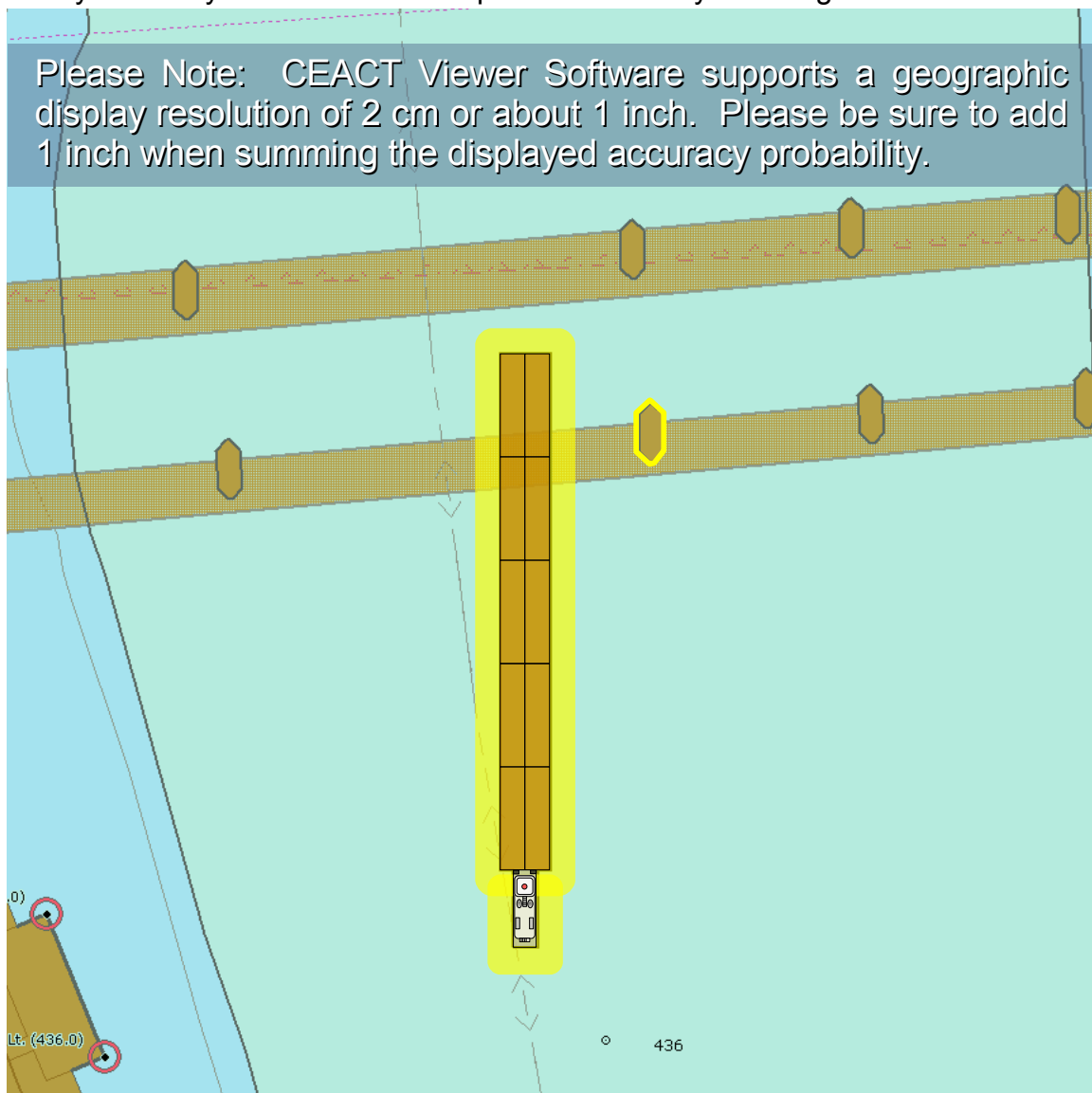


## GPS Compass Solutions      Application -vs- Accuracy

This paper summarizes in limited detail equipment accuracy probability specifications related to GPS Heading Compass equipment, and how they can effect the position of the head and stern of the vessel.

In the image below the yellow shadow accompanying the towboat depicts the accuracy probability of the horizontal position of an uncorrected GPS. Uncorrected GPS accuracy probability is typically rated at approximately  $\pm 15$  meters or about 50 feet. This image shows the accuracy probability of the horizontal position and does not take into account the Heading accuracy probability.

Survey data is typically said to have an average accuracy probability of about 2 meters. The Yellow shadow around the Bridge Pylon shows the approximate survey accuracy. Never assume a particular survey as being even this accurate.



