using a combined solution derived from a DGPS trajectory and the IMU inputs. A laser optical detector detects reflected photons. The detector employs narrow bypass filters to block detection of energy at all wavelengths other than that of the LSU laser. A photodiode detector converts the photons into an electrical current. The current is registered as a return that is recorded and attributed to form a data element that comprises the point cloud data.

(U) Target characteristics extracted from a waveform include range, elevation variation, and reflectance, which correspond to waveform attributes of time, width, and amplitude. Each laser pulse has unique data attributes, and each backscatter or echo return signal has properties dependent on energy of the transmitted pulse, distance to target, reflectance of the target, transmission properties of the atmosphere, area of the receiver focal plane array, and amplification gain of the receiver.

(U) In a discrete return analog detector system, the received signal is converted from backscatter optical laser light energy (photons) into an output voltage that gives signal strength (amplitude) as a function of time. When comparing elapsed time on the x-axis with backscatter signal strength on the y-axis, the resultant data is used for full-waveform exploitation. The initial LIDAR operating parameters for analog ranging utilizing high power lasers involved single profile footprints collected in an along-track scan.



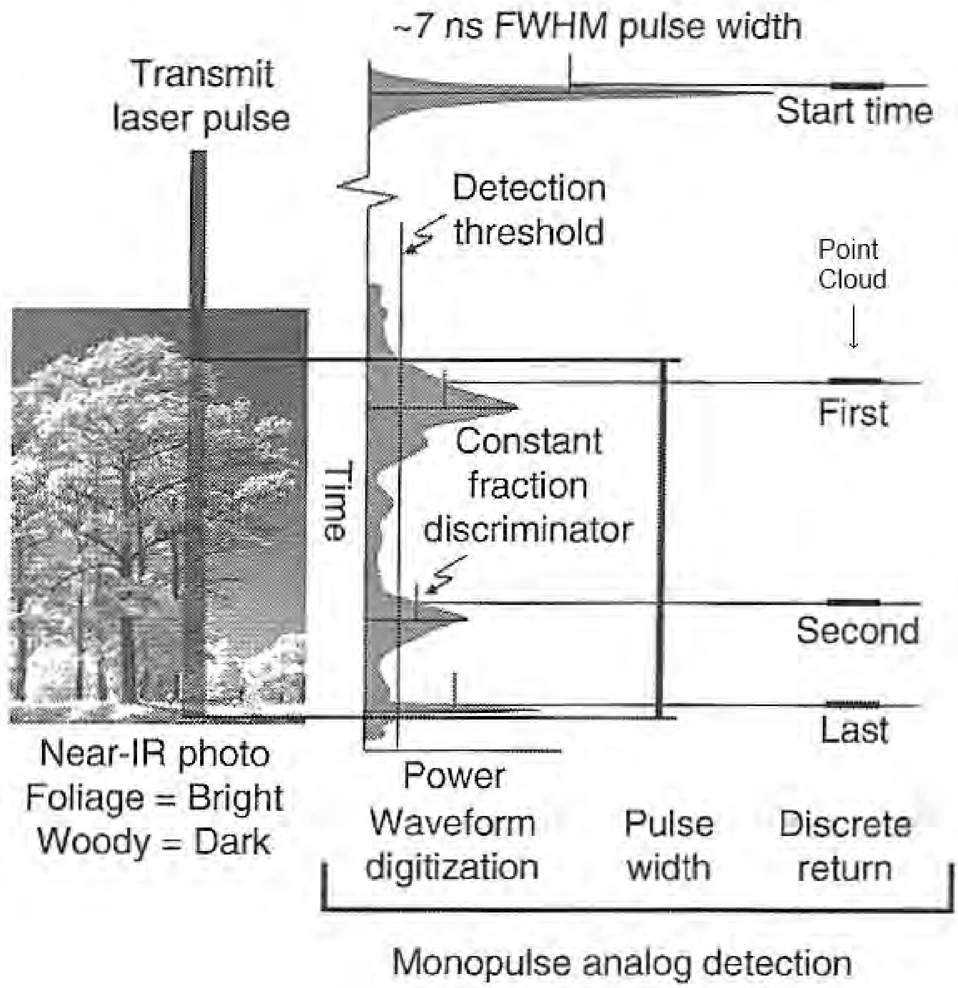
(U) Figure 5-4. Ranging: Full Waveform Analysis

(U) Source: Claus Brenner, *Aerial Laser Scanning*, International Summer School "Digital Recording and 3D Modeling", Aghios Nikolaos, Crete, Greece, 24-29 April 2006

(U) In Figure 5-4, the backscatter first return indicates the range to the powerline, a second peak is indicative of an intermediate return from the tree crown, the third return indicates a return signal from the bush, and the last return indicates the furthest backscatter return from the ground. Further developments in waveform digitization allowed detection and discrimination of multiple vertically distributed targets within the footprint, as displayed in graph B.

(U) The Optech ALTM 3100EA has the capability to record up to 4 range measurements per return pulse. The LSU receiver captures multiple backscatter reflections from objects that are within the footprint at different ranges. By analyzing the full backscatter return waveform, it is possible to determine the strength of the return and classify surface properties. The full waveform pulse width, amplitude, and temporal displacement are measured to determine range, reflectance, and surface roughness. For example, a backscatter return exhibiting pulse broadening would be indicative of a rough surface.

(U) One of the cross sectional pulse analysis techniques used to determine range and amplitude values utilizes the Full Width at Half Maximum (FWHM) method, which measures the reflected signal pulse width at half the maximum amplitude to determine pulse duration. As depicted in Figure 5-5, the constant fraction discriminator method establishes a defined value for measuring the reflected pulse at a constant fraction of the peak pulse amplitude to derive range. Other schemes available for waveform analysis are peak detection, leading edge detection, and center of gravity detection.

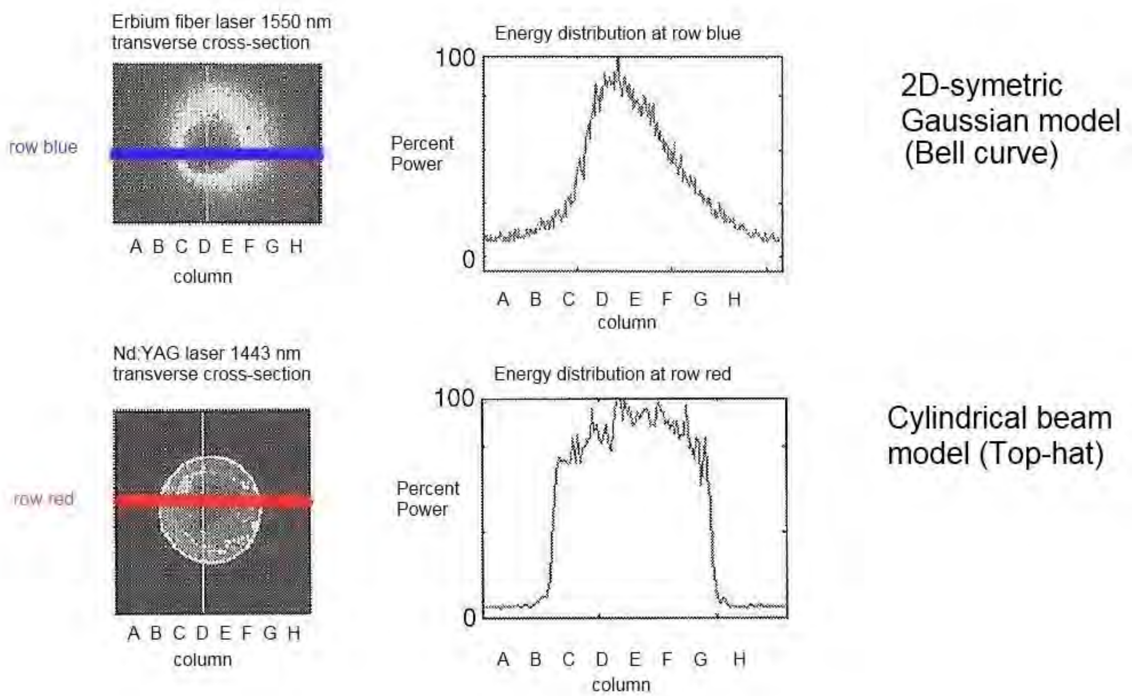


(U) Figure 5-5. Waveform Laser Ranging

(U) Source: Jie Shan and Charles K. Toth, *Topographic Laser Ranging and Scanning: Principles and Processing* (New York: CRC Press, 2009), 179.

(U) Beam spatial energy distribution model

(U) As depicted in Figure 5-6, the transmitted laser spatial energy distribution, or beam profile within the footprint, is not homogenous. Incident laser energy distribution within the footprint may be modeled by a cylindrical (top-hat form) distribution or a two dimensional Gaussian (bell curve) distribution.[171] This energy distribution model can be used to further refine analysis of backscatter data. The backscatter return signal amplitude will be proportionally related to the spatial distribution of the incident laser energy illuminating the footprint. Full waveform analysis of backscatter return should accommodate the variance of incident laser energy based on beam profile characteristics.



(U) Figure 5-6. Spatial Energy Distribution

(U) Source: Jie Shan and Charles K. Toth, *Topographic Laser Ranging and Scanning: Principles and Processing.* (New York: CRC Press, 2009), 222.

[171] "Laser Ranging," 222.

From the perspective of airborne LIDAR collectors operating in the atmosphere, the culmination of advanced full waveform digitization and analysis techniques will support the detection and classification of VOs.

(U) Incorporating LIDAR as GEOINT

(U) NGA has promulgated an InnoVision Program Plan for Light Detection and Ranging (LIDAR) to define the programmatic approach for NGA's participation in the use of LIDAR. LIDAR has the capability to support the VO program and should be exploited. An example of using LIDAR for VO data is the Richmond LIDAR collect.

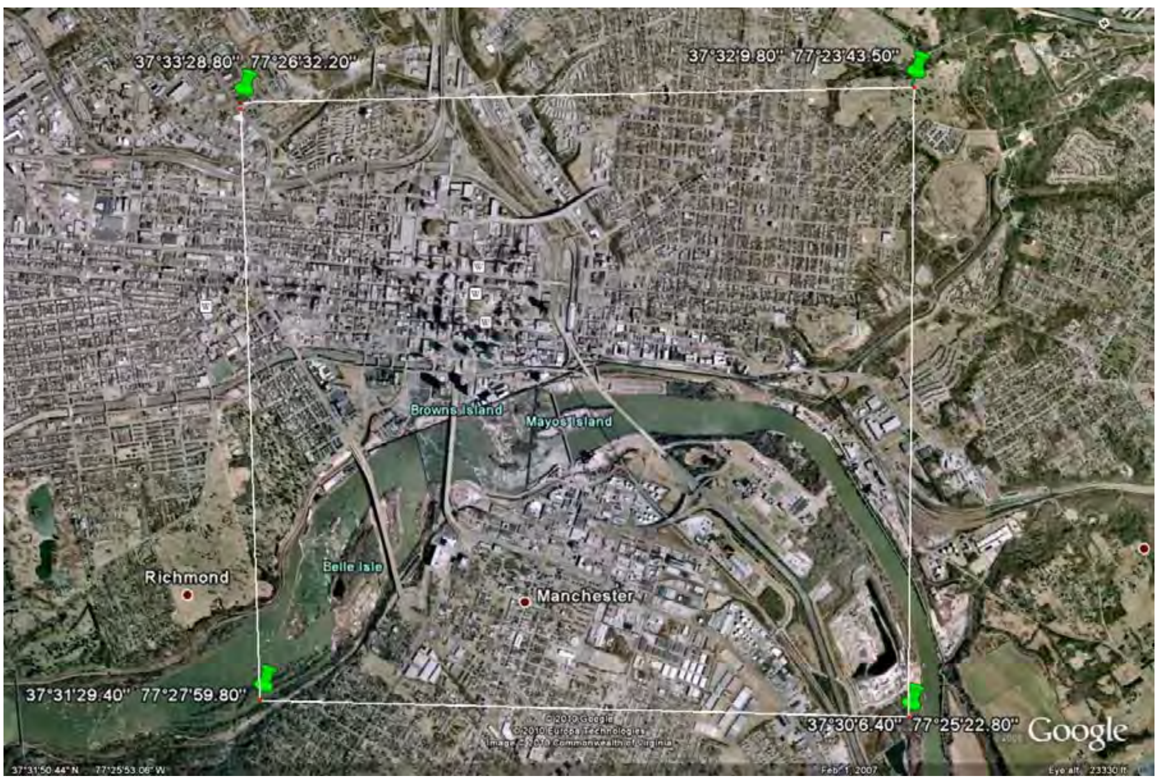
CHAPTER 6

(U) A practical application of using LIDAR for VO collection was illustrated through the Richmond LIDAR collect. VO data manually derived from LIDAR point cloud data viewed with QTM was analyzed for deviation from DVOF, and possible explanations for differences in data were proposed. Additionally, an assisted VO data extraction and analysis was performed using the PC_VO tool software program. The PC_VO tool automatically documents VOs for further examination using co-registered EO imagery using QTM.

(U) Richmond LIDAR Collect

(U//~~FOUO~~) On 14 and 16 January 2009, through the joint efforts of NGA and the John Hopkins University Applied Physics Laboratory (JHUAPL), LIDAR data was collected over Richmond, Virginia, in a Beechcraft King Air A90 using a modified Optech Airborne Laser Terrain Mapper (ALTM) 3100D. The collection flights were planned using altitude, speed, swath-width and swath-overlap to provide the desired data density (longitudinal down-track and lateral cross-track footprint spacing effecting sample resolution) of the region of interest (ROI). The collection area was defined by the bounding box 373328.8N 0772632.2W, 373209.8N 0772343.5W, 373006.4N 0772522.8W, and 373129.4N 0772759.8W, which encompassed 20 km^2 and is depicted in Figure 6-1.

(U//~~FOUO~~) The flight track scan strip dimensions were typically 4500m x 275m. The author examined 31 flight track collections that were flown on a longitudinal axis of 010° - 190° and 29 flight track collections that were flown on a longitudinal axis of 100° - 280°. Swath overlap was required to ensure complete coverage of the ROI by accommodating GPS error and pilot-induced error. Sixty flight track strips were reviewed to identify DVOF VOs in order to compare LIDAR versus DVOF geodetic coordinates and AGL height values. The coverage provided by the North-South and East-West flight strips over the same area provided greater fidelity of LIDAR data for the manual data extraction process. Multiple tracks were simultaneously opened in QTM to increase the point cloud density and improve the visual presentation.



(U) Figure 6-1. Richmond LIDAR Collection Area

(U) Source: Google Earth

(U) LIDAR Operating Characteristics

(U/~~/FOUO)~~ Operating performance of the LSU was upgraded to enhance the JAUDIT LIDAR collection. Depending on GPS/DGPS variables, IMU, and POS performance, the 3D positional accuracy of the LSU could be established within a few centimeters. These variables included a minimum of 6 satellites tracked by the GNSS receivers; satellites positioned at least 10° above the horizon; a DOP value < 4; and the collecting aircraft remaining within 30 km of the DGPS base station.[172] LSU performance included a 9 nanosecond laser pulse and a timer capable of measuring ≤ 30 picosecond intervals. The LSU receiver was capable of detecting up to four return pulses per transmitted pulse. The LSU bi-directional saw-tooth pattern scan frequency was upgraded to 100 Hz. Laser beam divergence for the narrow-beam operating mode was 0.13 mrad, or 0.372 mrad for the wide-beam operating mode. Footprint diameter is listed in Table 6-1 based on flight altitude and LSU operating mode.

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[172] (U~~//FOUO)~~ John Hopkins University, Applied Physics Laboratory, *ALTM 3100D System Specifications,* 2 October 2006, Laurel, MD, Chapter 2, 3. Cited hereafter as “JHUAPL.”

Flight Altitude (m) AGL	Beam divergence (mrad) Narrow / wide	Footprint diameter (cm) Narrow / wide
1000	0.130 / 0.372	13 / 37
2000	0.130 / 0.372	26 / 74
3000	0.130 / 0.372	39 / 111

(U/~~FOUO~~) Table 6-1. Flight Altitude, Laser Beam Divergence, Spot Size

(U/~~FOUO~~) Source: John Hopkins University, Applied Physics Laboratory, *ALTM 3100D System Specifications,* 2 October 2006, Laurel, MD, Chapter 2, 3

(U/~~FOUO~~) Due to a standard linear (no transmit/receive overlap) operating mode, the following performance parameters were available as shown in Table 6-2.

Flight Altitude (m) AGL	Pulse Repetition Frequency kHz	Pulse energy level mJ
1100	100	179
3500	33	69

(U/~~FOUO~~) Table 6-2. Flight Altitude, PRF, Pulse Energy

(U/~~FOUO~~) Source: John Hopkins University, Applied Physics Laboratory, *ALTM 3100D System Specifications*, 2 October 2006, Laurel, MD, Chapter 2, 4.

(U) Laser safety

(U/~~FOUO~~) The Eye Safety NOHD for a single pulse of 179 mJ for the unaided eye was 518 meters, and 2998 meters for an aided eye utilizing a 7x50 pair of binoculars.[173] The LIDAR system was equipped with an automatic shutdown feature to activate within 0.001 seconds when the distance from the collection aircraft to an object was less than the NOHD[174].

[173] (U/~~FOUO~~) "JHUAPL," Chapter 3, 1.

[174] (U/~~FOUO~~) "JHUAPL," Chapter 3, 1.

(U) Manual VO Data Extraction and Analysis

Two separate data extractions and comparisons were performed for defined areas using the DVOF as one source of VO data and the Richmond LIDAR collect as the other source for VO data. Both analyses used co-registered EO imagery and LIDAR point cloud data viewed with QTM for VO processing. The first analysis comprised a manual analysis of DVOF and LIDAR-derived VO data. The second analysis used VOs extracted using the PC_ VO tool program for assisted VO detection. For each data source, the number of VOs collected, height values, and geodetic coordinates were analyzed.

(U) Manual Analysis of Vertical Data for DVOF and LIDAR VOs

(U) DVOF contained 76 VOs within the bounded area defining the Richmond collect. Appendix H contains a list of the VOs captured in DVOF. Thirty-five of these 76 obstructions were manually examined. The VOs, consisting of 20 buildings, 10 power pylons, 3 towers, and 2 smokestacks, were compared to analyze AGL height and geodetic coordinate values obtained from DVOF and LIDAR source data. The data gathered from the comparison of the DVOF and LIDAR source data for the 35 selected VOs is presented in Appendix I.

(U) DVOF AGL height greater than LIDAR AGL height

(U) Of the 35 VO entries examined, 13 VOs listed the DVOF height an average of 24 feet greater (standard deviation 24.8 feet) than the measured LIDAR height. Ten of twenty buildings registered a DVOF AGL height greater than the measured LIDAR AGL height. The AGL height differences may be due to the method used to obtain the base terrain measurement and the top-of-building measurement. A building AGL height on sloping ground is dependent on the ground level value that is used as the base measurement. On sloping terrain, a building may have different ground level MSL values depending on the method used to obtain the ground level. For a point base height measurement, the value may be obtained around the periphery of the building footprint. Many buildings in the Richmond urban area are located on hilly, sloping terrain. The uphill side of a building may not have as great of a vertical extent as the downhill side of a building. A base height value may also be calculated by averaging the footprint bare Earth height of the building footprint. These two different methods for obtaining base height may yield different values. In a built-up urban area, a structure may be situated on a pedestal, support base, pad, or any number of foundational objects that complicate the definition of bare Earth used to define an MSL value within a specified distance from the base of the VO.

(U) The maximum HaE value defines the top of a VO. Generally, the top-of-building pixels are more clearly discernable and defined than the base-of-building ground pixels. However, in some instances, the pinnacle of a tower may present a small cross-sectional area or surface to reflect the laser light back to the LSU for detection. Depending on LIDAR performance parameters, these needle-like targets may be more difficult to detect.

U) DVOF AGL height less than LIDAR AGL height

(U) Twenty-two of the thirty-five VO entries listed the DVOF AGL height an average of 39 feet (standard deviation 39.0) less than the measured LIDAR AGL height. A disparity arises from the generic 79 foot default pylon AGL height value assigned by legacy Digital Feature Analysis Data (DFAD) documented in DVOF. DFAD has not been updated since 2001. In ten of ten cases, the LIDAR measured pylon AGL heights were greater than the DVOF assigned 79 foot default heights. The Boeing Study also noted the same phenomena of the default 79 foot pylon height under-reporting the true pylon height.[175] Examination of stand-alone poles, smokestacks, and tower features (other than DFAD documented 79 feet pylons), revealed that DVOF AGL height values were more consistent with LIDAR AGL height values. Unambiguous mensuration, with obvious base and top measurements, yielded like values from LIDAR and DVOF data.

(U) In the case of 10 of 20 buildings documented, DVOF AGL height was less than LIDAR AGL height. The lesser height could be due to the installation of communication towers, flag poles, equipment or utility structures on roof tops that were installed subsequent to the original DVOF AGL height entry date.

(U) With the accuracy offered by LIDAR, height measurements are subject to additional factors for consideration. If increased height accuracy is desired, measurements expressed as HaE values eliminate many variables introduced by utilizing MSL values. The precision and accuracy offered by the LIDAR HaE values exceed the data available from DTED Level 2 (sampled at 1 arcsecond ≈ 30 meter post spacing) DEMs used for EO mensuration to determine MSL height calculations. If the increased

[175] (U) "Boeing Analysis," 13.

accuracy offered by LIDAR is not required, VO data format can be adjusted to desired specifications.

