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GPS Surveyed Time-Invariant Sea Floor Depths

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Abstract

Maritime practice has been to calculate keel and masthead clearances with respect to local datums such as mean lower low water and mean high water. With time and locale, these datums change, yet the requirement for safe navigation of ever larger vessels is increasingly stringent. Herein it is proposed to use the WGS'84 ellipsoid as a global datum, which coupled with the Global Positioning System, provides mariners with a reference surface that is invariant. Properly equipped ships can expect clearances in the decimeter range using the ellipsoid and GPS in an operational differential mode when entering and leaving harbors.

1 Introduction

For safe sailing, two of the most important requirements are to be able to determine clearances between the sea floor and the keel of the ship, and between the top of the mainmast and overhead structures, such as cables and bridges. For these clearances, the mariner has to know correctly and accurately the following:

1. Location of the sea floor or ocean depth,
2. Height of the overhead structure,
3. Location of the ship's keel,
4. Location of the top of the mainmast.

For centuries and even in current practice, the above four surveyed positions are referenced to more than one datum such as mean lower low water for depths and mean high water for vertical clearances. Furthermore, these datums are time-dependent and time-variant.

We propose (Kumar and Maul 2005) that the two clearances or the four positions are measured with respect to a time-invariant ellipsoid surface as the zero reference. Then, mariners would have them correctly and accurately in *one datum*, whenever required. In shallow waters and inside harbors, the captain of a ship would be able to measure the clearances accurately and with confidence to avoid grounding or striking overhead obstructions. Pilothouse computer displays can be programmed to show real-time clearances in a manner familiar to traditional mariners.

Combining GPS surveys and acoustic soundings, highly accurate ellipsoid depths of the sea floor can be established in new areas or by filling gaps – independent of the stage of the tide and any tidal datum. In separate GPS surveys, the ellipsoid heights for overhead structures can be determined. The *time-invariant* sea floor depths and heights of the overhead structures can then be stored in the Marine Information System (MIS) database for future use. While underway in shallow waters, in berthing, in approaching channels, and inside harbors, using a mainmast-mounted GPS antenna and the ship's general arrangement drawings, the shipboard computer will determine the positions of the ship's keel, mainmast, and Plimsoll marks. Then, recovering the already established sea floor depths and overhead heights, it can compute the two clearances for safe navigation without any reference to the time-variant tides, tidal datums, and ship's draft.

This article describes the surveying mode to establish time-invariant ellipsoid depths or heights of the sea floor in the open ocean. A few additional survey procedures have been specified to achieve higher accuracy for shallow waters and inside harbors. A step-by-step algorithm is also included to compute the ship's two vertical clearances.

2 Surveying the Sea Floor and Overhead Structures

In the marine scenario, the Ellipsoid of the World Geodetic System (WGS) 1984 (NIMA 1997), the coordinate system used within GPS, is both below and above the sea surface, which can result in the surveyed ellipsoid depths or heights to be plus or minus respectively. In the following figures, ellipsoid depths or heights are positive upwards with respect to the ellipsoid surface.

A. *When the WGS 84 Ellipsoid is below the sea surface* - Figure 1 shows schematic locations for the overhead structure, ship's mainmast, pilothouse deck, keel, sea surface, sea floor, and ellipsoid zero reference surface.