## Accuracy Probability of GPS Compass Solutions.

Accuracy probability as stated in GPS Compass manufacturer's specifications can sometimes be confusing because various standards can be used to state the accuracy probability of a particular model of device.

It is important to understand these terms because the computed positional accuracy probability of the ship and or it's associated tow outline is based on the sum of the accuracy probabilities of the horizontal geographic position, heading solution and the distance from the GPS compass to any horizontal extremity of the ship and or it's tow.

When choosing a device, the application for which it will be used must be taken into account. For instance, applications such as mapping survey, dredging, and precision navigation require far better device specifications than applications such as pleasure craft usage, general navigation or radar overlay.

The tables below provide a convenient method to analyze and compare specifications of different GPS compass systems on the market today.

### Accuracy Probability Statistics

Accuracy Unit of Measure	Probability Percentage of Time
CEP ( circular error probability )	50%
rms ( root mean square )	63% to 68 %
R95 ( 95% radius )	95%
2drms ( twice the distance root mean square )	95% to 98%

*The table below can be used to convert one accuracy unit to another. For example: If a manufacturer states a device heading accuracy of .5 degrees rms, it means the accuracy is better than .5 degrees 63 to 68 percent of the time. The rms value can be converted to R95 by multiplying .5° by **1.7**. Once the rms value has been converted to R95, one could reason that the same device would have a heading accuracy of .85 degrees or better 95% of the time.*

### Accuracy Statistic Conversion Table

From Unit	To Unit			
	CEP	rms	R95	2drms
CEP	1	1.2	2.1	2.4
rms	0.83	1	<b>1.7</b>	2.0
R95	0.48	0.59	1	1.2
2drms	0.42	0.5	0.83	1

## Short Term Position and Heading Stability

Short Term Stability is one of the least understood aspects of GPS Compass systems that are sold today. Short Term Stability briefly stated, is the ability of the GPS Compass to continue to provide position, heading, pitch and roll calculations when the GPS system suffers an outage or other anomaly from an obstruction, multi-path, antenna damage, etc.

High performance survey grade, precision navigation GPS compass systems derive their Short Term Stability and their Accuracy Probability from a device known as an Inertial Measurement Unit, ( IMU ). IMU's are typically fitted with 3 solid state rate of turn sensors, and three solid state accelerometers. The quality of the IMU will determine how long the system can provide a relatively accurate dead reckoned position and heading when the GPS Compass satellite solutions have been corrupted.

The diversity of the GPS / IMU Heading Compass one of it's finest attributes because both of these devices work on totally different principles. For instance, a GPS solution can be temporarily affected when passing under a bridge. The IMU doesn't care how many bridges it passes under. The GPS solution can be temporarily affected by multi-path from antenna masts, but the IMU is totally unaffected by multi-path.

On the other hand, the accuracy of the IMU can be affected by temperature change, but temperature change has little to no affect on the GPS solution. You could say the integration of the GPS with the IMU was a perfect marriage. It is definitely very close to that. While it takes a significant amount of engineering to produce the desired result, it can be worth it. Some of the higher performance survey grade IMU's on the market today can provide a Short Term Heading Stability solution of better than 1 degree for an entire hour. This can be very important when making a precision navigation maneuver or when performing multi-beam sonar surveys. Who has time to stop.

Lower performance GPS Compass systems designed for general navigation, pleasure craft, and radar overlay applications are typically designed to provide only a few seconds or minutes of Short Term Stability. This amount of stability is will allow the system to maintain heading while passing under bridges. These devices typically contain only rate sensors that provide short term heading, pitch and roll solutions. Short term position and velocity solutions of many of these devices are simply based on the dead reckoned last valid speed and position from the GPS system because they do not contain accelerometers.

