# Multibeam Water Column Imaging : Improved Wreck Least-Depth Determination

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## Abstract

Water Column imaging, using hydrographic-grade multibeam echo sounders is now available commercially. Such a capability was originally developed primarily for fisheries imaging, but provides significant advantages for hydrographic data quality control. Most immediately apparent is the ability to view the near 2-D scattering field around wrecks or other man-made objects.

Robust bottom tracking algorithms have to be optimized for likely seabed geometry. To avoid excessive outlier density, mistracking on spurious echoes is often discouraged by the use of gating or neighbour-proximity rules. Such methods, however, can fail spectacularly on abrupt non-continuous surfaces, commonly found over submerged man-made structures like wrecks or oil and gas infrastructure. These structures are often unsuspected and imaged only in a random pass of a regular survey. Based on prior experience, the least depth determination is often questionable from the real-time bottom tracking solutions. The main submerged superstructure is usually apparent but concern over protruding features can result in the need for bar or wire sweep investigations.

Nevertheless, if the complete water-column trace from each beam is retained it is possible to review the full volume of scattering targets in the vicinity of the suspected object during post-mission feature examination. The interpretation of such imagery is prone to error unless the operator fully comprehends the imaging geometry. Particularly significant is the role of sidelobe echoes, both from the transmit and receive beams, producing secondary, ghost-like targets in the vicinity of point scattering features, such as masts or abrupt hull forms.

This paper will review the imaging geometry and resulting scattering field that would be produced by such targets. Real examples of wrecks, imaged using EM3002 and EM710 sonars, are presented as case studies.

## Introduction

Multibeam sonars have revolutionized the practice of hydrography. By providing near-continuous bathymetric coverage of the seafloor, they have increased the accuracy of and confidence in hydrographic charts. It was, however, quickly recognized that there were limitations to these systems, most notably in achieving 100% coverage (Miller et al., 1997) and in detecting objects as small as, or smaller than the beam footprint (Hughes Clarke, 1998, Hughes Clarke et al., 1998).

The most extreme target detection problem is that of discontinuous, small cross-section targets such as protruding mast and spars from shipwrecks. Despite their small size, these targets are disproportionately important in hydrography, as they often represent the minimum clearance required to be represented on the chart. Prior to the advent of the multibeam sonar there were four common approaches to establishing the minimum clearance:

1. tracking the apex of hyperbolae seen in broad-angle single beam soundings.
2. measuring shadow length from sidescan imagery.
3. diver investigations.
4. bar or wire sweeping.

The first approach takes advantage of the broad angle of a single beam, and relies on the tip of the mast being a strong scatterer. Even if not directly below, the scattering point should show up within the beam cone and would produce a characteristic hyperbolic series of echoes from a moving vessel. By moving randomly over the suspected centre of the wreck, a minimum depth from the apex of the hyperbolae can be used as an estimate of the least-depth.

The second approach assumes that the sidescan is of sufficiently high resolution and stable enough to detect the shadow cast by the mast. Using flat seafloor assumptions, the maximum protrusion can be estimated. However, even if a mast is seen, the horizontal position of the top of its top is not precisely known, as it is rarely vertical anymore. Thus the distance over which the shadow is cast cannot be properly estimated.

The third and fourth approaches are the least ambiguous, but require the largest investment in ship-time and pose a risk to livelihood. Depending on the exposure and the depth, these may not be practically employable.

All the methods of course, required prior knowledge of the wreck. Multibeam sonar bathymetry is an ideal method for locating wrecks, as the main superstructure will reliably show up. The first pass however, rarely provides reliable detections above the wreck. Because of the finite beam widths and spurious sidelobe artefacts, singular outliers around the wreck cannot be used with confidence.

The quality of the soundings on the wreck depends primarily on three factors:

- the physical apertures which control the beam widths,
- the side-lobe suppression and
- the bottom detection algorithm.