(U) FAA/NACO DDOF VO data supplied to the DVOF utilizes the WGS 84 datum for the geodetic coordinate reference system and a mix of NAVD 88 and NVGD 29 vertical datums for height values. However, the application of incompatible horizontal and vertical reference systems can introduce error. The height values should be referenced to the current DoD EGM 96 geoid model for proper MSL values when incorporated into the DVOF.

(U) Analysis of Horizontal data for DVOF and LIDAR VOs

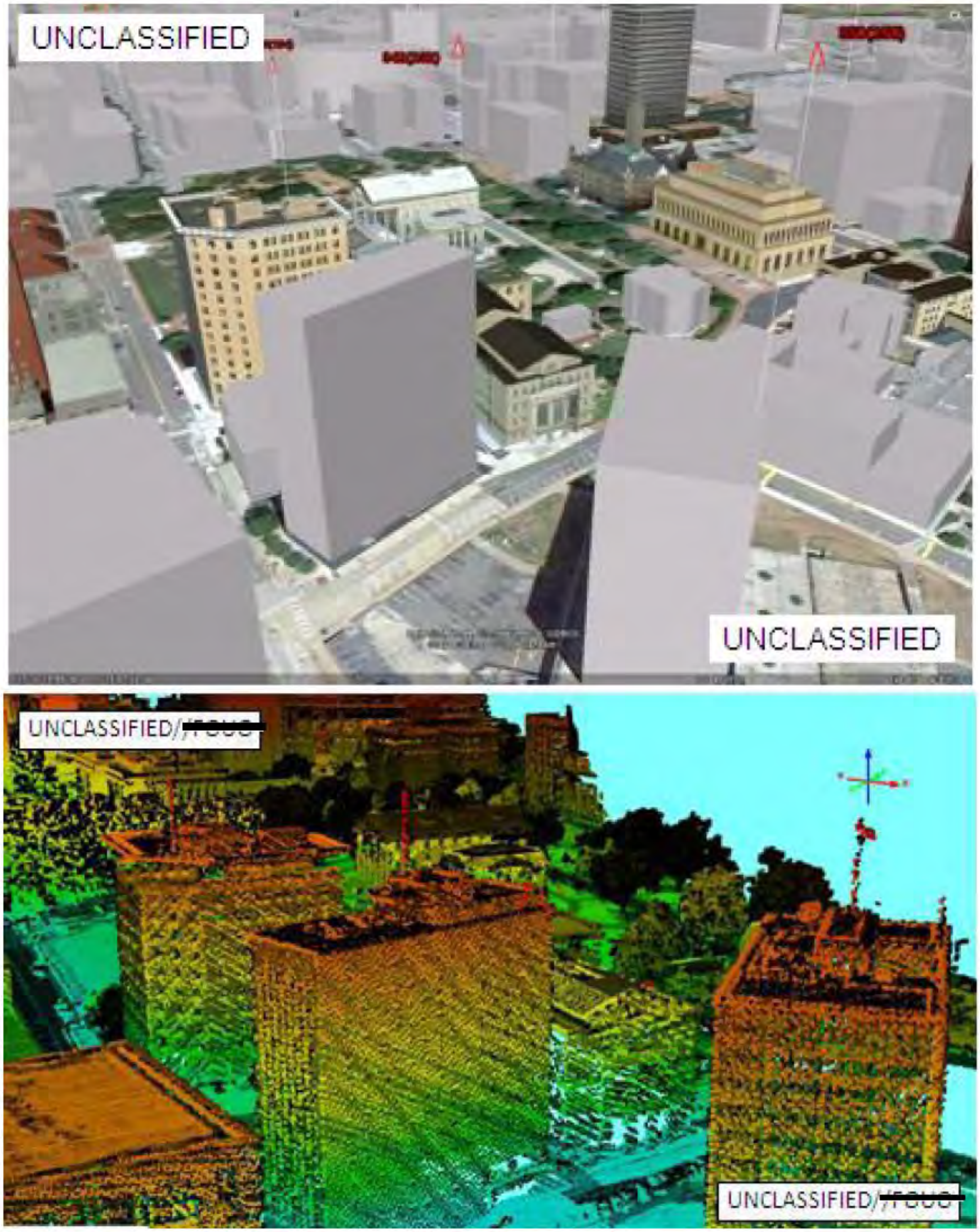
(U/~~/FOUO~~) LIDAR WGS-84 (G1150) coordinate precision was computed to the hundredth of an arcsecond. DVOF coordinate precision was calculated to the arcsecond. Rounding error for the truncated DVOF value will accommodate positional differences of 64 feet. The average observed positional difference for pylons, smokestacks, and towers was 71 feet, which yielded a refined average positional difference between LIDAR and DVOF of 7 feet. The average observed positional difference for buildings was 109 feet, which yielded a refined average positional difference between LIDAR and DVOF of 45 feet. A possible explanation for the greater difference observed between buildings (area targets) vice pylons, smokestacks, and towers (point targets) lies with the observation that point targets generate easily discernable center point coordinates. Area targets have polygonal shapes that can require various strategies to calculate a center point. Symmetrical and irregular polygons may have different methods to determine a center point or centroid. The diversity of building shapes, footprints, and vertical composition could account for the greater positional difference in LIDAR and DVOF data for buildings as compared to point VOs such as pylons, smokestacks, or light poles.

(U) Visual Comparison of EO with LIDAR

(U/~~/FOUO)~~ Figures 6-2, 6-3, and 6-4 illustrate the comparison of Google Earth imagery with LIDAR point cloud images. Figure 6-2 was composed of flight strips 9 and 50, which were flown on 14 January 2009. Figures 6-3 and 6-4 LIDAR point clouds are composites of flight strips 9, 50, and flight strip 40, which was flown on 16 January 2009. The fidelity of the LIDAR graphics were improved by merging point cloud data from different flight strips. The three combined flight strips render a richer dataset than a single flight strip. Figure 6-5 offers a comparison of Pictometry oblique imagery and a composite of five LIDAR flight strips. The ability of LIDAR to detect VOs is exemplified in Figure 6-6 by the three flagpoles on the three building rooftops.

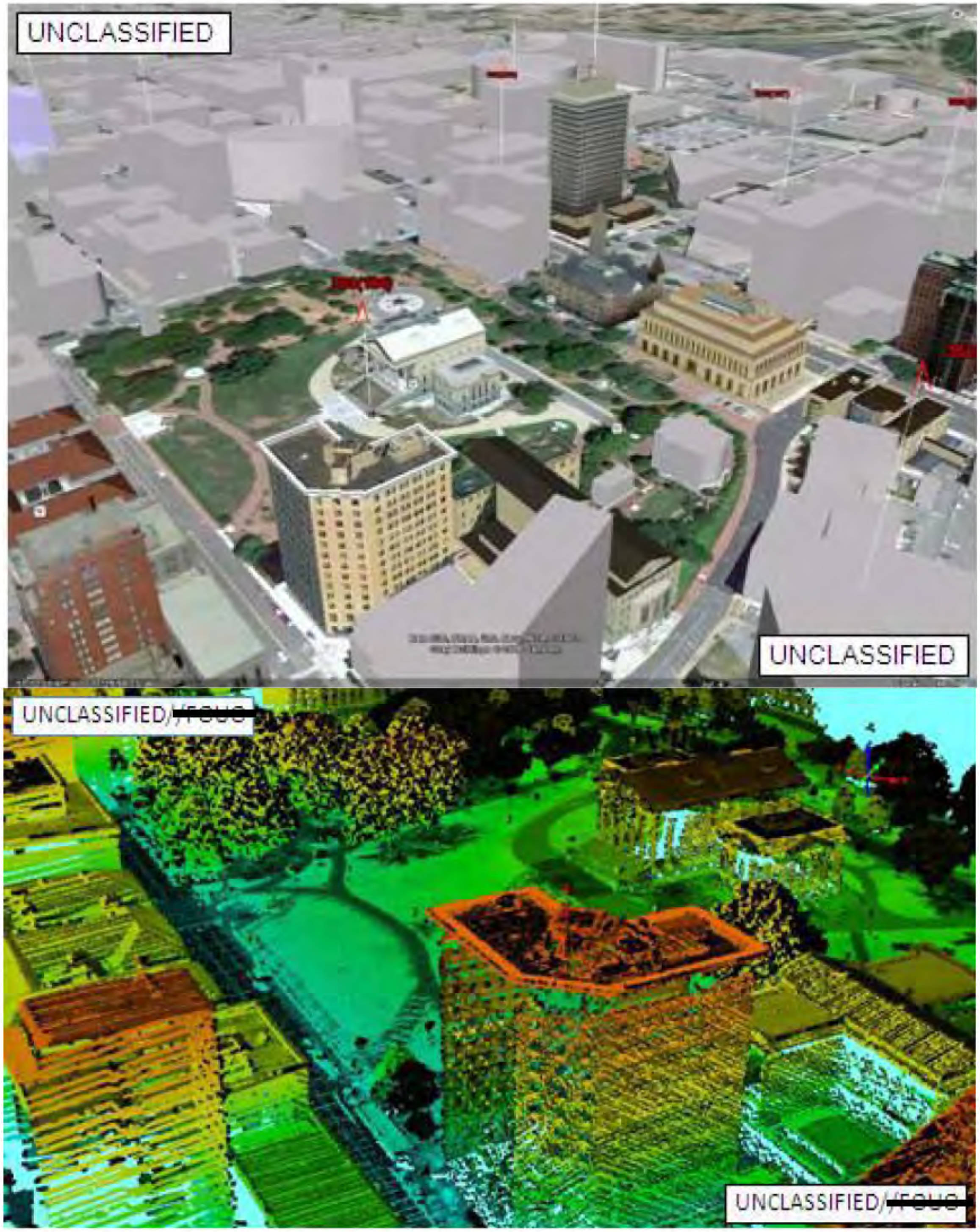
(U/~~/FOUO~~) Figure 6-2. Google Earth-LIDAR: Madison Building

(U) Source: Author's Analysis



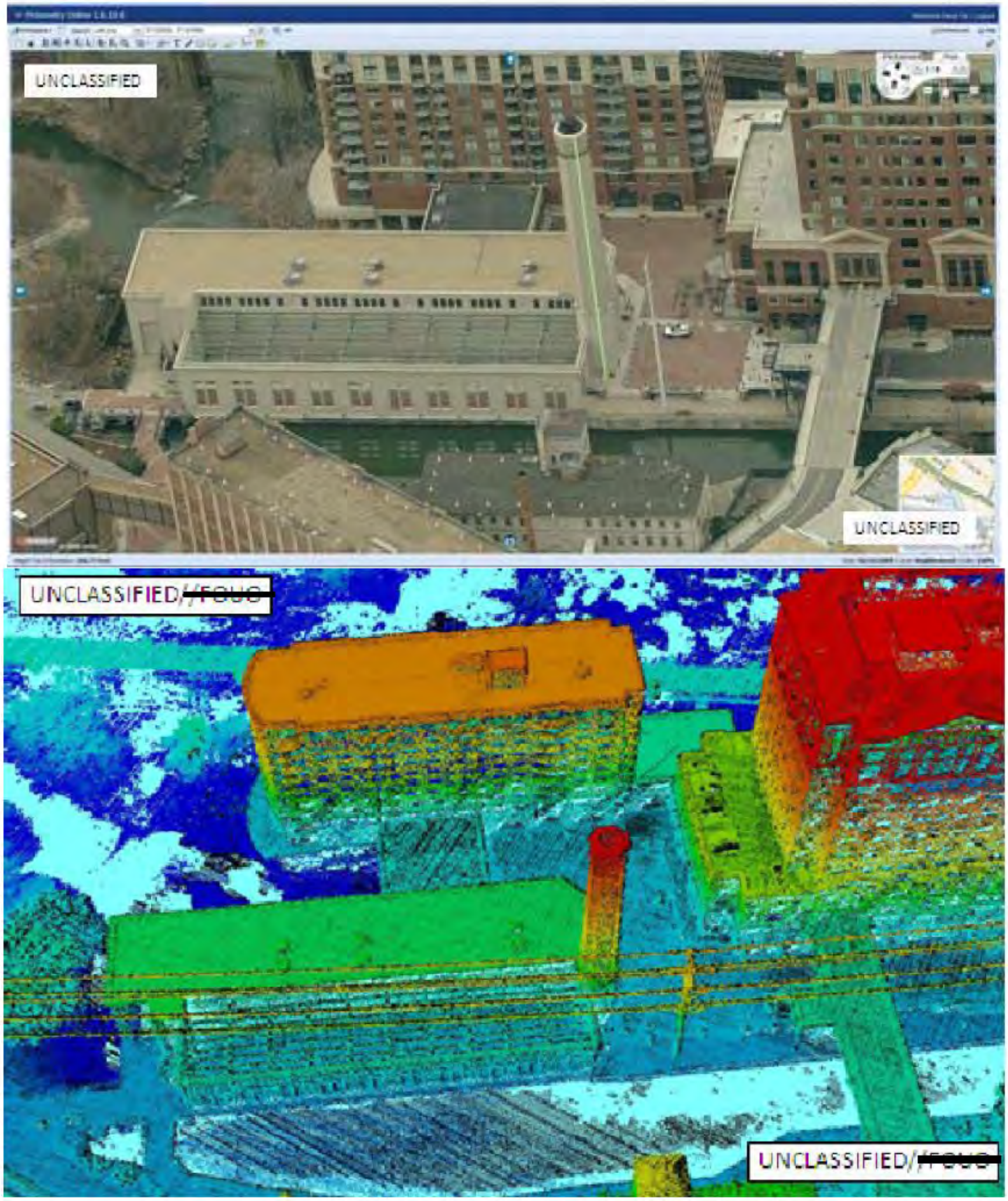
(U/~~/FOUO)~~ Figure 6-3. Google Earth-LIDAR: Jefferson Building

(U) Source: Author's Analysis



(U//~~FOUO~~) Figure 6-4. Google Earth-LIDAR:
Washington Building (front) and State Capital (rear)

(U) Source: Author's Analysis



(U/~~/FOUO~~) Figure 6-5. Pictometry-LIDAR: Brown's Island Powerplant

(U) Source: Author's Analysis

(U/~~FOUO~~) Figure 6-6. LIDAR: Flag Poles on Washington Bldg (l), Jefferson Bldg (c), and Madison Bldg (r)

(U) Source: Author's Analysis

(U) Assisted VO Data Extraction and Analysis

(U) The PC_VO tool program assists the analyst with VO detection and documentation. By setting detection parameters, the analyst can adjust the VO capture capability of the program. Analysis of the VO attributes derived from the point cloud data is used to explain PC_VO tool search results. A search area defined by LIDAR strip 09 was examined to compare VOs detected with PC_VO tool with VOs documented in DVOF.

(U) PC_VO tool Point Cloud Data Analysis

(U) Subsequent to the LIDAR collect and preparation of the LAS files, an analyst must extract the VOs from the data. The NGA LIDAR Program point of contact (POC) Lesley Pearson (NGA-IBE) sponsored the development of a tool for the PC platform to assist in extracting VOs for LAS or other point cloud files. This tool, known as the "PC_VO tool," was developed by Lockheed Martin Space Systems POC (b)(6) [redacted]. The PC_VO tool incorporates algorithms to automatically analyze clusters of points to detect potential VOs. The detected results can subsequently be loaded into another tool, the QTM, which incorporates functionality to assist the analyst in identifying the VO. With the ever evolving state of the art, PC_VO tool strives to attribute every conceivable aspect of LIDAR derived VO data in order to maximize its utility across the spectrum of LIDAR analysis. As shown in Appendix J, ninety-three attributes are assigned to each VO.

(U) The PC_VO tool allows the analyst to adjust several processing parameters. The analyst can specify the VO AGL height and footprint size (cylinder) parameters that are used to identify candidate VOs. The program may be adjusted to maximize the VO probability of detection (POD), minimize vegetative classification of trees as VOs, and minimize the False Alarm Rate (FAR). A search cylinder is used to sample point cloud data within a defined area. Also, the inter-cylinder sample spacing distance can be adjusted to optimize results. To modify the POD, the first return pixel nearest-neighbor-values are adjusted within a defined cylinder search area to set detection threshold values. To reduce outliers and the FAR, the analyst can adjust the nearest neighbor value within a specified cylinder sleeve that envelopes the VOs. By examining the vertical histogram of points in the cylinder, birds or aircraft will display first return pixels without any supporting returns beneath the target, and therefore be tagged as a potential flying object or outlier.

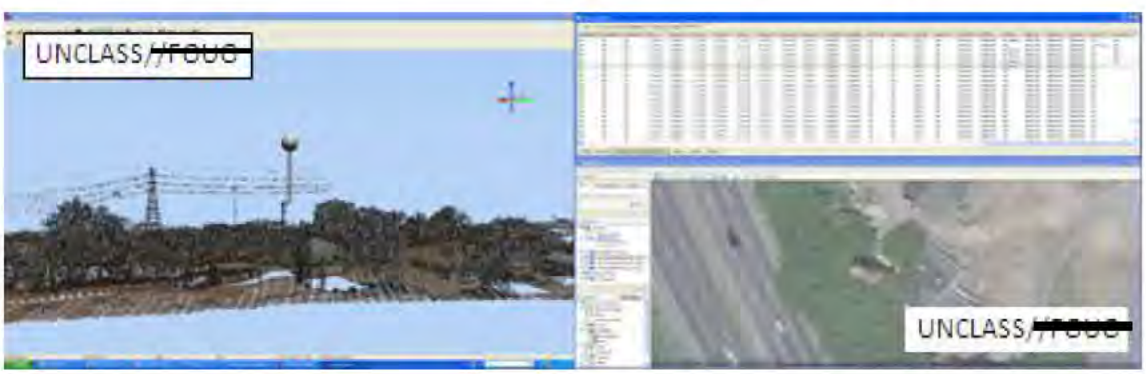
(U) Output can be displayed in any number of formats, such as tab delimited or CSV file. Appendix K contains a list of the 64 VOs that the PC_VO tool program derived from the Richmond LIDAR collect strip 09. Figure 6-7 depicts flight strip 09 crossing Richmond urban center from the northwest to the southeast.

(U//~~FOUO~~) Figure 6-7. Google Earth image with Flight Strip 09 depicted in red

(U) Source: Author's analysis

(U) The military services request that NGA continue to work toward meeting a technical objective to capture 60 feet AGL VOs in support of future mission requirements; therefore, the list contains VOs 60 feet or greater. For the same LIDAR strip 09 area of coverage, the DVOF contained 3 entries: the Washington Building, the Jefferson Building, and the Madison Building.

(U) The PC_VO tool provides the analyst with the data to utilize a multi-view display to examine a LIDAR point cloud concurrently with co-registered imagery. The multi-view display analysis function is a product of Applied Imagery© and its versatile QTM 3-D point cloud and terrain visualization software package. QTM also provides functionality to "drape" ortho-rectified images onto the point cloud to aid in identifying the VO. Possible geo-referenced/ortho-rectified EO imagery providers available for use include NGA, GeoEye, Digital Globe, or Pictometry. Acceptable imagery formats include NITF, Mr SID, GEOTIFF, ERDAS IMAGINE, and ECW. The use of QTM's "Assisted Mode" allows the analyst to sequentially step through each VO marker and concurrently display linked geo-referenced imagery for verification of the VO. In Figure 6-8 below, note the LIDAR Point Cloud marker annotated smokestack on the left side and the same smokestack centered in the Google Earth image in the right side.



(U//~~FOUO)~~ Figure 6-8. QTM LIDAR-Co-registered Imagery Comparison

(U) Source: (b)(6) [redacted], Lockheed Martin Space Systems Company, Waterton, CO, email interview by author, 10 January 2011.

(U) When the User presses the "Advance to Next Uninspected Point" button, the Point Cloud view and Google Earth view automatically advance to display the next VO that requires classification. The ability of QTM to automatically step through VOs and correlate EO for confirmation and classification ensures complete systematic coverage and is a time saver. The confirmation and classification process offers great potential to support the mature URGENT program for object recognition, identification, and automatic feature extraction.

(U) Richmond LIDAR Collect Strip 09

(U/~~/FOUO)~~ The PC_VO tool program was used to document VOs in Strip 09 of the Richmond LIDAR Collect. A phenomenon related to cylinder size and cylinder sample spacing settings was evident with regard to structures with varying heights within a building footprint. As listed in Appendix K, VO numbers 4, 5, 7, and 9 were detected within the footprint of the Madison Building. The four VO markers on the Madison Building are visible in Figure 6-9. Other building structures also registered as multiple VOs. This VO capture scenario occurred in part due to values assigned in the PC_VO tool program.

(U//~~FOUO~~) Figure 6-9. PC_VO tool program documented VOs

(U) Source: (b)(6) [redacted], Lockheed Martin Space Systems Company, Waterton, CO, email interview by author, 10 January 2011.

(U) Attribute Characteristics

(U//~~FOUO~~) As listed in Appendix J, "PC_ VO TOOL LIDAR FILE ATTRIBUTES," item 36 ALGDIAMVOD (algorithm cylinder diameter) was set at 30 meters and item 37 ALGSPACVOD (algorithm cylinder spacing) was set at 20 meters. The ground was measured at different locations with item 19 attribute VODGRDMSLM (VO ground mean sea level metric units) values of 37.51, 30.03, 44.15, and 38.88 meters, respectively. The designated 30 meter diameter search cylinders overlapped by 10 meters due to a cylinder spacing value set at 20 meters. This coverage ensured all VOs were collected, but may have resulted in duplicative reporting. The ground measurement varied within the different cylinder samples by 14 meters. The Madison building is surrounded by walkways, courtyards, and parking lots at varying ground levels. Item 42

ALGCLTRCMP computed local ground clutter height estimated over a slightly larger area than the search cylinder diameter. Item 43 ALGCLTRUSD listed the local ground clutter height used (within the ALGDIAVOD diameter search cylinder area). Item 44 ALGRND3SIG algorithm calculated local ground terrain variation within ±3σ over a slightly larger area. Items 42, 43, and 44 were used to define the ground height. As demonstrated by the example of the Madison building that is located in a developed urban cultural area, establishing ground height can be problematic.