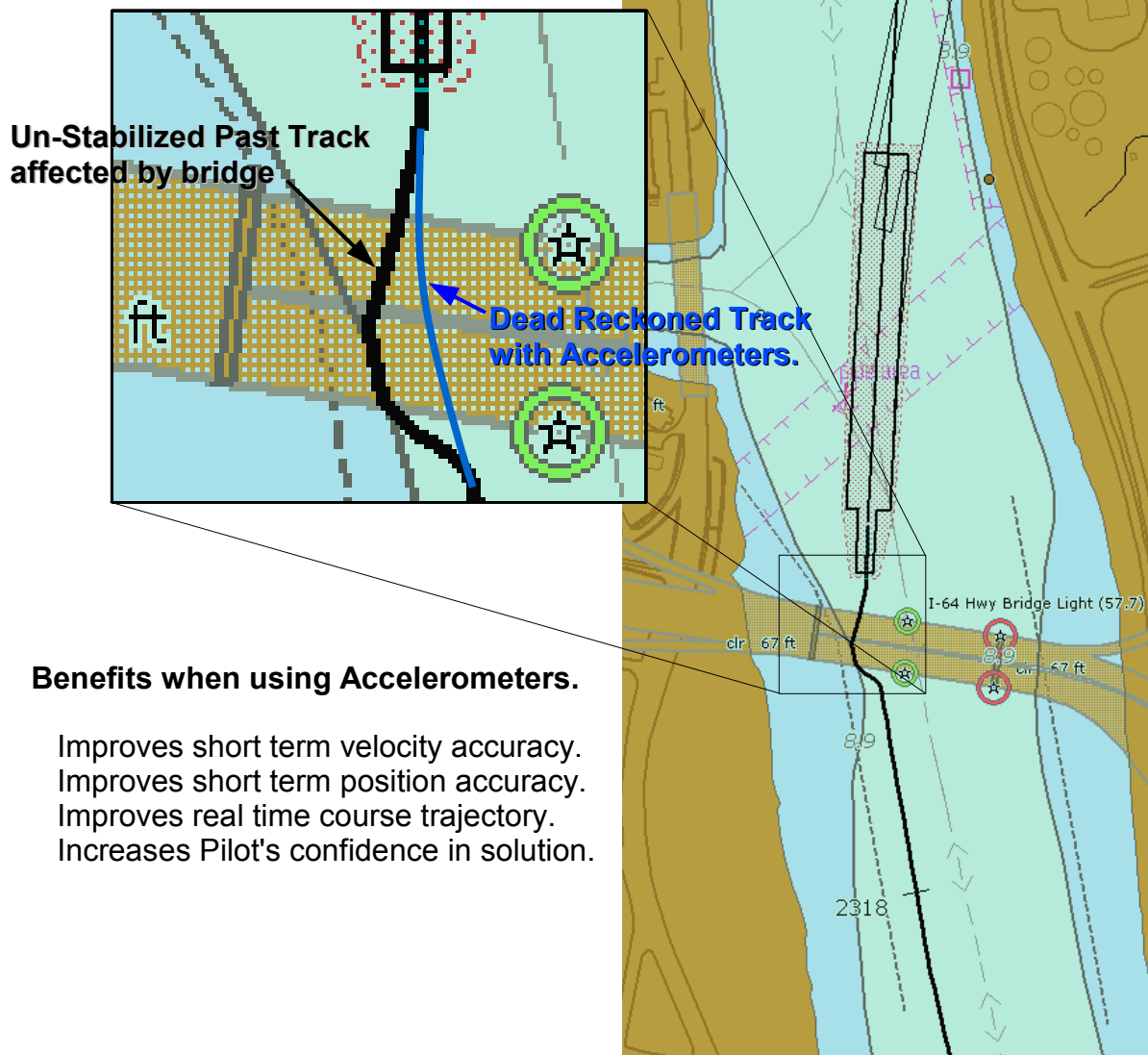
While these devices may be of lower performance, they do meet the needs they were designed for and are very popular because of their lower cost and solid state reliability. Some of the newer systems are even becoming quite accurate.

## Short Term Position and Heading Stability

### Dead Reckoning with Accelerometers.

GPS Heading Compass systems that incorporate accelerometers in their IMU provide much better performance when the GPS antennas are obstructed or when multi-path problems occur.

The Blue line below shows how an integrated three axis accelerometer can increase the short term position performance of the GPS based Heading Compass when passing under bridges.



### Benefits when using Accelerometers.

- Improves short term velocity accuracy.
- Improves short term position accuracy.
- Improves real time course trajectory.
- Increases Pilot's confidence in solution.

## Satellite Compass Accuracy Probability Comparisons at 95%

The device data in columns 2 and 3 for System Models listed below was obtained from brochures that were downloaded from the internet. All data was converted to R95 per the **Accuracy Statistic Conversion Table** from page two of this document. Position and Heading accuracy values taken from brochures were typically based on static conditions. Real world conditions can affect these values.

The intent is to determine the Positional Accuracy at the Head of a 15 unit barge tow located 1000 feet ahead of the GPS Compass under static conditions. The Positional Accuracy Probability for the head of the tow is stated at 95% confidence in column 6 of the table and the values are expressed in ft.

Positional Accuracy for each device was limited to uncorrected GPS or WAAS as both of these coverage solutions are nation wide. DGPS and RTK solutions were not considered because they are not available nation wide. There is one exception. The X-Span system at the bottom is utilizing a nationwide pay subscription correction service.

Note: The X-CrescXnt system listed below is an OEM board. This board is not currently available in a finished package at the time this document was prepared. This new OEM board appears to provide better performance when using WAAS corrections than other systems listed. It is however premature to judge this solution until a packaged system becomes available.