To date, by far the best published results have been obtained by the RESON 8125 which, until recently, had the narrowest beamwidths available on the market (1.0° transmit by 0.5° receive), and thus had the best chance of completely occluding the beam on a narrow target like a mast. Even with these results however, one is faced with editing an unattributed cloud of solutions, many of which appear to define linear features, but need not be contextually related. Subjective decisions are required to accept or reject a singular solution. Statistical methods developed for cleaning soundings (e.g. Ware et al, 1991, Eeg, 1995, Calder, 2003) all base their sounding confidence on an association with others on an assumed continuous surface. Such statistics will obviously not be appropriate here.

Another way of validating outlying solutions is clearly required. Water-column imaging from the newest generation of multibeam sonars provides one plausible means of achieving this.

**Beam Occlusions**

Ultimately, for a single beam of a multibeam to unambiguously lock onto the top of a narrow cross-sectional target like a mast, the echo from that mast should be the strongest, and preferably the only one at that beam elevation. The reality however, is that the projected solid section of the mast is likely to be smaller than the main lobe of the beam. Therefore some of the main lobe and most of the surrounding sidelobes will completely miss the mast.

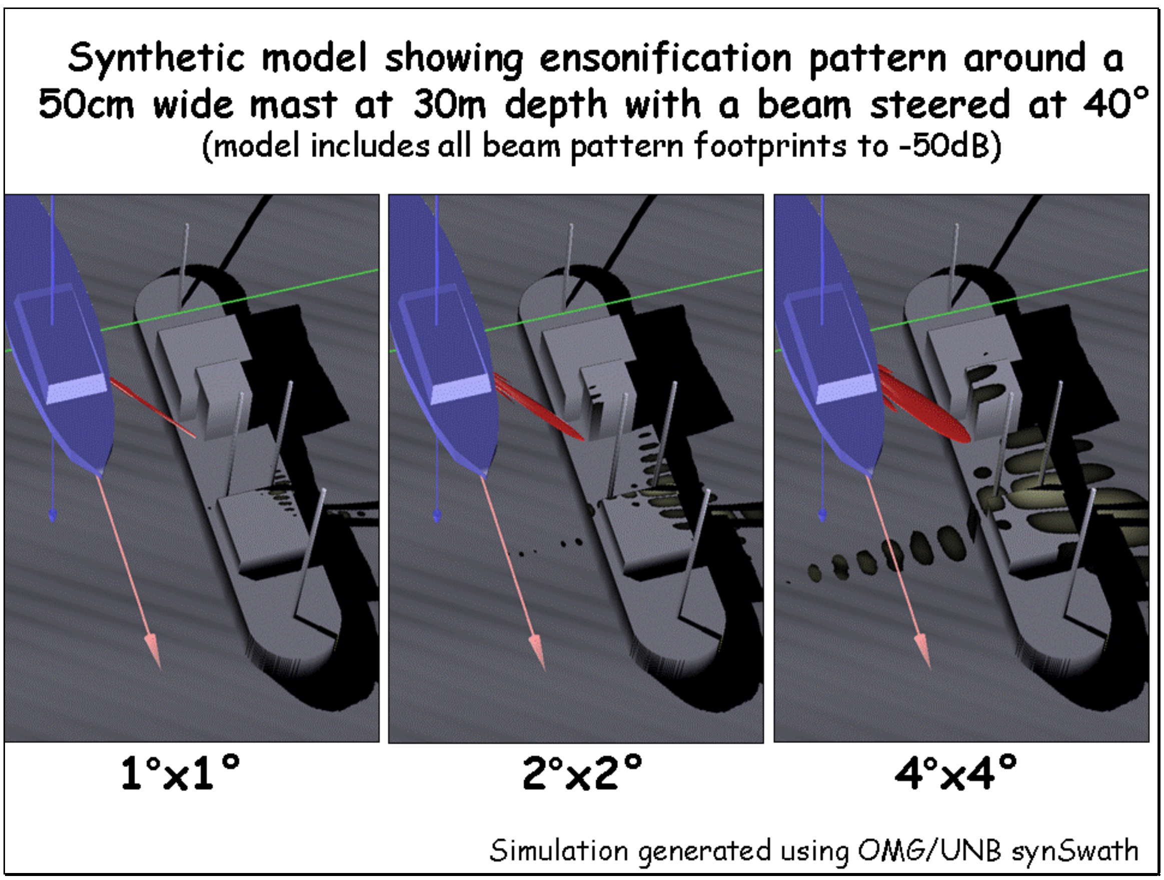


*Figure 1: simulation showing the full ensonification pattern of 1°, 2° and 4° beams on a wreck with typical dimension (30m depth, 50cm diameter mast with a beam steered at 40°). Note, the illustrated main lobe footprint is drawn to the first null ,NOT to the 3dB limits and thus appears significantly wider.*

If some of the energy in the main lobe, and/or significant energy from side-lobe contributions make it past the target, the energy would be able to scatter from the more distant surface, resulting in more than one echo in a time series. There is thus a case for tracking multiple solutions for a given beam boresite. Examples given below illustrate how echoes from protruding targets such as masts clearly coexist with later echoes at the same apparent elevation angle. This is indicating that much of the projected energy is bypassing the intended target.