(U) The algorithm parameters can be modified to optimize VO capture in various geographic settings. Topographic features such as flat or hilly terrain, hydrographic features, VO target density characteristics in rural or urban areas, and land cover composition all affect the texture or relief of the vertical profile structure in a search area. The cylinder size and cylinder spacing values can be optimized for VO detection in pre-determined search area classification types. In a high density urban area, a smaller cylinder diameter, coupled with larger cylinder spacing, may be desired. In a low density flat desert area, where a high confidence level for VO detection is required, a large cylinder size with small cylinder spacing may be optimal. Different scenarios require different default cylinder size and spacing values. Additionally, LIDAR point detection sensitivity can be adjusted with item 38 attribute ALGREQDPT1 (algorithm required minimum number of x, y, z points1: above ground clutter height used) and item 39 attribute ALGREQDPT2 (algorithm required minimum number of x, y, z points2: greater than 10 feet above the base surface estimate). Item 40 attribute ALGMEASPT1 (algorithm measured number of x, y, z points1 for this VO: above local ground clutter height used) and item 41 attribute ALGMEASPT2 (algorithm measured number of x, y, z points2 for this VO: total greater than 10 feet above base surface estimate) are indicators of the number of returns or robustness of the point cloud.

(U) Items 45 – 47 attributes ALGHSTNUL1/2/3 are algorithm parameters used to identify the largest gap in the vertical histogram, in 5 meter increments. These values are useful for identifying outliers and reducing the False Alarm rate. Items 48 – 55 attributes ALGREQDV1/2/3/4 (minimum quality value) and ALGMEASQV1/2/3/4 (measured quality value) are algorithm parameters used to establish a quality value assessment for the VO. By integrating the overall attribute values for the VO, confidence metrics are established.

(U) PC_VO tool program offers an important step in establishing an automated VO detection and classification capability. Further development of PC_VO tool program in conjunction with the URGENT program will advance the state of the art to handle the future requirements of the VO program.

CHAPTER 7

(U) With the ability to collect VO data on a world-wide scale, space-based LIDAR offers advantages over conventional airborne collection methods. Advances in LIDAR engineering will enable the development of a LEO VO collection platform.

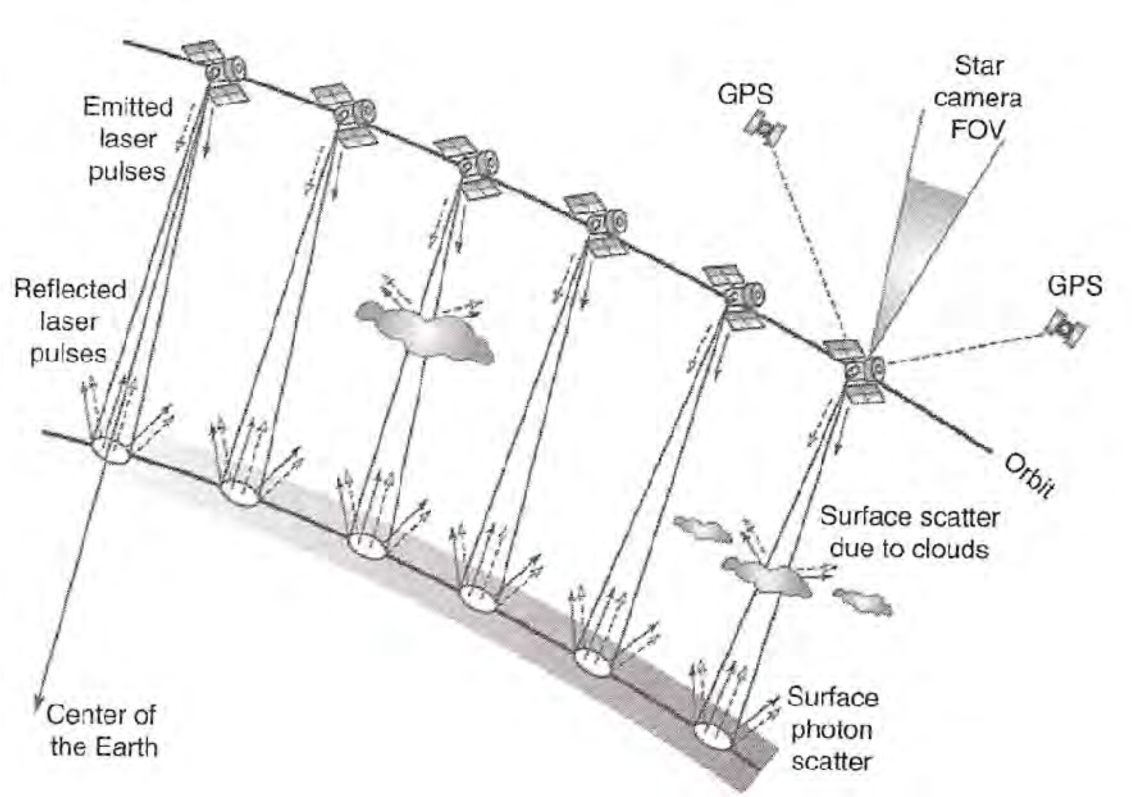
(U) Space-borne LIDAR

(U) The past fifteen years of space-based LIDAR has shown continuous improvement in LSU performance. LSU components; including lasers, optics, POS, and avalanche photo-diode sensor efficiencies, have improved.

(U) In order for a space-based LIDAR to function in the hostile environment of low-Earth orbit (LEO), it must be a compact, rugged, and lightweight design. Figure 7-1 depicts a notional example of space-based LIDAR. The LIDAR package must be able to withstand the stresses of launch, orbital insertion, and the thermal and radiation extremes of the space environment.

(U) The initial use of space-borne LIDAR has been to measure the structure and heights of clouds, aerosols, and dust layers. The remote sensing capabilities of LIDAR have been used to detect water droplets and ice particles in the Earth's atmosphere. The NASA LIDAR In-space Technology Experiment (LITE) was conducted onboard the Space Shuttle Discovery in 1994. The laser, emitting ultraviolet (355 nm), visible green light (532 nm), and infrared (1064 nm) pulses, produced a 290 m diameter footprint on the Earth's surface. LITE collected data on atmospheric particulates, suspended aerosols, cloud composition, and environmental pollution concerns.

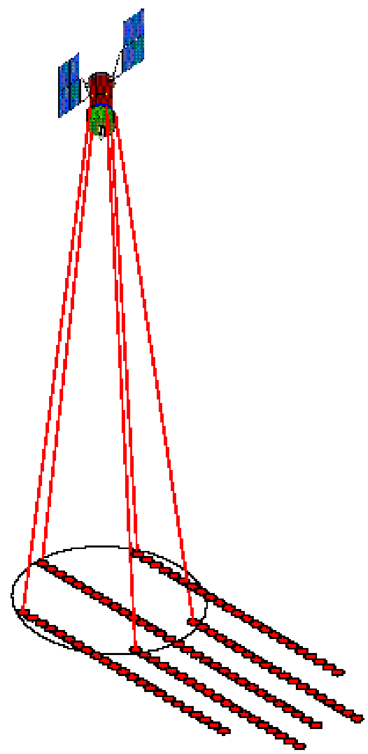
(U) Subsequent Space Shuttle missions in 1996 and 1997 supported the Shuttle Laser Altimeter (SLA) program. SLA utilized LIDAR to collect Digital Surface Model (DSM) and vegetation canopy topographic data. The SLA produced a 100 m diameter footprint on the Earth's surface with 700 m footprint spacing. As a further development in NASA's Earth Observing System, the Ice, Cloud, and land Elevation Satellite (ICES) was launched in 2003. Onboard the ICES, the Geoscience laser altimeter system primarily collected data on the Earth's ice sheets and sea level changes, and also monitored clouds and aerosols. ICES produced a 70 m diameter footprint with 170 m spacing.



(U)Figure 7-1. Space-based LIDAR

(U) Source: Jie Shan and Charles K. Toth, *Topographic Laser Ranging and Scanning: Principles and Processing* (New York: CRC Press, 2009), 36.

(U) In an effort to continue exploitation of space-based LIDAR, NASA selected the University of Maryland to develop a multi-beam laser altimeter for the Vegetative Canopy LIDAR (VCL) program. The VCL mission was to survey vertical and horizontal structure of vegetative canopies and underlying topography. Through the use of five Nd:YAG lasers operating at 1064 nm mounted on a satellite in LEO as depicted in Figure 7-2, a full waveform analysis of the backscatter return obtained in clear atmospheric conditions would yield unprecedented data regarding canopy top height, vertical distribution of nadir intercepted surfaces, and surface topography elevation, including sub-canopy topography.[176] From a 400 km Earth orbit, VCL was to have a 25 m diameter footprint with 2000 m spacing. While operating on an austere budget, various modifications were made to the VCL program in an attempt to sustain its ambitious goals. However, as part of the NASA Earth System Science Pathfinder program, the VCL program was initially delayed and ultimately cancelled in 2003.



(U) Figure 7-2. Vegetative Canopy LIDAR (VCL)

(U) Source: Ralph Dubayah and others, University of Maryland, URL: < http://www.geog.umd.edu/vcl/vcltext.html>, accessed 5 September 2010.

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[176] (U) Ralph Dubayah and others, “The Vegetation Canopy Lidar Mission,” URL: < http://www.geog .umd.edu/vcl/vcltext.html>, accessed 21 December 2009.

(U) In 2001, scientists recognized the capability of space-borne wide swath LIDAR to completely illuminate the Earth's surface while maintaining a high absolute accuracy that would produce elevation measurements that were two orders of magnitude more accurate than Shuttle Radar Topography Mission (SRTM) data. To fully exploit LIDAR capabilities, additional advances in laser scanning and ranging post-processing techniques, along with development of solid-state scanning systems, high efficiency lasers, and large aperture deployable telescopes, will be required. [177]

(U) In 2007, the National Research Council recommended the development of the LIDAR Surface Topography (LST) mission. The LST mission primary objective is to map global topography and vegetative structure at a spatial resolution of 5 meters.[178] The advanced swath-mapping LIDAR system utilizes a push-broom type scan utilizing 1000 laser beams in a linear array. Using a similar 400 km LEO as proposed for the cancelled VCL program, the LST program will produce a 5 m footprint diameter spaced at a 0.7 m along-track interval. The laser backscatter from the surface is collected with a diffraction-limited telescope that images the footprint spots from the swath onto a sensitive detector array. The 10 kHz laser PRF will yield 7 pulses per pixel while the LIDAR satellite ground track advances at 7 km/sec on the Earth's surface.[179] A mathematical analysis of the performance characteristics for a space-borne LIDAR

[177] (U) J. Bryan Blair and others, "Wide-swath imaging LIDAR development for airborne and space-borne application," *International Archives of Photogrammetry and Remote Sensing*, 34, no.3/W4, (22-24 October 2001), URL: <www.isprs.org/commission3/annapolis/ pdf/Blair.pdf>, accessed 3 January 2010.

[178] (U) Anthony Yu and others, "Spaceborne lidar for high-resolution topographic mapping of the Earth's surface," *SPIE Newsroom*, *Remote Sensing*, 1 March 2010, 1, URL: < http://spie.org/x39305.xml?ArticleID=x39305>, accessed 11 April 2010. Cited hereafter as "LST."

[179] (U) "LST," 1.

system to conduct contiguous mapping includes scan speed, power-aperture product, and laser pulse repetition rate variables.[180] In order to achieve such a high pulse repetition rate at 400 km, the LIDAR system incorporates multi-pulse technology coupled with single photon counting modules.

(U) Additional technological advances in precise spectral width filtering and beam wavelength stability will minimize the background photon count rate from a noisy sunlit surface. In order to support LIDAR collection at high accuracies and resolutions from a 400 km orbit, pointing error jitter must be minimized. The thermal stress of structural heating and cooling, the vibration of cooling pumps and motors, the slewing of solar panels and communication antennas, and orientation/orbital station keeping maneuvers all present challenges to ensuring the stability and pointing accuracy of the LSU. The whisk broom and line scan methods of LSU beam propagation use a mechanically positioned mirror. However, as depicted in Figure 7-3, the push-broom scan system utilizing a fixed focal plane array on a stable space platform eliminates some of the vibration sources. By using fewer mechanical components, mass is reduced, and power requirements lowered, which helps improve geospatial accuracy.[181] The push-broom scan method, which is used on GeoEye-1 and IKONOS satellites, demonstrates reliability and component life.

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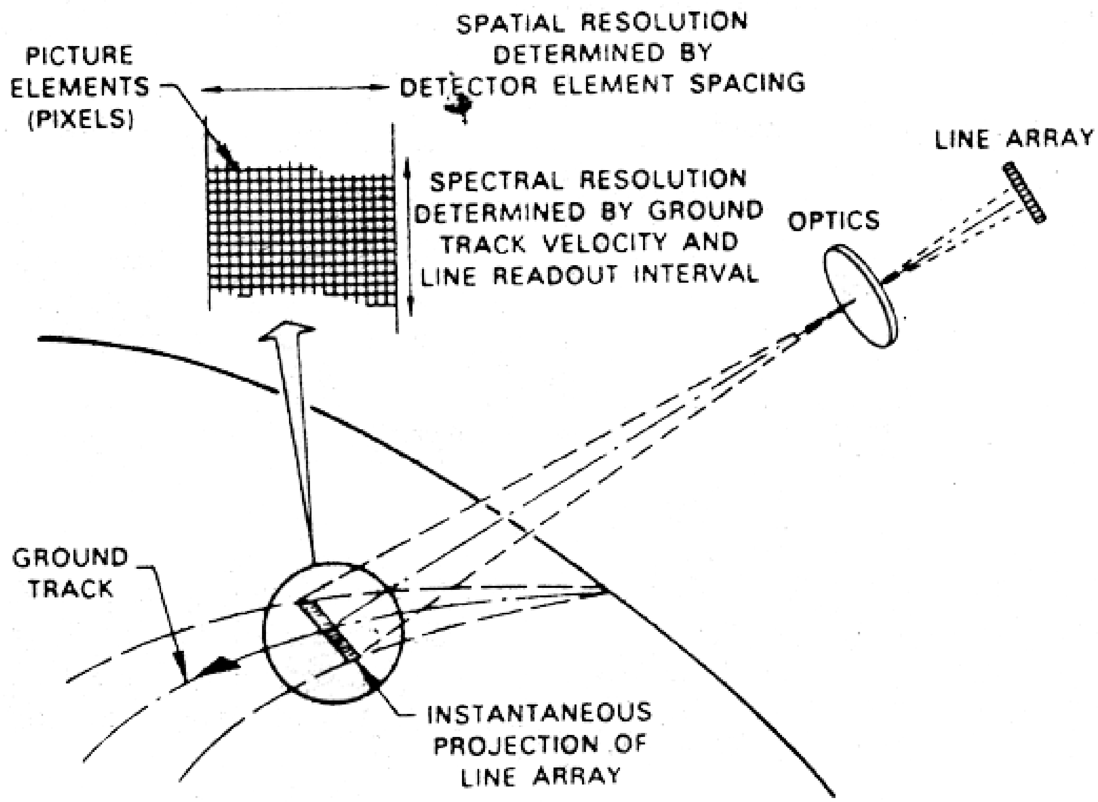
[180] (U) John J. Degnan, *Globally Contiguous, High Resolution Topographic Mapping of Planets and Moons via Photon-Counting*, Proceedings of the 16th International Workshop on Laser Ranging, Sigma Space Corporation, Lanham, MD, 659, URL: <http://cddis.gsfc.nasa.gov/lw16/docs/papers/adv _5_Degnan _p.pdf>, accessed 16 October 2010.

[181] (U) Thomas Avery and Graydon Berlin, *Interpretation of Aerial Photographs*, 4th ed. (Minneapolis: Burgess Publishing, 1985), 168.



(U) Figure 7-3. Characteristics of a Push Broom Scan

(U) Source:Thomas Avery and Graydon Berlin, *Interpretation of Aerial Photographs*, 4th ed. (Minneapolis: Burgess Publishing, 1985), 167.

(U) LSU optical performance

(U) The ability of the LSU to resolve backscatter return onto the receiver sensor array is defined by the elements of the optical system. Resolution (R) equals orbital height (h) multiplied by the laser light wavelength (λ) multiplied by 1.22, divided by the aperture diameter (d) of the optical mirror. $R = h\,\lambda\,1.22 / d$. This theoretical diffraction limit offers the best possible resolving power of the system discounting the effects of atmospheric turbulence and optical aberration. By applying this formula, in order to obtain a 0.5 m resolution using 1064 nm laser light at an orbital height of 400 km, the diameter of the mirror is calculated to be 0.9629 m.

(U) A large, lightweight aperture telescope designed for space-based LIDAR using thin active mirror technology can provide performance characteristics that will enhance photon capture.[182] Atmospheric aberration is created by turbulence associated with changes in wind speed, temperature gradients, and air density fluctuations. These phenomena cause changes to the refractive index of the atmosphere. The strongest turbulence tends to be concentrated in the first kilometer of the troposphere near the Earth's surface.[183] The varying refractive index leads to wave front phase variance in time of arrival of the backscatter laser return. The LSU uses a reference laser guide spot to measure the wave-front aberration and generate a corrective input for adaptive optics.

(U) The effects of atmospheric turbulence may be mitigated through adaptive optics. A deformable mirror may be shaped by thousands of micro-sized piezoelectric actuators that correct for atmospheric turbulence.[184] This technology, which is present in visible light electro-optical sensors, is particularly effective at near-IR wavelengths because the stringency of the required wave-front phase correction is considerably less than for visible wavelengths.[185]

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[182] (U) Piero Mazzinghi and others, "Deployable, lightweight and large aperture spaceborne telescope for lidar-based earth observations," *SPIE, The International Society of Optical Engineering*, 6750 (3 October 2007), URL: <http://spie.org/x648.html?product_id=737853>, accessed 31 December 2009.

[183] (U) Richard Meyers, "Progress in Adaptive Optics," *SPIE Newsroom*, URL: <http://spie.org/x40799.xml?ArticleID=x 40799>, accessed 15 October 2010. Cited hereafter as "Adaptive Optics."

[184] (U) Richard Dekany, "Innovative Deformable Mirror for Palomar Observatory," *SPIE Newsroom*, URL: <http://spie.org/x39226.xml?highlight=x2418&ArticleID=x39226>, accessed 15 October 2010.

[185] (U) "Adaptive Optics."

(U) However, with the high pulse repetition rate (on the order of femtoseconds) of a multi-pulse mode laser, one must consider the wave-front sensor sampling frequency and the response time of the actuators to effectively deform the mirror for improved LIDAR system performance.

(U) The preceding space-based LIDAR programs reveal a continuously evolving capability to incorporate LIDAR for remote sensing requirements. From 1994 through 2007, laser ground footprint diameter has been reduced from 290 m to 5 m. Laser footprint size continues to shrink as the potential to achieve smaller ground sample distances and better resolution increases. LIDAR transmission and receiver systems are gaining efficiencies that will permit a viable system for VO processing. With continued technological development, the goal of utilizing space-based LIDAR for VO detection and data collection is feasible.

(U) Recent advancements in IR detector technology have enhanced the prospects of developing a space-borne LIDAR system capable of VO detection. An innovative high speed optical detector for receiving the backscatter LIDAR return signal is the Avalanche Photo-Diode (APD).

