Multibeam Performance Testing

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Abstract

Software for a multibeam performance test is now available to determine how any multibeam boat conforms to published USACE accuracy standards. Test methods and calculated results are taken from the USACE Engineering Manual. This testing particularly addresses the concerns of hydrographic offices and contractors involved with dredge work and the inevitable challenge of sounding data.

The three stages of performance testing are: (1) creation of a reference surface, (2) comparison of the reference surface with multibeam check lines and (3) comparison with single beam check lines. The results are presented as absolute and statistical data; maximum outlier, average difference, standard deviation and 95% confidence.

Introduction

One of the more important questions to answer, particularly in the emerging field of multibeam surveys, is this: how accurate are the depths? Because "Really Accurate" is often inadequate, methods have been developed to provide a more quantitative answer, which can be compared to documented accuracy standards. For example, required depth accuracy for multibeam surveys done by the U.S. Army Corps of Engineers and it's contractors are given in the Engineering Manual[1] (see table 1).

It's not as easy as it seems to determine depth accuracy. The problem is to find one unknown quantity (depth accuracy) from a couple of other unknowns (sounding depth and position) under normal working conditions. Therefore, the method is indirect and involves three distinct steps:

- A small multibeam survey to generate a reference surface.
- Comparison of the reference surface to multibeam check lines.
- Comparison of the reference surface to single beam check lines.

The reference surface is the clever part used to turn unknown depth and position into a statistical best estimation within a small area. The rest is straight forward; comparison of the check lines to the reference surface gives the sought after accuracy results.

Before the performance test is done the multibeam system should be completely calibrated. A bar check will validate depths of near vertical beams and a patch test will properly account for mounting offsets of the sonar and other onboard sensors.

[1] U.S. Army Corps of Engineers, Engineer Manual EM 1110-2-1003 Hydrographic Surveying.

Reference Surface

The reference surface is created by processing a small survey into an XYZ surface. Because the reference surface is an estimation of the true bottom, it is restricted to insure that it is a *good* estimation. The main restriction is that it is flat, which minimizes the effects of position errors during survey. Note that horizontal positions are typically accurate to +/- 6 feet (DGPS), which would lead to a very poor reference if it were not flat. When choosing the survey location, look for the flattest, smoothest bottom around.

The reference survey (figure 1) consists of two sets of 5 parallel lines. Line separation is the approximate water depth, insuring 400% coverage within the boundaries of the survey. The lines are run at the boat's normal survey speed, with a sound velocity cast before and tide measurements and draft adjustments (if required) while in progress. If tide measurements are a problem in the area, it's best to run the survey at low or high tide to avoid skewing the surface.

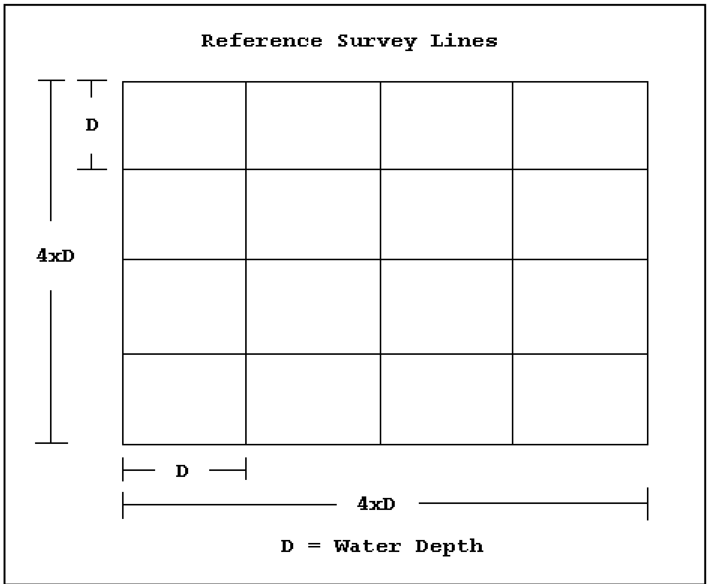

Figure 1: Map view of the reference survey lines.

