U.S. Department of
Homeland Security

United States
Coast Guard

Aids to Navigation Manual – Positioning & Range Surveying

COMDTINST M16500.1D
18 December 2012

U.S. Department of Homeland Security
United States Coast Guard

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United States Coast Guard

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COMMANDANT INSTRUCTION M16500.1D

Subj: AIDS TO NAVIGATION MANUAL, POSITIONING & RANGE SURVEYING

Ref. (a) Aids to Navigation Manual – Administration, COMDTINST M16500.7 (series)
(b) Differential Global Positioning System Broadcast Standard, COMDTINST 16577.1 (series)

1. PURPOSE. This Manual promulgates policy and guidance for the positioning of aids to navigation.

2. ACTION. All Coast Guard unit commanders, commanding officers, officers-in-charge, deputy/assistant commandants, and chiefs of headquarters staff elements shall comply with the provisions of this Manual. Internet release is not authorized.

3. DIRECTIVES AFFECTED. Aids to Navigation Manual, Positioning, COMDTINST M16500.1C is cancelled.

4. SUMMARY OF CHANGES. This revision constitutes a major overhaul of the USCG Aids to Navigation Positioning policy. Significant changes include the elimination of Accuracy Classification for buoys, addition of a chapter dedicated to range surveying, and removal of survey sextants as a positioning method.

5. REQUESTS FOR CHANGES. Area, District and Sector Commanders are encouraged to provide feedback and input for developing optimal policies and tools needed to carry out their Waterways Management responsibilities. Units and individuals may recommend changes by writing via the chain of command to:

Commandant (CG-5PW)
U. S. Coast Guard
2100 2nd St. SW, Stop 7580
Washington, DC 20593-7851

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6. DISCLAIMER. This document is intended to provide operational requirements for Coast Guard personnel and is not intended to nor does it impose legally-binding requirements on any party outside the Coast Guard.

7. RECORDS MANAGEMENT CONSIDERATIONS. This Manual has been evaluated for potential records management impacts. The development of this Manual has been thoroughly reviewed during the directives clearance process, and it has been determined there are further records scheduling requirements in accordance with Federal Records Act, 44 U.S.C. 3101 et seq., National Archives and Records Administration (NARA) requirements, and the Information and Life Cycle Management Manual, COMDTINST M5212.12 (series). This policy makes significant and substantial changes to existing records management requirements.

8. ENVIRONMENTAL ASPECT AND IMPACT CONSIDERATIONS.

a. The development of this Manual and the general policies contained within it have been thoroughly reviewed by the originating office in conjunction with the Office of Environmental Management, and are categorically excluded (CE) under current USCG CE # 33 from further environmental analysis, in accordance with Section 2.B.2. and Figure 2-1 of the National Environmental Policy Act Implementing Procedures and Policy for Considering Environmental Impacts, COMDTINST M16475.1 (series). Because this Manual contains guidance on, and provisions for, compliance with applicable environmental mandates, Coast Guard categorical exclusion #33 is appropriate.

b. This directive will not have any of the following: significant cumulative impacts on the human environment; substantial controversy or substantial change to existing environmental conditions; or inconsistencies with any Federal, State, or local laws or administrative determinations relating to the environment. All future specific actions resulting from the general policies in this Manual must be individually evaluated for compliance with the National Environmental Policy Act (NEPA), DHS and Coast Guard NEPA policy, and compliance with all other environmental mandates. Due to the administrative and procedural nature of this Manual, and the environmental guidance provided within it for compliance with all applicable environmental laws prior to promulgating any directive, all applicable environmental considerations are addressed appropriately in this Manual.

9. FORMS/REPORTS. The forms referenced in this Instruction are available in USCG Electronic Forms on the Standard Workstation or on the Internet: http://www.uscg.mil/forms/; CG Central at http://cgcentral.uscg.mil/; and Intranet at http://cgweb.comdt.uscg.mil/CGForms.

D. A. GOWARD /s/
Director, Marine Transportation Systems

RECORD OF CHANGES			
CHANGE NUMBER	**DATE OF CHANGE**	**DATE ENTERED**	**BY WHOM ENTERED**

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CHAPTER 1 - INTRODUCTION

A. Aids to Navigation Manual – Positioning & Range Surveying.

1. Purpose. The United States Coast Guard (USCG) operates and administers the United States Aids to Navigation System. The principle policy statements, administrative practices, and technical information needed to position visual aids to navigation (ATON) are presented in this Manual. Accurately positioned ATON are critical to:

    a. Assist the navigator in determining their position.

    b. Assist the navigator in determining a safe course.

    c. Warn the navigator of dangers, obstructions, and restricted areas.

    d. Promote the safe and economic movement of commercial vessel traffic.

    e. Promote the safe and efficient movement of military vessel traffic, and cargo of strategic military importance.

2. Content. This Manual contains instructions and policies governing the positioning of buoys, beacons, and ranges. Reference material is included where the source documents are not widely distributed. References are also made to Coast Guard and other Federal publications and to various Commandant Instructions.

3. Use. This manual is not intended to nor does it impose legally binding requirements on any party. Any requirements or obligations created by this Manual flow only from those involved in Coast Guard aids to navigation positioning administration to the Coast Guard, and the Coast Guard retains the discretion to deviate or authorize deviation from these requirements. This Manual creates no duties or obligations to the public to comply with the procedures described herein, and no member of the public should rely upon these procedures as a representation by the Coast Guard as to the manner of performance of our aids to navigation mission. Questions or comments from the public concerning compliance with any statutory or regulatory requirements referenced in the Manual should be addressed to Commandant, Visual Aids to Navigation Division (CG-NAV-1).

4. Positioning Objective. To ensure each ATON is placed as close as is reasonably possible to its Assigned Position (AP). However, placing an ATON at a specific geographic location is secondary to ensuring the ATON's actual location best marks the waterway and serves the purpose for which it is intended.

5. ATON Manual Organization. The Aids to Navigation Manual suite is comprised of the following five core Manuals:

    a. Aids to Navigation Manual – Positioning & Range Surveying, COMDTINST M16500.1 (series). Prepared and revised by Commandant (CG-NAV-1).

b. Aids to Navigation Manual – Administration, COMDTINST M16500.7 (series). Prepared and revised by Commandant (CG-NAV-1).

c. Aids to Navigation Manual – Seamanship, COMDTINST M16500.21 (series). Prepared and revised by Commandant (CG-751).

d. Aids to Navigation Manual – Technical, COMDTINST M16500.3 (series). Prepared and revised by Commandant (CG-432).

e. Aids to Navigation Manual – Structures, COMDTINST M16500.25 (series). Prepared and revised by Commandant (CG-432).

B. Professionalism.

1. Responsibility. Lawsuits brought against the USCG beginning in the 1950s revealed inadequacies in the USCG ATON positioning program. In a particularly notable 1972 case involving the M/V TAMANO, a Federal court found "USCG ATON positioning and recordkeeping was sloppy, inaccurate, and inadequate." It further noted that "ATON personnel were grossly untrained and lacking in experience and general knowledge." As a result, the ATON Positioning Project was commissioned to examine positioning practices and develop solutions to improve USCG ATON positioning professionalism. The first ATON Positioning Manual documenting these improvements was signed as a Commandant Instruction Manual in 1982.

C. Visual ATON Positioning Data Management.

1. Assigned Position (AP). With the exception of most buoys on the U.S. Western Rivers, aids to navigation are assigned a specific geographical location, known as an "AP." These positions are expressed in latitude and longitude to the thousandths of a second (less than 1.2 inches). The specific geographic location of a range structure prior to construction is known as Design Position (DP). Ranges shall be surveyed after construction is completed and the recorded surveyed position is known as As Built Position (ABP).

   Automated Aid Positioning System (AAPS). The USCG uses the AAPS application, which interfaces with the Global Positioning System (GPS), Differential GPS (DGPS), and GPS Receiver Autonomous Integrity Monitoring (GPS-RAIM) positioning data to graphically depict the position of ATON and the attributes of that position on a computer display.

2. Integrated Aids to Navigation Information System (I-ATONIS). AAPS data are transferred to I-ATONIS, a web-based application that is the central data repository for ATON data and related information. This information in turn is used to populate various nautical publications and charts; namely USCG Light Lists, Local Notices to Mariners (LNM), and Electronic Navigation Charts (ENCs). These data are directly imported from I-ATONIS into these nautical products; requiring due care for ensuring data integrity.

3. Positioning Requirements for Ranges. Ranges are a unique type of ATON and require High Accuracy Survey Systems (HASS) to locate their design position. An as-built HASS position is required after a range structure has been built. As-built positions are used to populate the I-ATONIS database to describe the precise location of the range. A HASS position exceeds the accuracy ability of AAPS. The Deputy Commandant for Mission Support (DCMS) is responsible for HASS support.

D. Visual Navigation – Organization.

1. Commandant (CG-NAV-1). Responsible for the overall administration of the visual ATON positioning program; promulgates policy, standards, and procedures. Also coordinates with other USCG Headquarters staff elements and other Federal agencies at the national level in support of the ATON positioning program.

2. District (dpw). Administers visual ATON positioning policy within their District, determines APs for buoys/beacons and DPs for ranges. Also coordinates with Federal, state, and local agencies regarding Waterways Management.

3. Sector Commanders. Provides oversight to ensure proper execution of visual ATON positioning policy within their area of responsibility.

4. Unit Commanding Officers and Officers-in-Charge. Responsible for properly positioning buoys and beacons and maintaining accurate records as required. Responsible for ensuring the accuracy of all marine information associated with the ATON under their primary responsibility (to include I-ATONIS, Hydrographic Office issued charts, Coast Pilots and Light Lists).

5. National Aids to Navigation (NATON) School, Training Center Yorktown. NATON provides training in ATON positioning. Personnel who successfully complete the AP course and receive their Commanding Officer's approval are assigned an ATON positioning competency code (ATNNL).

6. USCG Navigation Center (NAVCEN). NAVCEN, in addition to their other navigation projects, manages the I-ATONIS database which is used by the USCG ATON community as a management information and marine information system for tracking visual aids to navigation. I-ATONIS information is used to create the Local Notice to Mariners (LNM) and the seven volumes of the Light List. NAVCEN posts the weekly LNMs and annual Light List on its website (http://www.navcen.uscg.gov/) for reporting of marine information for public use.

7. Operations System Center (OSC), Martinsburg WV. OSC is a government-owned, contractor-operated facility with the primary function of providing full life-cycle support for operationally-focused Coast Guard Automated Information Systems. OSC provides Information Technology (IT) support for the I-ATONIS database and provides field support. More information can be obtained at: https://cgportal.uscg.mil/delivery/Satellite/OSC/

E. Exemptions.

1. Western Rivers. Buoys on the Western Rivers are exempt from the assigned position provisions of this Manual. On the Western Rivers, because of the dynamic nature of these waterways, it is not practical to assign buoys to a predetermined AP.

2. Positioning Data from External Sources. Positioning data obtained from National Oceanic and Atmospheric Administration (NOAA), U.S. Army Corps of Engineers (USACE), or contracted surveyors may be accepted by District (dpw) offices in lieu of AAPS generated ATON Positioning Reports (APR). Examples of this data include terrestrial/hydrographic surveys and photogrammetry.

CHAPTER 2 - POSITIONING SYSTEMS AND EQUIPMENT

A. General. The Global Positioning System (GPS), Differential Global Positioning System (DGPS), and GPS Receiver Autonomous Integrity Monitoring (GPS-RAIM) (formally referred to as GAPPS) are the primary methods for positioning USCG ATON with the exception of range structures. Satellite (i.e. GPS) based High Accuracy Survey Systems (HASS) are the primary methods for surveying USCG range structures or other beacons requiring high accuracy survey positions (e.g. Sector & Directional lights). Traditional survey methods (e.g. use of a Theodolite) are authorized, but must meet the accuracy and documentation requirements contained in Chapter 7 of this Manual. The matrix in Figure 2-1 lists the approved positioning methods for the three types of ATON.

Positioning System	Buoys	Beacons	Range Structures, Sector/Directional LTs
GPS	Yes	Yes	No
DGPS	Yes	Yes	No
GPS-RAIM	Yes	Yes	No
HASS	N/A	Yes	Yes

Figure 2-1

B. Global Positioning System (GPS). GPS is a space-based radionavigation system that provides reliable positioning, navigation, and timing services. GPS provides accurate location and time information in all-weather, day and night, anywhere in the world. Positions provided by the GPS constellation are expressed in WGS-84 Datum.

1. GPS Segments. The system consists of three segments: space, control, and user.

    a. Space. The space segment consists of a constellation of a minimum of 24 operating satellites that transmit one-way signals giving the current GPS satellite position and time.

    b. Control. The control segment consists of worldwide monitor and control stations that maintain the satellites in their proper orbits through occasional command maneuvers and adjustment of the satellite clocks. The control segment tracks the GPS satellites, uploads updated navigational data, and maintains health and status of the satellite constellation.

    c. User. The user segment consists of the GPS receiver equipment that receives the signal from the GPS satellites and uses the transmitted information to calculate the user's three-dimensional position and time.

