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LOOKING FORWARD TO BETTER FEATURE DETECTION

by Lt. Cdr. Colin K. ELLIS [1]

Abstract

This is a military surveyor's perspective on the potential for the Three Dimensional Forward Looking Sonar (TDFLS) and reports on the Australian developments todate with this concept. The TDFLS concept as currently being developed in Australia, can enhance navigation safety and optimise specific military missions by providing systematic sonar ensonification and intuitive, high resolution data. TDFLS may also revolutionise mission efficiency and safety within the Hydrographic feature detection mission by allowing faster vessel speeds, wider line spacings and easier planning.

The views expressed in this paper are those of the author but reflect Royal Australian Navy (RAN) Hydrographic Service policy on feature detection.

1. OVERVIEW OF THREE DIMENSIONAL SONAR GENERATION EMPLOYING VOLUMETRIC ACOUSTIC PROCESSING

1.1 TDFLS provides instantaneous ensonification of the volume of water ahead of the vessel including the sea-floor within each transmission as shown in Figure 1. Vertical discrimination is achieved by propagating a number of different frequencies from a vertical array all broad in horizontal plane but narrow in the vertical plane each layered one above the other. The returns of each separate frequency are received concurrently at a single frequency agile transducer array orientated in the horizontal plane, azimuthal discrimination is by phase comparison techniques. Beam

[1] Hydrographic Projects Officer, RAN Hydrographic Service, Campbell Park 1.6.03, Canberra ACT, Australia.