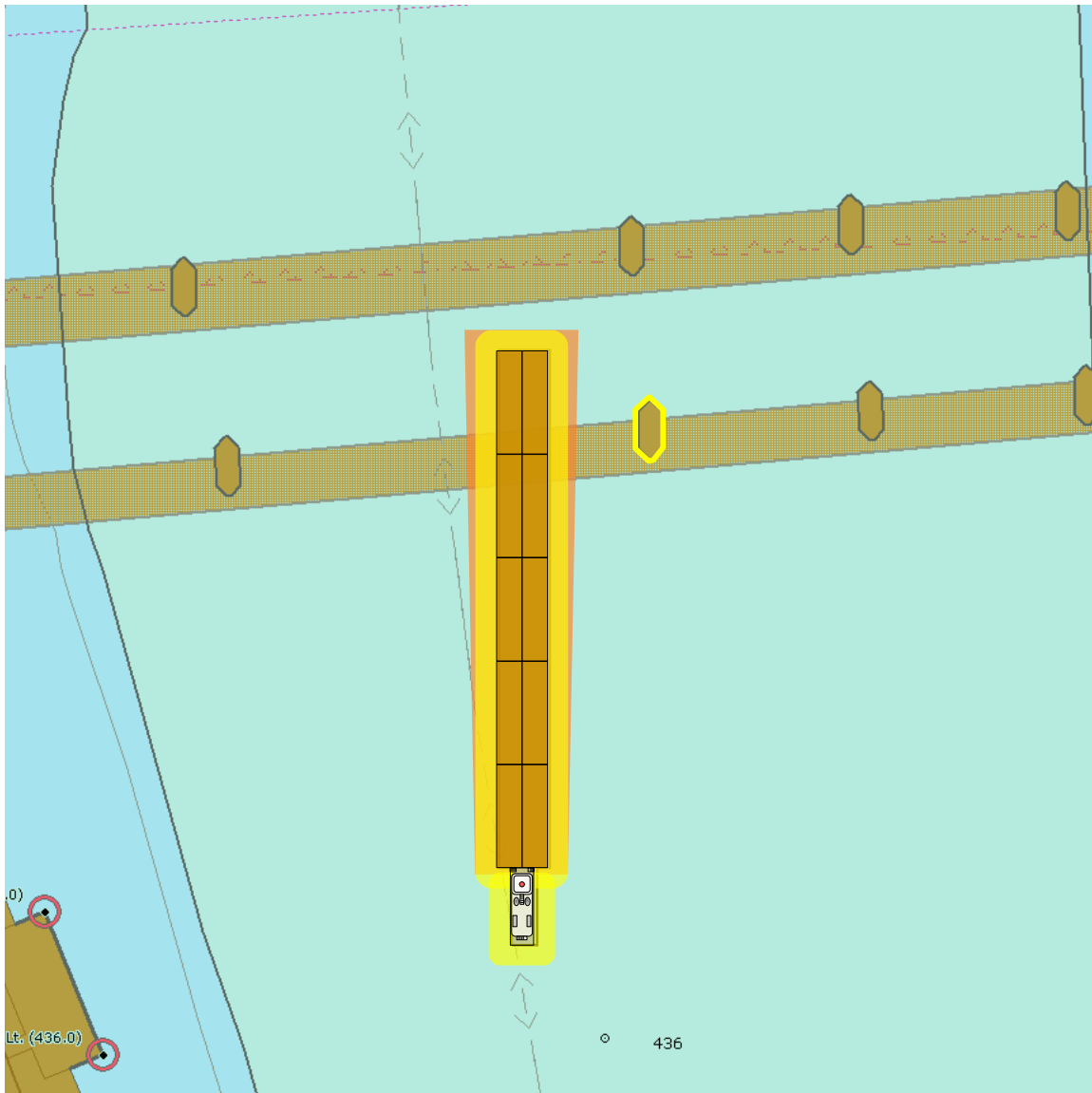
Note: Manufacturers specifications may be subject to change at any time. The Model X-MT is a Magnetic compass marketed for pleasure craft. All Accuracy Probability values in columns 4, 5 and 6 are in feet.