Next the soundings are carefully edited to remove outliers. All beams greater than 45 degrees from vertical are discarded in keeping with the best estimation theme. The edited soundings are then gridded into 1' x 1' cells (approximate size of beam footprint) and the cell averages are saved to an XYZ file – the reference surface.

A good reference surface should have small standard deviations within cells. This is logical considering the bottom is flat - differences in soundings can only be due to errors. Coastal Oceanographics' MB Max, the software used for processing performance test surveys, has a feature to locate all cells with excessive standard deviation. One can then decide to remove isolated points, or scrap the reference surface if a trend toward poor data is detected. Possible causes of poor data are patch test calibration errors and errors in tide or sound velocity measurement.

Multibeam Check Lines

The multibeam check lines are run in both directions through the center of the reference surface. Check lines can be run immediately after the reference survey if it's convenient or any time after. Editing is similar to the reference survey except that no beams are filtered based on angle, which would preclude comparisons based on beam angle (below).

After editing, MB Max's **Beam Angle Test** feature is used to compare the reference surface to the multibeam check lines. The test derives a difference population by comparing every check line point to the nearest point on the reference surface. All statistical results are calculated from the difference population:

- Max outlier: Maximum difference between the reference surface and check line. The presence of excessive outliers can indicate calibration or sound velocity errors (or faulty editing!)
- Mean difference: This is the average of the difference points. This is a critical check in that it shows the depth bias between the reference surface and check lines. Excessive difference can be caused by faulty tide, draft or sound velocity measurement.
- Standard deviation (sigma): Measures the dispersion of the difference population. Small standard deviation is good in that it shows a tight clustering of depth differences around the average value. The trend toward larger standard deviation indicates an increase in depth difference and a corresponding decrease in depth accuracy.
- 95% confidence: 1.96 times the standard deviation gives the 95% confidence level: 95 percent of the difference population is less than this value. USACE accuracy specifications are given at the 95% confidence level.

MB Max presents these statistics at various angle limits and graphs the 95% confidence result as a function of beam angle (figure 2).

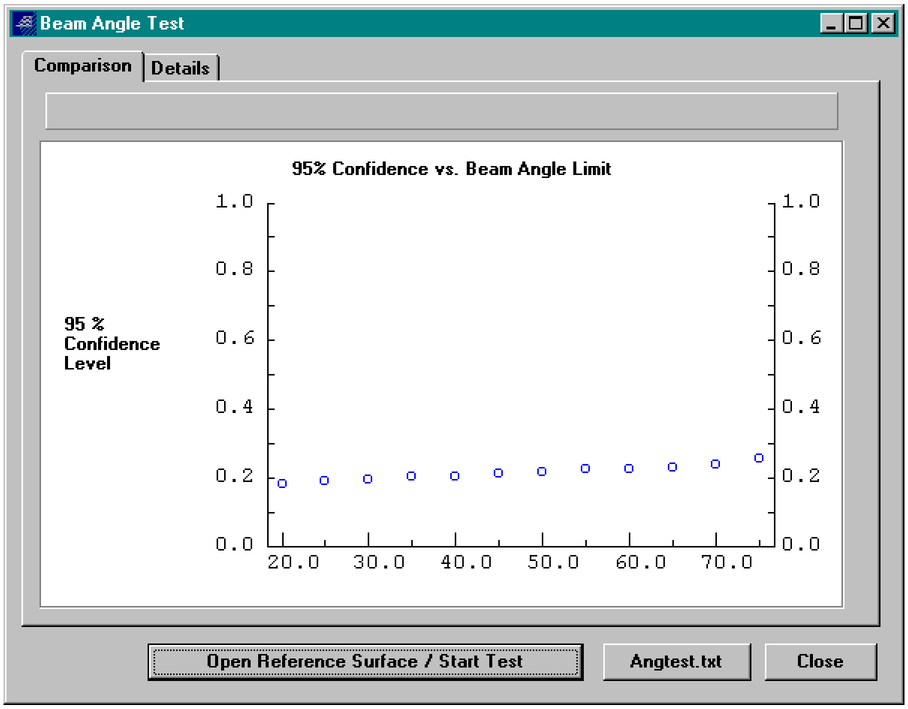

Figure 2: Graph of accuracy vs. beam angle limit shows that accuracy decreases with increasing beam angle. But not a lot.