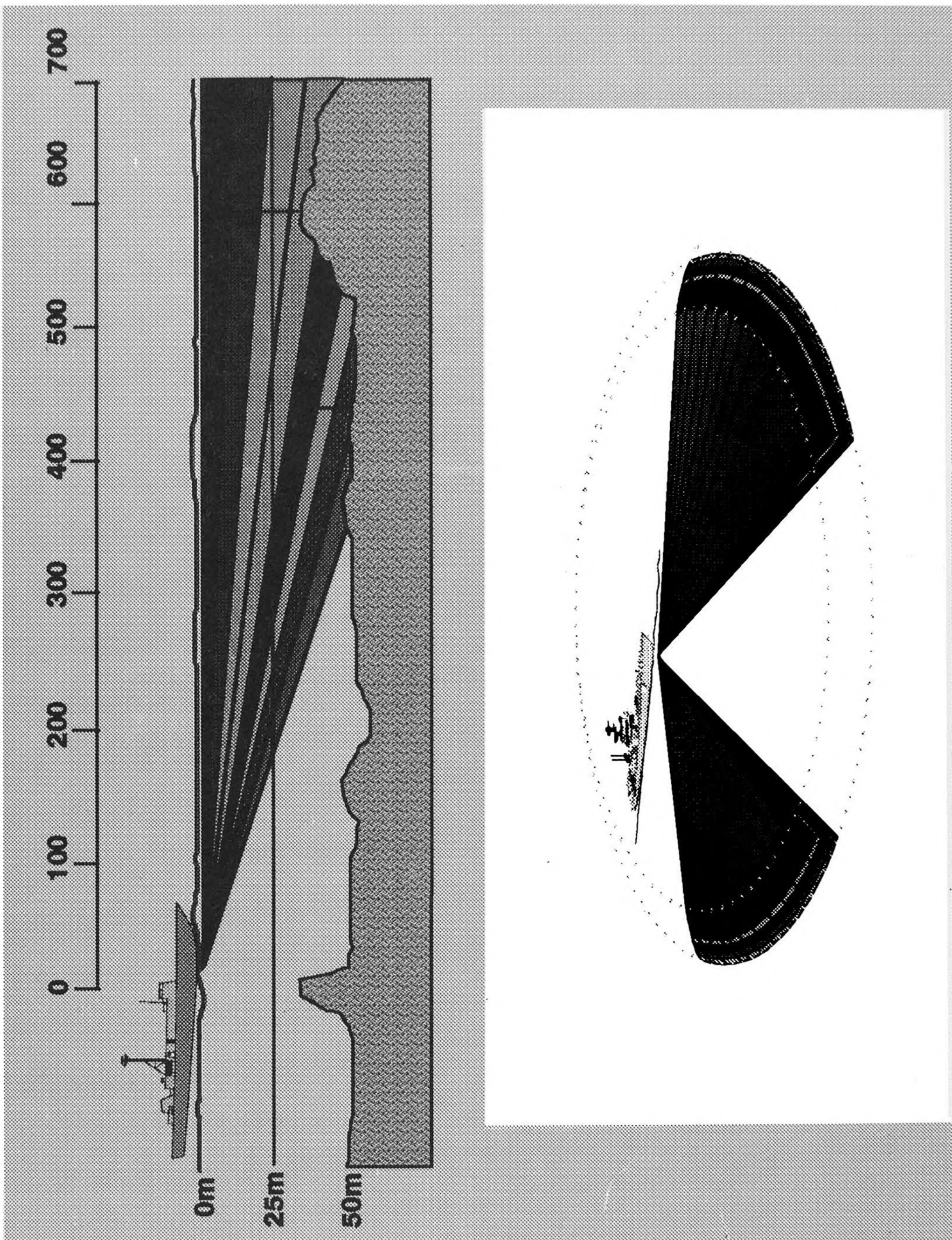


FIG. 1.- Three Dimensional Sonar.

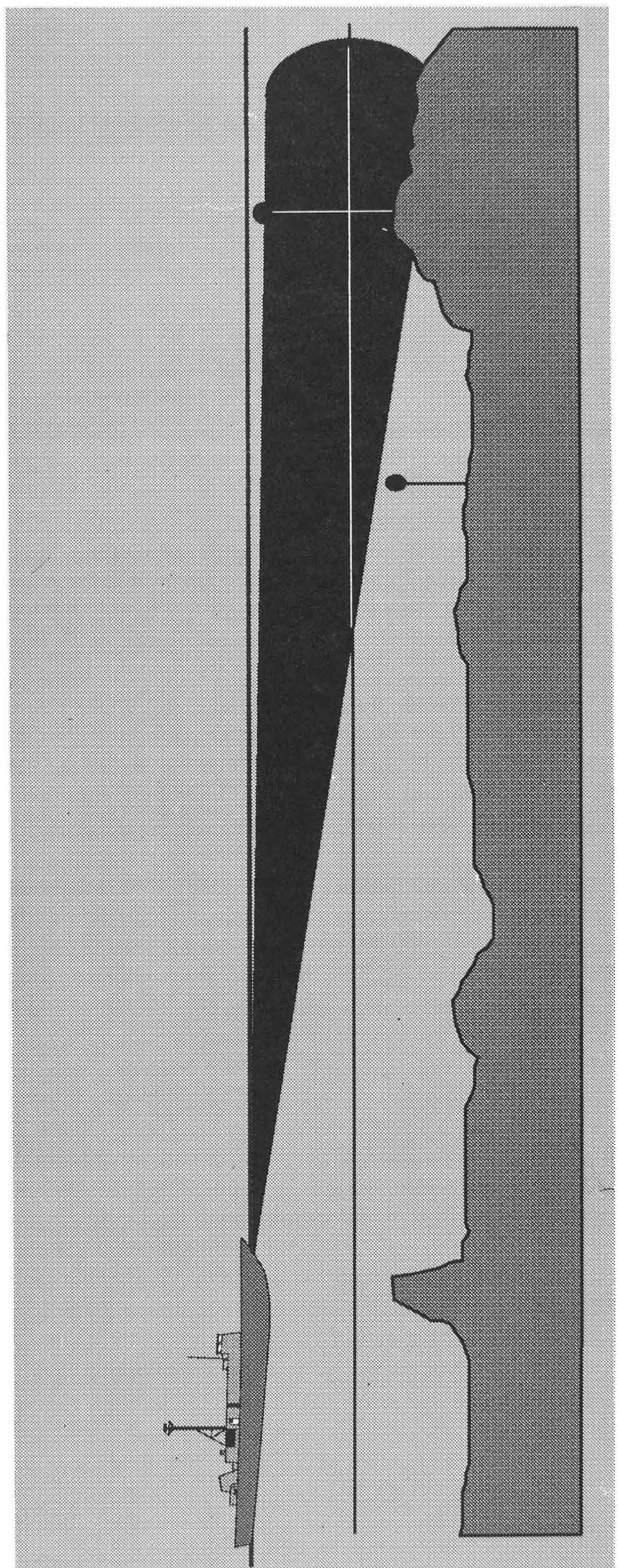


FIG. 2.- Search Light Obstacle Avoidance Sonar.

resolution is achieved by time series in the transmission, thus creating the 3D volume resolution.