(U) Linear-Mode Avalanche Photo-Diode (L-M APD)

(U) The L-M APD is a photodetector that is biased at close-to, but below, the breakdown voltage of the semiconductor, so a single photon detected is multiplied to produce at most a few hundred electrons.[186] In a conventional L-M APD, silicon is used as the detector substrate. An incoming photon hits an outer shell valence electron in the

[186] (U) Myron Brown, *LIDAR and Compressive Sensing*, National Geospatial-Intelligence Agency, 26 February 2009, 9, URL: <http://people.ee.duke.edu/~lcarin/brown.pdf>, accessed 28 December 2009. Cited hereafter as "*Compressive Sensing*."

silicon photodiode to convert light (photon) into an electrical signal. To optimize near-IR (1064 nm) photon collection, a thick silicon band gap absorption region is required. Unfortunately, this also increases the dark-current noise (electrical signals not caused by photons), which limits silicon APD sensitivity.[187] To reduce dark–current noise, an Indium Gallium Arsenide (InGaAs) L-M APD has been developed to enhance detection of single photons; however, the APD has been shown to be susceptible to space-radiation damage, which limits its applicability to multiyear LEO missions.[188] Generally, ionizing radiation (such as x- and gamma rays) causes an increase in dark signals and decrease in detector threshold sensitivity, while high energy particles (such as protons and neutrons) cause lattice-displacement damage in the sensor substrate.[189]

(U) Geiger-Mode Avalanche Photo-Diode (G-M APD)

(U) To better meet the requirements for low count photon detection, an alternative Geiger-Mode Avalanche Photo-Diode has been developed. The use of the G-M APD that can detect minute quantities of backscatter energy mitigates the need for a high power LIDAR transmitter. As depicted in Figure 7-4, in a G-M APD, an electrical field multiplies the electrical signal to cause a cascade effect to multiply the number of electrons discharged to strengthen the electrical signal. This detection of a photon triggers an avalanche of electrons that triggers a detection timing event that lacks an intensity value. The L-M APD may register intensity information, whereas a G-M APD

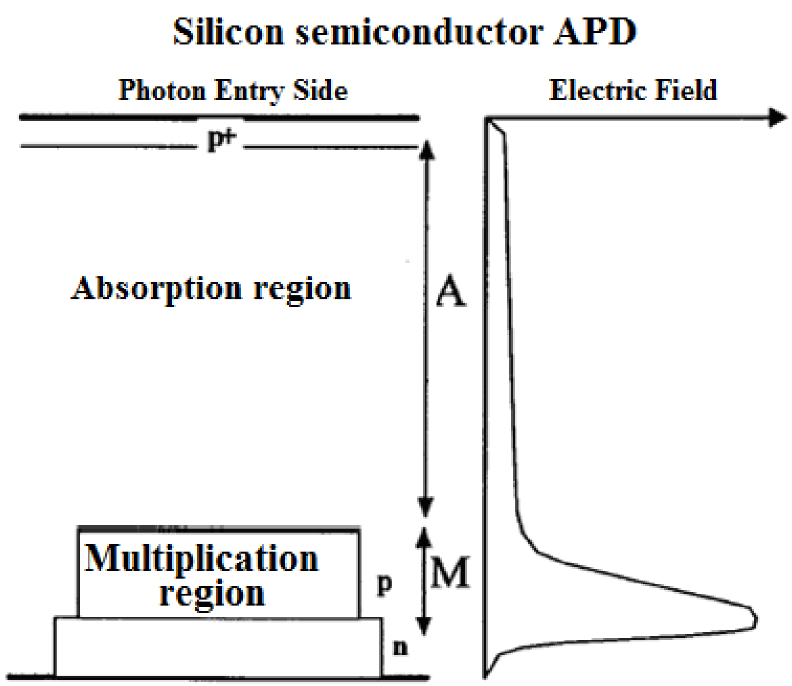
[187] (U) Michael Krainak, Xiaoli Sun, and Guangning Yang, "IR Detectors for Spaceborne Laser Receivers," *SPIE Newsroom*, 1, URL: <http://spie.org/x41340.xml?ArticleID =x41340>, accessed 22 September 2010. Cited hereafter as "Spaceborne Laser Receivers."

[188] (U) "Spaceborne Laser Receivers,"1.

[189] (U) James Endicott, "Improving CCD Radiation Tolerance," *SPIE Newsroom*, URL: <http://spie.org/x36689.xml?highlight=x2418&ArticleID=x36689>, accessed 2 October 2010.

detection event does not give intensity information. The electrical pulse produced by the detection of a single photon by the G-M APD is indistinguishable from that produced by the detection of many simultaneously absorbed photons.

(U) The avalanche region of the detector that produces the electron gain resets every few nanoseconds, and is ready to detect a new photon and produce the avalanche multiplication of electrons. The discharge-and-reset cycle is known as the Geiger mode of operation.[190]



(U) Figure 7-4. Avalanche Photo-diode Structure

(U) Source: Perkin Elmer, *Avalanche Photodiode, A User Guide*, URL: http: //optoelectronics.perkinelmer.com/content/applicationnotes/app_apdusersguide.pdf, accessed 22 December 2009

[190] (U) Earl Hergert and Maridel Lares, “APD Arrays: Geiger-mode APD arrays detect low level light,” *Laser Focus World*, 45, no. 12 (December 2009), URL: <http://www.laserfocusworld.com/ articles/335986>, accessed 22 December 2009.

(U) The G-M APD uses a detector element that is capable of being triggered by a single photon. Operating through an optical system, a notional receiver sensor comprising a 32 x 32 flat planar array of G-M APD detector elements is capable of detecting minute quantities of backscatter photons. Additionally, the greater sensitivity of G-M APD that operates at the single photon detection level allows the LSU to operate with lower laser power levels and shorter pulse duration. Shorter pulse duration allows more data points to be generated in a given time frame while less energy is applied to each pulse.

(U) Advances in micropulse technology have enabled laser systems to operate in the range of femtosecond (10^{-15}) pulse duration. The pulse duration is many orders of magnitude shorter than the nanosecond (10^{-9}) pulse currently employed in the Buckeye LIDAR system. By utilizing a greater pulse repetition rate, a laser can transmit more pulses per unit time, enabling a potential gain in performance of the LSU and the extraction of processed data.

(U) Linear – Geiger mode comparison

(U) In the past, infrared APD focal plane arrays operating in the Geiger-Mode have been used for single photon counting. The L-M APD could not provide enough proportional gain with sufficiently low noise to make the photocurrent from a single photon detectible using existing amplifier technology. However, recent improvements in APDs, sub-micron Complementary Metal-Oxide-Semiconductor (CMOS) technology, and advanced amplifier designs have made the L-M APD possible for space-borne applications.[191] In order to take advantage of this capability, an L-M APD has been developed that can operate at 150 picosecond (10^{-12}) pulse response time, with a resolution of pulse pairs (events) at less than 1 nanosecond apart.[192]

(U) In comparison with G-M APDs that use fast active-quenching circuits that reset after each detection in a few nanoseconds, the L-M APD pulse can be processed in less than a nanosecond. This capability will enable the L-M APD to operate faster than a conventional G-M APD.

(U) The APD array is able to collect large areas rapidly, from high altitudes, using a smaller aperture receiver, at high pulse repetition frequencies, with reduced power requirements. High day-time background noise for space-borne LIDAR receivers are minimized through a very narrow field-of-view (~1 milliradian) and an extremely narrow bandwidth filter (~0.1 nm).[193] Challenges raised by G-M APD usage include the greater amounts of raw data collected compared to conventional LIDAR, and the additional processing time required to remove noise.[194]

(U) Photon Counting

(U) A photon counting detector records the arrival of single photons, and the digital output is either off (absence of signal) or on (discrete detection of a photon).

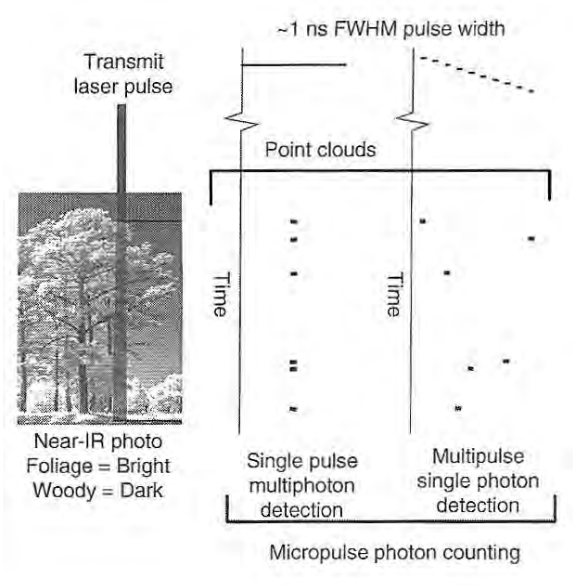
[191] (U) George M. Williams and Andrew S. Huntington, *Probabilistic Analysis of Linear Mode vs Geiger Mode APD FPAs for advanced LADAR enabled interceptors*, SPIE Security and Defense Symposium – Manuscript 6220-8, URL: <http://www.voxtel-inc.com/whitePapers/6220-8_SPIE _LINEAR_vs_GEIGER.pdf>, accessed 26 August 2010.

[192] (U) Voxtel, *LADAR and LIDAR Detector Systems*, URL: <http://www.voxtel-inc.com/ datasheets/LADAR_datasheet.pdf>, accessed 27 August 2010.

[193] (U) John A. Regan and others, *Assessment of Some Remote Sensing Techniques for Spaceborne LIDAR*, Department of Electrical and Computer Engineering, University of Arizona, URL: <ieeexplore. ieee.org/iel4/121/3531/00688787.pdf?arnumber=688787>, accessed 2 January 2010.

[194] (U) “Compressive Sensing,” 12.

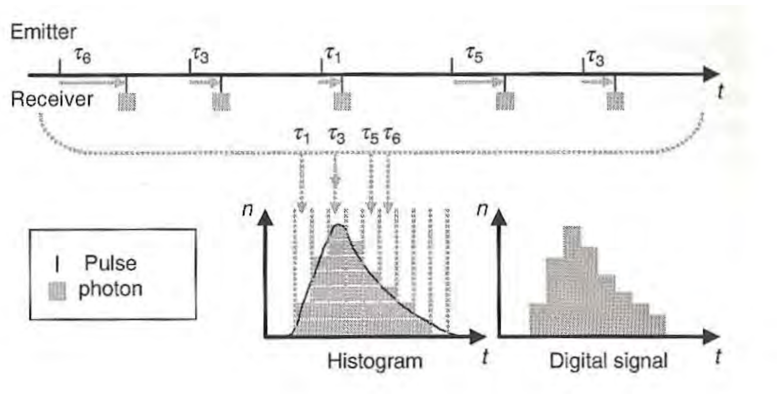
Micro-pulse LIDAR operating at a one nanosecond pulse duration captured by a digital count APD offers different capabilities than a mono-pulse analog LIDAR operating at a seven nanosecond pulse for collecting full-waveform analysis data. Note in the example of Figure 7-5 that 10 micro pulses are transmitted within a 1 nanosecond full width half maximum (FWHM) pulse width that produces 10 discreet returns.



(U) Figure 7-5. Photon Counting Laser Ranging

(U) Source: Jie Shan and Charles K. Toth, *Topographic Laser Ranging and Scanning:Principles and Processing* (New York: CRC Press, 2009), 179.

(U) By integrating the photon counting detector with timing electronics, the time-of-flight between the pulse transmission and the detection of the photon is recorded. As shown in Figure 7-6, a single photon detected from the backscatter footprint is recorded, and the accumulation of many single photon ranges at different time intervals creates a height structure of the target within the footprint.



(U) Figure 7-6. Digital recording using single-photon detection

(U) Source: Jie Shan and Charles K. Toth, *Topographic Laser Ranging and Scanning: Principles and Processing* (New York: CRC Press, 2009), 220.

(U) Only a small number of photons per pulse need to be detected to form a digital signal. With the short pulse width of 1 nanosecond, measuring decimeter to centimeter ranges is possible. Photon counting systems have the potential to more efficiently acquire Airborne Laser Swath Mapping data than do analog systems, while using less power, smaller receiver apertures, and /or higher pulse repetition rates.[195]

(U) Space-based LIDAR offers great potential for VO detection and collection. The persistence and access afforded by a LIDAR satellite in LEO can offer improvements in VO currency and coverage areas. Similar to visual electro-optical imagery, using LIDAR for VO detection is limited by atmospheric transmissivity. Most of the infra-red light transiting the atmosphere is absorbed by water vapor and carbon dioxide depending on concentrations of H_20 and CO_2 molecules, pressure, temperature and the presence of rain, fog, haze, or clouds. However, the near infra-red 1064nm

[195] (U) Laser Ranging, 188.

energy transits the atmosphere with minimal attenuation through an optical window. By providing its own illuminating energy source, LIDAR is capable of VO collection during the day or night. Additionally, micropulse LIDAR operations using a solid state fiber or Nd:YAG laser at 1064 nm are not visible to the unaided eye and are eye-safe at attainable operating power levels. Micropulse LIDAR operations should be exploited as an additional tool NGA can utilize to fulfill its requirement to provide a world-wide VO database.

(U) In summary, a new generation of high-sensitivity near-IR detectors for space-borne laser instruments will enable high-precision global measurements of terrestrial and planetary topography.[196] Continuous global surveillance that is free of denied areas restrictions, but subject to atmospheric conditions, makes space-borne LIDAR an excellent tool for topographic and VO data collection. Continuing research and technological advances should produce components for a space based LIDAR system capable of meeting NGA's VO program requirements.

[196] (U) Spaceborne Laser Receivers.

CHAPTER 8

(U) The Way Forward

(U) Issue

(U) The DVOF must continue to evolve in order to meet customer requirements. The effort to improve the VO program incorporates input from a broad spectrum of VO data users that includes the NSG, ASG, FAA, ICAO, and RTCA. The universal nature of world-wide VO data mandates a vision to incorporate overarching interoperability for the processing and dissemination of all VO data sources. The NCGIS in conjunction with the GWG ensures the proper development and implementation of geospatial-intelligence standards that embody the tenets of the ISO standardization principles.

(U) NGA continues to develop strategies to improve the VO program tasking, collection, processing, exploitation, and dissemination. Customer requirements and funding will dictate the integration of new technologies and the harmonization of multi-source VO datasets. The capabilities of the VO program to fulfill the customer's spatial and temporal requirements for VO data will be expanded. VO tasking and collection processes will evolve as new sources and methods are incorporated.

(U) LIDAR, EO, and SAR VO collection capabilities will continue to improve as new hardware and software are developed. The VO program concept of operations will be refined to enable global VO data creation from new collection platforms. LIDAR offers the best solution for active VO data production. The Richmond LIDAR collect is an example of the practical application of existing technology to support NGA's mission to provide VO data to DoD customers.

(U) Data from manual analysis

(U) The Richmond LIDAR collect encompassed approximately 20 square kilometers of urban Richmond, Virginia, and comprised 60 flight strips. In the manual VO data extraction and analysis study, the NGA DVOF was examined to extract all 76 VOs documented within the Richmond LIDAR collection area.

(U) Findings from manual analysis

(U) Of these 76 VOs, a representative sample, comprising 35 VOs, was correlated with the corresponding LIDAR-derived VOs. In this manual analysis, differences were observed for VO height and geodetic coordinates.

(U) VO height differences in power pylon poles were attributable to DVOF source data originating from legacy DFAD that assigned a default value to pylon height. Building heights varied due to mensuration techniques and temporal structure changes.

(U) VO horizontal position location differences were due to coordinate precision differences in LIDAR and DVOF, and mensuration techniques for establishing a VO centroid for non-symmetrical structures.

(U) Data from PC_VO tool analysis

(U) In the assisted VO data extraction and analysis study, 3 DVOF VOs were present in Richmond LIDAR collect flight strip 09 area. PC_VO tool detected 64 LIDAR derived VOs within flight strip 09 area that were 60 feet tall or greater.

(U) Findings from PC_VO tool analysis

(U) PC_VO tool detected 61 VOs that were not in DVOF. Of the 3 VOs that were held in both datasets, height values were irregular for the PC_VO tool results for the Madison building. Due to PC_VO tool program settings, 4 VOs were registered to the Madison building roof top. Multiple VOs emanating from a single building was observed in several other locations. The phenomenon is attributable to the parameters specified for the PC_VO tool search of the point cloud data files. The definable cylinder search area and cylinder spacing can be modified to tailor VO search results. Other search parameters can be adjusted to reduce outliers and reduce the false alarm rate.

(U) VO program objectives

(U)Existing sources of VO datasets from trusted partners will continue to be collected, and new partnerships will be established with global entities. Open source VO data will be exploited to the extent permitted by its quality attributes. VO data attributes should address the ICAO ETOD program VO data requirements to promote data commonality. Due to the capabilities available with LIDAR, one must address how the VO-specific requirements affect overall tasking, collection, processing, exploitation, and dissemination of LIDAR.

(U) Through the new GNS-A program, VO processing will be improved beyond the current AOE functionality. Improved VO source validation, ingest, and auto-conflation will be supported by universal VO data standards as promulgated by the NSG through the efforts of the NCGIS, GWG and global VO data providers.

(U) VO data will be accessible as a data-centric product with the capability to meet customer-tailored requirements. VO data will be shared through increased on-line, on-demand accessibility. The user can import raw VO data from WebDVOF to be used for customer applications. WebDVOF supports customer mission requirement through various data file formats. Flight planning, flight management, and flight simulator systems continue to utilize specified format VO data. Customer input for future VO data requirements will focus the DVOF modernization efforts. GNS-A will incorporate an improved DVOF to ensure seamless dissemination of VO data to the customer through a web-based interface.

(U) Conclusion

The overall strategy for improving the VO program encompasses new hardware, software, personnel, inter-agency agreements, contracts, and plans. LIDAR is a viable source for VO data. The ability to provide the customer with near real-time ground truth VO data for emergent specified areas can be an achievable goal.

APPENDIX A

(U) NGA Vertical Obstructions Branch DVOF Guidance

DIGITAL VERTICAL OBSTRUCTION FILE (DVOF) GUIDANCE

1. Explanation of the Validation Code column in the DVOF report:
   2.1. The Validation Code identifies the process that was used in the location of each vertical obstruction listed in the DVOF. The code is a number from 1-6:
   1 = *survey*-derived VO[1]2 = *stereo*-derived VO [197]
   3 = *mono*-derived VO[2]4 = *carto*-derived VO [198]
   5 = *reported* VO[3] 6 = *temporary* VO [199]

2. Explanation of the Transaction Codes ("T" column in the DVOF report):
   N = new V = minor revision R = major revision S = VO ID change only
   D = deletion X = deletion

3. Explanation of the Deficiency Codes:
   0-No deficiency, data meets all accuracy requirements

   1-Deficiency in horizontal accuracy and/or datum of obstruction

   2-Deficiency in vertical accuracy of obstruction elevation above mean sea level

   3-Deficiency in accuracy of obstruction height above ground

   4-Deficiency in horizontal and vertical accuracies

   5-Deficiency in horizontal and obstruction height accuracies

   6-Deficiency in vertical and obstruction height accuracies

   7-deficiency in horizontal, vertical and obstruction height accuracies

4. When in doubt, report all discrepancies and all new or unverifiable features as seen on the new source.

5. Reference Section 'S' of the *Ancillary Source Guidance Manual* for DVOF-to-FACC code mappings.

About The DVOF Database

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[197] Under no circumstances is a VO originally extracted using *survey or stereo* source/s to be relocated.
[198] VOs collected with *mono or carto* source/s may be relocated using a newer source equal to or better than the original.
[199] *Reported and temporary* VOs are not guaranteed to be accurate; the Contractor may relocate them using newer, reliable source/s.

The Vertical Obstruction database contains all of the manmade point, line, and area features known by National Geospatial-Intelligence Agency (NGA) projecting above the earth's surface that could obstruct point-to-point activity, posing a hazard to flight. Each vertical obstruction has its own unique record. A complete record describes the obstruction, country location (or state in the U.S.), geographic coordinates, height, material composition, and lighting information.

The overall database has a classification of secret, but the individual records vary from UNCLASSIFIED up to SECRET. Classification of the file output depends on the source and accuracies of the data.

Information about the Vertical Obstruction (VO) database may be obtained by contacting the NGA COR.

Accuracy

The accuracy of information will vary with the collection process. Information can be derived from DoD surveys, stereoscopic imagery, monoscopic imagery, cartographic sources, reported data, and unknown source.

Datums

Vertical Datum - Height information is entered in both Above Ground Level (AGL) and Above Mean Sea Level (AMSL). Height information is stored in feet values.

Horizontal Datum - The horizontal datum for the position of all vertical obstructions will be the World Geodetic System (WGS-84). Coordinate information will be provided in decimal degrees.

Obstructions

There are different categories of obstructions within the VO database:

1. Single obstructions. Single obstructions are included in the Vertical Obstruction (VO) database. Obstructions validated with imagery are populated into the database as single point features. Multiple point features that are validated may be changed to single feature entries or collected and stored as line/area features.

2. Aerial cables and powerlines. Aerial cables and powerlines are included in the VO database. Their supporting structures may also qualify as obstructions. The cable features are stored as linear features with multiple geographic coordinates. The VO database also stores the supporting pylons and highest segment AMSL height between pylons when that information can be obtained.

3. Area features. Area features will be described by geographical coordinates linked to an enclose area and height determination will reflect the tallest obstruction contained within that area. Obstruction type codes and Feature and Attributes Coding Catalogue (FACC) are enclosed in this attachment.

Deriving Obstruction Data

The bulk of new obstruction data is derived in conjunction with, or as a by-product of, routine production programs. Minimum height requirement for obstructions is 150 feet (46 meters). Regardless of the accuracy, all obstructions shall be entered into DVOF.