2. GPS Positioning Theory. The GPS concept is predicated upon accurate and continuous knowledge of the spatial position of each satellite in the system with respect to time and distance from the user. The GPS receiver makes time-of-arrival measurements of the satellite signals to obtain the distance between the user and the satellites. These distance calculations, called pseudoranges, together with range rate information, are combined to yield system time and the user's three-dimensional position and velocity with respect to

the satellite system. A time coordination factor then relates the satellite system to Earth coordinates.

3. GPS Accuracy. GPS provides two levels of service for position determination, Standard Positioning Service (SPS) and Precise Positioning Service (PPS). Additionally, the accuracy of a GPS fix varies with the capability and quality of the equipment used.

   a. Standard Positioning Service (SPS). SPS is available, without qualification or restrictions, to all users on a continuous, worldwide basis. The 2010 Federal Radionavigation Plan specifies the global average of predictable positioning accuracy is 9 meters with a probability of 95 percent horizontally with time transfer accuracy within 40 nanoseconds (95 percent) of UTC (Coordinated Universal Time). USCG visual ATON positioning systems are based on this service.

   b. Precise Positioning Service (PPS). PPS is the most accurate positioning, velocity, and timing information continuously available, worldwide, from GPS. This service is restricted, through the use of cryptography, to U.S. Department of Defense (DOD) and select allied armed forces and governments. These restrictions are based on national security considerations.

4. Fix Rate. The fix rate is essentially continuous. Actual time to a first fix depends on user equipment capability and initialization with current satellite almanac data.

5. Fix Integrity. The GPS system architecture incorporates many features including redundant hardware, robust software, and rigorous operator training to minimize integrity anomalies. In accordance with DOD's Concept of Operation, GPS satellites are monitored more than 95 percent of the time by a network of five monitoring stations spread around the world. The information collected by the monitoring stations is processed by the Master Control Station at Colorado Springs, CO, and used to periodically update the navigation message (including a health message) transmitted by each satellite. The satellite health message, which is not changed between satellite navigation message updates, is transmitted as part of the GPS navigation message for reception by both SPS and PPS users. Additionally, satellite operating parameters such as navigation data errors, signal availability/anti-spoof failures, and certain types of satellite clock failures are monitored internally within the satellite. If such internal failures are detected, users are notified within six seconds via GPS receiver alarms. Other failures detectable only by the ground control segment may take from 15 minutes to several hours to detect. GPS receivers use the information contained in the navigation and health messages, as well as self-contained satellite geometry algorithms and internal navigation solution convergence monitors, to compute an estimated figure of merit. This number is continuously displayed to the operator, indicating the estimated overall confidence level of the position information.

C. Differential GPS (DGPS). DGPS is an augmentation of the GPS through the use of differential corrections to the basic satellite measurements performed within the user's receiver. DGPS is based upon accurate knowledge of the geographic location of a reference station. A DGPS reference station is fixed at a geodetically surveyed position. From this computes corrections based on its measurements and geodetic position. These corrections are then broadcasted to GPS users to improve their navigation solution.

1. DGPS Segments.

   a. Reference Station. A reference station generates corrections to pseudoranges for broadcast to users within its coverage area. This consists of a high quality, all-in-view GPS receiver with the additional computational capability to generate Radio Technical Commission for Maritime Services (RTCM) messages for the broadcast and to communicate with a remote control system. Pseudorange Corrections (PRCs) are broadcast for up to nine satellites which are above a 5° mask angle. It also accepts a watch-dog signal from the co-located integrity monitor, and is prepared to broadcast an integrity warning in the event of loss of monitoring or when an anomaly is detected by the integrity monitor. Co-location with the broadcast transmitter has been found to be the most economical and highest performing option.

   b. Broadcast Transmitter. Differential correction transmitters are marine radiobeacons that have been modified to accept MSK (Minimum Shift Keying) modulation. MSK is a spectrally efficient, advanced form of digital modulation. Real time DGPS correction data is input in the RTCM SC-104 format and broadcast to all users capable of receiving the signals.

   c. Control Station. The USCG's Navigation Center (NAVCEN) oversees a computerized control system operated by live watchstanders. The control station is connected to all broadcast sites by a packetized data communication network. The control station performs system level monitoring and configuration control of the data communication network and equipment at each individual site and is capable of handling the entire network in an emergency or for maintenance purposes. With the reference station and the integrity monitor co-located, the broadcast can remain healthy for a prolonged period of time if communications are severed from the control station. However, the NAVCEN DGPS watch will issue a Broadcast Notice to Mariners when communications with the station are lost to warn users of potential signal disruption or accuracy degradation.

   d. Integrity Monitor. An integrity monitor consists of an MSK receiver and a GPS receiver. Integrity is monitored on both the pseudorange and the position domain level. The integrity monitor is connected to the GPS reference receiver through a one way port and continuously informs the reference receiver of the broadcast status as received at the broadcast site.

   e. Shipboard Equipment. The USCG's DGPS system broadcasts corrections to users in the RTCM SC-104 format. The RTCM has defined data messages for use in the transmission of DGPS corrections, ancillary information, and integrity information. As the RTCM format allows flexibility in its implementation and use, the Differential Global Positioning System Broadcast Standard, COMDTINST 16577.1 (series), further defines the use of this format along with specifying the various broadcast parameters.

2. DGPS Theory. There are two well-developed methods of handling the computation of differential corrections to the basic satellite measurements performed within the user's receiver.

    a. Method 1. The first method, in which the correction terms for the x-y-z coordinates are broadcast, requires less data in the broadcast than the second method; but the validity of those correction terms decreases rapidly as the distance from the reference station to the user increases. Additionally, this method requires both the reference station and the user to compute the navigation solution using the same set of satellites, when that is not necessarily the case.

    b. Method 2. In the second method, several GPS observations along with the broadcast satellite parameters are used by a reference station which compares the measured ranges (pseudoranges) for up to nine satellites in view to a precise position of the reference station. The reference station then generates pseudorange corrections (PRCs) for these satellites. The corrections are simply the difference between the pseudorange and the calculated range of each satellite. The corrections are calculated using the difference between the satellites' broadcast position and the geodetic position of the reference station. Since the reference station does not maintain an absolute time of very high accuracy that would require expensive time transfer equipment, an equal time bias term resides in every PRC. This term is of no consequence when the user is utilizing PRCs from a single reference station since this common time bias drops out when computing a position solution. This method provides the best position solution for the user and is the preferred method. This is the method employed by the USCG maintained DGPS Service.

3. DGPS Accuracy. Differential pseudorange corrections typically improve GPS accuracy to 3-5 meters (95 percent).

4. DGPS Reference Station Sites. A listing of the operational DGPS reference station sites, frequencies, effective ranges, and other data is contained in Enclosure (1) of this Manual. Additional DGPS reference station information can be found in the Light Lists and on the NAVCEN's website (http://www.navcen.uscg.gov).

5. Information Updates. The latest updated information pertaining to DGPS is available on the NAVCEN's website (http://www.navcen.uscg.gov). NAVCEN also maintains a twenty-four hour watch and can be contacted by telephone at (703) 313-5900. The information available from NAVCEN's website includes: DGPS Site Status, DGPS Site Coverage Plots, DGPS Broadcast Site Listings, and Current Plans/General Information. A wide range of GPS information is also available, including GPS precise ephemeris data. Current USCG publications which are of interest to a large user segment are available as well.

D. GPS Receiver Autonomous Integrity Monitoring (GPS-RAIM). Receiver Autonomous Integrity Monitoring (RAIM) is a GPS integrity monitoring scheme that uses redundant ranging signals through the L1/L2 frequencies to detect a satellite malfunction, which results in a large range error due to either erroneous satellite clock or erroneous satellite ephemeris data. RAIM involves two functions: detection of the presence of a malfunctioning satellite and identification of which satellite (or satellites) is malfunctioning. If a satellite provides an out of tolerance fix, that satellite's information is removed from the set of information used to create a final fix. RAIM provides integrity monitoring of GPS to evaluate the quality of a position solution. A GPS-RAIM receiver requires a minimum of five satellites with satisfactory geometry to perform RAIM fault detection functions. RAIM solutions are transmitted to the AAPS application using a National Marine Electronics Association (NMEA) message. The position accuracy of GPS-RAIM is equal to GPS, but with improved accuracy confidence provided by the application of the RAIM solution.

E. High Accuracy Survey Systems (HASS). HASS is a USCG term for a multitude of high accuracy survey methods used by commercial and government surveyors (i.e. NOAA, USACE and USCG). Methods include the use of survey-level GPS receivers and traditional survey instruments. To qualify as a HASS, the equipment and procedures must be able to yield a position with an accuracy of better than 4 centimeters (cm).

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CHAPTER 3 - AID POSITIONS

A. General. With the exception of most aids to navigation on the U.S. Western Rivers, visual aids to navigation are assigned a specific geographical location. This location, authorized by the cognizant District Commander, is known as an Assigned Position (AP) for buoys and beacons. APs are expressed in latitude and longitude to the thousandths of a second (less than 1.2 inches).

1. Buoys and Beacons. The objective of positioning buoys and beacons is to ensure they are placed as close as is reasonably possible to their AP. The AP recorded in the District-controlled field of I-ATONIS is conveyed to the mariner through the Light Lists and other automated processes that produce charts and related hydrographic products. Therefore, the data integrity of the AP is paramount and its importance cannot be overstated. However, placing an ATON at a specific geographic location is secondary to ensuring the ATON's actual location best marks the waterway and serves the purpose for which it is intended. In these cases, a detailed description of the reason for the change shall be included in the remarks section of the Aid Positioning Report (APR) along with a request to change the AP.

2. Range Structures. The predetermined position for a range structure is known as its Design Position (DP). The post-construction or actual location of a range structure is known as its As-Built Position (ABP). The ABP recorded in the District-controlled AP field of I-ATONIS is conveyed to the mariner through the Light Lists and other automated processes that produce charts and related hydrographic products. As with APs, the data integrity of the ABP is paramount and its importance cannot be overstated. Positioning range structures requires a significantly higher level of accuracy and precision than buoys and beacons. Chapter 7 contains the specific procedures and standards for determining DPs and ABPs.

3. Western Rivers Buoys. The Western Rivers Marking System (as defined by 33CFR Section 62.51) reflects the unique environmental conditions that characterize these waterways: constantly shifting channels due to shoaling, current, and changes in river stage levels. Consequently, it is not practical to establish permanent buoy positions marking the navigable channel. The Western Rivers Marking System concept places a great deal of responsibility on ATON units to position floating aids to meet the changing river conditions based on a continuous assessment of the river to ensure that the ATON best marks the waterway. Unit Commanding Officers and Officers in Charge must use their best judgment concerning the number and placement of aids.

B. Waterway Types. For the purpose of developing APs, there are five general types of waterways; each requiring different considerations for development of AP/ DPs for ATON. When designing the channel and determining ATON AP/DPs, the largest vessel expected to use the waterway is most often the primary consideration. Additional guidance for waterway ATON design is contained in the Aids to Navigation Manual – Administration, COMDTINST M16500.7 (series).

1. Deep Water – Maintained. These waterways are generally restricted by nature, are assigned a project depth, and may require periodic dredging to maintain that project depth. The waterway depth is greater than 12 feet.

2. Deep Water – Not Maintained. These waterways are generally unrestricted. The channel boundaries are not delineated; however, ATON may be established to mark a desired depth or hazard. The waterway depth is greater than 12 feet.

3. Shallow Water – Maintained. These waterways are generally restricted by nature, are assigned a project depth, and may require periodic dredging to maintain that project depth. The waterway depth is 12 feet or less.

4. Shallow Water – Not Maintained. These waterways are generally unrestricted. The channel boundaries are not delineated; however, ATON may be established to mark a desired depth or hazard. The waterway depth is 12 feet or less.

5. Seacoast and Coastal Waters. ATON in these unrestricted waterways are generally used for geographic reference or to mark specific hazards to navigation.

C. Geodetic Datum and Coordinates Systems.

1. Geodetic Datum. A geodetic datum is a reference from which measurements are made. In surveying and geodesy (the science that deals with the precise measurement of the size and shape of the Earth), a datum is a set of reference points on the Earth's surface against which position measurements are made, and an associated model of the shape of the earth to define a geographic coordinate system. Horizontal datums are used for describing a point on the earth's surface, in latitude and longitude (Lat/Long) or other coordinate system. Vertical datums measure elevations or depths. The National Oceanic and Atmospheric Administration (NOAA) and their subordinate hydrographic office, the National Ocean Service (NOS); USACE and USCG use the following three horizontal datum reference systems.

    a. World Geodetic System 1984 (WGS 84). WGS 84 is a horizontal datum using a consistent set of parameters describing the size and shape of the earth, the positions of a network of points with respect to the center of mass of the earth. It forms the common geodetic reference system for modern Electronic Navigation Charts (ENC) on which positions from electronic navigation systems (e.g. GPS) can be plotted directly without correction. All ENCs, regardless of the issuing Hydrographic Office use WGS 84 datum.

    b. North American Datum 1983 (NAD 83). NAD 83 is the geodetic horizontal datum for North America and is the functional equivalent of the World Geodetic System (WGS). NAD 83 is the datum used on all NOS issued paper charts and their equivalent electronic Raster Navigation Chart with exception of the western Pacific.

    c. North American Datum 1927 (NAD 27). Prior to NAD 83 there was NAD 27, a horizontal datum constructed in 1927 based on the Clarke 1866 ellipsoid. NAD 27 was in use for many years and still appears on United States topographic maps. Older beacons and range structures may have historical Lat/Long or State Plane Coordinate (SPC) system positions expressed in NAD 27 datum.