2. NAVIGATIONAL POTENTIAL

2.1 Navigational incidents involving the grounding of vessels result in devastating impact on the environment, and, in cases, tragic loss of life. For these reasons all mariners have a critical need, and one argues a moral obligation, to optimise the navigational safety of their vessels. This is especially critical for modern warships which must maximise their freedom of manoeuvre for tactical advantage. Whilst it is the author's strong conviction that the main safety feature is, and always will be, the presence of properly trained and experienced mariners, technology does, and should continue to provide the best possible systems to aid that mariner.

2.2 For many years such technology has included the availability of search-light navigation safety sonars. These sensors propagate a one dimensional transmission of finite beam-width ahead of the vessel. This beam is mechanically or electronically swept through separate sections of the water to build up, with time, a picture of the sea-bed ahead of the vessel as shown in Figure 2. Despite the excellent capability of some such systems, there has been a noted lack of exploitation of search-light sonar technology in Navy warships and many commercial vessels. This is due, in part, to the non systematic nature of these systems and the interpretative skills required to use them safely. As a result, the presence of a search-light sonar may result in a false sense of security, and can make the vessel less safe than if it did not have the system at all.

2.3 The nature of the search-light means that only a small section of the water ahead of the vessel is ensonified, therefore a clear sonar screen may be indicative of a slow sweep and misinterpreted echo rather than safe water. This problem can be exacerbated by inexperienced operators becoming engrossed in one detected danger to the extent that they continue to manually track the search-light beam on this danger rather than sweeping ahead, the resultant clear sonar screen ahead is now a dangerous liability, representing a totally false picture of the navigational situation. Potentially as dangerous is the high false alarm rate inherent within search-light systems that are tuned to high sensitivity, continuous false alarm will lead to operator fatigue and inattention to warnings exacerbating the detection problem. In total contrast to the search-light system, a TDFLS system will ensonify its entire planned volume ahead of the vessel during each and every transmission epoch. Such a systematic coverage will clearly optimise vessel safety by significantly reducing the danger of missed contacts. The greater level of data on contacts gained by ensonification within each transmission epoch will also lower the false alarm rate by rapidly providing sufficient high resolution information for automatic and/or manual detection and recognition procedures with a high confidence level of detection and a low rate of false alarm.