System Model Reference No.	Heading Accuracy in Deg. 95%	Position Accuracy meters. 95%	Heading Accuracy Probability at 1000 ft. @ 95%	Position Accuracy Probability @ 95%	Sum of Position & Heading Accuracy Probability @ 1000 ft. @ 95%	AD10 Out for Radar overlay of AIS Targets	Solution not affected by disturbance of nearby magnetic field	Integrated Accelerometers for improved Dead Reckoning
X-MT	1.7	5	29.67	16.4	46.07	N	N	N
X-JLR-10	1.19	12.45	20.77	40.85	61.62	N	Y	N
X- SC50	1	3	17.45	9.84	27.30	Y	Y	N
X-Sperry Navistar	0.85	3.15	14.84	10.33	25.17	Y	Y	Y
X-SC110	0.6	3	10.47	9.84	20.31	Y	Y	N
X-CrescXnt V OEM	0.25	0.5	4.36	1.64	6.00	N/A	N/A	NA
X-Span DL4 Omni	0.09	0.21	1.48	0.69	2.17	N	Y	Y

## Accuracy Probability of GPS Compass Solutions.

The example below shows the typical positional accuracy probability of one commonly used GPS Heading compass that is marketed today. These units use two or more GPS antennas to determine Heading and an uncorrected GPS to determine positional accuracy. The uncorrected positional accuracy of this GPS is about 12.5 meters is shown in yellow. The stated Heading accuracy for the device, shown as an orange shadow below, is approximately 1.19° and is added to the positional error.

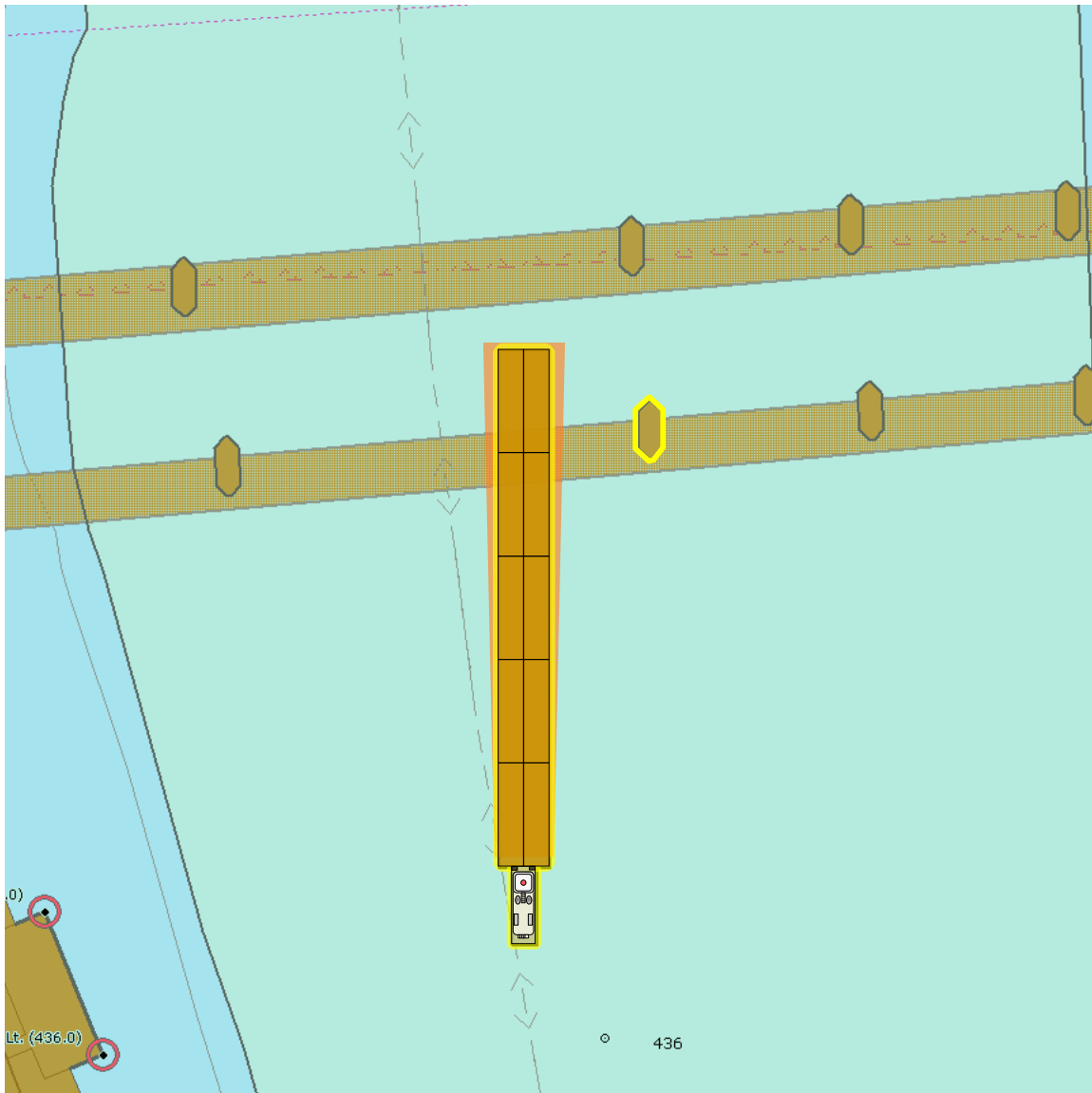
The positional accuracy probability equals about  $\pm 41$  feet and the Heading accuracy probability equals about  $\pm 21$  feet at the end of 1000 ft. of tow, for a total accuracy probability at the head of the tow of less than  $\pm 62$  feet 95 % of the time.