2. Latitude and Longitude. Latitude (Lat) is the angular distance measured north or south of the equator and longitude (Long) is the angular distance measured east or west of the Prime Meridian. Latitude is referred to as Parallels; longitude is referred to as Meridians. By convention, the Equator establishes the position of zero degrees latitude and the Prime Meridian, which passes through the Royal Observatory, Greenwich, England, establishes the position of zero degrees longitude. Together, latitude and longitude are used as a geographic coordinate system to specify a location on the globe.

3. State Plane Coordinate System. The State Plane Coordinate (SPC) system is based on the Cartesian coordinate system. There are 124 geographic zones or coordinate systems designed for specific regions of the United States. Each state contains one or more SPC zones, the boundaries of which usually follow county/state lines. An SPC system is an X-Y grid with increasing Y values to the north and increasing X values to the east. Smaller states have one SPC zone and larger states have multiple zones. Every SPC zone is identified by a unique 4-digit number. The unit of measure used for State Plane Coordinates is feet. However, there are two different lengths of "feet;" the US Survey Foot and the International Foot. The difference between the measurements is very small, but becomes significant when dealing with measured distances across a state. Most states use the US Survey Foot but notable exceptions include South Carolina, Michigan, and Oregon. USCG waterway designers must know which datum, SPC zone, and which foot measurement is being used when using State Plane Coordinates for determining APs or DPs.

D. Channel Coordinates. The coordinates of maintained channels include the channel boundaries, centerline, and quarter lines. NOAA and NOS refer to these coordinates as the channel framework. The Cartesian coordinate system is used to describe channel coordinates that use a grid system with the same distance-unit-of-measure in both horizontal directions. Channel coordinates for maintained channels are typically established and maintained by the USACE and can be obtained from the appropriate USACE District Office.

1. USACE Channel Coordinates. USACE District offices use the appropriate SPC zone that a navigation project is located in to depict a channel. The SPC is usually referenced to the NAD 83 datum, but in some circumstances the SPC is referenced to NAD 27 datum. Particular care must be used when looking at a waterway that separates two states to ensure that the correct zone is used. The USACE identifies the SPC zone in the title block of their drawings.

2. High Precision Geodetic Network (HPGN). In rare cases USACE Districts will use the World Geodetic System of 1984 (WGS 84) coordinate system. This system uses meters as the unit of measure and requires particular care when using it.

   Coordinate System Conversions. Converting SPC and HPGN to latitude and longitude is accomplished by using the CORPSCON software program, which is available from the USACE. **CORPSCON is not an authorized program for use on the Coast Guard**

computer system, therefore it must be downloaded and installed on a standalone computer. Further information on CORPSCON and position conversions can be found in a job aid on the CG-NAV-1 Website (https://cgportal2.uscg.mil/units/cgnav1). Additional information and a downloadable version of CORPSCON can be found at: http://crunch.tec.army.mil/software/corpscon/corpscon.html

E. Determining Assigned Positions (AP) for Buoys and Beacons. The AP for buoys and beacons should best mark the waterway. In maintained waterways, APs for buoys should be placed on the channel's shoulder or as near to the channel's toe as possible. However, input from user groups or other considerations may require placement of ATON at a set distance away from the channel's toe on the channel shoulder (see Figures 3-1, 3-2, 3-3). Placement of an AP on a channel's slope should be avoided. Other considerations include vessel size, traffic density, environmental conditions, shoaling, and/or channel design objectives. There are five authorized methods for determining an AP with various levels of accuracy, these include:

1. USACE Computer-Aided Design (CAD) Software Programs. The USACE maintains channel drawings in various CAD electronic formats. USCG District (dpw) staffs can obtain CAD programs that are compatible with their local USACE District. These CAD programs, used in conjunction USACE drawings, will provide accurate channel boundary. Use of CAD software, like CORPSCON, may require a standalone computer.

2. **CO**ordinate **G**e**O**metry (COGO) Program. Positions can be determined by using a grid system with the same distance-unit-of-measure in both horizontal directions (i.e. an X-Y grid). These calculations are typically made using a COGO program. A USCG program is available to calculate positions on a channel boundary as well as positions set back from the boundary. Inputs include the channel centerline coordinates and the width of the channel. The program yields extremely accurate target positions that can be used as AP. In addition, the program can be used to calculate the positions of existing AP's relative to a channel toe. The USCG AP COGO program is posted on the CG-NAV-1 website (https://cgportal2.uscg.mil/units/cgnav1).

3. Paper Drawings. USACE and NOS print large-scale drawings that show channel boundaries and bathymetries (depth contours and bottom features). These drawings are usually scaled in feet using State Plane Coordinates (SPC). Positions can be determined from a paper drawing and converted to latitude and longitude using the CORPSCON software.

4. Nautical Charts. APs can be obtained by evaluating a nautical chart to determine a position. The accuracy of this crude method is dependent on the chart scale and is the least accurate of all authorized methods.

5. Determining AP On-Scene. Occasionally, an AP is determined from a recommended position obtained from an ATON servicing unit. This method is commonly known as "request MPP become AP." This is not an accurate method of determining AP when the goal is to place the ATON inside the channel toe, or as near to the channel toe as possible, or on the shoulder. Note: Channel Toe refers to the edge of a defined channel.

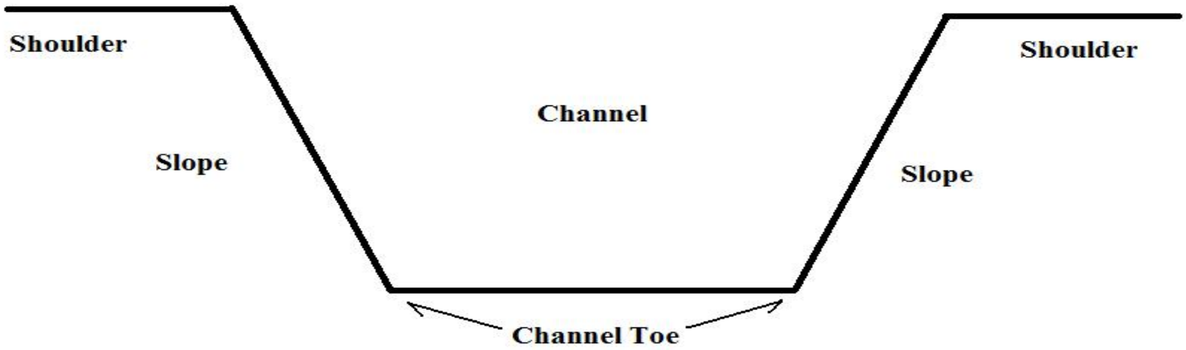

Figure 3-1
Example of Channel Toe, Slope, and Shoulder

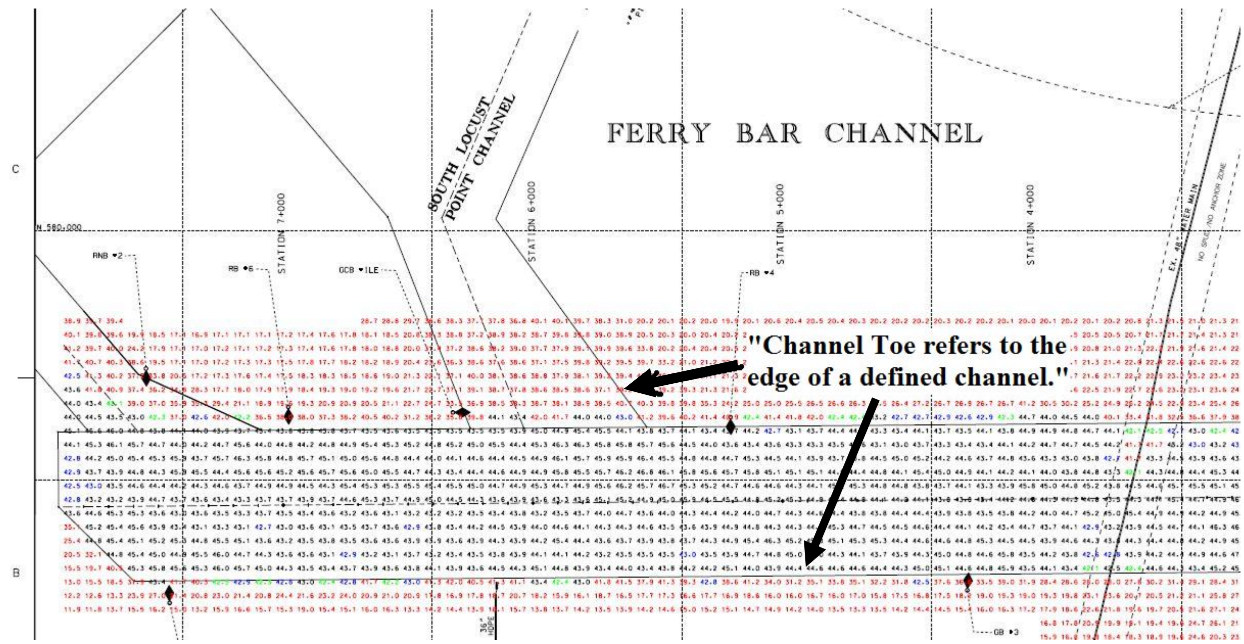

Figure 3-2
Channel Toe on USACE Survey Sheet

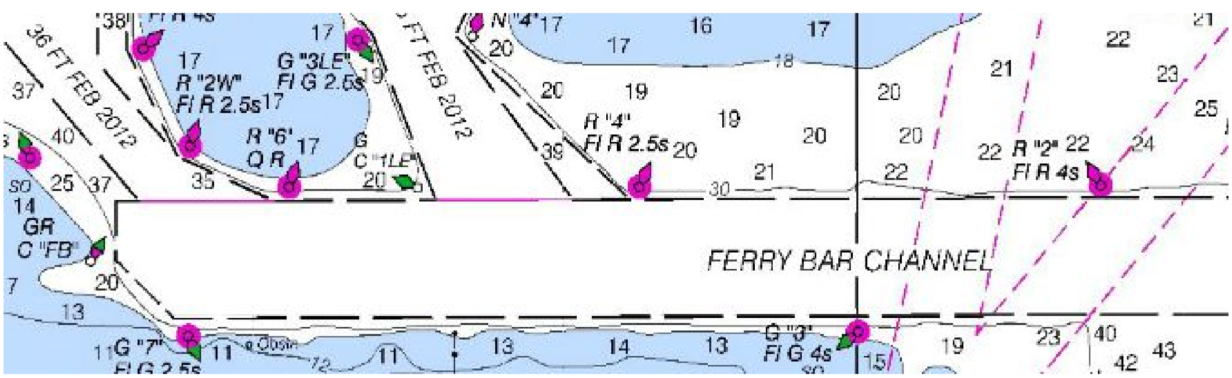

Figure 3-3
Channel Toe on a Raster Navigation Chart (RNC)

F. Changing AP to Coincide with the Most Probable Position (MPP). The MPP of an ATON is the most probable position of a buoy's sinker or a beacon. On occasion, it may be appropriate for a Commanding Officer or Officer-in-Charge to request changing the AP of an ATON. In these cases, a detailed description of the reason for the change shall be included in the remarks section of the Aid Positioning Report (APR). The practice of changing an ATON's AP is authorized under the following conditions:

1. When, under the premise of best marking the waterway, an ATON is intentionally not placed as close as is reasonably possible to its AP. **Servicing units should not confuse slight variations between MPP and AP as a requirement to request a change to AP.**

2. When, for a variety of reasons, it is necessary to place a beacon more than 3.0 yards from AP. Note: all relocations (temporary or permanent) must be advertised by a Broadcast Notice to Mariners (BNM) and in the Local Notice to Mariners (LNM).

CHAPTER 4 - GENERAL PROCEDURES

A. General. The Automated Aid Positioning System (AAPS) is the only authorized software tool used by ATON servicing units to ensure that each ATON is placed as close as reasonably possible to AP. Additional instructions for setup and maintenance of AAPS software, positioning laptop computers, and authorized positioning electronics (e.g., DGPS receivers) can be found on the NATON website.

B. Systems Used for Determining Most Probable Position (MPP). The following authorized positioning systems, listed in hierarchal order, are used by AAPS to determine MPP.