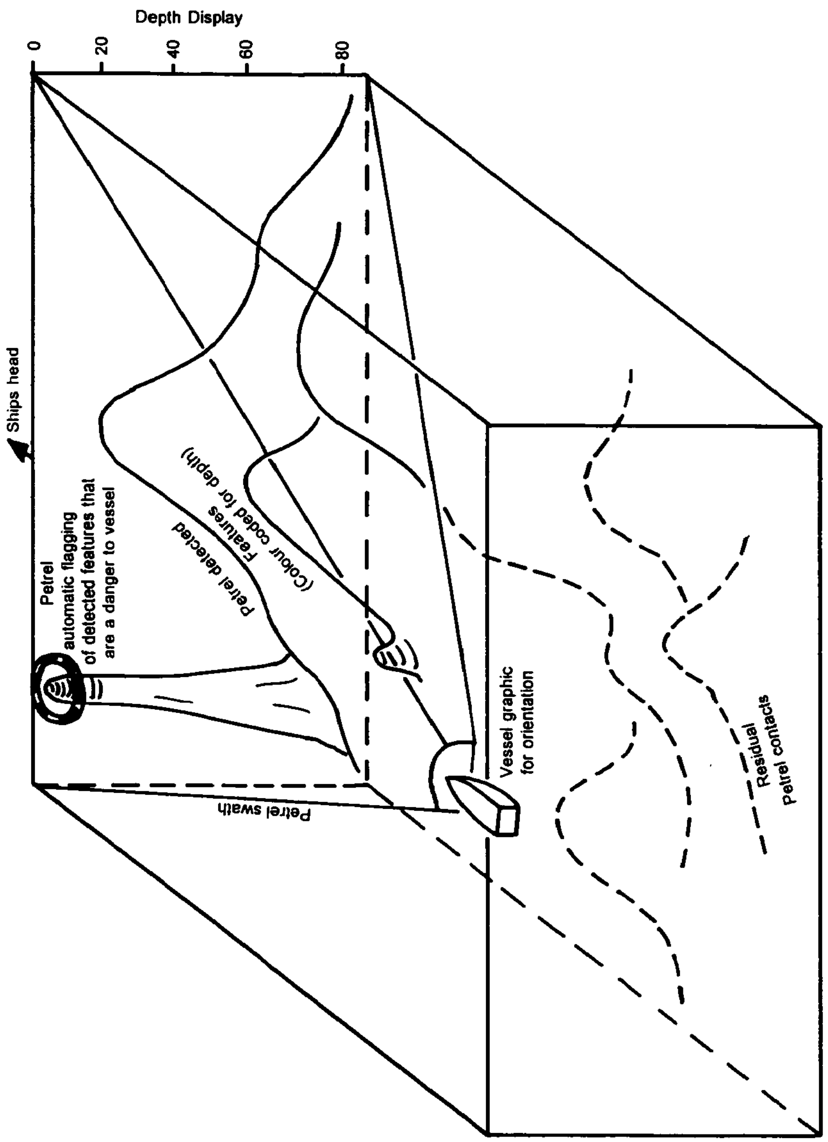


FIG. 3.- Proposed Navigational Three D Real Time Display.

2.4 The second problem with search-light systems concerns the presentation of the data. The beam must be sufficiently wide to ensure a full sweep in a reasonable time-frame which means the data can have low resolution levels particularly in elevation. Inherently this return will include surface returns, bottom returns and volume reverberation all presented one dimensionally within the beam time series. These aspects not only lower the detection capability and increase false alarms but also significantly complicate the sonar picture and increase the skills required to efficiently interpret the data, recognise dangers from background reverberations and make decisions about avoidance manoeuvres. The TDFLS capability for resolution of the horizontal and vertical within the volume means resolution is enhanced, with reverberation and other unwanted returns isolated from the sea-bed and detected dangers in the data presented. As significant is the additional information available from TDFLS concerning the nature of the danger including the contacts shape, extent, least depth and discrimination of contacts on the sea-bed to those floating in the water column.

2.5 It follows that this high resolution three dimensional data should be presented in a high resolution three dimensional display to provide an intuitive interpretation and exploitation as shown in Figure 3 below. This display can incorporate the use of vessel graphics for a quick operator recognition and orientation. The display should be designed to the needs of a broad range of mariners of varying experience and skill. The display can encompass simple, key-board free functionality, that does not require the operator to become overly obsessed with one sensor by inclusion of automatic detection and tracking capabilities. This hands free readily interpretable feature is notable as it further releases mariners from system manipulation allowing them more time to perform their main function which is keeping a proper lookout by all available means. Finally TDFLS data permits the display to be intelligent, warning the mariner of targets that are shallower than vessel draught, proposing avoidance courses and presenting the relative movement of detected contacts until they are past and clear.

2.6 A significant advance in navigational safety world-wide has been the introduction of Electronic Chart Display Information Systems (ECDIS). The resolution of TDFLS can be commensurate with that of an ECDIS exploiting vector data. This conceivably permits correlation of the ECDIS historic data to TDFLS real-time data. Such integration would allow the mariner's monitoring burden to again be reduced whilst optimising vessel safety. In such a scenario the TDFLS/ECDIS data correlation could be monitored automatically within the integrated environment, warning the mariner when the separate three dimensional surfaces did not correlate, i.e. when an unmodelled feature such as an unsurveyed danger of floating contact where ahead of the vessel.

3. OTHER MILITARY POTENTIAL

3.1 Sea-lane mining represents an intentional form of navigation incident and a number of past incidents where sophisticated warships have been damaged by relatively unsophisticated floating mines highlights the dangers in littoral waters during and for some time after times of conflict or tension. The systematic high resolution three dimensional capability of TDFLS offers a viable mine avoidance system for general navigation. This is enhanced by the TDFLS ability to differentiate shallow water sea-bed contacts and/or small floating contacts, such as low technology mines, from sea-bed returns in a three dimensional tracking and avoidance display. Again the large number of returns possible from the TDFLS in the mine avoidance scenario will increase detection probability whilst reducing false alarm rates and permitting the mariner the maximum possible information when choosing the safest possible course to avoid the danger.