## Accuracy Probability of GPS Compass Solutions.

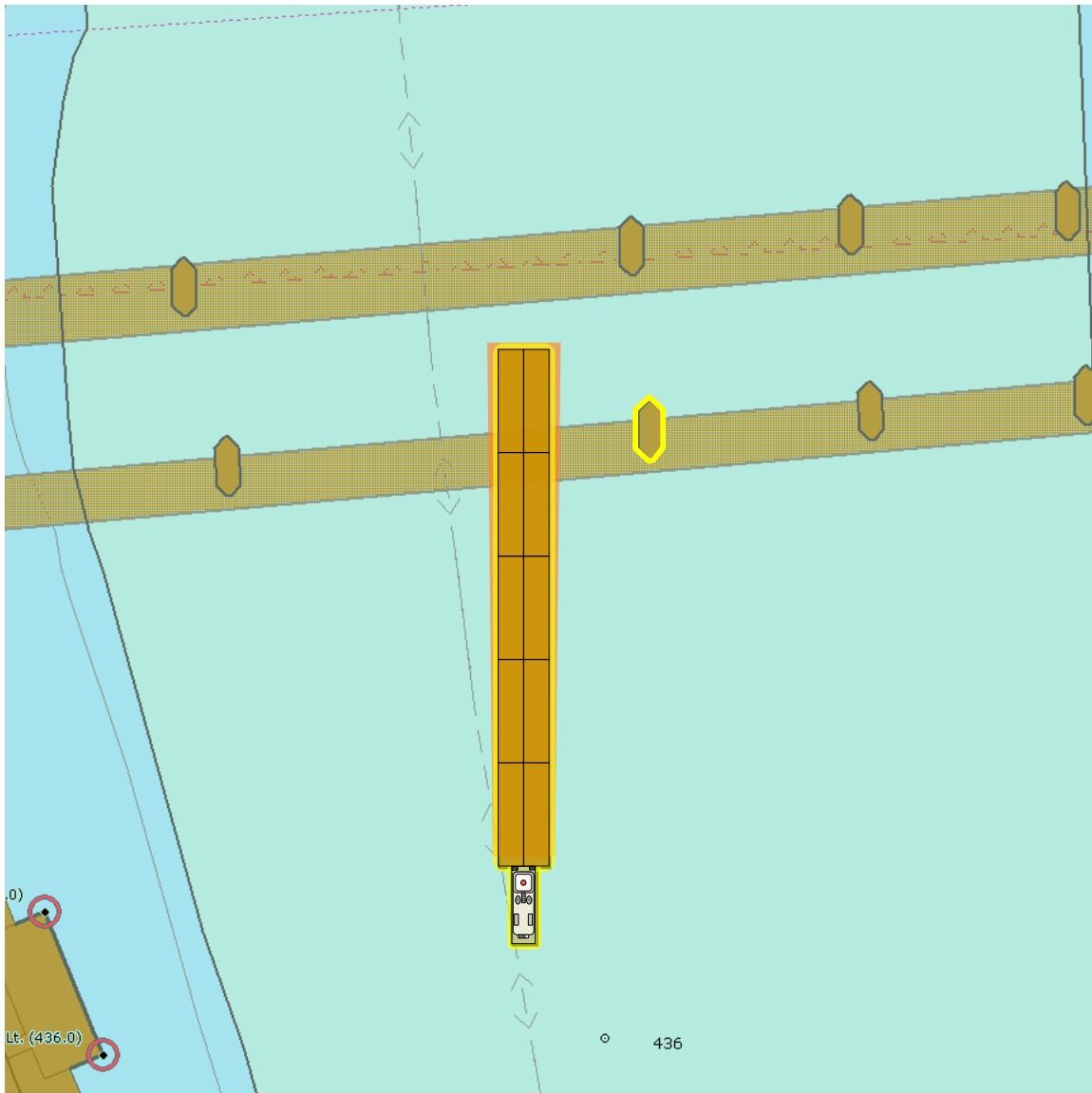
The introduction of WAAS or Wide Area Augmented System in 2004 provided the best overall improvement in GPS positional accuracy in years. GPS systems that utilize WAAS usually have a stated accuracy or error of  $\pm 1\sim 3$  meters. The image below shows a typical 3 meter accuracy detailed as a yellow shadow around the vessel and it's tow. The heading accuracy shown below is approximately  $1^\circ$ , or roughly  $\pm 17.5$  feet at the end of 1000 feet of tow.