1. Differential Global Positioning System (DGPS). Use of DGPS is subject to the following conditions:

    a. DGPS data must be electronically transmitted into AAPS.

    b. DGPS receivers must (at a minimum) be capable of supplying the following National Marine Electronics Association (NMEA) sentences: GGA, GRS, GST, GSA, and DTM. Additional NMEA strings such as gyro compass heading input are authorized. (See Enclosure (2) of this Manual for explanation of NMEA data strings)

    c. DGPS reference station signals cannot be used for positioning aids to navigation beyond 260 NM. This distance was derived from Differential Global Positioning System Broadcast Standard Manual, COMDTINST M16577.1 (series) which states: “If no closer satisfactory beacons can be utilized a satisfactory beacon can be used beyond its advertised range if the user is within 300 statute miles of the broadcast site.” (300 statute miles = 260.7 nautical miles)

    d. DGPS receivers must be programmed to block signals if the age of the pseudorange correction exceeds 30 seconds.

    e. GPS provides Lat/Long positions in WGS 84 datum. DGPS Stations convert the Lat/Long into NAD 83 datum, therefore to avoid double conversions; the DGPS receiver's datum must be set to WGS 84. (See Chapter 3.C of this Manual for explanation of Geodetic Datums)

    f. When positioning ATON, the DGPS receiver must be set to Manual beacon selection mode. Manual selection of an operational beacon prevents the use of test beacons and beacons beyond the 260nm range restriction.

    g. The 2DRMS reading must be greater than zero (0). A reading of 0 indicates that the system is not functioning properly.

    h. Commanding Officers, Officers in Charge and coxswains will verify the DGPS receiver is operating properly as specified in the operator’s Manual prior to positioning ATON.

i. If there is reason to doubt the performance of the receiver, then the receiver operation shall be verified by conducting the reference check described in Enclosure (2) of this Manual.

j. In cases where there has been an equipment (hardware) configuration change, the verification procedure in Enclosure (2) of this Manual must be performed prior to using the DGPS equipment for positioning ATON.

2. <u>GPS Receiver Autonomous Integrity Monitoring (GPS-RAIM).</u> Use of GPS-RAIM is subject to the following conditions:

   a. GPS-RAIM data must be electronically transmitted into AAPS.

   b. GPS-RAIM receivers must (at a minimum) be capable of supplying the following NMEA sentences: GGA, GRS, GST, GSA, DTM, and RAIM. Additional National Marine Electronics Association (NMEA) strings such as gyro compass heading input are authorized.

   c. RAIM status is indicated by a green, yellow, or red light on the AAPS program plotting screen. A green light reported through RAIM indicates a valid MPP. Red and yellow light indicators reported through RAIM prohibit the use of positioning information in determining MPP.

   d. The 2DRMS reading must be greater than zero (0). A reading of 0 indicates that the system is not functioning properly.

   e. Commanding Officers, Officers in Charge and coxswains will verify the GPS-RAIM receiver is operating properly as specified in the operator's Manual prior to positioning ATON.

   f. If there is reason to doubt the performance of the receiver, then the receiver operation shall be verified by conducting the reference check described in Enclosure (2) of this Manual.

   g. In cases where there has been an equipment (hardware) configuration change, the verification procedure in Enclosure (2) of this Manual must be performed prior to using the GPS-RAIM equipment for positioning ATON.

   h. The GPS-RAIM receiver's datum must be set to NAD 83. The datum will be set to WGS 84 in cases where the paper chart's datum is in WGS 84 (e.g. western Pacific). (See Chapter 3.C of this Manual for explanation of Geodetic Datums)

3. <u>Global Positioning System (GPS).</u> Use of GPS is subject to the following conditions:

   a. GPS data must be electronically transmitted into AAPS.

b. GPS receivers must (at a minimum) be capable of supplying the following NMEA sentences: GGA, GRS, GST, GSA, and DTM. Additional NMEA strings such as gyro compass heading input are authorized.

c. The 2DRMS reading must be greater than zero (0). A reading of 0 indicates that the system is not functioning properly.

d. Commanding Officers, Officers in Charge and coxswains will verify the GPS receiver is operating properly as specified in the operator’s Manual prior to positioning ATON.

e. If there is reason to doubt the performance of the receiver, then the receiver operation shall be verified by conducting the reference check described in Enclosure (2) of this Manual.

f. In cases where there has been an equipment (hardware) configuration change, the verification procedure in Enclosure (2) of this Manual must be performed prior to using the GPS equipment for positioning ATON.

g. The GPS receiver's datum must be set to NAD 83. The datum will be set to WGS 84 in cases where the paper chart’s datum is in WGS 84 (e.g. western Pacific). (See Chapter 3.C of this Manual for explanation of Geodetic Datums)

C. Determining and Recording Water Depth. Aids to navigation must mark the depth of water appropriate to the waterway, and these positions must be verified in relation to the charted depth. An observed water depth (known as soundings) adds confidence that the ATON best marks the waterway as well as the MPP. An inconsistent sounding may indicate that the ATON is not in its AP or that the AP no longer best marks the waterway. Soundings should be taken as near to the ATON as possible. Soundings are observed using a fathometer, weighted line (lead line), or sounding pole.

1. Sounding Datums. Soundings used for ATON positioning are corrected to either Mean Low Water (MLW) or Mean Lower Low Water (MLLW) using NOAA predicted tide data and is indicated on the chart.

2. Sounding Methods. Soundings are taken and recorded on the APR when determining MPP.

a. Electronic Soundings. A fathometer obtains depth measurements by transmitting ultrasound waves and measuring the time it takes for their echo to return after hitting the seabed. Electronic sounding equipment must be calibrated in accordance with the manufacturer's instructions. When soundings are obtained by fathometer, the vertical distance from the vessel's waterline to the fathometer transducer must be taken into account. The AAPS software provides users the ability to record the vessel’s draft in the vessel configuration file and can automatically apply the draft correction to the recorded electronic sounding.

b. <u>Manual Soundings.</u> Manual soundings are obtained using a lead line or sounding pole and are typically more accurate in shallow water. A lead line consists of a length of line with a weight attached to one end and markings to indicate depth. A sounding pole is marked (usually in feet), normally has a metal shoe on one end, and is used in water depths of less than 20 feet.

CHAPTER 5 - POSITIONING BUOYS

A. General. A buoy is defined as a floating object of defined size, shape, and color, usually made of steel, plastic, or foam, which is anchored at a given position and serves as an aid to navigation. It may be equipped with a light, sound, or other signal. Buoyant beacons are considered buoys for positioning purposes.

B. Positioning Accuracy Standards for Buoys. Accuracy standards for positioning buoys have been established in order to assist units in meeting the objective of this Manual. Buoys are assigned three levels of accuracy based on risk associated with a waterway type (i.e. Great, Moderate, and Low).

1. Positioning Tolerance (PT). The radius of a circle, expressed in yards, that represents the maximum distance in which a buoy sinker may be placed in relation to AP. The PT is an assessment of risk that considers the waterway type as defined in Paragraph 3.B of this Manual.

2. A Positioning Tolerance shall be assigned to all buoys except buoys that have been granted an exemption (see Paragraph 1.E. of this Manual). Table 3-1 illustrates the three levels of positioning tolerance.

Waterway Type	**Buoy Positioning Tolerance**
Deep/Shallow Water Maintained-Restricted	**15 yards**
Deep/Shallow Water Not Maintained-Unrestricted	**25 yards**
Sea Coast and Coastal	**40 yards**

Table 3-1

C. Determining MPP. The MPP of a buoy's sinker is determined while the buoy is at *Short Stay* or *Not at Short Stay*. The MPP is recorded as either *Set* or *Found*. A set MPP can only be determined while the buoy is at short stay or when the sinker is released from a mechanical chain stopper. A *found* MPP can be determined when the buoy is at short stay or not at short stay.

1. Short Stay – MPP Determination. Short stay is defined as when the scope of chain is equal to, or nearly so, the depth of water, thereby having the sinker directly underfoot. MPP is recorded as *set* when the chain is at short stay or when the sinker is released (e.g. mechanical chain stopper, dump board, etc.).

2. Not at Short Stay – MPP Determination. Not at short stay is defined as when the scope of chain is greater than the depth of water and the buoy is subject to natural forces, creating a situation where the sinker and buoy are not vertically aligned. This situation

necessitates an approximation of the horizontal distance and direction of the buoy from the sinker; known as *excursion*. MPP is recorded as *found* whenever the buoy is not at short stay.

a. Excursion. The preferable method for determining a sinker's MPP is while at short stay. Recognizing that circumstances may not allow this on every occasion, the calculation and assessment of excursion shall be used to determine the sinker's MPP. The direction of excursion is determined by a careful consideration of all the forces acting on or applied to the buoy and is expressed in degrees true from the sinker to the buoy. The length (horizontal distance) of excursion is determined by using the following methods:

(1) Hypotenuse Method. Excursion using this method is determined by extending the mooring to its maximum length and using Pythagorean's Theorem to calculate the distance. This is classically known as the watch circle radius.

$$\text{Excursion}_{\text{Hypotenuse Method}} = \sqrt{(\text{Chain Length})^2 - (\text{Water Depth})^2}$$

(2) L method: Excursion using this method is determined by an assessment of environmental factors to determine the direction (bearing) of the buoy from the sinker and subtracting the observed water depth from the total length of the mooring (consider buoy draft and bridle length for larger buoys) to determine the horizontal distance between the sinker and buoy.

$$\text{Excursion}_{\text{L Method}} = \text{Length of Mooring} - \text{Observed Water Depth}$$

b. Watch Circle Radius. Watch circle radius is a function of ocean engineering requirements used to keep a buoy moored to the seabed. Watch circle radius is used to help calculate excursion for MPPs that are recorded as found when not at short stay. Watch circle radius does not influence or contribute to the determination of On/Off Station. Care should be taken to appropriately design a buoy's mooring while considering the watch circle relative to the channel width and any other limits of the waterway.

$$\text{WCR} = \sqrt{(\text{Chain Length})^2 - (\text{Water Depth})^2}$$

D. ON/OFF Station Determination. A buoy is determined to be on station when its sinker is within the prescribed positioning tolerance. The three functions that determine ON-Off Station are:

1. Assigned Position (AP). As described in Chapter 3, ATON with the exception of most buoys on the Western Rivers, are assigned a specific geographic location known as an Assigned Position.

2. Distance Root Mean Squared (DRMS). The DRMS represents the radius of a circle of probable error where the MPP will be located. At 95% probability, this analysis is extended to twice the DRMS and is referred to as 2DRMS. The 2DRMS for a fix equals 2

times the square root sum of the squares of the standard deviation of latitude error and the standard deviation of longitude error, both obtained from the GST (GPS Pseudo Range Noise Statistics) NMEA sentence.

3. Most Probable Position (MPP). The MPP of an ATON is the most probable position of its sinker based on an error analysis of the positioning fix (known as 2DRMS). MPP is located in the center of the 2DRMS probability circle. Figure 5-1 depicts the "circle within a circle" positioning concept used by AAPS when making on/off station determinations.

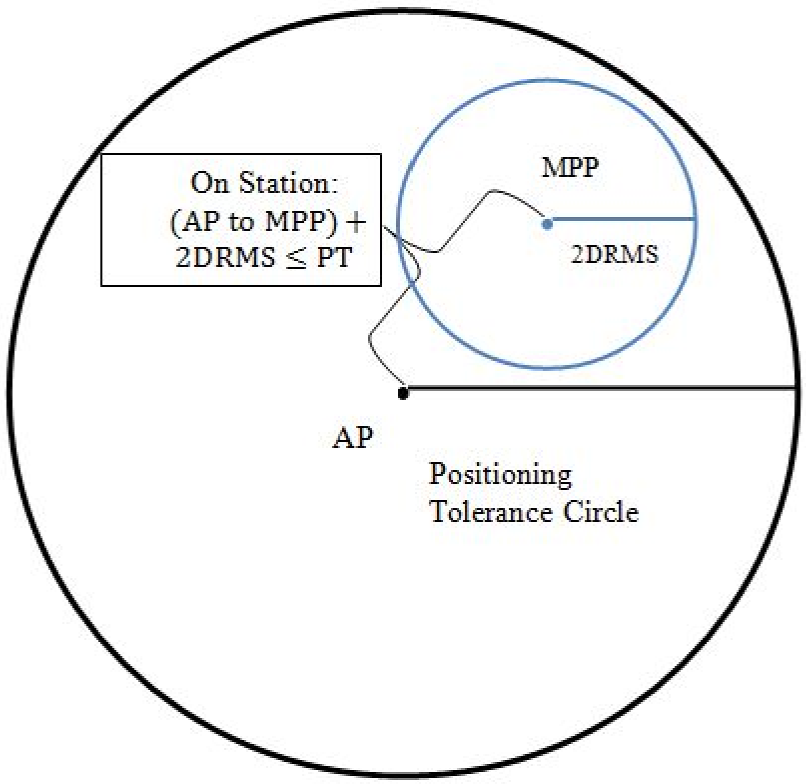

Figure 5-1
On Station: $(AP\ to\ MPP) + 2DRMS \leq PT$

E. AAPS. The plotting screen within AAPS is the primary tool used to make the on-or-off station determination. With automated input from satellite geometry, it calculates and displays MPPs relation to AP and factors in 2DRMS.

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CHAPTER 6 - PROCEDURES FOR POSITIONING BEACONS

A. General. A beacon is defined as an aid to navigation that is constructed on land or in the water and is permanently affixed to the terrestrial surface or sea bed. Beacons are usually constructed of steel, wood, or cement with defined size, shape, and color. They may be equipped with a light, sound, or other signal. For positioning purposes, range structures are not considered as beacons. Positioning requirements for Range structures are located in Chapter 7.