3.2 Amphibious warfare requires bathymetric data on the planned landing beach particularly the gradient of the beach and any dangers within the approach area. Nations retaining amphibious capability invest large resources in beach intelligence operations to gather the requisite data on beaches anticipated to be of military interest. The prior gathering is reduced in effectiveness by the highly dynamic nature of sand sediment in beach waters meaning gradients can change quickly particularly after storms, by dilution of the effort from the need to survey all possible beaches, by the political inability to pre-survey beaches of other nations and by the likelihood that artificial dangers may be constructed on targeted beaches during periods of tension. TDFLS will permit the instantaneous gathering of sufficient data for individual vessel safety on any beach during the actual approach. The TDFLS display can be intelligent allowing automatic assessment of the actual beach gradient to within default margins. The width of the effective TDFLS swath and its range of accurate real-time vector mapping ahead of the vessel will permit the vessel to determine the suitability of the beach, establish safe approach and departure routes and then raise the sonar for the final beaching.

3.3 Warships at anchor are at risk from underwater diver attack, with the logistic effort for the ship required to prevent such attack disproportionate to the effort of attack itself. The lung cavity and/or breathing apparatus on the diver means TDFLS will be capable of detecting the diver within a high resolution sector including data on his depth, angle of approach and subsequent tracking once detected. The provision of accurate real-time information on the diver's depth is of significance as such information has not been generally available in the past. By allowing optimised timing of anti-diver charge fuses to the exact diver depth, TDFLS significantly increases the effectiveness of diver counter-measures.

4. HYDROGRAPHIC POTENTIAL

4.1 The primary requirement for hydrographic surveys within coastal waters (0-200m) can be described as finding how little, as opposed to how much water, is available within an area for safe navigation. The primary task therefore for a Charge Hydrographic Surveyor is detecting all navigationally significant features within his area of operations and determining the least depth and position of these features to prescribed accuracy standards. The author's use of "detection" in this case is the resolution of a feature against the background data from a sufficient number of acoustic returns, generically this has been assessed as a minimum of three such returns as shown in Figure 4. The term "navigationally significant" also has a broad