The total combined accuracy probability at the head of the tow for this type of sensor is approximately  $\pm 17.5$  feet for Heading and  $\pm 10$  feet for position or better than  $\pm 27.5$  feet 95% of the time.



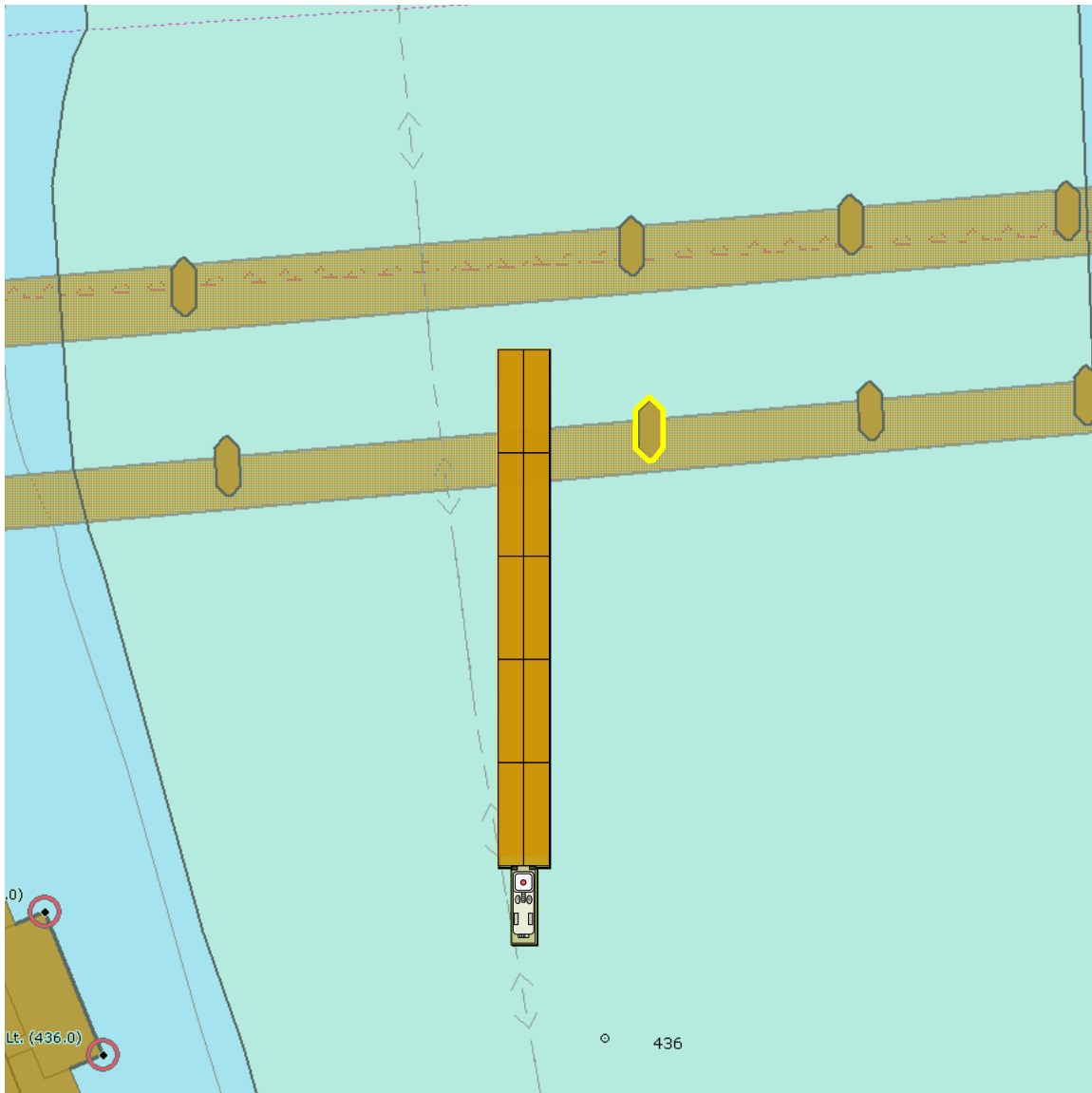
## Accuracy Probability of GPS Compass Solutions.

Still better, the system below utilizes WAAS for GPS positional corrections and has a stated heading accuracy of  $.6^\circ$ . This type of system has a typical positional accuracy of about  $\pm 3$  meters or 10 feet shown as a yellow shadow around the vessel and its tow, and a Heading accuracy or error of about  $\pm 10.5$  feet at the end of 1000 ft. of tow. The combined positional accuracy probability at the head of 1000 feet of tow is better than  $\pm 20.5$  feet 95 % of the time.