B. Positioning Standards for Beacons. Accuracy standards for positioning beacons have been established in order to assist units in meeting the objective of this Manual. The positioning objective for beacons is to place them within 3 yards of AP.

   3. Positioning Tolerance. A beacon's positioning tolerance is described within AAPS as either Position Exact (PE) or Position Exact – Relocate (PER), which is determined by the distance of MPP to AP. When MPP to AP is 3.0 yards or less, AAPS describes MPP as PE. When MPP is greater than 3.0 yards from AP, AAPS describes MPP as PER. As described in Chapter 3, it may be necessary to place a beacon outside the 3-yard tolerance, necessitating that MPP become AP and corrections are issued for the appropriate charts and Light List.

   4. Positioning Source Confidence. Historically, positioning requirements for beacons were divided into "High" and "Low" accuracy categories. Additionally, requirements for accuracy were influenced by "Cartographer's Tolerance" which determined if the beacon's positioning accuracy was sufficient to justify advertising the aid with a closed circle navigation symbol on paper charts based upon the scale of the chart. However, with the advent of the electronic charts and satellite positioning systems, the USCG has adopted one level of certainty for positioning beacons. The 2DRMS of a MPP cannot exceed 9.8yds (9 meters). AAPS will not allow a fix to be taken when the 2DRMS is greater than 9.8 yards.

C. Verifying the Position of Beacons. The AP of a beacon is recorded in I-ATONIS and is the position provided to NOS to depict the aid on nautical charts. The set fix obtained when a beacon is constructed must be within 3.0 yds of AP. MPP must be made AP if the distance is greater than 3.0yds. Once the position of the beacon has been recorded, there is no requirement to periodically position check the structure unless there is reason to doubt the accuracy of the original set fix, such as the beacon appearing incorrectly on the chart. If a new fix is obtained, a comparison of the AP and new fix must be made to determine if the AP should be changed. If the 2DRMS of the new fix encompasses the AP, then AP should not be changed. If the 2DRMS of the new fix does not encompass the old fix and the distance from AP is greater than 3.0yds, MPP should be made AP with I-ATONIS, Light List, and Chart corrections issued, or the aid should be relocated to be within 3 yards of AP. Figures 6-1 and 6-2 illustrate this concept.

Figure 6-1
The 2DRMS of the new fix encompasses the AP. AP should not be changed.

Figure 6-2
The 2DRMS of the new fix does not encompass the old fix and the distance from AP is greater than 3.0yds, MPP should be made AP.

CHAPTER 7 - RANGE STRUCTURES

A. <u>General</u>. Positioning range structures requires a significantly higher level of precision and accuracy than other ATON. A small error in the position of a Range Front Light (RFL) or Range Rear Light (RRL) can result in an unacceptable error in the rangeline and reduce the effectiveness of the range. This Chapter describes the standards and procedures for developing a range structure Design Position (DP) and As-Built Position (ABP).

B. <u>Determining Design Positions (DP) for Range Structures.</u> The specific geographic location assigned to range structures is known as DP. The following sections describe the standards and procedures for developing a DP.

1. <u>Rangeline</u>. The term “rangeline” is defined to be the line that passes through the ABP of the RFL lantern and RRL lantern. The objective is to position the RFL and RRL so that the resultant rangeline best serves the mariner and is normally the USACE defined channel centerline. Calculating the location of the desired rangeline requires use of channel coordinates. Using a chart (paper or electronic) to extend a rangeline to determine a DP will not yield a position with an acceptable accuracy. The following are three examples of rangelines used in waterway design.

    a. <u>Channel Centerline</u>. The majority of navigational channels with range structures have parallel boundaries. The objective of this design is to mark the USACE defined centerline of the channel.

    b. <u>Parallel to Channel Centerline</u>. The waterway design objective of some channels is to mark a line offset from, but parallel to the channel centerline. An example is a channel with an upbound range and a downbound range, with both rangelines offset from the centerline to allow meeting vessels to pass safely while on their respective rangelines.

    c. <u>Irregular Channel Boundaries</u>. In some cases channel boundaries are not parallel and there is no distinct channel centerline (see Figure 7-1). The objective for these range structures is to provide a rangeline that best marks the waterway.

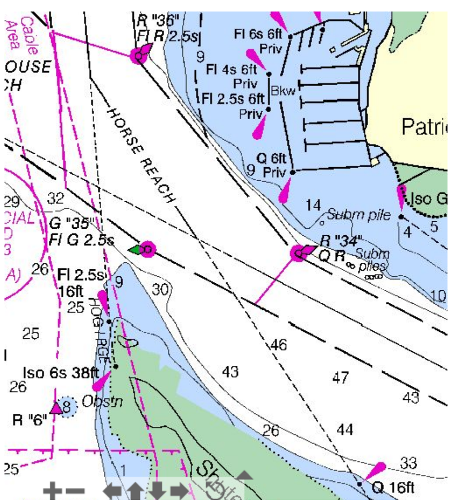

Figure 7-1

2. Coordinate Geometry Programs. COordinate GeOmetry (COGO) programs are used to find positions, distances and/or bearings given other positions, distances and/or bearings when using a grid system with the same distance-unit-of-measure in both horizontal directions (i.e. an X-Y grid). A USCG Range COGO program specifically tailored for range calculations is posted on the CG-NAV-1 Website. (https://cgportal2.uscg.mil/units/cgnav1). Generic, commercially-available COGO programs are also available but the use of the USCG Range COGO program is encouraged.

3. Design Positions (DP) for Ranges. When building a new RFL, RRL, or both, Design Positions (DP) that yield the best rangeline are calculated using the USCG Range COGO program and X-Y coordinate system (e.g. SPC).

   a. Design Positions (DP) for New RFL and RRL. When building a RFL and RRL the DPs lie on a line defined by the channel centerline. Inputs include the channel centerline coordinates, the desired distance from the near end of the channel to the RFL, and the desired distance from the RFL to RRL. There is a worksheet on the USCG Range COGO program that performs the required calculations.

   b. Design Positions (DP) for either a New RFL or RRL. When building either a new RFL or RRL, and retaining its paired range structure, the DP of the new structure is calculated with due regard for the ABP of the retained structure. Sometimes the new structure must be built off the channel centerline to yield an acceptable rangeline. Consider the following example:

      (1) Figure 2 shows a 400-foot-wide channel with ranges prior to a required RRL rebuild. The RRL and RFL are both 8 feet right of the extended channel centerline. The rangeline, shown in red, parallels the channel centerline 8 feet to the right of centerline. Unless the RFL and RRL were previously surveyed, it is unlikely that anybody knows that the RRL and RFL are off the centerline.

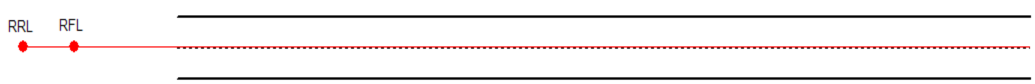

Figure 7-2
Rangeline vs Centerline Before RRL Rebuild

      (2) Figure 3 shows the new rangeline after the new RRL was built on the extended channel centerline. Because the RRL is on the extended centerline, and the RFL is 8 feet right of the extended centerline, the resultant rangeline is skewed.

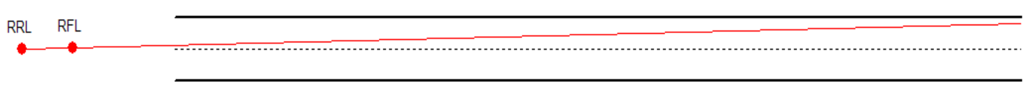

Figure 7-3
Rangeline vs Centerline After RRL Rebuild

(3) The USCG Range COGO Program has a worksheet that can be used to calculate the DP for a RFL or RRL rebuild when one of the paired range structures will be retained. Required inputs are the channel coordinates and a surveyed position for the range structure that will be retained. The Range COGO program displays rangeline vs centerline for potential positions of the new structure. The new structure should be built on centerline if the resultant rangeline is acceptable. If not, the COGO Program will show alternate, off-centerline options for the new structure. Every range structure rebuild should be preceded by a thorough evaluation of the geometry and the identification of a DP that will yield the best possible rangeline.

4. Evaluation of Rangeline vs Centerline. The USCG Range COGO program has a worksheet that can be used to compare rangeline vs centerline for an existing range. Inputs include channel centerline coordinates and surveyed positions for RFL and RRL. Output is a visual and quantitative comparison of rangeline vs centerline.

C. Determining As-Built Positions (ABP) for Range Structures.

1. General. For decades, the ATON Program has required surveyed positions for all range structures. Most surveys will be conducted using survey-grade GPS receivers or HASS. However, other survey techniques can be used as long as they meet the minimum survey requirements specified below. DGPS positions do not provide an acceptable level of accuracy for ranges and shall not be used to position a range structure.

2. Ranges to be Surveyed. All ranges in the Coast Guard shall have an as-built survey.

3. Position to be Surveyed. The horizontal position of a range shall be the horizontal position of the range lantern. The range lantern is often not centered on the tower; in these cases the position of the tower is of no significance. For an omni-directional range light, such as a 155mm or 250mm, the surveyed position should be the horizontal center of the lantern (the lantern's finial (i.e. the bird spike) if so configured). For a directional lantern, such as an RL14 or RL24, the surveyed position should lie along the lantern's horizontal centerline. The chosen position along horizontal centerline of the lantern is arbitrary, but the chosen position must be clearly specified in the final survey report. For an RL14 range lantern the lifting eye is a good position to survey. If the lifting eye is not chosen as the survey position, it can serve as a reference point for the surveyed position (i.e. "the surveyed position lies along the horizontal axis of the RL14 range lantern, 1.30" in front of the forward vertical face of the lifting eye). The horizontal position of an unlit range shall be the center of the daymark and the location shall be appropriately addressed within the survey report.

4. Minimum Survey Requirements. Surveys shall yield a position with an accuracy of better than 4 cm at 1DRMS. The surveyed position shall be reported in Lat/Long, State Plane Coordinates, and datum. The survey report shall thoroughly describe equipment and procedures used to obtain the position and shall include a complete error analysis that shows a positional accuracy of better than 4 cm at 1DRMS. The error analysis must not

be a simple restatement of equipment specifications and shall include an analysis of the factors germane to the specific survey.

5. Historic Survey Requirements. Previous versions of the ATON Positioning Manual required a Third Order Class I survey for all range structures. A Third Order Class I survey is an appropriate standard for surveys conducted using theodolites to measure angles. It is not an appropriate standard for positions obtained using survey-level GPS receivers.

6. Previous Surveys. Many existing range structures have been surveyed using historic methods. Most of these earlier surveys meet the minimum survey requirements described above for a new survey. Older surveys should be evaluated to ensure they provide adequate positioning information. At a minimum, to be acceptable, there must be an understanding of the procedures used, the accuracy of the survey, and the location of the position (e.g. the lantern/daymark). Depending on the range and the nature of the survey, an older survey can be judged acceptable. A simple Lat/Long, without information of how the position was obtained, cannot be considered an acceptable surveyed position.

7. In-House District Survey Teams. Districts with construction tenders have created in-house survey teams. The survey teams work with the construction tender to ensure that ranges are built in the desired position. This requires the ability to position "real time." Real time positioning is considerably more complicated than some "post processing" survey techniques used to survey established ranges.

   a. District Survey Teams. Districts with assigned construction tenders used to construct range structures and in-house survey teams shall conduct surveys that meet or exceed the minimum survey requirements specified above. Enclosure (4) of this Manual contains a sample USCG Survey Report for use by USCG surveyors.

   b. Districts Without Construction Tenders. Ranges in Districts without construction tenders are typically built under commercial contract. For new construction, survey requirements for obtaining the ABP shall be included in the construction contract. Enclosure (5) of this Manual contains a sample Statement of Work for use when developing a contracted survey service.

8. Surveying in Support of New Construction. A project to build a new range structure requires several stages of field survey support. It starts with locating (staking) the previously-calculated DP. Then, as the structure is being built, there are opportunities to make adjustments. The final step is to obtain the ABP.

   a. Locating (Staking) the Design Position for a Terrestrial Range. Locating the DP for a terrestrial range structure is relatively simple. The surveyor locates the target position and typically marks the position with a survey marker. The surveyor then locates the positions for the foundations that will support the tower.

   b. Locating (Staking) the Design Position for an Aquatic Range. For construction of an aquatic range a surveyor will guide the construction barge into position to drive the first pile. The first pile is a reference pile and is may be referred to as a "Hurricane

Pile or Ice Pile". If a storm destroys the range structure the hurricane pile will be used to position the new range structure. However, the position of the hurricane pile shall not be considered the ABP of the range structure.

c. Adjustments During Construction. The design of a structure will often allow for positioning adjustments as a range structure is built. For example:

(1) The surveyor guides the construction tender into position. The hurricane pile is established.

(2) The surveyor surveys the position of the hurricane pile after it is driven.

(3) The range foundation is constructed around the hurricane pile.