**Instrumentation**

Simultaneous, hydrographic-grade bottom tracking and multibeam water-column imaging is now offered from Kongsberg (EM3002, EM710, EM302) and RESON (7000 series). Herein, examples presented will be from the EM3002 and the EM710 multibeam sonars installed on the CCGS Otter Bay and the CCGS Matthew respectively.

The EM3002 (KSM, 2004) is a single sector multibeam operating at ~ 300 kHz. The transmit beam width is 1.5°, and the receive beam width is 1.5° at broadside (growing with steering angle to be 3° at 60° off nadir). The EM3002 forms 164 physical beams. In the usual mode of beam forming, (termed, High Definition (HD)), the beams are spaced in an equi-angular geometry. The HD beamforming provides more bottom detection solutions (256) than physical beams. Such an approach, however, cannot be used for the water column imaging and thus only 164 radial channels are recorded for that purpose, irrespective of bottom detection approach. The data herein is collected using a roll – stabilized 130° sector with the physical beams spaced at ~ 0.8°.

The EM710 (Kongsberg, 2005) model used was operated in two modes:

- the 2.0° transmit, 2.0°* receive version (June 2005) and
- the 0.5° transmit, 1.0°* receive version (May 2006)

(*: the receive beam width again growing with steering angle)

The exact beam widths depend on the centre frequency of the sector used, being slightly wider for the lower frequency sectors. The three sectors are at 97kHz (centre), 71kHz (port) and 83 kHz (starboard). As with the EM3002, more bottom detection solutions than physical beams can be achieved, but for water column imaging purposes there are 135 (270) receiver channels for the 2° (1°) version.

In the HD mode used throughout, the physical beams are spaced in an equi-angular manner. Bottom detection cannot usually be achieved past ~ 70°, but the water column data can be acquired out to the full roll-stabilized +/-75°.Under this geometry, the beams are spaced at 1.1° (0.55°). One should be aware though, that the outermost receiver beams are approximately 4 times wider than the nadir receive beams at that steering angle. For the angular sectors presented (+/-65° and +/- 45°), the physical beam spacing was 0.96° (0.48)° and 0.7°, (0.35) °for the 2° (1°) beam widths, always corresponding to tighter than half the 3dB beamwidths.

The EM3002 uses a 0.15ms pulse for all operations and the EM710 uses a 0.167 ms pulse for the water depths from which these examples are taken. The beam forming channels on the EM3002 are sampled at a 14.9 kHz and on the EM710, they are sampled at a 15.1 kHz .