## Accuracy Probability of GPS Compass Solutions.

Last but not least, the most expensive equipment on the market utilizes a subscription based satellite correction system, or a Real Time Kinematic local correction base station to provide positional corrections to within 20 cm or about 9 inches. The position correction for the ship and it's tow is shown below in yellow, however at this scale it is nearly impossible to see. These systems also have an excellent Heading accuracy or error of less than  $.05^\circ$ . Using this type of Survey Grade equipment can provide a positional accuracy at the end of 1000 feet of tow of better than  $\pm 24$  inches 95% of the time. Great for precision navigation, but it comes with a price tag between 40K and 120K . As prices fall several years from now, these devices are expected to find there way to the Inland Waterways and other areas of restricted maneuverability. The heading and positional errors shown below are barely visible.



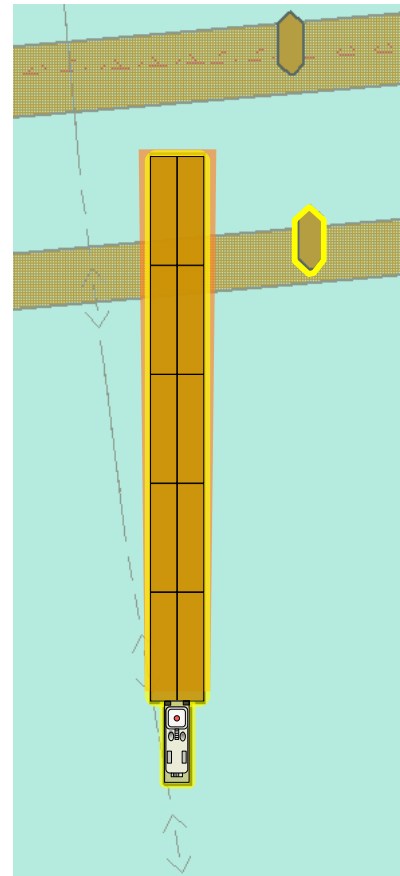
## Estimating the Satellite Compass Accuracy Probability Outline.

Listed below are the technical specs for a premium WAAS based satellite compass. Under normal conditions when utilized in the CONUS, the WAAS corrected static horizontal position accuracy probability is better than 3.1 meters R95. This horizontal position accuracy probability is represented in the picture to the right by the Yellow outline around the ship and it's tow. The Yellow outline can be computed based on the Sensor X Y Offset, the Ship Dimension, the Tow Dimensions and the Heading Angle.

**Table 1-1. Functional and Interface Requirements**

Accuracy
Heading + 0.5° RMS (static)
Rate of turn 0.5°/min or better
GPS position 10 m (95%)
DGPS position 5 m (95%)
WAAS position 3.1 m (95%)
Speed over the ground 0.2 knots or 2% of true speed
Rate of Turn Follow-up speed +25°/sec
Settling Time 4 minutes coast time

In Table 1-1 above the Heading Accuracy is stated at .5° RMS. This value can be converted to R95 by multiplying the RMS value by 1.7 as detailed in the Accuracy Statistic Conversion Table from page 2. With a static heading accuracy of .85° R95, and with the known parameters for the ship, tow and sensor offset, the accuracy probability for the head of the tow can be estimated.



With a Ship 150 feet long, with a Sensor Y offset is 125, with 5 rows of barges that are 195 feet long each, one could determine that the radial length between the GPS Heading Compass and the Head of the tow would equal 1000 ft or radius =1000. Diameter of full circle would equal 2000 ft. Circumference =  $\pi \cdot D$  or 6283 ft. Divide the Circumference by the number of degrees in a circle, (360) to determine the distance between each degree at the head of the tow. Therefore 1 degree at a radial distance of 1000 feet = approximately 17.45 ft. Multiply 17.45 by the R95 heading accuracy probability stated above at  $\pm .85^\circ$  for a grand total of  $\pm 14.83$  ft.

Last, Sum the 14.83 feet R95 with the 3.1 meters R95 from above to estimate the R95 accuracy probability at the head of the tow. Convert meters to feet by multiplying 3.1 by 3.2808399 for a horizontal position accuracy probability of 10.17 ft R95. Add 10.17 to 14.83 to estimate the sum for positional accuracy probability at the head of the tow of less than approximately  $\pm 25$  feet R95.

*Note: The calculations above are presented for explanation only, however they do form the basis for a new standard by which GPS based satellite compass systems could be judged.*

*Note: Most of the specifications that are given by manufacturers for their gps satellite compass systems are based on a static condition in a low multi-path environment. The results presented here could differ significantly due to shipboard real world dynamic conditions and by the ever changing multi-path environments into which they may have been installed into or operated within close proximity of.*