Single Beam Check Lines

As above, the single beam check lines are run in both directions through the center of the reference surface. After editing and reformat to XYZ, the single beam lines are loaded into MB

Max and the **Single Beam Test** is run. Again, the maximum outlier, mean difference, standard deviation and 95% confidence level are calculated, this time comparing the single beam check lines to the multibeam reference surface.

This is a valuable test in that it departs from the somewhat unhealthy reliance on multibeam data of the previous test. REALITY CHECK. It's possible to achieve great results in the multibeam vs. multibeam test only to find that all the multibeam depths are 0.5' too shallow. This test will detect that condition.

Test Case

Performance tests were run September 27 – 29, 2000 to compare survey results of the multibeam survey vessel Shuman (Philadelphia District) with USACE standards and acceptance criteria. For shallow water work, the Shuman is a large, stable platform with a hull mounted multibeam sonar, so it was expected that performance results would be well within accuracy limits.

The testing was done on the Delaware River in the vicinity of the Fort Mifflin field office during slack tide periods. Four individual tests were run:

- Patch Test
- Bar Check
- Multibeam Performance Test
- Single beam vs. Multibeam Comparison

Patch testing verified the results of previous tests and the bar check showed agreement to +/- 0.1 foot at 10 foot depth increments from of 10 to 50 feet.

The performance test was done over an exceedingly flat anchorage area with depth variation of less than one foot over the 200' x 200' test area. A reference surface was created by running two sets of parallel lines, line sets perpendicular to each other with line spacing equal to the approximate water depth (45 feet). After editing and application of tide and sound velocity corrections, the reference survey was gridded into 1 x 1 foot cells. The average of each cell was saved to an XYZ reference file, with the requirement of three sounding points per cell for averaging.

The comparison of multibeam check lines to the reference surface is shown in Figures 2 and 3. Figure 2 graphs depth accuracy at selected beam angle limits. On the left side is the accuracy result at the 20 degree limit, i.e., all beams with takeoff angle greater than 20 degrees from vertical are discarded. The far left side shows accuracy at the 75 degree limit. A trend toward decreasing accuracy can be seen but the change is small and even at the 75 degree limit, results are well within specifications.

Figure 3 contains the quantitative results and the histogram of depth errors at the 45 degree limit. The histogram is a normal distribution skewed slightly positive, showing the check line depths a little deeper than the reference surface.