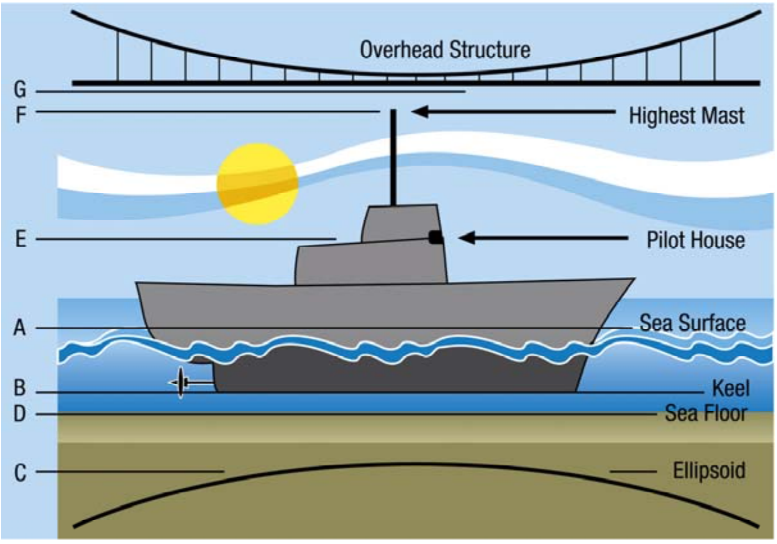

Figure 1. Ellipsoidal heights when ellipsoid is below the sea surface.

DC	=	Ellipsoidal Height of sea floor (+h)
AC	=	Ellipsoidal Height of sea surface (+h)
BC	=	Ellipsoid Height of ship's Keel (+h)
CE	=	Ellipsoidal Height of the Pilothouse (+h)
CF	=	Ellipsoid Height of Ship's Mainmast (+h)
CG	=	Ellipsoid Height of the Overhead Structure (+h)
BD	=	Depth of Sea Floor from keel as measured by acoustic sounding.

During GPS surveying, the distance BD between the ship's keel and sea floor will be measured with presently used acoustic sounding techniques. Then, the ellipsoid height (h) of the sea floor DC will be:

$$DC = BC - BD = [CF - BF] - BD.$$

In this configuration, the distances CF, BF, and BD are measured during GPS surveys *without any reference to the stage of the tide and/or tidal surface.* This is the decided advantage over the depths determined with respect to time-variant tidal datums. In many cases, especially in deep water, the sea floor will be below the ellipsoid and have a negative height (-h). Here, the accuracy of the distance BD is accepted as achievable by acoustic techniques.

B. *When the WGS 84 Ellipsoid is above the sea surface* - Figure 2 shows schematic locations when the ellipsoid is above the sea surface.

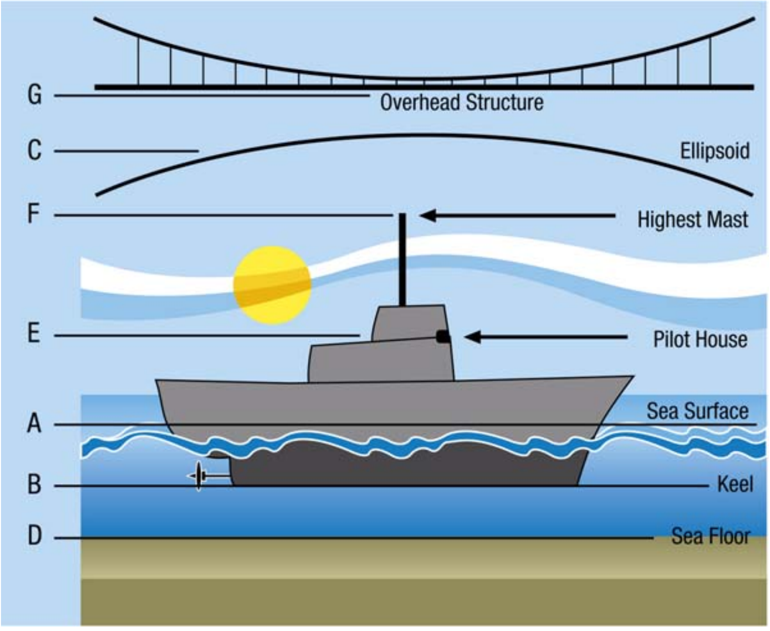

Figure 2. Ellipsoidal heights when ellipsoid is above the sea surface.