To handle this water-column data, a new suite of software tools are gradually emerging. Herein, all processing and manipulation is being done using SwathEd, the proprietary swath sonar processing suite of tools developed at UNB, primarily by the first author.

## Multibeam Imaging Geometry.

For a full review of the multibeam water-column imaging geometry, the reader is referred to Hughes Clarke (2006). In brief, it should be emphasized that the polar plots presented are not exactly a measure of the 2D scattering field beneath the sonar. All echoes heard by a single beam-forming channel are plotted by time along the intended beam boresite elevation angle. Due to the pattern of receiver sidelobes (Fig 2 A), a series of echoes from the seafloor inboard of the main beam will be received before the main lobe echo and plotted, as if they really had occurred along the boresite (Fig 2 B).

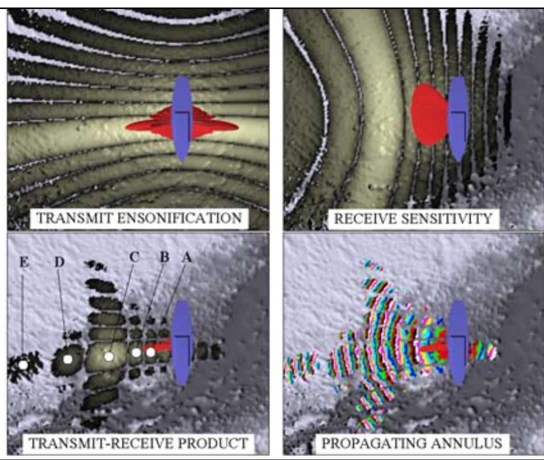


*Fig 2A: showing ensonification patterns for transmit and receive beam patterns and the product of the two.(from Hughes Clarke, 2006)*

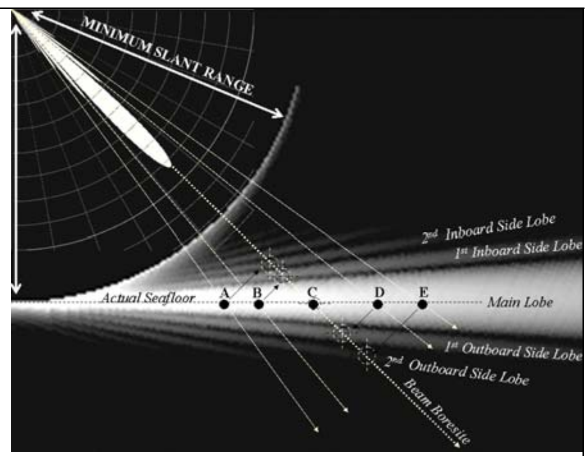


*Fig 2B: showing the representation of the sidelobe echoes, as they occur and where they end up being plotted in the radial display.*

This will produce an apparent “halo” effect along the true seafloor. The width of the central band of echoes around the true seabed location will reflect the length of the projected main lobe beam footprint at that location. Beam spacing tighter than the 3dB limits will not significantly improve the achievable angular resolution of the image.

Any particularly bright target (such as an inward facing facet on a wreck), often referred to as a glint, will tend to show up as a circular arc at that common slant range in all the receiver beams. Thus, any two targets lying at the same slant range, but separated by an elevation angle difference greater than the beam width, may still be confused if one is a significantly stronger scatterer than the other. Significantly stronger is herein defined as greater than the sidelobe suppression at the angle offset between the scatterers.

## MV G.B. Church

To test out the wreck-tracking capability of the EM3002, an artificial reef was used. The MV G.B. Church, a 54m long coastal freighter, was deliberately sunk in 1991 to serve as a recreational dive facility. The vessel was sunk in water depths of 24 to 27m with all the upper deck rigging in place, including masts, loading spars and davits.

The wreck was well photographed whilst being sunk and thus the locations and dimension of all the main protuberances are well documented. The aim of the trials was to compare the real time bottom tracking solutions from the EM3002 to both documented records and the new multibeam water-column imaging capability.