The following attributes are collected for each feature (* Denotes mandatory fields):

1. Geographic coordinates*
2. Horizontal datum
3. Height above ground*
4. Height above mean sea level*
5. Type of obstruction
6. Lighting
7. Surface Material
8. Source
9. Security classification
10. Accuracy

DVOF OBSTRUCTION TYPE CODES

(Numerical Order by VO Feature Type Code)

Feature Type Code	FACC Code	Feature Type	Point Features
99	AL015	Building	General (All types)
101	AA040	Industrial Structure	Structure, General, Extraction Industry
103	AA040	Tower	Derrick, Gas Oil
104	BD110	Platform	Offshore Platform
105	AA040	Platform	Offshore Platform with Derrick
106	AA040	Mining Structure	Mine Shaft Superstructure
107	BD110	Platform	Offshore Platform with Helipad
110	AL015	Industrial Structure	Structure, General, Processing Industry
111	AC000	Industrial Plant	Chemical Processing Plant
112	AC000	Industrial Plant	Metal Processing Plant
115	AC000	Industrial Plant	Coke Plant
116	AC010	Industrial Structure	Blast Furnace
120	AC000	Industrial Plant	Refinery
121	AC020	Industrial Structure	Catalytic Cracker
122	AF070	Industrial Structure	Flare Pipe -On Land (in refinery)
123	AF070	Industrial Structure	Flare Pipe -Off Shore
130	AD010	Industrial Plant	Power Plant
136	AF010	Smokestack	Thermal Power-Plant Smokestack
137	AD030	Pylon	Transformer Yard
145	AD010	Industrial Structure	Solar Energy Electrical Collection Panels
146	AD010	Industrial Structure	Solar Energy Heat Collection Panels
150	AL015	Industrial Plant	Building, Heavy Fabrication Industry, General

151	AL015	Industrial Plant	Building with Flat Roof, Heavy Fabrication
152	AL015	Industrial Plant	Building with Flat Roof and Monitor, Heavy
153	AL015	Industrial Plant	Building with Gable Roof (pitched), Heavy
154	AL015	Industrial Plant	Building with Gable Roof (pitched) and Monitor,
155	AL015	Industrial Plant	Building with Sawtooth Roof, Heavy Fabrication
156	AL015	Industrial Plant	Building with Covered Roof, Heavy Fabrication
160	AL015	Industrial Plant	Building, Light Fabrication Industry, General
161	AL015	Industrial Plant	Building with Flat Roof, Light Fabrication Industry
162	AL015	Industrial Plant	Building with Flat Roof and Monitor, Light
163	AL015	Industrial Plant	Building with Gable Roof (pitched), Light
164	AL015	Industrial Plant	Building with Gable Roof (pitched) and Monitor,
165	AL015	Industrial Plant	Building with Sawtooth Roof, Light Fabrication
166	AL015	Industrial Plant	Building with Curved Roof, Light Fabrication
170	AB000	Waste Pile	Disposal, General
172	AB000	Waste Pile	Metal Ore Slag Dump
173	AB000	Waste Pile	Tailing/Waste Pile
180	AL015	Industrial Plant	Industrial Structure, General
181	AL015	Industrial Plant	Building, Industrial, General
182	BH010	Smokestack	Smokestack, General
183	AF020	Industrial Plant	Conveyor, Industrial
185	AF040	Crane	Bridge Crane, Industrial
186	AF040	Crane	Rotating Crane, Industrial
187	AF040	Crane	Rotating Crane on Tower, Industrial
188	AF030	Cooling Tower	Cooling Tower, Industrial
189	AF080	Industrial Plant	Hopper, Industrial
190	AF050	Industrial Plant	Dragline/Powershovel Boom, Industrial

221	AL015	Building	Railroad Terminal Building
222	AL015	Building	Railroad Station
223	AQ060	Tower	Railroad Control Tower
224	AL015	Building	Railroad Roundhouse
260	AQ040	Bridge	Bridge, General
261	AQ040	Bridge	Suspension Bridge
262	AQ040	Bridge	Cantilever Bridge
263	AQ040	Bridge	Arch Bridge
264	AQ040	Bridge	Truss Bridge
265	AQ040	Bridge	Moveable-Span Bridge
266	AQ055	Tower	Bridge Tower
267	AQ040	Bridge	Deck Bridge
270	AQ050	Bridge	Superstructure – General
271	AQ050	Bridge	Superstructure – Suspension
272	AQ050	Bridge	Superstructure – Tower Suspense
273	AQ050	Bridge	Superstructure – Cantilever
274	AQ050	Bridge	Superstructure – Arch
275	AQ050	Bridge	Superstructure – Truss
276	AQ050	Bridge	Superstructure – Moveable Span
280	AQ113	Conduit	Conduit, General
281	AQ113	Conduit	Pipeline (above ground)
282	BH010	Conduit	Aqueduct
290	AL015	Transportation	Associated Structure, Transportation Structure
301	AL015	Building	Commercial Building, General
302	AL015	Building	Commercial Building with Flat Roof
303	AL015	Building	Commercial Building, Circular with Flat Roof

304	AL015	Building	Commercial Building with Gable Roof
305	AL015	Building	Commercial Building with Curved Roof
321	AK160	Stadium	Stadium, Enclosed
322	AK160	Stadium	Stadium, Open-ended
323	AK160	Stadium	Stadium, Domed
324	AK160	Stadium	Grandstand
331	AK020	Amusement Park Structure	Roller Coaster
332	AK020	Amusement Park Structure	Ferris Wheel
334	AK020	Amusement Park Structure	Artificial Mountain
335	AK150	Ski Jump	Ski Jump
340	AL050	Sign	Display Sign, General
350	AL015	Amusement Park Structure	Commercial/Recreational Structure, General
401	AL015	Building	Dwelling, Multi – family
402	AL015	Building	Apartment/Hotel with Flat Roof
403	AL015	Building	Apartment/Hotel with Gable Roof
434	AJ050	Windmill	Windmill, Truss
435	AJ050	Windmill	Windmill, Solid
437	AJ051	Windmill	Windmotor / Wind Powered Generator -On Land
438	AJ051	Windmill	Windmotor / Wind Powered Generator -Off Shore
450	AL015	Building	Associated Structure, Agricultural/
501	AT080	Tower	Communication Tower, General
511	AT080	Tower	Radio/TV Tower, Type A
512	AT080	Tower (Mast)	Radio/TV Tower, Type I
520	AT080	Tower	Microwave Tower, Type A (has reflector/cone)
521	AT080	Tower (Mast)	Microwave Tower, Type I (has reflector/cone)
530	AL240	Tower	Miscellaneous Tower

531	AL240	Tower	Observation Tower
532	AL240	Tower	Tower on Structure
533	GB040	Tower	Rocket Launch Tower
535	AL110	Tower	Athletic Field Lights/ Light Standards/ Light Poles
537	AT070	Pylon	Telephone Pylon/ Poles
538	AQ020	Pylon	Aerial Cableway Pylon/ Ski Lift Pylon
540	AT040	Pylon	Powerline Pylon, General
541	AT040	Pylon	Powerline Pylon, Type A
542	AT040	Pylon	Powerline Pylon, Type H
543	AT040	Pylon	Powerline Pylon, Type I
544	AT040	Pylon	Powerline Pylon, Type Y
561	AT050	Building	Communication Building
601	AL015	Building	Governmental Building, General
602	AL015	Building	Capitol Building
603	AL015	Building	Administrative Building, Governmental
604	AL015	Building	Prison
605	AL015	Building	Palace
606	AL015	Building	Castle
607	AH050	Building	Fortification- Constructed for Military Use
610	AL015	Building	Institutional Building, General
620	AL015	Building	School, General
621	AL015	Building	School with Flat Roof
622	AL015	Building	School with Gable Roof
630	AL015	Building	Hospital
631	AL015	Building	Hospital with Flat Roof
632	AL015	Building	Hospital with Gable Roof

640	AL015	Building	Observatory
641	AL015	Building	Observatory with Dome Roof
650	AL015	Building (Church)	House of Religious Worship, General (Church,
651	AL015	Building (Minaret)	House of Religious Worship - Minaret
652	AL015	Building (Mosque)	House of Religious Worship - Mosque
653	AL015	Building (Synagogue)	House of Religious Worship - Synagogue
654	AL015	Building (Temple)	House of Religious Worship - Temple
680	AL130	Tower (Monument)	Government/Institutional/Religious Structure,
681	AL015	Building (Steeple)	House of Religious Worship with Steeple
682	AL130	Tower (Monument)	Monument/Obelisk
683	AL130	Arch	Arch
684	AL130	Pyramid	Pyramid
702	AQ060	Tower	Airport/Airbase Control Tower
704	AL015	Building (Hangar)	Aircraft Hangar with Flat Roof
705	AL015	Building (Hangar)	Aircraft Hangar with Curved Roof
710	GB035	Radar Antenna	Navigation Aid Airbase/Airbase Electronic
711	AT010	Radar Antenna	Radar Reflector
714	GB035	Radar Antenna	VOR/VORTAC/TACON Facility
715	GB035	Radar Antenna	Antenna (Radar with Radome)
716	GB035	Radar Antenna	Antenna (with Radar Tower Mounted with Radome)
717	GB035	Radar Antenna	Antenna Radar
718	GB035	Radar Antenna	Radar Antenna (Tower Mounted)
720	GB221	Misc Man-Made	Miscellaneous Air Obstruction (Man Made)
755	BB170	Platform	Offshore Loading Facility
761	BC070	Lightship	Navigation Lightship, Permanently Moored
765	BC050	Lighthouse	Lighthouse

785	AQ110	Tethered Balloon	Tethered Balloon
801	AM070	Tank	Tank, General
802	AM070	Tank	Tank, Cylindrical, Flat Top
803	AM070	Tank	Tank Cylindrical, Dome Top
804	AM070	Tank	Tank, Cylindrical, Peaked Top
805	AM070	Tank	Tank, Cylindrical, Peaked Top Mounted
806	AM070	Tank	Tank, Spherical
807	AM070	Tank	Tank, Spherical with Column Support
811	AM070	Tank	Tank, Bullet
812	AM070	Tank (Gasholder)	Tank, Telescoping Gasholder (Gasometer)
820	AM010	Storage Structure	Closed Storage Structure, General
821	AM020	Storage Structure	Silo
822	AM030	Storage Structure	Grain Elevator
824	AM080	Tank (Water Tower)	Water-Tower Building, Masonry/Concrete
830	AM010	Open Storage	Open Storage, General
831	AM010	Open Storage	Open Storage, Mineral
861	AL015	Building	Warehouse
865	BB020	Ship Storage	Ship Storage (Semi – permanently moored ships)
900	AT006	Aerial Cable	Aerial Cable, Aerial Tramway, or Power
925	BI020	Dam	Dam
926	BI050	Tower	Water Intake Tower
954	GB220	Misc Natural (Trees/Woods)	Miscellaneous Air Obstruction (Natural Growth)
U	GB221	Undetermined	Undetermined

APPENDIX B

(U) FAA Notice of Proposed Construction or Alteration

NOTICE OF PROPOSED CONSTRUCTION OR ALTERATION

§77.13 Construction or alteration requiring notice.

(a) Except as provided in §77.15, each sponsor who proposes any of the following construction or alteration shall notify the Administrator in the form and manner prescribed in §77.17.

(1) Any construction or alteration of more than 200 feet in height above the ground level at its site.
(2) Any construction or alteration of greater height than imaginary surface extending outward and upward at one of the following slopes:
(i) 1 00 to 1 for horizontal distance of 20,000 feet from the nearest point of the nearest runway of each airport specified in paragraph (a)(5) or this section with at least one runway more than 3,200 feet in actual length, excluding heliports.
(ii) 50 to 1 for horizontal distance of 10,000 feet from the nearest point of the nearest runway of each airport specified in paragraph (a)(5) of this section with its longest runway no more than 3,200 feet in actual length, excluding heliports.
(iii) 25 to 1 for a horizontal distance of 5,000 feet from the nearest point of the nearest landing and takeoff area of each heliport specified in paragraph (a)(5) of this section.

(3) Any highway, railroad, or other traverse way for mobile objects, of a height which, if adjusted upward 17 feet for an Interstate Highway that is part of the National System of Military and Interstate Highways where overcrossings are designed for a minimum of 17 feet vertical distance, 16 feet for any other public roadway, 10 feet or the height of the highest mobile object that would normally traverse the road, whichever is greater, for a private road, 23 feet for a railroad, and for a waterway or any other traverse way not previously mentioned, an amount equal to the height of the highest mobile object that would normally traverse it, would exceed a standard of paragraph (a)(1) or (2) of this section.

(4) When requested by the FAA, any construction or alteration that would be in an instrument approach area (defined in the FAA standards governing instrument approach procedures) and available information indicates it might exceed a standard of Subpart C of this part.

(5) Any construction or alteration on any of the following airports (including heliports):
(i) An airport that is available for public use and is listed in the Airport Directory of the current Airman's Information Manual or in either the Alaska or Pacific Airman's Guide and Chart Supplement.
(ii) An airport under construction, that is the subject of a notice or proposal on file with the Federal Aviation Administration, and except for military airports, it is clearly indicated that airport will be available for public use.
(iii) An airport that is operated by an armed force of the United States.

(b) Each sponsor who proposes construction or alteration that is the subject of a notice under paragraph (a) of this section and is advised by an FAA regional office that a supplemental notice is required shall submit that notice on a prescribed form to be received by the FAA regional office at least 48 hours before the start of construction or alteration.

(c) Each sponsor who undertakes construction or alteration that is the subject of a notice under paragraph (a) of this section shall, within 5 days after that construction or alteration reaches its greatest height, submit a supplemental notice on a prescribed form to the FAA regional office having jurisdiction over the region involved, if –
(1) The construction or alteration is more than 200 feet above the surface level of its site; or
(2) An FAA regional office advises him that submission of the form is required.

§77.15 Construction or alteration not requiring notice.

No person is required to notify the Administrator for any of the following construction or alteration:
(a) Any object that would be shielded by existing structures of a permanent and substantial character or by natural terrain or topographic features of equal or greater height, and would be located in the congested area of a city, town, or settlement where it is evident beyond all reasonable doubt that the structure so shielded will not adversely affect safety in air navigation.
(b) Any antenna structure of 20 feet or less in height except one that would increase the height of another antenna structure.
(c) Any air navigation facility, airport visual approach or landing air, aircraft arresting device, or meteorological device, of a type approved by the Administrator, or an appropriate military service on military airports, the location and height of which is fixed by its functional purpose.
(d) Any construction or alteration for which notice is required by any other FAA regulation.

§77.17 Form and time of notice

(a) Each person who is required to notify the Administrator under §77.13 (a) shall send one executed form set of FAA Form 7460-1, Notice of Proposed Construction or Alteration, to the Manager, Air Traffic Division, FAA Regional Office having jurisdiction over the area within which the construction or alteration will be located. Copies of FAA Form 7460-1 may be obtained from the headquarters of the Federal Aviation Administration and the regional offices.

(b) The notice required under §77.13 (a)(1) through (4) must be submitted at least 30 days before the earlier of the following dates –
(1) The date the proposed construction or alteration is to begin.

(2) The date an application for a construction permit is to be filed.

However, a notice relating to proposed construction or alteration that is subject to the licensing requirements of the Federal Communications Act may be sent to the FAA at the same time the application for construction is filed with the Federal Communications Commission, or at any time before that filing.

(c) A proposed structure or an alteration to an existing structure that exceeds 2,000 feet in height above the ground will be presumed to be a hazard to air navigation and to result in an inefficient utilization of airspace and the applicant has the burden of overcoming that presumption. Each notice submitted under the pertinent provisions of this part 77 proposing a structure in excess of 2,000 feet above ground, or an alteration that will make an existing structure exceed that height, must contain a detailed showing, directed to meeting this burden. Only in exceptional cases, where the FAA concludes that a clear and compelling showing has been made that it would not result in an inefficient utilization of the airspace and would not result in a hazard to air navigation, will a determination of no hazard be issued.

(d) In the case of an emergency involving essential public services, public health, or public safety that required immediate construction or alteration, the 30 day requirement in paragraph (b) of this section does not apply and the notice may be sent by telephone, telegraph, or other expeditious means, with an executed FAA Form 7460-1 submitted within five (5) days thereafter. Outside normal business hours, emergency notices by telephone or telegraph may be submitted to the nearest FAA Flight Service Station.

(e) Each person who is required to notify the Administrator by paragraph (b) or (c) of §77.13, or both shall send an executed copy of FAA Form 7460-2, Notice of Actual Construction or Alteration, to the Manager, Air Traffic Division, FAA Regional Office having jurisdiction over the area involved.

ADDRESSES OF THE REGIONAL OFFICES

Alaska Region
AK
Alaskan Regional Office
Air Traffic Division, AAL-530
222 West An Avenue
Anchorage, AK 99513
Tel: 907-271-5893

Central Region
IA, KS, MO, NE
Central Regional Office
Air Traffic Division, ACE-520
60 East 12th Street
Kansas City, MO 64106
Tel: 816-426-3408 or 3409

Eastern Region
DC, DE, MD, NJ, NY, PA, VA, WV
Eastern Regional Office
Air Traffic Division, AEA-520
JFK International Airport
Fitzgerald Federal Building
Jamaica, NY 11430
Tel: 718-553-2616

Great Lakes Region
IL, IN, MI, MN, ND, OH, SD
Great Lakes Regional Office
Air Traffic Division, AGL-520
2300 East Devon Avenue
Des Plaines, IL 60018
Tel: 847-294-7568

New England Region
CT, MA, ME, NH, RI, VT
New England Regional Office
Air Traffic Division, ANE-520
12 New England Executive Park
Burlington, MA 01803-5299
Tel: 781-238-7520

Northwest Mountain Region
CO, ID, MT, OR, UT, WA, WY
Northwest Mountain Regional Office
Air Traffic Division, ANM-520
1601 Lind Avenue, SW
Renton, WA 98055-4056
Tel: 425-227-2520

Southern Region
AL, FL, GA, KY, MS, NC, PR
SC, TN, VI
Southern Regional Office
Air Traffic Division, ASO-520
1701 Columbia Avenue
College Park, GA 30337
Tel: 404-305-5685

Southwest Region
AR, LA, NM, OK, TX
Southwest Regional Office
Air Traffic Division, ASW-520
2601 Meacham Boulevard
For Worth, TX 76137-0520
Tel: 817-222-5531

Western Pacific Region
HI, CA, NV, AZ, GU
Western-Pacific Regional Office
Air Traffic Division, AWP-520
15000 Aviation Boulevard
Hawthorne, CA 90260
Tel: 310-725-6557

A Form 7460-1 (2-99) Superseded Previous Edition   Electronic Version (Adobe)   NSN: 0052-00-012-000

U.S. Department of Transportation
Federal Aviation Administration

Failure To Provide All Requested Information May Delay Processing of Your Notice

Notice of Proposed Construction or Alteration

FOR FAA USE ONLY
Aeronautical Study Number

1. Sponsor *(person, company, etc. proposing this action)*:
Attn. of: ____
Name: ____
Address: ____

City: ____ State: ____ Zip: ____
Telephone: ____ Fax: ____

2. Sponsor's Representative *(if other than #1)*:
Attn. of: ____
Name: ____
Address: ____

City: ____ State: ____ Zip: ____
Telephone: ____ Fax: ____

3. Notice of: ☐ New Construction ☐ Alteration ☐ Existing

4. Duration: ☐ Permanent ☐ Temporary (____ months, ____ days)

5. Work Schedule: Beginning ____ End ____

6. Type: ☐ Antenna Tower ☐ Crane ☐ Building ☐ Power Line ☐ Landfill ☐ Water Tank ☐ Other ____

7. Marking/Painting and/or Lighting Preferred:
☐ Red Lights and Paint
☐ White - Medium Intensity
☐ White - High Intensity
☐ Dual - Red and Medium Intensity White
☐ Dual - Red and high Intensity White
☐ Other

8. FCC Antenna Structure Registration Number *(if applicable)*:
____

9. Latitude: ____ ° ____ ' ____ . ____ "

10. Longitude: ____ ° ____ ' ____ . ____ "

11. Datum: ☐ NAD 83 ☐ NAD 27 ☐ Other

12. Nearest: City: ____ State ____

13. Nearest *Public-use* *(not private-use)* or Military Airport or Heliport:
____

14. Distance from #13. to Structure: ____

15. Direction from #13. to Structure: ____

16. Site Elevation *(AMSL)*: ____ ft.

17. Total Structure Height *(AGL)*: ____ ft.

18. Overall Height (#16 + #17) *(AMSL)*: ____ ft.

19. Previous FAA Aeronautical Study Number *(if applicable)*:
____ -OE

20. Description of Location: *(Attach a USGS 7.5 minute Quadrangle Map with the precise site marked and any certified survey)*

21. Complete Description of Proposal:

Frequency/Power (kW)	

Notice is required by 14 Code of Federal Regulations, part 77 pursuant to 49 U.S.C., Section 44718. Persons who knowingly and willingly violate the notice requirements of part 77 are subject to a civil penalty of $1,000 per day until the notice is received, pursuant to 49 U.S.C., Section 46301(a)

I hereby certify that all of the above statements made by me are true, complete, and correct to the best of my knowledge. In addition, I agree to mark and/or light the structure in accordance with established marking & lighting standards as necessary.