(4) After the foundation is built, the surveyor climbs the structure and locates the position of the desired rangeline as it crosses the structure. The tower is positioned on the foundation based on this survey.

(5) After the tower is secured the surveyor climbs the tower and locates the position of the desired rangeline as it crosses the tower's platform. The lantern stand is positioned on the platform based on this survey.

d. Final As-Built Survey. After the lantern is installed the surveyor conducts the final as-built survey of the lantern's position.

D. Design Position (DP) vs Final As-Built Position(ABP). When building a new range structure the positioning process starts with a DP and ends with an ABP. There will always be a difference between DP and ABP. For rebuilds via commercial contract the contract should specify the maximum allowable difference between the DP and ABP.

1. Maximum Allowable Difference Between Design Position and As-Built Position. A range construction contract shall require the new structure to be built so that the horizontal center of the range lantern is as close as possible to the DP. The contract's maximum allowable difference between the DP and ABP will establish the acceptable tolerance.

2. Acceptable Tolerance Parallel to Rangeline. A maximum 2-3 foot difference DP and ABP in a direction parallel to the rangeline will have a negligible impact on the performance of a range.

3. Acceptable Tolerance Perpendicular to Rangeline. A small difference between DP and ABP in a direction perpendicular to the rangeline will have a negative impact on the location of the rangeline. The maximum acceptable difference between DP and ABP in a direction perpendicular to the rangeline depends on the geometry of channel and the RFL and RRL setbacks relative to the near end of the channel. A COGO program can be used to calculate the maximum allowable difference between DP and ABP.

4. Sample Range Survey Contract Specifications. Samples for surveying requirements for commercial contract specifications are posted on the CG-NAV-1 Website. (https://cgportal2.uscg.mil/units/cgnav1).

5. Superseded Range Design Manual Positioning Tolerance. The Range Design Manual, COMDTINST M16500.4B (series) specifies a 1-foot maximum tolerance in the position of a range in a direction perpendicular to the rangeline. The guidance in this Chapter supersedes the requirements of the Range Design Manual.

E. Focal Plane. The focal plane height of a range light is a critical component in the range design process. The height of the light is measured in reference to Mean High Water (MHW). Surveyors refer to heights as elevations.

F. North American Vertical Datum of 1988 (NAVD 88). Surveyors in the United States usually express elevations using NAVD 88. A surveyor using a HASS receiver can easily measure the height of an existing lantern referenced to NAVD 88.

G. NAVD 88 to MHW Conversions. There is no single number that can be used to convert an elevation from NAVD 88 to MHW. Waterway designers can obtain localized NAVD 88 to MHW conversion data information on the CG-NAV-1 Website. (https://cgportal2.uscg.mil/units/cgnav1).

CHAPTER 8 - AID POSITIONING RECORD

A. Introduction. The Aid Positioning Record (APR) is the document which records the relevant and necessary information used to determine the position of an ATON. The purpose of the APR is to document observations made, environmental data, and actions taken when positioning an ATON. The APR is also used to communicate information to the district office. All relevant information shall be recorded to allow verification or validation of an aid's position at a later date.

B. Submission of Reports. Each time a buoy is visited, units shall complete an APR. Units will complete an APR for a beacon when it is initially built or if it is relocated or rebuilt. The original APR must be submitted to the District (dpw) by the servicing unit within ten working days of the visit or upon first return to port, whichever is later. A copy of the APR will be sent to the Primary Servicing Unit if the servicing unit is not the primary unit. Primary Servicing Units will retain a copy in the unit aid folder until the original APR has been reviewed, signed, and returned to the Primary Servicing Unit by the District (dpw). The original APR will be retained in the official aid file.

C. Disposition of Reports. The APR will be disposed of in accordance with the Information and Life Cycle Management Manual, COMDTINST M5212.12 (series). Original APRs filed under previous guidance shall not be re-filed in the unit's aid folder, but shall remain filed at the District (dpw) until properly disposed of as outlined below.

1. Copies may be destroyed after ten years.

2. Originals may be destroyed three years after discontinuation of the aid.

3. APRs with historical or legal significance shall not be destroyed unless microfilmed, or stored on other digital media, for future reference.

D. Instructions for Completing an APR and Conducting APR Verifications. A job aid is provided in the AAPSilver Help file to assist units in the preparation and verification of the APR. The following fields are required to be completed on the APR.

1. Aid Name. The aid name shall be the same as it appears in the Light List.

2. Aid Number. The aid number represents the I-ATONIS number of the aid.

3. Latitude Longitude. Latitude and Longitude of the assigned position.

4. LLNR. Enter the Light List number of the aid. For those aids with more than one LLNR the lowest number is used.

5. Unit/Vessel. The Unit/Vessel name represents the name of the unit and the platform used to position the aid.

6. Positioning Tolerance Radius. Represents the positioning tolerance of the buoy in yards.

7. Chart Number and Edition. The number and edition of the chart used of the largest scale Raster Navigation Chart (RNC) on which the aid appears.

8. GPS Receiver Type. The manufacturer and model of the GPS unit.

9. GPS Serial #. The serial number of the GPS unit.

10. Geodetic Datum. Represents the datum of the assigned position.

11. Measurement Section. APRs will include measurements used to calculate the found and/or set fix. When positioning with DGPS, GPS-RAIM, or GPS this will include: corrected true heading and the NMEA 0183 sentences GGA, GRS, GSA, GST, DTM, and RAIM (when applicable). Information on the NMEA sentences can be found in Enclosure (2) of this Manual. The above NMEA sentences are the minimum required for positioning with GPS.

12. Results Section. The Fix Results data is electronically transmitted to the APR and cannot be edited. All changes must be done in the Observations section (of AAPS program), then re-transmitted.

13. Fix Date. The date the fix was taken.

14. Fix Time. The time the fix was taken.

15. Unit/Vessel. The Unit/Vessel name represents the name of the unit and the platform used to position the aid.

16. Measured Depth. Represents the unadjusted depth of water measured at the time of the fix as measured by echo sounder, lead line, or sounding pole.

17. Tide Correction. Represents the tide correction computed from the Tide Tables for the time of the fix.

18. Draft. Represents the draft of the vessel used to visit the aid. If depth was obtained by lead line or sounding pole, the draft must be zero.

19. Datum. Represents the corrected water depth for the time of the fix and is calculated using the measured depth, draft and tide correction. This depth shall be compared with the charted datum to ensure the aid best marks the waterway.

20. EST Wind. The estimated direction the wind is coming from at the time the aid was positioned. The direction shall be entered in degrees true and the speed shall be entered in knots.

21. EST Current. The estimated direction the current is flowing at the time the aid was positioned. The direction shall be entered in degrees true and the speed shall be entered in knots.

22. Heading. The heading of the positioning vessel.

23. Buoy Port. The buoy port used for positioning.

24. Short Stay. Aid was serviced at Short Stay Yes (Y) or No (N).

25. Excursion. The bearing and distance of excursion (if used).

26. MPP Latitude/Longitude. The Most Probable Position of the buoy sinker of beacon.

27. AP to MPP. The bearing and range between the Assigned Position and MPP.

28. 2DRMS. The 2DRMS value of the fix.

29. Found/Set Station. On or Off station determination calculated by AAPSilver.

30. Remarks. The remarks section shall be used to record any additional information necessary to verify or validate the aid's position. At a minimum the following items will be entered if not previously recorded:

    a. Reason for visit.

    b. Aid On or Off Station when found. If excursion was used, the method used to determine excursion must be listed

    c. Light List, I-ATONIS Chart verification.

    d. Departures from normal procedures (if any).

    e. Any other information that may be required by the district office.

31. Signatures.

    a. Prepared by. This line shall be signed by the individual completing the form.

    b. CO/OIC. This line shall be signed by the Commanding Officer or Officer-in-Charge. Purpose of CO/OIC signature is to verify:

        (1) APR is complete.

        (2) Aid is on or off station.

        (3) Aid best marks the waterway or hazard.

        (4) Light List/I-ATONIS/Charts have been verified.

32. District Review. This line shall be signed by the District representative responsible for reviewing the APR for compliance and correctness, after the review is completed.

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Glossary

1DRMS	1X Distance Root Mean Squared
2DRMS	2X Distance Root Mean Squared
AAC	Aid Availability Category
AAPS	Automated Aid Positioning System
ABP	As Built Position
AP	Assigned Position
APR	ATON Positioning Report
ATNNL	ATON Positioning Competency Code
ATON	Aids to Navigation
BNM	Broadcast Notice to Mariners
CAD	Computer-Aided Design (software)
CG-NAV-1	Commandant, Visual Aids to Navigation Division
cm	Centimeter
COGO	Coordinate Geometry Program (software)
CORPSCON	USACE State Plane Conversion Software
DCMS	Deputy Commandant for Mission Support
DGPS	Differential Global Positioning System
DOD	Department of Defense
DP	Design Position
DPW	District Waterways Management Branch
DRF	Discrepancy Response factor
DRMS	Distance Root Mean Squared
DTM	GPS Receiver Datum
ENC	Electronic Navigation Charts
GGA	Global Positioning System Fix Data
GPS	Global Positioning System
GPS-RAIM	GPS Receiver Autonomous Integrity Monitoring
GRS	GPS Range Residual Data
GSA	GPS DOP and Active Satellites Data
GST	GPS Pseudorange Noise (PRN) Statistics
HASS	High Accuracy Survey Systems
I-ATONIS	Integrated Aids to Navigation Information System
Lat	Latitude
LNM	Local Notice to Mariners
Long	Longitude
MHW	Mean High Water
MLLW	Mean Lower Low Water
MLW	Mean Low Water
mm	Millimeter
MPP	Most Probable Position
MSK	Minimum Shift Keying
NAD 27	North American Datum 1927
NAD 83	North American Datum 1983

NAVCEN	USCG Navigation Center
NAVD 88	North American Vertical Datum 1988
NMEA	National Marine Electronics Association
NOAA	National Oceanic and Atmospheric Administration
NOS	National Ocean Service
OSC	Operations System Center, Martinsburg WV
PE	Position Exact
PER	Position Exact – Relocate
PPS	Precise Positioning Service
PRC	Pseudorange Correction
PT	Positioning Tolerance
RFL	Range Front Light
RRC	Range Rate Correction
RRL	Range Rear Light
RTCM	Radio Technical Commission for Maritime Services
SPC	State Plane Coordinate System
SPS	Standard Positioning Service
USACE	U.S. Army Corps of Engineers
WAMS	Waterway Analysis and Management System
WCR	Watch Circle Radius
WGS 84	World Geodetic System 1984

DGPS Broadcast Stations

Frequency (KHZ) & BPS	STATE	SITE NAME	LATITUDE	LONGITUDE	RANGE (NM)	SITE STATUS
323/100	AK	Annette Island	55 04.10 N	131 36.00 W	214	Operational
305/100	AK	Biorka	56 51.28 N	135 32.47 W	196	Operational
292/100	AK	Cape Hinchinbrook	60 14.30 N	146 38.80 W	138	Operational
289/100	AK	Cold Bay	55 11.37 N	162 42.30 W	112	Operational
288/100	AK	Gustavus	58 24.96 N	135 41.80 W	106	Operational
310/100	AK	Kenai	60 40.50 N	151 21.01 W	106	Operational
313/100	AK	Kodiak	57 37.14 N	152 11.61 W	112	Operational
295/100	AK	Level Island	56 28.01 N	133 05.58 W	196	Operational
298/100	AK	Potato Point	61 03.40 N	146 41.80 W	115	Operational
307/100	AL	Hackleburg	34 16.80 N	087 51.39 W	124	Operational
320/200	AL	Millers Ferry	32 05.43 N	087 23.50 W	150	Operational
319/100	AZ	Flagstaff	35 13.32 N	111 49.51 W	280	Operational
305/100	CA	Bakersfield	35 07.93 N	119 06.51 W	171	Operational
292/100	CA	Cape Mendocino	40 26.51 N	124 23.78 W	207	Operational
318/100	CA	Chico	39 25.8 N	121 39.94 W	250	Operational
298/100	CA	Essex	34 45.12 N	115 13.78 W	155	Operational
314/200	CA	Lincoln	38 50.77 N	121 20.98 W	87	Operational
321/100	CA	Lompoc	34 49.53 N	120 33.87 W	129	Operational
287/100	CA	Pigeon Point	37 11.20 N	122 23.40 W	155	Operational
302/100	CA	Point Loma	32 39.97 N	117 14.60 W	207	Operational
307/100	CO	Pueblo	38 17.23 N	104 20.83 W	124	Operational
309/200	DE	Reedy Point	39 33.69 N	075 34.19 W	70	Operational
289/100	FL	Cape Canaveral	28 27.62 N	080 32.74 W	231	Operational
314/200	FL	Card Sound	25 25.90 N	080 27.09 W	162	Operational
286/100	FL	Key West	24 34.94 N	081 39.18 W	127	Operational
312/200	FL	Tampa (Macdill)	27 51.01 N	082 31.95 W	242	Operational
301/200	GA	Macon	32 41.67 N	083 33.62 W	186	Operational
319/100	GA	Savannah	32 08.40 N	081 42.00 W	185	Operational
300/200	HI	Kokole Point	21 59.03 N	159 45.53 W	130	Operational
290/100	HI	Pahoa	19 31.10 N	154 57.80 W	155	Operational
286/100	HI	Upolu Point	20 14.85 N	155 53.07 W	196	Operational