Figure 3 illustrates four passes over the foredeck mast of the wreck. The shallowest point on the mast lies approximately 4.5m below the instantaneous transducer depth (1.0m). As the masthead was so close to the water surface, if the survey vessel was more than 10m to the side of the mast, it would not be visible within the +/-65° sector.

As can be seen from Figure 3, the real-time bottom tracking rarely locked onto the mast at all. On the one occasion when it did (Fig. 3 bottom right), it created a false arc of solutions, extending right up to the transducer.

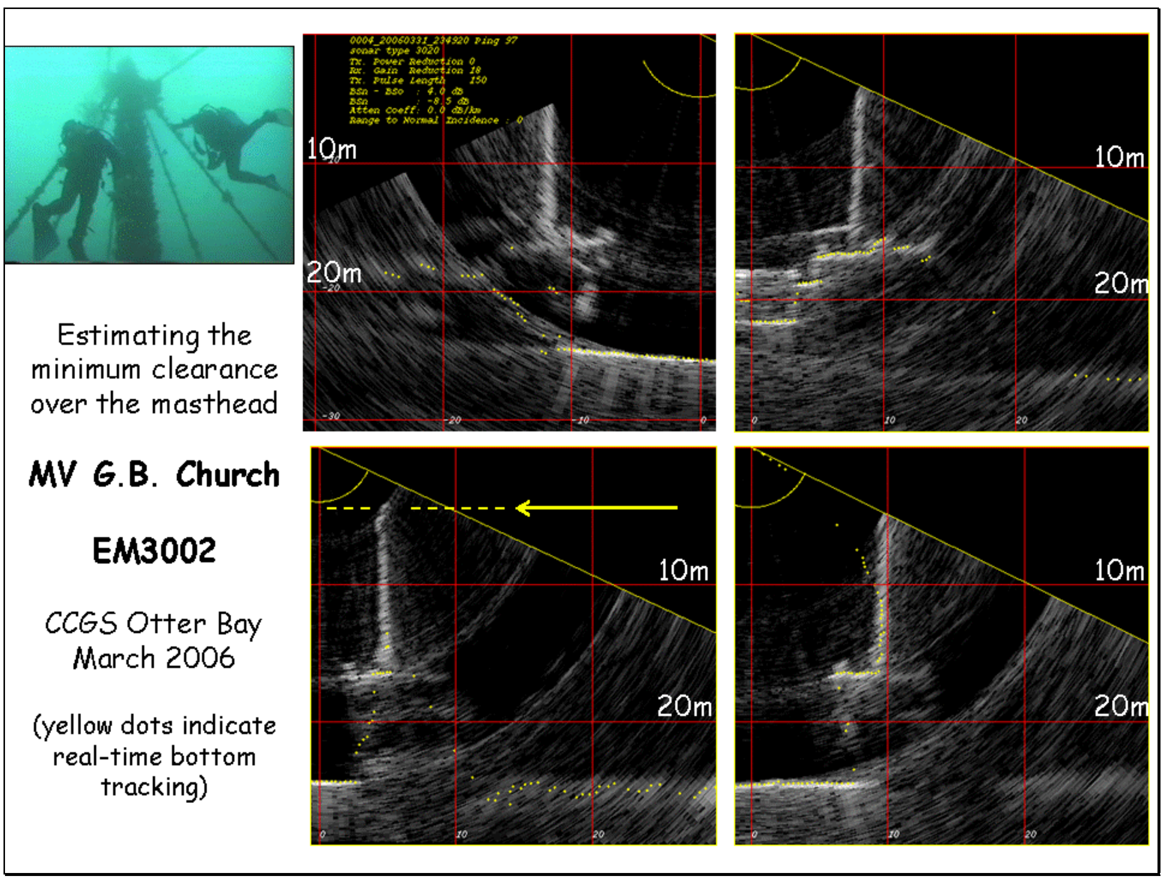


*Figure 3: showing 4 instantaneous water-column images of the ping that best ensonified the mast of the G.B. Church. Note that in all geometries, there are faint echoes beyond the mast illustrating that complete beam occlusion never occurs.*