Date	Typed or Printed Name and Title of Person Filing Notice	Signature

FAA Form 7460-1 (2-99) Supersedes Previous Edition Electronic Version (Adobe) NSN: 0052-00-012-0009

APPENDIX C

(U) NGA Aeronautical CHUM, Volume III of III, March 2004
CHUM Items for Correction

GENERAL INFORMATION

CHART DISCREPANCIES (to be shown in the CHUM/CHUM Supplement)

CHART SERIES

All mislocated, incorrectly identified, or new International Boundaries/Sovereignties on all chart series will be included in the CHUM/CHUM Supplement.	1501 AIR & COMBINED (1:250,000)	TPC, FRC (1:500,000)	ONC (1:1,000,000)	JNC (1:2,000,000) JNCA, LCC (1:3,000,000)	GNC, GLCC (1:5,000,000)
<u>Spot Elevations (Dot, X, Area)</u>					
Vertical Error of ± 100 ft or more	X	X	X		
Vertical Error of 500 ft or more too low				X	X
New	X	X	X	X	X
<u>Airfields</u>					
Vertical Error of ± 100 ft or more	X	X	X		
Vertical Error of + 500 ft or more too low				X	X
New (5000 ft or more hard surface, 8000 ft or more non-hard surface)	X	X	X	X	X
<u>Radar Altimetry Areas</u>					
Vertical Error of ± 100 ft or more				X	
<u>Maximum Terrain Elevations/Maximum Elevation Figures</u>					
Vertical Error of more than 400 ft.	X	X	X		
New	X	X	X		
<u>Projection, Military Grid, Navigation Grid or Mag. Variation</u>					
Incorrectly Identified	X	X	X	X	X
Incorrectly Plotted	X	X	X	X	X
<u>Power Transmission Lines</u>					
Mislocated more than 1 NM	X	X			
Mislocated more than 2 NM			X		
Missing (except within major cities)	X	X	X		
<u>Major Cultural, Aeronautical, Hydrographic & Landmark Features</u>					
Mislocated more than 1 NM	X				
Mislocated more than 2 NM		X			
Mislocated more than 3 NM			X		
Mislocated more than 5 NM				X	
Mislocated more than 10 NM					X
New	X	X	X	X	X
Missing	X	X	X	X	X
<u>Vertical Obstructions 200 feet and higher</u>					
Mislocated more than 1 NM	X	X			
Mislocated more than 2 NM			X		
Vertical Error of ± 100 ft or more	X	X	X		
New	X	X	X		
<u>LORAN</u>					
Change in Rate Designator				X	X
Change in Skywave Corrections				X	X

5

APPENDIX D

(U) NGA Quality Feedback Form

NGA QUALITY FEEDBACK CARD

NGA ACCOUNT NUMBER	SUBMISSION DATE	PRODUCT TYPE	PRODUCT NAME/NUMBER/EDITION/DATE	PAGE/PARA.NO./ETC

COMPONENT
- ☐ AIR FORCE
- ☐ NAVY
- ☐ DOD
- ☐ COAST GUARD
- ☐ ARMY
- ☐ MARINES
- ☐ CIVILIAN
- ☐ OTHER ________

NAME

ORGANIZATION/ADDRESS

PHONE (DSN OR COMM)

E-MAIL ADDRESS

QUALITY PROBLEM
- ☐ RECEIVED WRONG PRODUCT
- ☐ RECEIVED INCORRECT QUANTITIES
- ☐ RECEIVED IN POOR CONDITION
- ☐ PRODUCTS RECEIVED LATE
- ☐ REQUESTED PRODUCTS MISSING
- ☐ DUPLICATE FEATURE
- ☐ BORDER INFO INCORRECT
- ☐ HEIGHT/DEPTH INCORRECT
- ☐ INCORRECT POSITION
- ☐ OBSCURE/MISSING DATA
- ☐ INCONSISTENT DATA
- ☐ OTHER

DOD FLIP USERS REFER TO GP CHAPTER 11 FOR GUIDANCE

DISTRIBUTION OR PRODUCT RATING
POOR → EXCELLENT
1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ 10 ☐

REQUISITION/ VOUCHER NUMBER ________________

COMMENTS/DESCRIPTION OF QUALITY PROBLEM

FOR NGA USE ONLY

CONTROL NUMBER	RECEIVED BY/DATE	REPLY DATE

CUSTOMER HELP DESK 1-800-455-0899 OR E-MAIL quality@nga.mil

THIS CARD DOES NOT REPLACE EXISTING PROCEDURES FOR SUBMITTING REQUISITIONS OR REQUESTING AUTOMATIC DISTRIBUTION.

-UNCLASSIFIED DATA ONLY-

NGA FORM 8560-1, AUG 04 REPLACES NIMA FORM 8560-1, OCT 96 WHICH IS OBSOLETE.

APPENDIX E

(U) DVOF Input Form

For Submitting
New/Changed Vertical Obstructions to NGA, Concept of Operations for Vertical Obstruction Feature Data, 11 March 2008.

COUNTRY CODE: ☐ WAC # ☐

DVOF Submittal Form
Date:
POC:

Required Data											Desired Data									
LATITUDE				LONGITUDE				HGT ft/m	DESCRIPTION											
DD	MM	SS.SS	N/S	DDD	MM	SS.SS	E/W	AGL	VO TYPE	HGT ft/m AMSL	SOURCE MM/YY	Mono/ Stereo	AIRFIELD ELEV ft/m	HORIZ ACC	VERT ACC	# of VO's S/M	SURVEY PROCESS	ANALYST	REVIEW DATE	
30	45	47.40	N	86	18	30.50	W	230	Water Tower								Aircraft Survey			
31	07	16.00	N	86	02	29.40	W	290	Communication Tower								Ground Survey - GPS			
30	46	23.60	N	86	21	10.20	W	250	Power Transmission Pylon								Imagery Analysis			

ANALYST:
OFFICE:
TELEPHONE:

Minimum required information required includes geographic coordinates, datum, AGL height, and description of obstruction. Additional optional information includes elevation and/or AMSL height of the top of the obstruction above mean sea level, feature type code, validation code, source date, and accuracy data.

APPENDIX F

(U) Royal Australian Air Force

Vertical Obstruction Report Form

YOUR CONTACT DETAILS

Rank/Title ____ Name ____

Unit/Organisation ____

E-mail ____

Telephone ____

FAX ____

NOTIFICATION OF

- New structure
- Removal of structure
- Changes made to structure

LOCATION AND DESCRIPTION OF STRUCTURE

Type of structure ____ Other ____

Identification of the Structure (if known) e.g. Company reference No. ____

State or territory ____

Nearest Town/Landmark

Locality or featurename

Description of structure

Owner of structure

Is structure temporary? YES NO Not sure.

If YES, expected date of removal

SURVEY DATA

Datam type Other

Position Latitude (eg S 34 44' 14.5") or UTM Grid reference Zone other

Position Longitude (eg E 149 26' 54")

Positional accuracy (if available) Meters Feet

Date of last survey (if known) Year of erection

Height of obstruction Meters Feet

Height accuarcy (±) Meters Feet

Ground level elevation at base of structure (if known) Meters Feet

Height of structure from ground level including antenna/aerial(s) Meters Feet

Elevation* to top of structure including antenna/aerial(s) Meters Feet

* Elevation values are referenced in Mean Sea Level (AMSL) or the Australian Height Datum (AHD) and values are requested in feet or to the 1/10th metre.

How was the data captured:

1st order survey ☐ Stereo photogrammetric ☐ Mono photogrammetric ☐

Chart/map derived ☐ Handheld GPS (non survey) ☐ Reported ☐

Other

Guy-wire footprint Meters Feet *(Lateral distance from structure eg. 35 metres)*

MARKING

Obstacle marking YES NO Not sure

Obstacle Lighting YES NO Not sure

OTHER REMARKS

Submit Form | Clear Form

APPENDIX G

(U) Australian Government Civil Aviation Safety Authority

Australian Government
Civil Aviation Safety Authority

Advisory Circular

AC 139-08(0) **APRIL 2005**

REPORTING OF TALL STRUCTURES

CONTENTS

1. REFERENCES

- CASR 139.360 and CASR 139.365
- MOS – Part 139-Aerodromes, Chapter 7-Obstacle Restriction and Limitation, Section 7.1 – General
- Airports (Protection of Airspace) Regulations 1996

2. PURPOSE

2.1 The purpose of this AC is to provide some guidance to those authorities and persons involved in the planning, approval, erection, extension or dismantling of tall structures so that they may understand the vital nature of the information they provide.

2.2 Information on tall structure is held centrally by the Royal Australian Air Force (RAAF) Aeronautical Information Service (AIS) who maintain a tall structure database. Information is also provided to a range of aviation organisations so that they can be identified on aeronautical charts, etc.

3. STATUS OF THIS AC

3.1 This is the first AC to be issued on this subject, however the content of this AC updates information previously published in CAAP 89W-2(0) — Reporting of Tall Structures.

Advisory Circulars are intended to provide advice and guidance to illustrate a means, but not necessarily the only means of complying with the Regulations, or to explain certain regulatory requirements by providing informative, interpretative and explanatory material.

Where an AC is referred to in a 'Note' below the regulation, the AC remains as guidance material.

ACs should always be read in conjunction with the referenced regulations.

5 April 2005

4. BACKGROUND

4.1 The Australian aviation community has identified a need to have information on tall structures available for publication on aeronautical charts.

4.2 The RAAF Aeronautical Information Service (AIS) has been assigned the task of maintaining a database of tall structures, the top measurement of which is:

- 30 metres or more above ground level — within 30 kilometres of an aerodrome; or
- 45 metres or more above ground level elsewhere

4.3 The database of tall structures will generally capture more information than what is required to be reported by the regulations.

4.4 The database will also be available for use by mapping agencies such as Australian Surveying and Land Information Group, and domestic and international aviation organisations.

5. WHY REPORT TALL STRUCTURES

5.1 Inadvertent collision with tall structures is a significant cause of aircraft accidents involved in low level flying operations. The risk posed by a tall structure to aircraft safety can be minimised if information on the tall structure is conveyed to pilots so that they can fly at a safe margin above the structure.

5.2 Low level flying operations are typically conducted during:

- approach, landing and take-off operations
- specialist flying activities (such as crop-dusting, cattle mustering, pipeline inspection, fire-fighting)
- search and rescue operations
- military low-level flying operations

5.3 Except for approach, landing and take-off operations (which are normally conducted in the vicinity of an aerodrome) low level operations can be conducted anywhere across Australia (subject to regulatory conditions/limitations).

5.4 In addition to the safety of aircraft operations, an inadvertent collision with a tall structure poses a number of other risks:

- business continuity if the services provided from the tall structure are unavailable e.g. communications services
- costs associated with the erection of a new structure
- liability issues

5.5 In the event of an aircraft hitting a tall structure, the role of persons and/or organisations associated with the operation of the tall structure would be a matter for the courts.

6. WHAT ARE THE AVIATION REGULATIONS THAT APPLY TO TALL STRUCTURES?

6.1 CASR 139.360 requires the operator of a certified or registered aerodrome to notify CASA of any development or proposed construction in the vicinity of the aerodrome (normally 15km) that is likely to be a hazard to air navigation.

6.2 In the vicinity of major capital city airports, the *Airports (Protection of Airspace) Regulations 1996* also apply. Under these regulations, the operator of such an aerodrome has to notify the Department of Transport and Regional Services (DOTARS) of any potential infringement to the prescribed airspace established for that aerodrome. DOTARS has the power to prohibit or limit erection of tall structures within the prescribed airspace of a Federal Airport covered by the *Airports (Protection of Airspace) Regulations*.

6.3 In areas remote from an aerodrome, CASR 139.365 requires the owner of a structure (or proponents of a structure) that will be 110m or more above ground level to inform CASA. This is to allow CASA to assess the effect of the structure on aircraft operations and determine whether or not the structure will be hazardous to aircraft operations.

7. WHAT DO I NEED TO REPORT?

7.1 Details should be provided on the construction, extension or dismantling of tall structures the top of which is:

- 30 metres or more above ground level (within 30 kilometres of an aerodrome); and
- 45 metres or more above ground level elsewhere.

7.2 Information provided to the database should be accurate and readily interpreted. The "TALL STRUCTURE REPORT FORM" at Attachment A has been designed to help owners and/or developers in this respect.

8. WHERE WILL THE INFORMATION BE HELD?

8.1 The information on all tall structures is held in a central database that is managed by the RAAF AIS.

9. HOW DO I REPORT?

9.1 Information on tall structures and any queries in regard to the database should be directed to:

Aeronautical Data Officer
RAAF AIS (VBM-M2)
Victoria Barracks
St Kilda Road
Southbank Vic 3006
Tel: (03) 9282 6282
Fax: (03) 9282-6695
Email: ais.charting@defence.gov.au

9.2 To assist all organisations to provide all of the necessary and complete information, use of the standard "Tall Structure Report" form attached to this AC (Attachment A) is encouraged.

Richard Macfarlane
Acting Executive Manager
Aviation Safety Standards

ATTACHMENT A
TALL STRUCTURE REPORT FORM

To:	**Aeronautical Data Officer**
Date:	**....................**
Tel:	**(03) 9282 6282**
Fax:	**(03) 9282-6695**
Email:	ais.charting@defence.gov.au

NOTIFICATION OF New
Removal of
Change made to Tall Structures
(Delete As Appropriate)

LOCATION and DESCRIPTION OF STRUCTURE

Site Name: ______

Identification of the Structure (if known)
e.g. Company Reference No. ______ State or Territory ______

Site Address: ______

Nearest town or prominent landmark: ______ Locality or feature name: ______

Municipality / Shire Council: ______ Postcode: ______

Description (type) of structure: ______

(e.g. 45m Guyed Mast, 38m Concrete Monopole, 60m Lattice Tower, Lighthouse, Beacon, Building, Chimney, Elevated Tank)

Owner of structure: ______

SURVEY DATA

Survey Datum: (Note: The use of the wrong datum will misplace obstructions by around 200 m)

WGS 84 / GDA 94 ☐ AGD 66 ☐ AGD 84 ☐

Latitude: S ______ Longitude: E ______

(Degrees, minutes and seconds to 1/100th of a second) (if available) (DD:MM:SS.SS) or (DD.DDDD)

Or UTM Grid Reference: Easting / X (m) ______ Northing / Y (m) ______

Zone: ________ Positional Accuracy ± (metres) (if available) : ________

Date of last survey (if known): / / Year of erection: / /

Height of structure: ________ Height Accuracy ± FT (if available): ________

Ground level elevation* at the base of the Structure (if known): ________

Height from ground level to the top most point of the obstruction in metres (including all antennae, aerials and other attachments) : ________

Elevation* to the top of the structure in metres, including all antennae, aerials and other attachments: ________

Note: *Elevation values are referenced to Mean Sea Level (AMSL) or the Australian Height Datum (AHD) and values are requested in feet or to 1/10th of a metre.

Value Code: How was the data captured? (1) (2) (3) (4) (5) (6) (*Please circle*)

1.	1st order survey	2.	Stereo photogrammetric
3.	Mono photogrammetric	4.	Chart/map derived
5.	Handheld GPS (non survey)	6.	Reported

Guy-wire footprint: ________ metres (*Lateral distance from structure*)

MARKING

Obstacle marking	(e.g. painted red or orange and white)	Yes / No
Obstacle lighting	(e.g. flashing red obstacle light)	Yes / No
Other obstacle markers	(e.g. orange balls on guy wires)	Yes / No
Is the Obstacle Permanent or Temporary ?		Perm / Temp
If Temporary, what is the intended removal date:		/ /

OTHER REMARKS

CONTACT DETAILS

Name of person making report: ________

Organisation and position within organisation: ________

Tel or Fax contact : Tel: . ________ Fax: ________

Email: ________

ELECTRONIC SUBMISSION OF DATA

An online Vertical Obstruction Report Form is available at www.raafais.gov.au/obstr_form.htm **or** via the RAAF Web site at www.raafais.gov.au Products Vertical Obstruction Report Form.

SITE SKETCH

Site sketch showing the proximity to roads, streets, tracks, buildings, creeks, trig points and any other suitable or relevant features to locate the obstruction.

Will forward details to AIS website: Yes / No

If you are able to provide RAAF AIS with site drawings or construction plans in a zipped format, it would add to data integrity and completeness whilst lessening the need to make follow up calls to confirm any missing data.

Attachment Data can be sent to: ais.charting@defence.gov.au

APPENDIX H

(U) DVOF VOs for JAUDIT Collection Area

VO#	VOIDENTIFIER	LATITUDE	LONGITUDE	FEATURETYPE	HEIGHT AGL	HEIGHT AMSL	LOCATIONELEV	REC DATE
1	5103570348N	37.541111	-77.433056	BUILDING	425	593	168	19800204
2	5103570350N	37.536667	-77.434722	BUILDING	367	464	97	19800204
3	5103570356N	37.538611	-77.436944	BUILDING	253	342	89	19800204
4	5103570402N	37.540833	-77.436667	TOWER	244	412	168	19800204
5	5103570546N	37.538056	-77.438889	BUILDING	340	425	85	19800204
6	5103570598N	37.540278	-77.431667	BUILDING	197	366	169	19800204
7	5103570599N	37.544167	-77.440278	BUILDING	280	458	178	19800204
8	5103570600N	37.543056	-77.434167	BUILDING	154	330	176	19800204
9	5103570601N	37.539444	-77.438611	BUILDING	212	331	119	19800204
10	5103570602N	37.541667	-77.438611	BUILDING	225	405	180	19800204
11	5103570603N	37.540556	-77.433611	BUILDING	200	368	168	19800204
12	5103570604N	37.539167	-77.4375	BUILDING	296	418	122	19800204
13	5103570605N	37.535833	-77.440556	BUILDING	430	510	80	19800204
14	5103570606N	37.538889	-77.436389	BUILDING	270	377	107	19800204
15	5103570607N	37.539722	-77.4375	BUILDING	233	355	122	19800204
16	5103570608N	37.540556	-77.429722	BUILDING	250	388	138	19800204
17	5103570609N	37.54	-77.430833	BUILDING	235	393	158	19800204
18	5103570610N	37.538056	-77.436389	BUILDING	209	306	97	19800204
19	5103570611N	37.536667	-77.43	BUILDING	450	512	62	19800204
20	5103570612N	37.5375	-77.431667	BUILDING	250	350	100	19800204
21	5103570613N	37.5375	-77.4325	BUILDING	232	342	110	19800204
22	5103570614N	37.538611	-77.436667	BUILDING	275	363	88	19800204
23	5103570615N	37.537778	-77.433333	BUILDING	194	303	109	19800204
24	5103570616N	37.538333	-77.429722	BUILDING	228	348	120	19800204
25	5103570617N	37.533333	-77.437222	SMOKESTACK	235	260	25	19800204
26	5103570618N	37.526944	-77.433611	BUILDING	243	263	20	19800204
27	5103570684N	37.537222	-77.436389	BUILDING	400	490	90	19820123
28	5103570806N	37.539722	-77.438333	BUILDING	277	420	143	19840613
29	5103571047N	37.538333	-77.435833	BUILDING	215	325	110	19890809
30	5103571048N	37.536389	-77.435833	BUILDING	305	393	88	19890809
31	5103571049N	37.536667	-77.437222	BUILDING	285	370	85	19890809
32	5103571291N	37.542222	-77.424722	SMOKESTACK	220	267	47	19941006
33	5103570141G	37.521944	-77.4525	TOWER	138	253	115	19990729
34	5103570437G	37.520278	-77.453333	TOWER	160	260	100	19990729
35	5103570737G	37.538889	-77.437778	TOWER	315	430	115	20010508
36	5103570738G	37.537778	-77.438889	TOWER	340	442	102	20010508
37	5103576346C	37.520248	-77.430557	PYLON	79	103	24	20010609

VO#	VOIDENTIFIER	LATITUDE	LONGITUDE	FEATURETYPE	HEIGHT AGL	HEIGHT AMSL	LOCATIONELEV	REC DATE
38	5103576347C	37.51889	-77.430191	PYLON	79	107	28	20010609
39	5103576348C	37.51753	-77.429802	PYLON	79	106	27	20010609
40	5103576349C	37.51619	-77.42942	PYLON	79	102	23	20010609
41	5103576350C	37.51483	-77.429031	PYLON	79	98	19	20010609
42	5103576351C	37.5135	-77.428665	PYLON	79	101	22	20010609
43	5103576352C	37.51214	-77.428307	PYLON	79	106	27	20010609
44	5103576353C	37.51053	-77.428276	PYLON	79	112	33	20010609
45	5103576354C	37.50895	-77.428253	PYLON	79	118	39	20010609
46	5103576355C	37.50736	-77.428223	PYLON	79	124	45	20010609
47	5103576356C	37.50575	-77.428169	PYLON	79	129	50	20010609
48	5103576955C	37.55467	-77.443336	PYLON	79	221	142	20010609
49	5103576980C	37.55425	-77.441055	PYLON	79	225	146	20010609
50	5103576981C	37.55464	-77.439056	PYLON	79	233	154	20010609
51	5103576982C	37.55503	-77.437057	PYLON	79	232	153	20010609
52	5103577055C	37.50997	-77.424278	PYLON	79	87	8	20010609
53	5103577056C	37.50864	-77.424469	PYLON	79	88	9	20010609
54	5103577057C	37.50733	-77.424637	PYLON	79	89	10	20010609
55	5103577058C	37.506	-77.424835	PYLON	79	92	13	20010609
56	5103577059C	37.5047	-77.425003	PYLON	79	93	14	20010609
57	5103577060C	37.50336	-77.425194	PYLON	79	90	11	20010609
58	5103577062C	37.5207	-77.42778	PYLON	79	105	26	20010609
59	5103577063C	37.51936	-77.42733	PYLON	79	107	28	20010609
60	5103577064C	37.51803	-77.426865	PYLON	79	113	34	20010609
61	5103577065C	37.51669	-77.426392	PYLON	79	104	25	20010609
62	5103577066C	37.51539	-77.425919	PYLON	79	102	23	20010609
63	5103577067C	37.51406	-77.425446	PYLON	79	102	23	20010609
64	5103577068C	37.51272	-77.424973	PYLON	79	101	22	20010609
65	5103577069C	37.51142	-77.42453	PYLON	79	96	17	20010609
66	5103577070C	37.52542	-77.431808	PYLON	79	100	21	20010609
67	5103577071C	37.52428	-77.430611	PYLON	79	100	21	20010609
68	5103577072C	37.52314	-77.42942	PYLON	79	92	13	20010609
69	5103577073C	37.522	-77.428223	PYLON	79	105	26	20010609
70	5103577165C	37.52628	-77.44017	PYLON	79	131	52	20010609
71	5103577166C	37.52686	-77.439163	PYLON	79	114	35	20010609
72	5103577167C	37.53078	-77.436668	PYLON	79	101	22	20010609
73	5103577168C	37.53164	-77.438805	PYLON	79	102	23	20010609
74	5103577169C	37.53264	-77.43853	PYLON	79	104	25	20010609
75	5103577170C	37.53314	-77.446831	PYLON	79	115	36	20010609
76	5103570016X	37.54119	-77.433056	TOWER	484	654	170	20030709