DC	=	Ellipsoidal Height of sea floor (- h)
AC	=	Ellipsoidal Height of sea surface (-h)
BC	=	Ellipsoid Height of ship's Keel (-h)
CE	=	Ellipsoidal Height of the Pilothouse (-h)
CF	=	Ellipsoid Height of Ship's Mainmast (-h)
CG	=	Ellipsoid Height of Overhead Structure (+h)
BD	=	Depth of Sea Floor from keel as measured by acoustic sounding.

In this case, the ellipsoid depth of sea floor DC will be:

$$DC = - BC - BD = - [CF + BF] - BD.$$

It may be pointed out that near Sri Lanka, the ellipsoid height of the sea surface AC has a maximum "low" of about -100 meters and this particular type of geometry is mostly not known to many users, particularly mariners.

3 Computing Ship's Two Clearances While Underway

A. *Clearance for ship's keel* - When the keel clearance (BD) is required, the mariner first surveys the geodetic position (φ, λ, h) of the ship's mainmast using GPS. Then, using the general arrangement drawings for the particular vessel, and combining with the ellipsoid depth or height of the sea floor, the clearance can be computed (when ellipsoid is below sea floor) as:

$$BD = BC - DC = [BF - CF] - DC$$

where BC is surveyed while underway and DC is taken from the MIS database. Similarly the freeboard distance to the Plimsoll marks can be readily known.

B. *Clearance for ship's mainmast* - The clearance for the mainmast GF can be computed as:

$$GF = CG - CF$$

where CF is surveyed with GPS while underway and CG is taken from the MIS database.

4 Ellipsoid Depths and Soundings Accuracy

In open ocean areas, the accuracy of an ellipsoid height (h) with GPS will be about ± 5 meters and thus the sea floor location with this order of accuracy will be sufficient for most practical purposes. In shallow waters, along coastlines, and inside harbors, specially designed Differential GPS (DGPS) surveys can measure ellipsoid heights in the range of ± 5-10 cm.

The accuracy for the keel clearance BD will be as per presently used acoustic soundings. To match the DGPS accuracy, it will be worthwhile that acoustic sounding techniques, procedures, and algorithms are examined again and updated as necessary.

5 Special Surveying for High Accuracy

In congested areas, the accuracy of ellipsoid heights and depths can be increased by surveying in DGPS mode. The following additional surveying procedures will help to improve the collected data for safer navigation, particularly to the traditional mariner:

1. In harbors, buoys with small DGPS receivers can monitor AC as it fluctuates with the tide, to provide real-time data to the ship's captain. Similarly the ship’s draft AD can be monitored with a keel-placed pressure sensor.

2. In cases where the sea floor heights vary significantly from one time to another, it will require regular DGPS surveys to keep the mariner informed of shoaling and other shifts in the channels.

3. In case of small ships, DGPS surveys for roll, pitch, and yaw will improve the accuracy of the ellipsoid heights of the keel and its clearance with the sea floor.

6 Conclusions

GPS and DGPS surveys provide the accuracy necessary for the ellipsoid depths and ship operations, whereby all measurements are referenced to the WGS 84 Ellipsoid. Thus, an time-invariant zero reference surface (or a vertical datum) will eliminate the necessity of measuring tides and ship’s draft, and settlement and squat during bathymetric surveying. In addition, this approach will replace any the time-variant tidal surfaces. The ellipsoid as the zero reference surface also allows the mariner, while underway, to determine keel and overhead obstruction clearance independent of the stage of the tide, the draft of the ship, and freeboard. As is traditional however, the prudent seaman will seek independent verification of all the available nautical information.

References

Kumar, M., and G.A. Maul (2005). Time-Invariant Sea-Floor Depths: Using the ellipsoid as zero-reference surface. *GPS World,* 16(9), pp: 16-21.

NIMA (1997). National Imagery and Mapping Agency. Department of Defense World Geodetic System 1984: Its Definition and Relationships with Local Geodetic Systems. National Imagery and Mapping Agency, Bethesda, MD, NIMA TR8350.2, Third Edition, 4 July 1997.