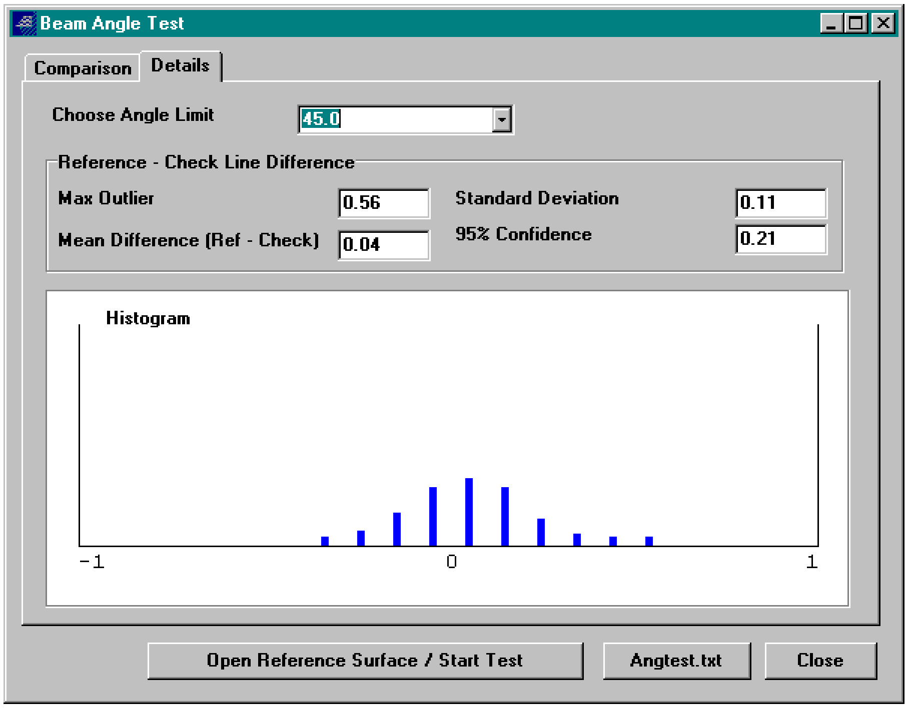

Figure 3: Statistics discarding all beams greater than 45 degrees from vertical.

Shuman statistical quantities are shown in Table 1 with comparison to USACE limits for navigation and dredging support surveys. All OK for hard or soft bottom classification.

Statistical Quantity	Shuman Result	Maximum Allowed – Hard Bottom	Maximum Allowed – Soft Bottom
Maximum Outlier	0.56 ft	1.0 ft	1.0 ft
Mean Difference (Reference surface – Check line)	0.04’	+/- 0.1 ft	+/- 0.2 ft
Standard Deviation	0.11’	---	---
Depth Accuracy at 95% Confidence	0.21’	+/- 1.0 ft	+/- 2.0 ft

Table 1: Shuman results vs. USACE standards.

Finally, figure 4 shows the comparison of single beam check lines to the reference surface. Interpretation indicates that Shuman multibeam and single beam depths will compare within a tenth or so.

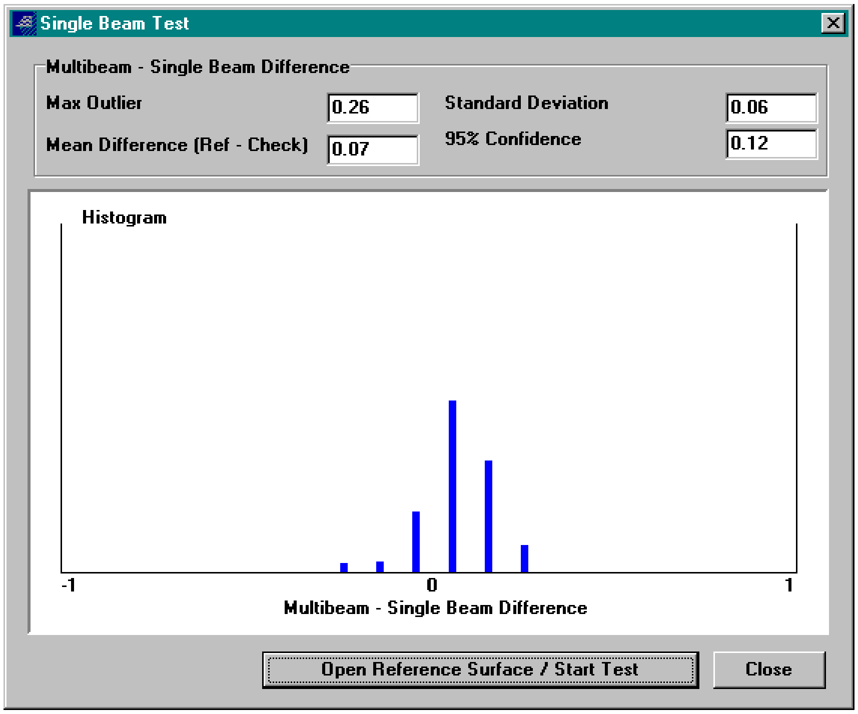

Figure 4: Results of single beam comparison to the reference surface.

Conclusion

In the test case, the Shuman easily surpasses the requirements for navigation and dredging support surveys over hard or soft materials.

The described methods and software can be easily applied to any multibeam survey vessel to find out if the vessel meets USACE depth accuracy requirement.