APPENDIX I

(U//~~FOUO~~) DVOF – LIDAR Height and Location Analysis

VO #	OBST IDENT	TYPE	LIDAR AGL HT FT	DVOF AGL HT FT	Δ AGL HT	LIDAR LAT	LIDAR LON	DVOF LAT	DVOF LON	Δ X,Y DVOF→LIDAR	VO NAME
1	5103571291NR	SMOKE	220.4	220	**0.4**	373232.49N	772529.06W	373232N	772529W	**174° / 50'**	SEED CO.
2	5103570615NR	BLDG	218.9	194	**24.9**	373215.16N	772559.89W	373216N	772600W	**354° / 85'**	WASHINGTON BLDG
3	5103570613NR	BLDG	231.9	232	**-0.1**	373214.24N	772557.28W	373215N	772557W	**016° / 80'**	VA SMALL BUS FINANCING
4	5103570612NR	BLDG	230.4	250	**-19.6**	373213.85N	772554.47W	373215N	772554W	**077° / 122'**	OLD DOMINION U.
5	5103570618NR	BLDG	237.6	243	**-5.4**	373135.97N	772559.73W	373137N	772601W	**315° / 146'**	GRAIN SILOS
6	5103570617NR	SMOKE	167.3	235	**-67.7**	373200.99N	772613.39W	373200N	772614W	**206° / 112'**	BROWNS IS PWR PLANT
7	5103570605NR	BLDG	399.7	430	**-30.3**	373208.44N	772626.27W	373209N	772626W	**021° / 61'**	FED RES BANK
8	5103577168C	PYLON	123.4	79	**44.4**	373154.04N	772620.49W	373154N	772620W	**096° / 40'**	MID RIVER
9	5103577169C	PYLON	130.0	79	**51.0**	373158.80N	772619.07W	373158N	772619W	**176° / 81'**	N BANK RIVER
10	5103570602NR	BLDG	380.0	280	**100.0**	373238.44N	772622.86W	373230N	772619W	**100°/180**	CENTRAL NATIONAL BANK
11	5103577070C	PYLON	114.9	79	**35.9**	373131.81N	772554.43W	373132N	772555W	**292° / 50'**	S BANK RIVER
12	5103577062C	PYLON	94.8	79	**15.8**	373114.78N	772540.08W	373115N	772540W	**016° / 23'**	TYPE A
	5103577062CM	PYLON-N	94.4		**94.4**	373115.11N	772539.15W	NEW	NEW		TYPE A
13	5103577073C	PYLON	130.4	79	**51.4**	373119.69N	772542.75W	373119N	772542W	**139° / 92'**	TYPE A
	5103577073CM	PYLON-N	84.3		**84.3**	373118.71N	772543.33W	NEW	NEW		TYPE H
14	5103577070C	PYLON	115.8	79	**36.8**	373131.78N	772554.40W	373132N	772555W	**294° / 53'**	TYPE A
15	5103570601N	BLDG	210.4	212	**-1.6**	373220.97N	772618.62W	373222N	772619W	**343° / 108'**	VA DEPT OF ENVIRONMENT
16	5103570806N	BLDG	344.9	277	**67.9**	373223.58N	772618.52W	373223N	772618W	**144° / 72'**	CHAMBER OF COMMERCE
17	5103570604N	BLDG	305.2	296	**9.2**	373221.75N	772615.45W	373221N	772615W	**154° / 84'**	KINIRY & CO
18	5103570350N	BLDG	359.9	367	**-7.1**	373211.22N	772604.57W	373212N	772605W	**336° / 86'**	BANK OF AMERICA
19	5103570738G	COM TWR	365.1	340	**25.1**	373215.93N	772619.88W	373216N	772620W	**353° / 7'**	ONE JAMES RIVER PLAZA
20	5103570546N	BLDG	303.9	340	**-36.1**	373215.59N	772620.28W	373217N	772620W	**008° / 144'**	ONE JAMES RIVER PLAZA

VO TYPE MINUS N DENOTES NEW PYLON

(U/~~/FOUO)~~ DVOF – LIDAR Height and Location Analysis

VO #	OBST IDENT	TYPE	LIDAR AGL HT FT	DVOF AGL HT FT	**Δ AGL HT**	LIDAR LAT	LIDAR LON	DVOF LAT	DVOF LON	**Δ X,Y DVOF→LIDAR**	VO NAME
21	5103570607N	BLDG	200.4	233	**-32.6**	373223.26N	772614.30W	373223N	772615W	**245° / 62'**	7TH & FRANKLIN BLDG
22	5103570611N	BLDG	456.1	450	**6.1**	373210.64N	772548.36W	373212N	772548W	**011° / 40'**	JAMES MONROE BLDG
23	5103570616N	BLDG	233.9	228	**5.9**	373216.61N	772547.32W	373218N	772547W	**010° / 142'**	VA DOT ANNEX
24	5103570602N	BLDG	224.4	225	**-0.6**	373228.63N	772618.85W	373230N	772619W	**355° / 139'**	JOHN MARSHALL HOTEL
25	5103570598N	BLDG	256.6	197	**59.6**	373223.91N	772553.33W	373225N	772554W	**333° / 122'**	VCU SANGER HALL
26	5103570609N	BLDG	293.3	235	**58.3**	373221.78N	772550.19W	373224N	772551W	**343° / 234'**	VCU WEST HOSPTAL
27	5103570603N	BLDG	268.3	200	**68.3**	373224.91N	772601.03W	373226N	772601W	**001° / 110'**	VA LIFE INSURANCE CO
28	5103570348N	BLDG	349.7	425	**-75.3**	373227.59N	772558.68W	373228N	772559W	**328° / 49'**	RICHMOND CITY HALL
29	5103570016X	TWR	459.2	484	**-24.8**	373227.52N	772558.70W	373228N	772559W	**333° / 54'**	RICH CITY HALL NC TWR
30	5103577062C	PYLON	92.9	79	**13.9**	373115.12N	772539.13W	373115N	772540W	**260° / 71'**	TYPE A EAST
	5103577062CM	PYLON-N	94.4		**94.4**	373114.79N	772540.06W	NEW	NEW		TYPE A WEST
31	5103577063C	PYLON	106.5	79	**27.5**	373108.71N	772537.18W	373110N	772538W	**333° / 146'**	TYPE A EAST
	5103577063CM	PYLON-N	56.1		**56.1**	373110.53N	772538.75W	NEW	NEW		TYPE H WEST
32	5103577064C	PYLON	82.0	79	**3.0**	373104.27N	772535.82W	373105N	772537W	**307° / 120'**	TYPE A EAST
	5103577064CM	PYLON-N	69.9		**69.9**	373105.99N	772537.35W	NEW	NEW		TYPE H WEST
33	5103577073C	PYLON	131.2	79	**52.2**	373119.69N	772542.74W	373119N	772542W	**139° / 92'**	TYPE A EAST
	5103577073CM	PYLON-N	83.6		**83.6**	373118.71N	772543.33W	NEW	NEW		TYPE H WEST
34	5103570599N	BLDG	381.2	280	**101.2**	373238.41N	772622.81W	373239N	772625W	**289° / 186'**	PARK PLAZA
35	5103570141G	COM TWR	131.1	138	**-6.9**	373118.63N	772708.98W	373119N	772709W	**358° / 37'**	CELL TWR
	5103577170C	PYLON	8.4	79	**-70.6**	373159.87N	772648.26W	373159N	772649W	**214° / 106'**	DLT PYLON TREDEGAR

VO TYPE MINUS N DENOTES NEW PYLON

APPENDIX J

(U) PC_VO Tool Attributes

LIDAR or C3D VERTICAL OBSTRUCTION DATA (VOD) COMMA

(ALL OF THESE ATTRIBUTES ARE POPULATED FOR EACH VOD. EXPECT MULTIPLE VODs WITHIN A SINGLE .csv FILE)

No.	ATTRIBUTE NAME (Max 10 Chara)	MAX #CHAR or input format	POPULATED TYPE	Cum. bytes in binary if char variables are max length	UNITS	SAMPLE VALUE	DESCRIPTION & COMMENTS
1	VOD_LON_DD	F13.8	DOUBLE	8	dec.deg	43.23142310	VOD Longitide Decimal Degrees (+/- values with eight decimal places)
2	VOD_LAT_DD	F13.8	DOUBLE	16	dec.deg	36.35372991	VOD Latitide Decimal Degrees (+/- values with eight decimal places)
3	VOD_HGT_EU	F10.2	DOUBLE	24	feet	1072.70	VOD Height - Above Ground Level (AGL) - English Units (populated to 0.01 ft)
4	VODHGTMSLE	F10.2	DOUBLE	32	feet	1963.51	VOD Height Above Mean Sea Level (MSL) - English Units (top of the object)
5	VODHGTUNTE	8	ASCII CHAR	40	N.A.	FEET	VOD Height Units - English Units (for ease in comparison to older databases)
6	VOD_UNIQID	6	ASCII CHAR	46	N.A.	A00001	VOD Unique ID - this file only (ASCII type supports >100K by use of alphanumeric characters)
7	COUNTRYCOD	2	ASCII CHAR	48	N.A.	IZ	Country Code
8	SENSORTYPE	16	ASCII CHAR	64	N.A.	LIDAR	Sensor Type (Examples: LIDAR, EO, SAR, LADAR, UNKNOWN, …)
9	VODCONFID1	F5.1	DOUBLE	72	N.A.	100.0	VOD Confidence Metric 1 (alg.estimate prior to manual review) (range: 0.0 to 100.0)
10	VODCONFID2	F5.1	DOUBLE	80	N.A.	0.0	VOD Confidence Metric 2 (to be populated after manual review) (range: 0.0 to 100.0)
11	MANLREVIEW	1	ASCII CHAR	81	N.A.	N	Manual Review performed on this VOD yet ? Yes or No (Y/N)
12	FLYR_OTLR1	8	ASCII CHAR	89	N.A.	NO	Automated Alg Estimate. Is this a Flying Object or Outlier ? (Yes, No, Unknown)

LIDAR or C3D VERTICAL OBSTRUCTION DATA (VOD) COMMA

(ALL OF THESE ATTRIBUTES ARE POPULATED FOR EACH VOD. EXPECT MULTIPLE VODs WITHIN A SINGLE .csv FILE)

No.	ATTRIBUTE NAME (Max 10 Chara)	MAX #CHAR or input format	POPULATED TYPE	Cum. bytes in binary if char variables are max length	UNITS	SAMPLE VALUE	DESCRIPTION & COMMENTS
13	FLYR_OTLR2	8	ASCII CHAR	97	N.A.	TBD	Manual Review Result. Is this a Flying Object or Outlier ? (Yes, No, Unknown)
		(Upon Manual Review: If found to be a					
14	UTMZONEHEM	3	ASCII CHAR	100	N.A.	38N	UTM Zone & Hemisphere (North or South) { UTM=Universal Transverse Mercator }
15	VOD_EASTNG	F13.3	DOUBLE	108	meters	341309.688	VOD Easting UTM Coordinate (three decimal places)
16	VOD_NORTHG	F13.3	DOUBLE	116	meters	4024635.500	VOD Northing UTM Coordinate (three decimal places)
17	VOD_HGT_MU	F9.3	DOUBLE	124	meters	326.959	VOD Height - Above Ground Level (AGL) - Metric Units (populated to 0.001 m)
18	VODHGTMSLM	F9.3	DOUBLE	132	meters	598.477	VOD Height Above Mean Sea Level - Metric Units (top of the object)
19	VODGRDMSLM	F9.3	DOUBLE	140	meters	271.518	VOD Ground in MSL (elevation) - Metric Units {difficult to estimate in cultural areas}
20	VODGRDELPM	F9.3	DOUBLE	148	meters	287.115	VOD Ground above Ellipsoid (grnd hgt) - Metric Units {difficult to estimate in cultural areas}
21	VODHGTELPM	F9.3	DOUBLE	156	meters	614.074	VOD Height Above Ellipsoid - Metric Units (top of the object)
22	VODHGTUNTM	8	ASCII CHAR	164	N.A.	METERS	VOD Height Units - Metric Units
23	HORIZDATUM	32	ASCII CHAR	196	N.A.	WGS84_ELLIPSOID	Horizontal Datum (needed for computation of Latitude & Longitude)
24	MSLVERTDTM	32	ASCII CHAR	228	N.A.	EGM96_GEOID	Mean Sea Level (MSL) Vertical Datum
25	ELPVERTDTM	32	ASCII CHAR	260	N.A.	WGS84_ELLIPSOID	Ellipsoid Vertical Datum
26	PREDABSLE9	F5.1	DOUBLE	268	meters	5.0	Predicted Accuracy 90% Absolute Linear Error
27	PREDABSCE9	F5.1	DOUBLE	276	meters	7.0	Predicted Accuracy 90% Absolute Circular Error

LIDAR or C3D VERTICAL OBSTRUCTION DATA (VOD) COMMA

(ALL OF THESE ATTRIBUTES ARE POPULATED FOR EACH VOD. EXPECT MULTIPLE VODs WITHIN A SINGLE .csv FILE)

No.	ATTRIBUTE NAME (Max 10 Chara)	MAX #CHAR or input format	POPULATED TYPE	Cum. bytes in binary if char variables are max length	UNITS	SAMPLE VALUE	DESCRIPTION & COMMENTS
28	PREDRELLE9	F5.1	DOUBLE	284	meters	2.0	Predicted Accuracy 90% Relative Linear Error
29	ACCURUNITS	8	ASCII CHAR	292	N.A.	METERS	Accuracy Units
30	SECURITYCL	1	ASCII CHAR	293	N.A.	U	Security Classification for this File (U=Unclassified/FOUO, S=Secret)
31	ALGRUNDATE	10	ASCII CHAR	303	N.A.	2008.04.04	Algorithm Run Date (year.month.day)
32	ALGDESNAME	24	ASCII CHAR	327	N.A.	LIDAR_VOD	Algorithm Description or Name (Examples: LIDAR_VOD or C3D_VOD …)
33	ALGORVERSN	9	ASCII CHAR	336	N.A.	V08.04.04	Algorithm Version Number (Example: V year.month.day)
34	ALGMINVODH	F9.3	DOUBLE	344	meters	24.384	Algorithm Min VOD Height (minimum height for VOD, within this ALGDIAMVOD search area)
35	ALGMAXVODH	F9.3	DOUBLE	352	meters	701.040	Algorithm Max VOD Height (maximum height for VOD, due to an algorithm "pull-in" limit)
36	ALGDIAMVOD	F9.3	DOUBLE	360	meters	30.000	Algorithm VOD search Diameter (for this run of the algorithm)
37	ALGSPACVOD	F9.3	DOUBLE	368	meters	20.000	Algorithm VOD cylinder Spacing (for this run of the algorithm)
38	ALGREQDPT1	I6	4 BYTE INT	372	N.A.	3	Alg Required Minimum Number of XYZ Points 1 (above ground clutter height used)
39	ALGREQDPT2	I6	4 BYTE INT	376	N.A.	3	Alg Required Minimum Number of XYZ Points 2 (> 10ft above base surface estimate)
40	ALGMEASPT1	I8	4 BYTE INT	380	N.A.	278	Alg Measured Number of XYZ Points 1 for this VOD (above local ground clutter height used)
41	ALGMEASPT2	I8	4 BYTE INT	384	N.A.	1871	Alg Measured Number of XYZ Points 2 for this VOD (total > 10 ft above base surface est.)
42	ALGCLTRCMP	F9.3	DOUBLE	392	meters	6.555	Alg Local Ground Clutter Height Computed (estimate over a slightly larger area)

LIDAR or C3D VERTICAL OBSTRUCTION DATA (VOD) COMMA

(ALL OF THESE ATTRIBUTES ARE POPULATED FOR EACH VOD. EXPECT MULTIPLE VODs WITHIN A SINGLE .csv FILE)

No.	ATTRIBUTE NAME (Max 10 Chara)	MAX #CHAR or input format	POPULATED TYPE	Cum. bytes in binary if char variables are max length	UNITS	SAMPLE VALUE	DESCRIPTION & COMMENTS
43	ALGCLTRUSD	F9.3	DOUBLE	400	meters	15.240	Alg Local Ground Clutter Height Used (within this ALGDIAMVOD diameter search area)
44	ALGRND3SIG	F9.3	DOUBLE	408	meters	2.587	Alg Local Ground Terrain Variation 3 Sigma (st. over a slightly larger area)
45	ALGHSTNUL1	F7.1	DOUBLE	416	meters	15.0	Alg Histogram Null 1 (largest gap in vertical histogram, 5 meter increment)
46	ALGHSTNUL2	F7.1	DOUBLE	424	meters	10.0	Alg Histogram Null 2 (2nd largest gap in vertical histogram, 5 meter increment)
47	ALGHSTNUL3	F7.1	DOUBLE	432	meters	10.0	Alg Histogram Null 3 (3rd largest gap in vertical histogram, 5 meter increment)
48	ALGREQDQV1	F9.3	DOUBLE	440	N.A.	0.000	Alg Required Minimum Quality Value 1 (if nonzero, this is an input for this run)
49	ALGREQDQV2	F9.3	DOUBLE	448	N.A.	8.500	Alg Required Minimum Quality Value 2 (if nonzero, this is an input for this run)
50	ALGREQDQV3	F9.3	DOUBLE	456	N.A.	0.000	Alg Required Minimum Quality Value 3 (if nonzero, this is an input for this run)
51	ALGREQDQV4	F9.3	DOUBLE	464	N.A.	0.000	Alg Required Minimum Quality Value 4 (if nonzero, this is an input for this run)
52	ALGMEASQV1	F7.1	DOUBLE	472	N.A.	3827.8	Alg Measured Quality Value 1 for this VOD {values > 100 are good} (range: 0 to 10000)
53	ALGMEASQV2	F7.1	DOUBLE	480	N.A.	313.6	Alg Measured Quality Value 2 for this VOD {values > 100 are good} (range: 0 to 10000)
54	ALGMEASQV3	F7.1	DOUBLE	488	N.A.	229.6	Alg Measured Quality Value 3 for this VOD {values > 100 are good} (range: 0 to 10000)
55	ALGMEASQV4	F7.1	DOUBLE	496	N.A.	166.0	Alg Measured Quality Value 4 for this VOD {values > 100 are good} (range: 0 to 10000)

LIDAR or C3D VERTICAL OBSTRUCTION DATA (VOD) COMMA

(ALL OF THESE ATTRIBUTES ARE POPULATED FOR EACH VOD. EXPECT MULTIPLE VODs WITHIN A SINGLE .csv FILE)

No.	ATTRIBUTE NAME (Max 10 Chara)	MAX #CHAR or input format	POPULATED TYPE	Cum. bytes in binary if char variables are max length	UNITS	SAMPLE VALUE	DESCRIPTION & COMMENTS
56	ALG_RUN_ID	128	ASCII CHAR	624	N.A.	..tile04..run_b	Algorithm Run ID (should be equal to the .csv filename prefix)
57	ALGCOMMENT	64	ASCII CHAR	688	N.A.	…PROTOTYPE_ALG…	Algorithm Comment (Example: LM_DENVER_TOPO_GROUP_LIDAR_VOD_PROTOTYPE_ALGORITHM)
58	MARKERNAME	8	ASCII CHAR	696	N.A.	1073ft	Marker Name for the VOD - (unlike the attribute VOD_UNIQID these may not be unique)
59	MARKERLABL	32	ASCII CHAR	728	N.A.	100%_CONFID_EST	Marker Label Place Holder - (unlike the attribute VOD_UNIQID these may not be unique)
60	RGB_REDVAL	I6	4 BYTE INT	732	N.A.	255	RGB Red Value for Color Coding VOD Markers - (supported by QT Modeler Software)
61	RGB_GRNVAL	I6	4 BYTE INT	736	N.A.	255	RGB Green Value for Color Coding VOD Markers - (supported by QT Modeler Software)
62	RGB_BLUVAL	I6	4 BYTE INT	740	N.A.	0	RGB Blue Value for Color Coding VOD Markers - (supported by QT Modeler Software)
63	DATAINPTYP	32	ASCII CHAR	772	N.A.	XYZPOINTCLOUD	Input Data - Type of Input Data (Example: 3D XYZ Point Cloud Data)
64	DATAINPNBR	I4	4 BYTE INT	776	N.A.	1	Input Data - Number of Inputs (Example: 1, 2, ... up to 8 supported below)
65	DATAINPUT1	64	ASCII CHAR	840	N.A.	Mosul_a1_tile04	Input Data - Number 1 (Example: 30OCT05….12045 or Baghdad_Downtown_2007_a1_tile01)
66	DATAINPUT2	64	ASCII CHAR	904	N.A.	NA	Input Data - Number 2 (Example: 02NOV05….12022)

LIDAR or C3D VERTICAL OBSTRUCTION DATA (VOD) COMMA

(ALL OF THESE ATTRIBUTES ARE POPULATED FOR EACH VOD. EXPECT MULTIPLE VODs WITHIN A SINGLE .csv FILE)