Frequency (KHZ) & BPS	STATE	SITE NAME	LATITUDE	LONGITUDE	RANGE (NM)	SITE STATUS
298/200	IA	Omaha	41 46.7 N	095 54.66 W	143	Operational
311/200	IA	Rock Island	42 00.73 N	090 13.52 W	150	Operational
289/200	KS	Topeka	39 02.72 N	096 02.33 W	233	Operational
290/200	KY	Louisville	38 00.63 N	085 17.96 W	150	Operational
293/200	LA	English Turn	29 52.70 N	089 56.50 W	196	Operational
313/200	LA	Vicksburg	32 19.82 N	090 55.22 W	115	Operational
306/200	MA	Acushnet	41 44.57 N	070 53.19 W	230	Operational
301/200	MD	Annapolis	39 00.65 N	076 36.36 W	180	Operational
307/100	MD	Hagerstown	39 33.19 N	077 42.79 W	155	Operational
316/100	ME	Brunswick NAS	43 53.40 N	069 56.80 W	200	Operational
290/200	ME	Penobscot	44 27.10 N	068 46.33 W	270	Operational
292/200	MI	Cheboygan	45 39.20 N	084 27.90 W	110	Operational
319/200	MI	Detroit	42 17.80 N	083 05.70 W	100	Operational
309/200	MI	Pickford	46 03.89 N	084 21.70 W	60	Operational
301/100	MI	Saginaw Bay	43 37.70 N	083 50.30 W	85	Operational
298/100	MI	Upper Keweenaw	47 13.60 N	088 37.40 W	130	Operational
292/100	MN	Pine River	46 51.85 N	094 43.27 W	155	Operational
322/200	MO	St. Louis	38 36.68 N	089 45.52 W	114	Operational
297/200	MS	Bobo	34 06.91 N	090 41.47 W	158	Operational
313/100	MT	Billings	45 58.33 N	107 59.82 W	249	Operational
287/100	MT	Polson	47 39.77 N	114 06.88 W	186	Operational
303/100	NC	Greensboro	36 04.10 N	079 44.17 W	124	Operational
294/100	NC	New Bern	35 10.50 N	077 02.91 W	259	Operational
325/100	ND	Medora	46 54.60 N	103 16.20 W	202	Operational
310/100	NE	Whitney	42 44.00 N	103 19.00 W	280	Operational
286/200	NJ	Sandy Hook	40 28.29 N	074 00.71 W	115	Operational
291/100	NM	Albuquerque	34 57.44 N	106 29.58 W	249	Operational
312/100	NV	Austin	39 23.46 N	117 18.54 W	155	Operational
324/200	NY	Hudson Falls	43 16.21 N	073 32.31 W	155	Operational
293/100	NY	Moriches	40 47.40 N	072 44.83 W	241	Operational
322/100	NY	Youngstown	43 13.80 N	078 58.20 W	241	Operational
287/100	OR	Fort Stevens	46 12.29 N	123 57.36 W	207	Operational
299/200	OK	Sallisaw	35 22.08 N	094 49.01 W	150	Operational

Frequency (KHZ) & BPS	STATE	SITE NAME	LATITUDE	LONGITUDE	RANGE (NM)	SITE STATUS
294/100	OR	Klamath Falls	42 17.30 N	121 40.23 W	217	Operational
310/100	OR	Seneca	44 09.86 N	119 03.59 W	186	Operational
291/100	PA	Hawk Run	40 52.72 N	078 10.81 W	186	Operational
295/100	PR	Isabela	18 27.99 N	067 04.32 W	78	Operational
292/100	SC	Kensington	33 28.86 N	079 20.58 W	124	Operational
309/100	SD	Clark	44 56.05 N	097 57.63 W	249	Operational
305/100	TN	Dandridge	36 01.21 N	083 18.24 W	121	Operational
317/100	TN	Hartsville	36 21.47 N	086 05.35 W	134	Operational
301/100	TX	Angleton	29 18.05 N	095 29.04 W	171	Operational
304/100	TX	Aransas Pass	27 50.30 N	097 03.55 W	207	Operational
318/100	TX	Summerfield	34 49.46 N	102 30.76 W	230	Operational
303/100	UT	Myton	40 06.12 N	110 02.96 W	171	Operational
289/100	VA	Driver	36 57.48 N	076 33.44 W	150	Operational
300/100	WA	Appleton	45 46.92 N	121 19.57 W	250	Operational
323/200	WA	Robinson Point	47 23.32 N	122 22.48 W	69	Operational
316/100	WA	Spokane	47 31.16 N	117 25.40 W	186	Operational
302/100	WA	Whidbey Island	48 18.80 N	122 41.80 W	103	Operational
304/200	WI	Mequon	43 11.69 N	088 03.59 W	143	Operational
317/200	WI	St. Paul (Alma)	44 18.23 N	091 54.21 W	150	Operational
314/100	WI	Sturgeon Bay	44 47.73 N	087 18.86 W	110	Operational
296/100	WI	Wisconsin Point	46 42.30 N	092 00.91 W	168	Operational
295/200	WV	St. Marys	39 25.77 N	081 09.93 W	155	Operational

Note: (1) If no closer satisfactory beacons can be utilized a satisfactory beacon can be used beyond its advertised range if the user is within 300 statute miles (260nm) of the broadcast site. The user should exercise extra caution in this situation since user reliability is reduced if the primary beacon for a subject waterway is unavailable.

(2) Information contained in this Enclosure was accurate at the date of release. Refer to the USCG NAVCEN website for up-to-date DGPS site status information. http://www.navcen.uscg.gov/?pageName=dgpsSelectStatus.

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<u>DGPS RTCM Broadcast</u>

A. <u>General</u>. The U. S. Coast Guard's DGPS system broadcasts corrections in the RTCM SC-104 (Version 2.3) format. The RTCM has defined data messages for use in the transmission of DGPS corrections, ancillary information, and integrity information. RTCM format allows flexibility in its implementation and use. The U.S. Coast Guard's Broadcast Standard further defines the use of this format along with specifying the various broadcast parameters. For more information on DGPS message types see COMDTINST M16577.1.

B. <u>Data Message Types</u>.

1. Type 1 Differential GPS Corrections. The Type 1 Message is not used due to the advantages of the Type 9 Message. The Type 9 Message serves as the exclusive message for the broadcast of pseudorange corrections.

2. Type 3 Reference Station Parameters. The NAD 83 coordinates of the reference station with a resolution of 0.01 meter are found here. This message is nominally broadcast twice per hour. User derived atmospheric corrections may be aided through use of this message type.

3. Type 5 Constellation Health. The main use of this message type is to notify the user equipment suite that a satellite which is deemed unhealthy by its current navigation message is unusable for DGPS navigation.

4. Type 7 Radiobeacon Almanac. This message provides location, frequency, service range, and health information for adjacent broadcast transmitters as well as the radiobeacon from which the message is broadcast. When broadcast from a given radiobeacon, it can be used to acquire the next transmitter when in transit down the coast. This message is normally sent every 10 minutes.

5. Type 9 Differential GPS Corrections. The Type 9 Message has been selected for broadcast of DGPS corrections over the Type 1 Message for the following reasons: 1) greater impulse noise immunity; 2) lower latency (when broadcast in groups of three); 3) less susceptibility to SA on one or more satellites; 4) a more timely alarm capability. Unlike the Type 1 message, partial Type 9 messages can be used in accordance with the RTCM and IALA standards.

6. Type 16 Special Message. This is an ASCII message up to 90 characters long. It can be sent by service providers to broadcast warning information, such as scheduled outages. User equipment should have the ability to display this information to the navigator, with audible warning of receipt.

C. Application of Type 9 corrections. Tests have demonstrated the substantial advantage gained through this use of the Type 9 Message. Pseudorange corrections (PRC) and range rate corrections (RRC) are broadcast for up to nine satellites which are above a 5° mask angle. The message indicates the nominal time (shown below as t_0) for which this data was valid. The current differential correction is computed as follows:

$$PRC(t) = PRC(t_0) + RRC \times (t - t_0),$$

where $PRC(t_0)$ is the PRC value in the PRC message. The PRC is then applied by adding it to the pseudorange measurement. The RRC is included in an attempt to extend the life of the PRC, as the RRC is a "rate" term which is used to propagate PRCs in time. Type 9 Messages contain the corrections for up to three satellites in each message.

Example: If the corrections for eight satellites are broadcast, the corrections will consist of three Type 9 Messages, two with the corrections for three satellites and one with the correction for two satellites. Because of the possibility of sudden pseudorange accelerations, it was decided that basing the Type 9 generation method on pseudorange velocity or acceleration would prove to be overly cumbersome and of considerable operational risk. A combination of a low drift frequency source (rubidium or a high grade crystal) and proper drift modeling is required. This is because the user will be mixing corrections which are generated at different epochs, and in periods of high noise the corrections received for a given satellite may be up to 30 seconds apart. Though a rubidium source is not necessarily required for Type 9 message generation, its low phase noise may improve the achievable accuracy to the user by 30-40cm due to the superior range rate correction which can be generated through its use. Velocity accuracy is enhanced as well.

Additionally, a rubidium source allows the reference station clock to achieve a greater degree of isolation from GPS anomalies since the derived GPS constellation time can be smoothed and checked over a longer period of time.

D. Explanation of National Marine Electronics Association (NMEA) 0183 data messages.

1. GGA - Global Positioning System Fix Data. The GGA NMEA 0183 data message is used to transmit time, position, and fix related data to AAPS. The sections are described below.

$--GGA,hhmmss.ss,llll.ll,a,yyyyy.yy,a,x,xx,x.x,x.x,M,x.x,M,x.x,xxxx*hh<CR><LF>

Data Field	**Description**
hhmmss.ss	UTC Time of Position (hours/minutes/seconds/decimal seconds)
llll.ll	Latitude of Position
a	N or S
yyyyy.yy	Longitude of Position
a	E or W
x	GPS Quality Indicator (0 = No Fix, 1 = GPS Fix, 2 = DGPS Fix, 3 = GPS PPS Fix)
xx	Number of Satellites in Use
x.x	Horizontal Dilution of Precision
x.x	Antenna Altitude Above Mean Sea Level (Geiod)

M	Units of Antenna Altitude (Meters)
x.x	Geoidal Separation
M	Units of Geoidal Separation (Meters)
x.x	Age of DGPS Data (seconds)
xxxx	Differential Reference Station ID
*hh	Checksum
<CR>	Carriage Return
<LF>	Line Feed

2. GRS - GPS Range Residual Data. The GRS NMEA 0183 data message is used to support the Receiver Autonomous Integrity Monitoring (RAIM).

$--GRS,hhmmss.ss,x,x.x,x.x,x.x,x.x,x.x,x.x,x.x,x.x,x.x,x.x,x.x,x.x*hh<CR><LF>

Data Field	Description
hhmmss.ss	UTC Time of Position (hours/minutes/seconds/decimal seconds)
X	Mode: 0 = residuals were used to calculate the position given in the matching GGA or GNS sentence, 1 = residuals were recomputed after the GGA or GNS position was computed
x.x	Range residuals in meters for satellites used in the navigation solution. Order must match order of the satellite ID numbers in GSA. When GRS is used, GSA and GSV are generally required.
*hh	Checksum
<CR>	Carriage Return
<LF>	Line Feed

3. GSA – GPS DOP and Active Satellites Data. The GSA NMEA 0183 data message indicates the GPS receivers operating mode and lists the satellites used for navigation and the DOP values of the position solution.

$--GSA,a,x,xx,xx,xx,xx,xx,xx,xx,xx,xx,xx,xx,xx,x.x,x.x,x.x*hh<CR><LF>

Data Field	Description
a	Mode: M = Manual, forced to operate in 2D or 3D mode. A = Automatic, allowed to automatically switch 2D/3D
x	Mode: 1 = Fix not available 2 = 2D 3 = 3D
xx	ID numbers of satellites used in solution
x.x	PDOP
x.x	HDOP
x.x	VDOP
*hh	Checksum
<CR>	Carriage Return
<LF>	Line Feed

4. GST - GPS Pseudorange Noise (PRN) statistics. The GST NMEA 0183 data message contains pseudorange measurement noise statistics that can be used to give statistical measures of the quality of the position.

$--GST,hhmmss.ss,x.x,x.x,x.x,x.x,x.x,x.x,x.x*hh<CR><LF>

Data Field	Description
hhmmss.ss	UTC Time of Position (hours/minutes/seconds/decimal seconds)
x.x	RMS value of the standard deviation of the range inputs to the navigation process.
x.x	Standard deviation (meters) of semi-major axis of error ellipse
x.x	Standard deviation (meters) of semi-minor axis of error ellipse
xxx.x	Orientation of semi-major axis of error ellipse (true north degrees)
x.x	Standard deviation (meters) of latitude error
x.x	Standard deviation (meters) of longitude error
x.x	Standard deviation (meters) of altitude error
*hh	Checksum
<CR>	Carriage Return
<LF>	Line Feed

5. DTM - Geodetic Datum Reference System. The DTM NMEA 0183 data message contains information regarding the Geodetic Datum used by the GPS receiver and the datum of the position contained in the GGA data message.