The mast is ~ 40cm diameter. Using a 1.5° beam subtended at a range of 10m, the main-lobe beam width is ~26cm wide and thus should be occluded. The fact that subsequent echoes are heard along the beam bore-site, after it has struck the mast, clearly illustrates the significance of the sidelobe beam footprint returns.

By altering the bottom tracking filter settings (to wide open), a greater density of true targets is revealed, but at the expense of more false echoes as well.

**MV British Freedom**

To test out the wreck-tracking capability at greater depths, the MV British Freedom was used as a test bed for the Kongsberg EM710 installed on the CCGS Matthew. British Freedom is a ~100m long, 7000 ton torpedoed oil tanker that lies in ~58m of water.

The vessel has been imaged over the years using EM100, EM1000, EM1002 and now the EM710. The vessel was imaged twice. In June 2005 the electronics for the EM710 on the CCGS Matthew were configured to use only a subset of the arrays, achieving a 2.0° transmit and a 2.0° receive, In May of 2006, the complete transceiver electronics were finally installed and the full 0.5° transmit array and 1.0° receive array could now be tested.

The wreck was surveyed at 10 knots from various azimuths using differing angular sectors. Figure 4 below shows four representative instantaneous cross-sections of the wreck obtained at almost the same location (the shallowest point on the wreck).

It is clear that the narrow receive beams provide far improved definition of the wreck upper surface. Nevertheless, even with the 2.0° beam, the shallowest point is still clearly illuminated. Apparently there is a remaining 3 inch gun still sitting on a section of the galley that is raised proud of the stern section of the wreck. It is also clear that the resolution is almost the same irrespective of the angular sector used. Compressing the physical beams together makes a slightly less blocky image but does not provide significantly greater clarity.

Note also that in none of the cases presented did the real-time bottom tracking actually lock onto the shallowest point. Indeed for all four cases the proud feature is actually ignored, and the projected seabed behind the proud target is tracked instead.