No.	ATTRIBUTE NAME (Max 10 Chara)	MAX #CHAR or input format	POPULATED TYPE	Cum. bytes in binary if char variables are max length	UNITS	SAMPLE VALUE	DESCRIPTION & COMMENTS
67	DATAINPUT3	64	ASCII CHAR	968	N.A.	NA	Input Data - Number 3 (Example: 03NOV05….13033)
68	DATAINPUT4	64	ASCII CHAR	1032	N.A.	NA	Input Data - Number 4 (Example: 04NOV05….14044)
69	DATAINPUT5	64	ASCII CHAR	1096	N.A.	NA	Input Data - Number 5 (Example: 05NOV05….15055)
70	DATAINPUT6	64	ASCII CHAR	1160	N.A.	NA	Input Data - Number 6 (Example: 06NOV05….16066)
71	DATAINPUT7	64	ASCII CHAR	1224	N.A.	NA	Input Data - Number 7 (Example: 07NOV05….10077)
72	DATAINPUT8	64	ASCII CHAR	1288	N.A.	NA	Input Data - Number 8 (Example: 08NOV05….11088)
73	DATA_LONUL	F13.8	DOUBLE	1296	dec.deg	43.20409134	Input Data-Upper Left Longitide (missing data within these four corners is possible)
74	DATA_LATUL	F13.8	DOUBLE	1304	dec.deg	36.39879365	Input Data-Upper Left Latitide (missing data within these four corners is possible)
75	DATA_LONUR	F13.8	DOUBLE	1312	dec.deg	43.26216480	Input Data-Upper Right Longitude (missing data within these four corners is possible)
76	DATA_LATUR	F13.8	DOUBLE	1320	dec.deg	36.39965303	Input Data-Upper Right Latitide (missing data within these four corners is possible)
77	DATA_LONLR	F13.8	DOUBLE	1328	dec.deg	43.26343399	Input Data-Lower Right Longitude (missing data within these four corners is possible)
78	DATA_LATLR	F13.8	DOUBLE	1336	dec.deg	36.34258492	Input Data-Lower Right Latitide (missing data within these four corners is possible)
79	DATA_LONLL	F13.8	DOUBLE	1344	dec.deg	43.20540289	Input Data-Lower Left Longitide (missing data within these four corners is possible)
80	DATA_LATLL	F13.8	DOUBLE	1352	dec.deg	36.34172732	Input Data-Lower Left Latitide (missing data within these four corners is possible)
81	DATAXYZPTS	I10	4 BYTE INT	1356	N.A.	60354480	Input Data Total # XYZ Points (use 2Gig, if future value exceeds 2Gig limit of 4byte int)
82	DATASPACNG	F9.3	DOUBLE	1364	meters	0.750	Input Data approximate Spacing of XYZ Point Cloud Points

LIDAR or C3D VERTICAL OBSTRUCTION DATA (VOD) COMMA

(ALL OF THESE ATTRIBUTES ARE POPULATED FOR EACH VOD. EXPECT MULTIPLE VODs WITHIN A SINGLE .csv FILE)

No.	ATTRIBUTE NAME (Max 10 Chara)	MAX #CHAR or input format	POPULATED TYPE	Cum. bytes in binary if char variables are max length	UNITS	SAMPLE VALUE	DESCRIPTION & COMMENTS
83	DATACOMMNT	128	ASCII CHAR	1492	N.A.	ARMY_TEC…	DATA Comment (Example: ARMY_TEC_LIDAR_POINT_CLOUD_DATA_WAS_THE_INPUT_TO_THIS_ALGORITHM)
84	SENSORCMNT	128	ASCII CHAR	1620	N.A.	FLIGHT_ALT…	Sensor Comment (Example:FLIGHT_ALTITUDE_9000_TO_10000_FEET_SENSOR_MODEL_OPTECH_ALTM_3100_LIDAR_SENSOR)
85	SNSR_SDATE	10	ASCII CHAR	1630	N.A.	TBD	Sensor Collection Start Date (Ex: 2007.01.12 year.month.day, UNKNOWN, TBD)
86	SNSR_EDATE	10	ASCII CHAR	1640	N.A.	TBD	Sensor Collection End Date (Ex: 2007.01.14 year.month.day, UNKNOWN, TBD)
87	SITE_DESCR	128	ASCII CHAR	1768	N.A.	Mosul	Site Description or Name
88	VODFTR_EST	64	ASCII CHAR	1832	N.A.	POSSIBLE…	VOD Feature Estimate (this is an an estimate made by the algorithm prior to manual review)
89	VODFTR_ACT	64	ASCII CHAR	1896	N.A.	TBD	VOD Feature Actual (this should be correctly populated after manual review)
	(Examples: Narrow Radio or TV Antenna, Electrical Tower, Water Storage						
90	VODCHAINYN	8	ASCII CHAR	1904	N.A.	UNKNOWN	VOD Chain Y/N (Is this part of a chain or string of VOD? Yes, No or Unknown)
91	VODCHNDIR1	8	ASCII CHAR	1912	N.A.	UNKNOWN	VOD Chain Direction 1 (Ex:315.2deg) {azimuth measured CW from North or Unknown}
92	VODCHNDIR2	8	ASCII CHAR	1920	N.A.	UNKNOWN	VOD Chain Direction 2 (Ex:135.2deg) {azimuth measured CW from North or Unknown}

LIDAR or C3D VERTICAL OBSTRUCTION DATA (VOD) COMMA

(ALL OF THESE ATTRIBUTES ARE POPULATED FOR EACH VOD. EXPECT MULTIPLE VODs WITHIN A SINGLE .csv FILE)

No.	*ATTRIBUTE NAME (Max 10 Chara)*	*MAX #CHAR or input format*	*POPULATED TYPE*	Cum. bytes in binary if char variables are max length	*UNITS*	*SAMPLE VALUE*	*DESCRIPTION & COMMENTS*
93	VODCOMMENT	128	ASCII CHAR	2048	N.A.	NA	VOD Comment (Example: after manual review, this VOD was found to be a very tall radio antenna.)

NOTE: ATTRIBUTE NAME IS A MAXIMUM OF 10 CHARACTERS DUE TO SHAPEFILE EXPLOITATION SOFTWARE LIMITATIONS.

APPENDIX K

PC_VO Tool Derived Data

PC_VO tools Strip 09

VO #	VOD_LON_DD	VOD_LAT_DD	VODGRD MSLFT	VOD_HGT_EU	VODHGT MSLE	ALGMEAS PT1	COMMENTS
1	-77.43259113	37.53723853	123.1597	230.42	342.2923	14	Jefferson Bldg
2	-77.43598364	37.54040143	123.1701	219.62	422.0886	982	Tower on Structure
3	-77.43331088	37.53742645	123.1603	208.29	329.1001	10	Washington Bldg
4	-77.43274317	37.53634551	123.1567	200.67	323.7359	39	Madison Bldg
5	-77.43186071	37.53692917	123.1587	196.79	295.3075	886	Madison Bldg
6	-77.43602267	37.54261069	123.1773	196.67	388.5979	1306	Building
7	-77.43180553	37.53726598	123.1598	194.56	339.4117	23	Madison Bldg
8	-77.43647548	37.5429618	123.1785	183.31	389.2311	664	Marriott Hotel
9	-77.43179793	37.53710844	123.1593	173.14	300.7143	1125	Madison Bldg
10	-77.43688377	37.54332509	123.1796	161.84	364.9431	1203	Marriott Hotel
11	-77.43490298	37.54031784	123.1698	154.38	323.4570	102	Building
12	-77.43390769	37.54021672	123.1695	150.63	316.2195	686	Building
13	-77.4325115	37.53618132	123.1562	150.20	262.8732	1254	Building
14	-77.43578846	37.54118495	123.1726	143.43	322.7648	10159	Crescent Building
15	-77.4359955	37.54100495	123.1720	143.03	318.4931	11977	Crescent Building
16	-77.43544887	37.54129108	123.1730	142.65	327.3579	10530	Crescent Building
17	-77.41495893	37.51578369	123.0893	142.15	193.3328	422	Water Tower
18	-77.43520905	37.54118114	123.1726	140.65	318.4702	14810	Crescent Building
19	-77.41602174	37.51818605	123.0972	140.50	170.3079	953	Smokestack
20	-77.43656196	37.54171868	123.1744	139.99	337.9583	33	Crane
21	-77.4322902	37.53649903	123.1573	138.25	262.9520	1081	Building
22	-77.43609083	37.54116294	123.1726	138.11	314.8941	8090	Building
23	-77.434781	37.54046004	123.1702	135.29	307.9978	1011	Building
24	-77.4340812	37.54025594	123.1696	134.89	300.9669	1534	Building
25	-77.4355986	37.54118661	123.1726	131.53	323.2569	12320	Building
26	-77.43616363	37.54042249	123.1701	129.96	415.3531	2170	Tower on Structure
27	-77.43550948	37.53985025	123.1682	126.30	319.4052	4	Building
28	-77.43500373	37.53990349	123.1684	115.49	286.6921	210	Tower on Structure
29	-77.42693006	37.53121823	123.1399	115.27	145.6524	85	Building
30	-77.43635607	37.54057622	123.1706	113.86	365.2647	4074	Tower on Structure
31	-77.45139839	37.55879452	123.2304	113.69	287.9420	27	Powerline Pylon
32	-77.42676539	37.53136355	123.1404	112.73	149.0940	125	Building

PC_VO tools Strip 09

VO #	VOD_LON_DD	VOD_LAT_DD	VODGRDMSLFT	VOD_HGT_EU	VODHGTMSLE	ALGMEASPT1	COMMENTS
33	-77.42665	37.53118	33.78	112.66	146.43	184	Building
34	-77.43359	37.53875	162.98	110.60	273.57	267	Tower on Structure
35	-77.43469	37.54006	167.76	109.60	277.35	819	Building
36	-77.43775	37.54238	210.85	109.54	320.38	929	Building
37	-77.42636	37.53138	39.97	106.90	146.87	102	Building
38	-77.44788	37.55679	151.43	106.87	258.30	19	Pylon - Powerline Pylon
39	-77.44946	37.55778	153.20	104.33	257.52	15	Powerline
40	-77.44977	37.55795	154.18	102.97	257.14	5	Powerline
41	-77.44999	37.55806	154.78	101.96	256.73	9	Powerline
42	-77.44815	37.55696	151.53	100.00	251.52	6	Powerline
43	-77.41354	37.5161	56.43	98.11	154.54	87	Microwave Tower
44	-77.43068	37.53496	39.16	97.85	137.00	582	Building
45	-77.44903	37.55751	151.64	97.32	248.95	3	Powerline
46	-77.43195	37.53578	63.17	95.32	158.49	788	Building
47	-77.43039	37.53298	23.06	94.70	117.76	359	Light Pole
48	-77.42957	37.53433	79.04	94.33	173.37	310	Church
49	-77.43536	37.53939	176.13	90.02	266.14	364	Building
50	-77.42556	37.53038	32.10	87.96	120.06	31	Building
51	-77.43264	37.53662	177.73	85.46	263.18	1107	Building
52	-77.43064	37.53275	27.81	85.07	112.88	323	Light Pole
53	-77.43035	37.53246	23.22	84.25	107.47	314	Light Pole
54	-77.43214	37.53587	74.88	83.96	158.83	1082	Building
55	-77.43233	37.53761	128.19	83.79	211.97	1136	Building
56	-77.43165	37.53552	52.80	83.49	136.29	331	Building
57	-77.41492	37.51651	53.19	83.47	136.66	1356	Building
58	-77.41591	37.517	48.12	80.73	128.85	848	Building
59	-77.41535	37.51694	51.11	80.65	131.76	1495	Building
60	-77.4339	37.53903	162.84	72.70	235.53	526	Tower on Structure
61	-77.44819	37.5557	153.88	72.50	226.37	21	Pylon - Transformer Yard
62	-77.43023	37.53323	60.19	61.14	121.33	10	Light Pole
63	-77.43396	37.53952	163.53	60.49	224.01	45	Monument
64	-77.42979	37.53375	81.33	60.37	141.69	9	Light Pole

GLOSSARY

AAFIF	Automated Airfield Flight Information File
ADDE	Aeronautical Digital Data Environment
ADS-B	Automatic Dependent Surveillance – Broadcast
AEM	Airfield Elevation Model
AFAIB	Air Force Accident Investigation Board
AFI	Air Force Instruction
AGCA	Australian Government Civil Aviation
AGL	Above Ground Level
AI	Airfield Initiative
AIDU	Aeronautical Information Documents Unit
AIP	Aeronautical Information Publication
AIRAC	Aeronautical Information Regulation and Control
AIS	Aeronautical Information Service
AIXM	Aeronautical Exchange Markup Language
ALTM	Airborne Laser Terrain Mapper
AMDB	Aerodrome Mapping Data Base

AMSL	Above Mean Sea Level
AOE	Aeronautical Obstruction Environment
AOR	Area of Responsibility
APD	Avalanche Photo-Diode
ARC	Equal Arc Second Raster Chart
ARP	Airport Reference Point
ASG	Allied System for Geospatial-Intelligence
ASIAS	Aviation Safety Information Analysis and Sharing System
A-SMGCS	Advanced Surface Movement Guidance and Control System
ASPRS	American Society for Photogrammetry and Remote Sensing
ASRP	Antenna Structure Registration Program
AVA	Absolute Vertical Accuracy
AVN	Aviation System Standards
AVOID	Aviation Vertical Obstruction Identification Database
CADRG	Compressed ARC Digitized Raster Graphic
CEP	Circular Error of Probability
CFIO	Controlled Flight Into Obstruction

CFIT	Controlled Flight Into Terrain
CFPS	Combat Flight Planning Software
CFR	Code of Federal Regulations
CHUM	Chart Updating Manual
CIB	Command Investigation Board
CIGA	Italian Aeronautical Cartographic Information Center
CMOS	Complementary Metal Oxide Semiconductor
CO	Commanding Officer
COCOM	Combatant Command
CORS	Continuously Operating Reference Station
CSAR	Combat Search and Rescue
CSD	CADRG Supplement Disc
CSV	Comma Separated Value
CW	Continuous Wave
DAFIF	Digital Aeronautical Flight Information File
DARPA	Defense Advanced Research Projects Agency
DD	Decimal Degrees

DDM	Degrees, Minutes, Decimal Minutes
DDOF	Downloadable Digital Obstacle File
DEM	Digital Elevation Model
DFAD	Digital Feature Analysis Data
DGPS	Differential GPS
DIGO	Defence Imagery and Geospatial Organization
DIJE	Defence Intelligence Joint Environment
DME	Distance Measuring Equipment
DMS	Degrees, Minutes, Seconds
DNC	Digital Nautical Chart
DoD	Department of Defense
DOF	Digital Obstacle File
DORIS	Doppler Orbit determination and Radio-positioning Integrated on Satellite
DOT	Department of Transportation
DPS	Data Product Specifications
DSM	Digital Surface Model
DTED	Digital Terrain Elevation Data

DTM	Digital Terrain Model
DVOF	Digital Vertical Obstruction File
ECHUM	Electronic Chart Update Manual
EGM	Earth Gravitational Model
EO	Electro-Optical
EOD	Electronic Obstacle Data
ESA	European Space Agency
ESRI	Environmental Systems Research Institute
ETOD	Electronic Terrain and Obstacles Database
EU	European Union
EUROCAE	European Organization for Civil Aviation Electronics
FAA	Federal Aviation Administration
FACC	Feature and Attribute Coding Catalogue
FAR	False Alarm Rate
FAR	Federal Aviation Regulation
FCC	Federal Communications Commission
FCIF	Flight Crew Information File

FLIP	Flight Information Publication
FLIR	Forward Looking Infra-Red
FTC	Feature Type Code
FTIP	Foreign Terminal Instrument Procedures
FW	Fighter Wing
FWHM	Full Width Half Maximum
GBAS	Ground Based Augmentation System
GEOINT	Geospatial-Intelligence
GEOTRANS	Geographic Translator
GIS	Geographic Information System
GLONASS	Global Navigation Satellite System
G-M APD	Geiger Mode Avalanche Photo-Diode
GNC	Global Navigation and Planning Chart
GNS-A	Global Navigation Services – Aeronautical
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GRS	Geodetic Reference System

GWG	GEOINT Standards Working Group
HaE	Height above Ellipsoid
HLZ	Helicopter Landing Zone
HSIP	Homeland Security Infrastructure Program
HTDP	Horizontal Time Dependent Positioning
HUD	Heads Up Display
IAP	Instrument Approach Procedure
IC	Intelligence Community
ICAO	International Civil Aviation Organization
ICES	Ice, Cloud, and land Elevation Satellite
IERS	International Earth Rotation and Reference Systems Service
IMU	Inertial Measurement Unit
InGaAs	Indium Gallium Arsenide
INS	Inertial Navigation System
IPB	Intelligence Preparation of the Battlefield
IPCICT	Italian Parliamentary Committee of Inquiry into the Cermis Tragedy
IR	Instrument Flight Rules Military Training Route

ITRF	International Terrestrial Reference Frame
ISO	International Organization for Standardization
JAGMAN	Judge Advocate General Manual
JAUDIT	Jungle Airborne Under Dense Vegetation Imaging Technology
JCS	Joint Chiefs of Staff
JHUAPL	John Hopkins University Applied Physics Laboratory
JMPS	Joint Mission Planning System
JNC	Jet Navigation Chart
JOG-A	Joint Operational Graphic - Air
JSAT	Joint Safety Analysis Team
JSIT	Joint Safety Implementation Team
JWICS	Joint Worldwide Intelligence Communications System
KDOTAD	Kansas Department of Transportation Aviation Division
KML	Keyhole Markup Language
LAAS	Local Area Augmentation System
LAS	LASer File Exchange Format
LEO	Low Earth Orbit

LIDAR	Light Detection and Ranging
LITE	LIDAR in space Technology Experiment
L-M APD	Linear Mode Avalanche Photo-Diode
LST	LIDAR Surface Topography
LSU	Laser Scanner Unit
MC&G	Mapping Charting and Geodesy
MDA	Minimum Descent Altitude
MEF	Maximum Elevation Figure
MFD	Multi – Function Display
MOA	Military Operating Area
MODU	Mobile Offshore Drilling Unit
MRR	Military Regional Representative
MSAW	Minimum Safe Altitude Warning
MSL	Mean Sea Level
NACO	National Aeronautical Charting Office
NAD	North American Datum
NAVD	North America Vertical Datum

NAVPLAN	Navigation Planning
NAVSAFECEN	Naval Safety Center
NAVSTAR	Navigation System for Timing and Ranging
NAWS	Naval Air Weapons Station
NCGIS	National Center for Geospatial Intelligence Standards
Nd:YAG	Neodymium Yttrium Aluminum Garnet
NDB	Non – Directional Beacon
NGA	National Geospatial-Intelligence Agency
NGS	National Geodetic Survey
NGVD	National Geodetic Vertical Datum
NIMA	National Imagery and Mapping Agency
NIPRnet	Non-Secure Internet Protocol Router Network
NIR	Near Infra Red
NITF	National Imagery Transmission Format
NOAA	National Oceanic and Atmospheric Administration
NOHD	Nominal Ocular Hazard Distance
NOLAT	Non Low Altitude Tactics

NOS	National Ocean Service
NOTAM	Notice To Airmen
NSAWC	Naval Strike and Air Warfare Center
NSG	National System for Geospatial-Intelligence
NTSB	National Transportation Safety Board
NVG	Night Vision Goggle
OHA	Obstruction Height Accuracy
OIP	Office of International Affairs and Policy
OIS	Obstruction Identification Surface
ONC	Operational Navigation Chart
OPAL	Obscurant Penetrating Auto synchronous LIDAR
OVA	Overall Vertical Accuracy
PDF	Portable Document Format
PDOP	Position Dilution of Precision
PFPS	Portable Flight Planning Software
POC	Point of Contact
POD	Probability of Detection

POS	Position and Orientation System
PRF	Pulse Repetition Frequency
PVA	Point Vertical Accuracy
QNE	Pressure Altitude (29.92 or 1013.2 mb/hPa)
QNH	Local station altimeter setting
QTM™	Quick Terrain Modeler
RAAF	Royal Australian Air Force
RBAI	Ron Brown Airfield Initiative
ROI	Region of Interest
RTCA	Radio Technical Commission for Aeronautics
RTK	Real Time Kinematics
RVSM	Reduced Vertical Separation Minimum
SAC	Stereo Airfield Collection
SACCA	South Africa Civil Aviation Authority
SAR	Search and Rescue
SAR	Synthetic Aperture Radar
SBAS	Space Based Augmentation System

SCE	Southern California Edison
SECDEF	Secretary of Defense
SID	Standard Instrument Departure
SIMPL	Swath Imaging Multi-Polarization Photon-counting LIDAR
SIPRnet	Secret Internet Protocol Router Network
SLA	Shuttle Laser Altimeter
SMA	Surface Movement Area
SNR	Signal to Noise Ratio
SOW	Scope of Work
SPECOPS	Special Operations
SQL	Structured Query Language
SRTM	Shuttle Radar Topography Mission
STAR	Standard Terminal Arrival
SWTI	Seahawk Weapons and Tactics Instructor
TACAN	Tactical Air Navigation
TAGGS	Terminal Aeronautical GNSS Geodetic Survey
TAINS	TERCOM Aided Inertial Navigation System

TAMAC	Tactical Moving Map Capability
TCPED	Tasking, Collection, Processing, Exploitation and Dissemination
TERCOM	Terrain Contour Matching
TERPS	Terminal Procedures
TFADS	Table Formatted Aeronautical Data Set
TIFF	Tagged Image File Format
TLM	Topographic Line Map
TMA	Aerodrome Terminal Area
TPC	Tactical Pilotage Chart
TVA	Tennessee Valley Authority
UCMJ	Uniform Code of Military Justice
URGENT	Urban Reasoning and Geospatial Exploitation Technology
USG	United States Government
USGS	United States Geological Survey
UUID	Universal Unique Identifier
VCL	Vegetative Canopy LIDAR
VFR	Visual Flight Rules

VO	Vertical Obstruction
VOMT	Vertical Obstruction Management Team
VOWG	Vertical Obstruction Working Group
VPF	Vector Product Format
VR	Visual Flight Rules Military Training Route
VVOD	Vertical Vector Obstruction Data
WAAS	Wide Area Augmentation System
WGS	World Geodetic System
WMS	Wide Area Master Station
WRS	Wide Area Reference Station
XML	Extensible Markup Language

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