$--DTM,ccc,a,x.x,k,x.x,l,x.x,ccc*cc<CR><LF>

Data Field	Description
ccc	Local datum (normally W84, but could be NAD83 when using beacon in North America)
a	Local datum subdivision code
X.X	Latitude offset, in minutes
K	Latitude indicator; value is N (North latitude) or S (South latitude)
X.X	Longitude offset, in minutes
L	Longitude indicator; value is E (East longitude) or W (West longitude)
X.X	Altitude offset, in meters
CCC	Reference datum (ex. W84)
*CC	Checksum
<CR>	Carriage return
<LF>	Line feed

6. VHW - GPS Water speed and heading. The VHW NMEA 0183 data message contains the compass heading to which the vessel points and the speed of the vessel relative to the water.

$--VHW,x.x,T,x.x,M,x.x,N,x.x,K*hh<CR><LF>

Data Field	Description
xx	Heading, degrees
T	True
xx	Heading, degrees
M	Magnetic
xxx	Speed
N	Knots
xx	Speed
K	km/hr
*hh	Checksum
<CR>	Carriage Return
<LF>	Line Feed

7. VTG - GPS Track Made Good and Ground Speed. The VTG NMEA 0183 data message contains information about the actual course and speed relative to the ground.

$--VTG,x.x,T,x.x,M,x.x,N,x.x,K,a*hh<CR><LF>

Data Field	Description
ddd.d	Course over ground
T	Degrees True
ddd.d	Course over ground
M	Degrees Magnetic
sss.s	Speed over ground
N	N = Knots
sss.s	Speed over ground
K	km/hr
x	Mode indicator: A = Autonomous mode D = Differential mode E = Estimated (dead reckoning) mode M = Manual input mode S = Simulator mode N = Data not valid
*hh	Checksum
<CR>	Carriage Return
<LF>	Line Feed

8. RAIM – Receiver Autonomous Integrity Monitor. A minimum of five satellites must be in view for the receiver to perform the required Receiver Autonomous Integrity Monitor (RAIM) calculation. A minimum of six satellites are required if a corrupt satellite is to be identified and removed from the calculation of a navigable solution. The GPS-RAIM receiver regularly calculates two separate navigation solutions based on two unique sets of satellites. The solutions are compared. If the two solutions differ by more than an allowable amount, the receiver displays a RAIM failure message and the stoplight on the

receiver will turn from Green to Red or Yellow. In AAPS the application will also display the stoplight color. See Chapter 2.D of this Manual for complete RAIM definition.

$--RMxxx,RAIM,x,hhmmss.ss,x,x,x,*xx

Data Field	Description
x	UTC Time Indicator: V indicates time is valid, N indicates time is not valid.
hhmmss.ss	UTC Time of Position (hours/minutes/seconds/decimal seconds)
x	RAIM Indication: 0 = position valid, 1 = RAIM is not able to detect anomalous measurements/poor geometry reposition antenna, 2 = RAIM has detected and excluded anomalous measurements (position is valid).
x	Total number of excluded bad measurements (bad satellites)
x	IDs of the satellites with bad measurements. Each bad satellite ID number is listed here in the string. Choices could include G if GPS satellite, R or F if GLONASS satellites. Could be many listed.
*xx	Checksum
<CR>	Carriage Return
<LF>	Line Feed

DGPS EQUIPMENT VERIFICATION PROCEDURES

A. Reference Check Guidelines. This Enclosure provides guidance when the Commanding Officer/Officer in Charge/Coxswain questions the integrity and/or performance of the DGPS/GPS equipment, or when there has been an on board equipment configuration change. This includes initial installation, replacement or relocation of the receiver or antennas. COs/OINCs/Coxswains must ensure that the receiver is operating properly prior to positioning an aid (similar guidance may be found in the Coast Guard Navigation Standards, COMDTINST M3530.2 (series)).

1. The check is completed by comparing a surveyed position to a DGPS/GPS-RAIM/GPS fix. A surveyed position is defined as a HASS generated position with an accuracy of better than 4 centimeters (cm) at 1DRMS or a traditional 3^{rd} order (or better) survey position.

    a. If using DGPS, the DGPS fix must have a 2DRMS less than or equal to 9.8 yards (9 meters). The comparison must show the MPP position to be 3.0 yards or less from the known position.

    b. If using GPS, the GPS fix must have a 2DRMS less than or equal to 9.8 yards (9 meters). The comparison must show the GPS position to be 3.0 yards or less from the known position.

    c. If using GPS with a RAIM solution, the GPS RAIM fix must have a 2DRMS less than or equal to 9.8 yards (9 meters). The comparison must show the GPS with RAIM position to be 3.0 yards or less from the known position.

2. If the DGPS/GAAPS/GPS comparison is mandatory due to an on board equipment (hardware) change, a comparison APR must be created. The APR shall be created in accordance with the procedures in Chapter 8. If the DGPS, GPS-RAIM, or GPS position does not meet the above standards, the receiver shall not be used for positioning until the cause of the error is determined.

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Sample Survey Report

Survey Report for Key West Main Channel RFL **(LLNR 14815)**

Aid Name (LLNR): Key West Main Channel RFL (LLNR 14815)

Surveyor: Larry Jaeger Date: April 6, 2011.

Equipment: Receiver: JAVAD Triumph-1 (serial number 01175; 5 Hz RTK rate)
Controller/data collector: Carlson Surveyor (serial number 36868-CAA30-151090-4041)
Controller software: Carlson Surv2.5

Overview: The receiver was set up above the RL14 range lantern. RTK positions were calculated using Florida Permanent Reference Network reference stations. Communication links to the Florida Permanent Reference Network were established via a cellular data link.

Configuration: The receiver was mounted above the RL14 range lantern using an RL14 bracket that was bolted to the lantern's lifting eye. After the bracket was bolted to the lifting eye a tribrach was screwed onto the bracket. The tribrach was leveled and the receiver was mounted above the tribrach. The horizontal position of the lantern was assigned the horizontal position of the receiver. This position corresponds to a point along the horizontal axis of the RF14 range lantern, 11/16" behind the rear vertical face of the lifting eye.

Pictures:

Data Collection: The Carlson Surveyor was configured to record positions for 300 epochs (300 time intervals). Three data sets were recorded; each data set consisting of 300 epochs. The final position was therefore based on 900 epochs.

Reference Stations: The first 2 data sets used Florida Permanent Reference Network station "KWST." The 3rd data set used the "MKEY" reference station.

Datums: Horizontal positions are provided using Florida EAST State Plane Coordinates (zone 0901). The unit-of-measure is the US Survey Foot. Latitude and Longitude values were computed from SPC using the USACE CORPSCON (v6.0.1) program. The elevation of the receiver's antennae reference plane (referenced to NAVD 88) was calculated by the Carlson Surveyor using SurvCE. A Geoid09 file for Key West was prepared and preloaded into the Carlson Surveyor using Carlson software.

Procedures used to identify and remove bad data: The Carlson Surveyor with SurvCE allows for the exclusion of data with a horizontal RMS value that exceeds a user-defined maximum value. All three data sets were collected with a user-defined max HRMS value of 0.040 feet. At this setting the controller rejected 4 of 900 positions.

Horizontal Results for the 3 data sets (for both receiver and lantern):

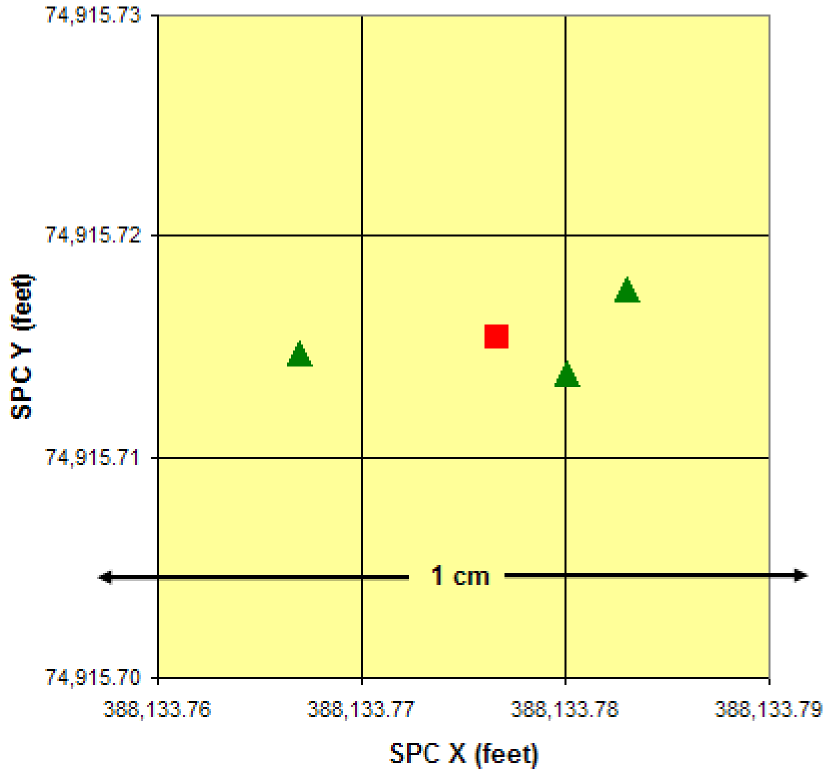
		Y (FL East SPC; Zone 0901)	**X** (FL East SPC; Zone 0901)	**HRMS*** (feet; avg)	**HRMS*** (cm; avg)
Data Set	#1	74,915.7147	388,133.7670	0.0333	1.01
	#2	74,915.7138	388,133.7801	0.0320	0.98
	#3	74,915.7176	388,133.7830	0.0320	0.98

*this is the average HRMS for the individual epochs.

Final Horizontal Position based on all data (for both receiver and lantern):

FL East SPC Y:	74,915.7154	Latitude:	24 32 14.43180N
FL East SPC X:	388,133.7767	Longitude:	81 48 22.73005W

The following diagram shows the positions for each of the 3 data sets (the 3 green triangles). The red square is the averaged final position. Note that each of the 9 yellow-shaded cells are 0.01' by 0.01' (about 1/8" by 1/8"). A 1 cm length is shown for reference.



Height of RL14 Range Lantern

Using the preloaded Key West Geoid09 file the survey equipment calculated the average height of the receiver for each of the 3 data sets. Referenced to NAVD 88, receiver heights for the 3 data sets were: 33.4453, 33.4983 and 33.4817 feet. The average of the three data sets is 33.47 feet (NAVD 88). The receiver was 2.70 feet above the vertical center of the RL14 lantern. This puts the lantern at 33.47 – 2.70 = 31.77 feet (NAVD 88). In Key West, a height referenced to MHW is 0.24 feet greater than the height referenced to NAVD 88. Referenced to MHW the lantern height is therefore: 31.77 + 0.24 = 32.01 feet (MHW). This is consistent with the 32' height currently listed in I-ATONIS, the Light List, and as shown on the chart.

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Sample Survey – Statement of Work

Survey Statement of Work

Survey the horizontal and vertical positions of the light (lantern). Vertically, use the vertical center of the lantern. If there are multiple lanterns seek guidance from the Coast Guard. Lantern heights should be referenced to NAVD 88. Horizontally, use the center of lanterns with horizontal symmetry (like a 155mm or 250mm lantern). For directional lanterns (like an RL14) use the center of lantern's base. It is critical that the surveyed position is on the horizontal centerline of the drum. The survey shall be conducted by a surveyor licensed by the State. The surveyed positioned shall have a horizontal accuracy of better than 4 cm (1DRMS). Each position surveyed shall have a survey report. The survey report shall contain the following:

- The surveyed horizontal position of the lantern expressed in Latitude and Longitude (NAD 83) and in State Plane Coordinates (SPC). Identify the SPC Zone.
- The surveyed vertical position of the lantern in feet referenced to NAVD 88.
- A description of the survey equipment.
- A description of survey methodologies including:
  - ✓ Identify the type of base station - or stations - used (i.e. CORS?, RTN?, own base station set up over monument?).
  - ✓ Identify the specific base station(s) used.
  - ✓ Identify the sampling rate and number of samples collected.
  - ✓ Describe the procedures used to identify and remove bad data.
  - ✓ A description of computational methods and software.

An error analysis showing that the horizontal accuracy is 4 cm or better calculated at 1DRMS. The stated accuracy shall NOT be a restatement of equipment specifications or generic process accuracies. Rather, the stated accuracy should be the product of an analysis of the data and of factors associated with this survey. Include:

- The results of the error analysis.
- Describe how the error analysis was conducted.
- Identify software.

If the survey used surveyor's own equipment as a base station, provide accuracy information for the position of the base station, provide data supporting the claimed accuracy of the base station position, and show how the accuracy of the base station position factored into the calculation of the accuracy of the surveyed position of the lantern.

Note: Refer to CG-NAV-1 Website for most current example scope of work statement: https://cgportal2.uscg.mil/units/cgnav1