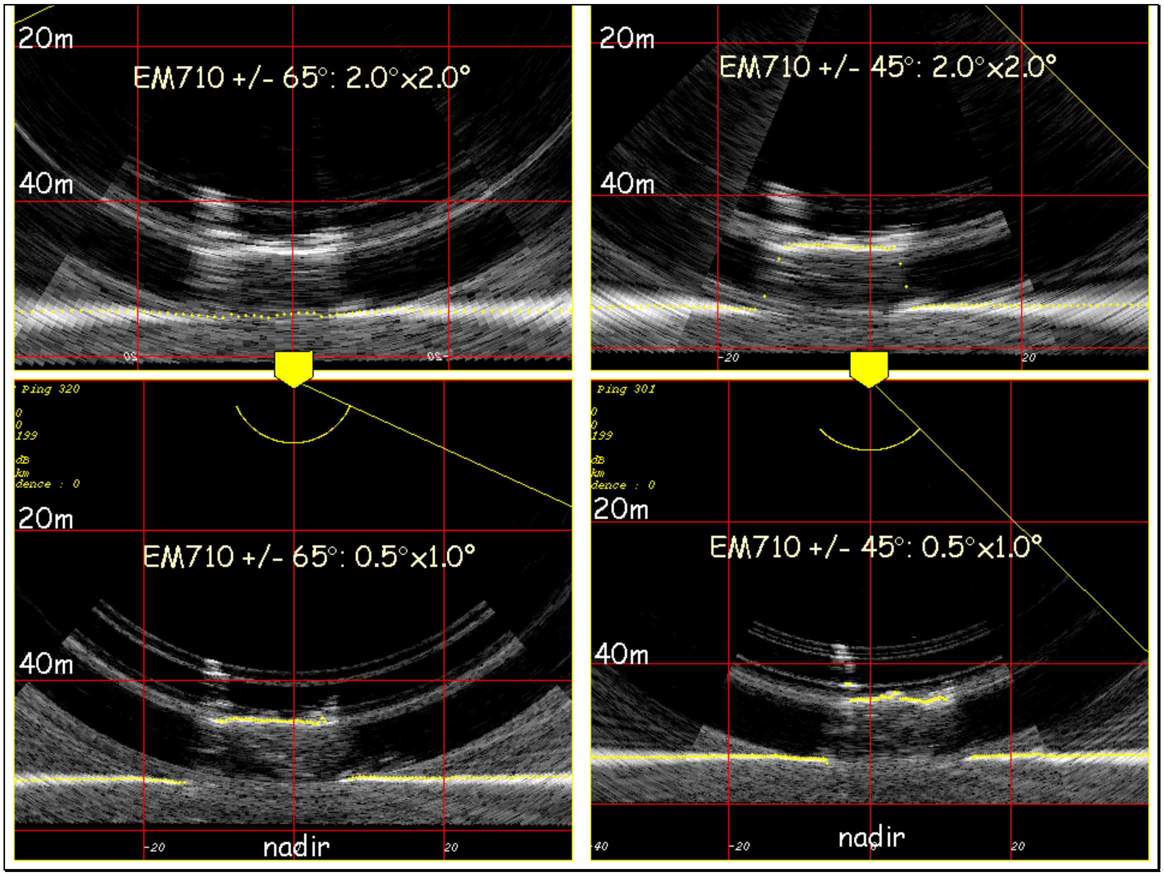


*Figure 4: Four cross-section images located in almost the identical slice across the MV British Freedom. The upper two images were obtained using the 2.0°x2.0° version of the EM710. The lower two images were obtained using the 0.5°x1.0° version of the EM710. Angular sectors of +/-65° and +/-45° were used.*

Having a 1.0° rather than a 2.0° receiver beamwidth significantly improves the definition of the across-track relief, but the narrowing of the transmitter beamwidth does not produce equivalent gains. With a 0.5° fore-aft beam width, the projected fore-aft beam dimension is ~ 0.5m, compared to ~ 2.0m for the 2.0° beam. Nevertheless, using a +/-65° sector, only a 4Hz ping rate was achieved (6Hz using at +/-45° sector). At the used survey speed of 10 knots, this corresponded to 1.25m (0.85m for +/-45°) forward advance between shots.

Thus the vessel advances further than the fore-aft beam width for each ping and therefore the full potential along-track resolution cannot be achieved. It is clear that the full benefit of the 0.5° transmit beamwidth will only be achieved by either slowing down, or when the system starts delivering the multiple fore-aft planes of solutions in the water. As designed (KM, 2005), the EM710 will require an extra 3 sectors (making a total of 6) to achieve this. However, whilst the three sectors are currently used for across-track yaw and pitch stabilization of a single swath, they could be rearranged instead to provide three narrow (e.g. +/-40°), identical vertically-referenced sectors, just separated fore-aft. This would involve sacrificing swath width for along-track density for this particular requirement of wreck surveying.

## Conclusion

It is clear, that multibeam water-column imaging provides a viable means of examining mid-water and near-bottom echoes. It contributes a context for making decisions about apparently-spurious, solitary, and discontinuous series of soundings in the vicinity of suspected wrecks. Feature detection is controlled primarily by beam widths, side-lobe suppression, noise-levels and rate of advance.

Using examples from wrecks in depths ranging from 20 to 50m (those of most interest for navigational hydrography), it is demonstrated that reliable detection of the shallowest point may be achieved without resorting to laborious wire-sweeping or diver methods. As such it represents a potential increase in the efficiency of hydrographic survey in wreck-strewn waters.

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