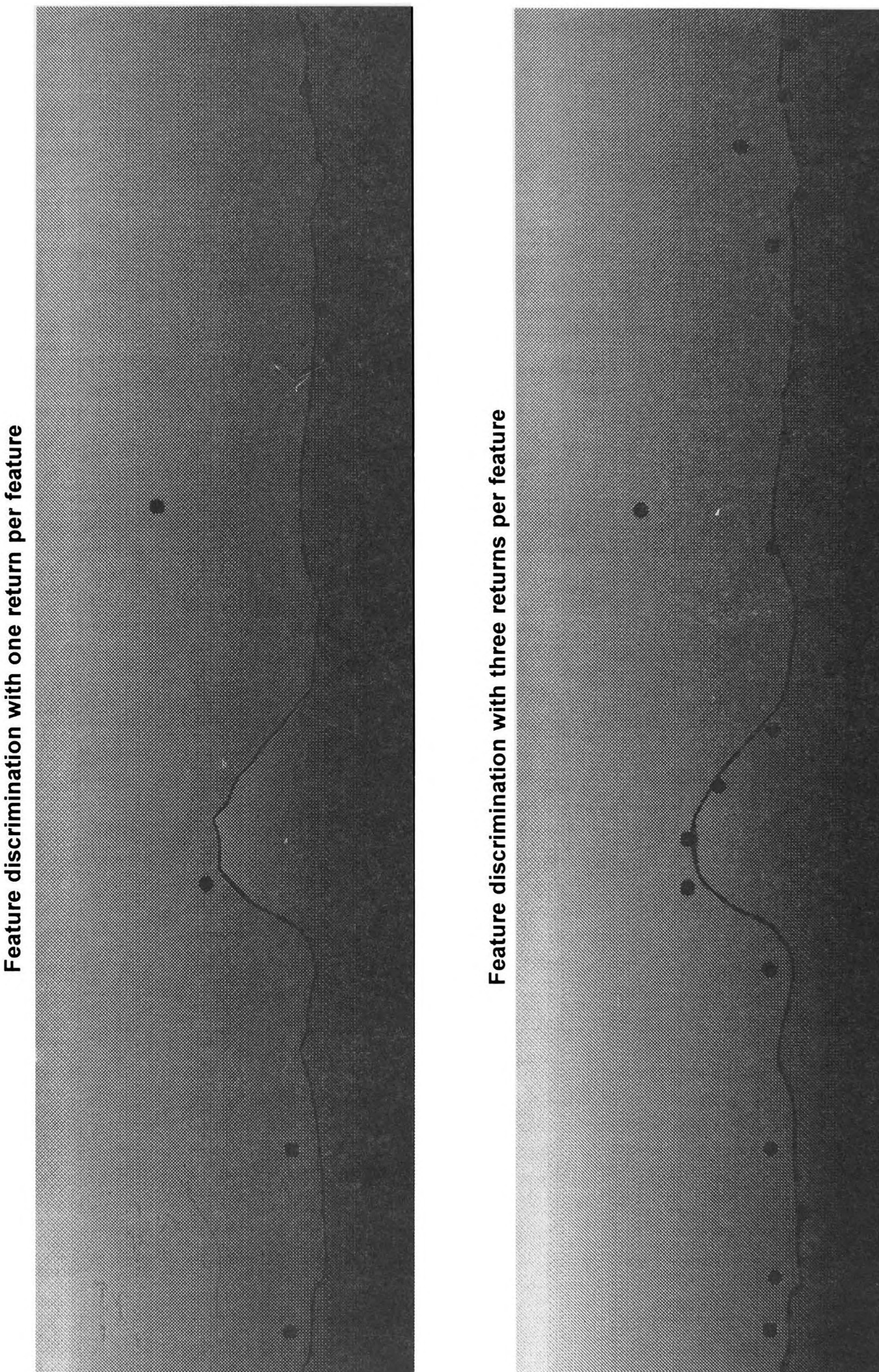


FIG. 4.- Feature Detection Limits Multi Beam Echo Sounders.

usage, for example a feature that would be seen as significant in a navigational channel or harbour may not be significant if lying in a unvisited area of coast. Generally features are viewed as significant with respect to their relative dimensions against the surrounding depth of water and each hydrographic organisation will have qualitative guidance for the nature and sizes of objects to be detected. For example, the RAN feature detection requirements are of the capability to detect and recognise underwater features lying on or being part of the sea floor to the sizes in Table 1.

Table 1

Depth (d)	Feature Size (x,y)	Feature height above surroundings
0-50m	1.0m x 1.0m	1.0m
50-70m	1.5m x 1.5m	1.5m
70-100m	5.0m x 5.0m	5.0m
100-200m	10.m x 10.m	10.m
200m-6000m		All changes in depth >0.1d

4.2 The survey mission is executed in planned lines of survey across the operational area to ensure that the entire area has been subject to full coverage by the feature detection sensor(s). It should be noted that this mission will be co-incident with one of establishing depths, bottom samples and other navigationally relevant data to present the form and nature of the sea-bed. The efficiency of this mission depends on a multitude of factors including the vessel employed, the weather, nature of the sea-bed and performance of the sensors. The Charge Surveyor's optimum desire is to achieve the finest possible resolution of features at the fastest possible vessel speed within the widest possible line-spacing

4.3 This leads the surveyor to choices on sensors to be employed. Traditionally the sensor suite was a down looking single beam echo sounder for depth data collection coupled with a sideways scanning side scan sonar for feature detection as in Figure 5. Recent developments in shallow water multi-beam echo sounder technology has been exploited for both depth collection and feature detection in conjunction with side scan sonar data from either the multi-beam itself or a separate sensor as shown in Figure 6.

4.4 Both the multi beam echo sounders and side scan sonar exploit ensonification within an athwartships plane swath. The athwartships environment is one of high rates of angular change in the feature's position relative to the sonar coverage resulting in the time available to detect the features being severely limited. Maximum vessel speed for successful detection will therefore be sensitive to the sonar along track pulse foot-print size which will govern the distance that can be travelled between pings without gaps, the Pulse Repetition Interval which determines how long between each ping, the planned target size and the desired swath width as in Figure 7. The sonar pulse foot-print size is in turn dependent on the width of the along track beam and the ambient water depth. Whilst the wider the along track beam the faster the possible vessel speed, a limit will be realised by the subsequent

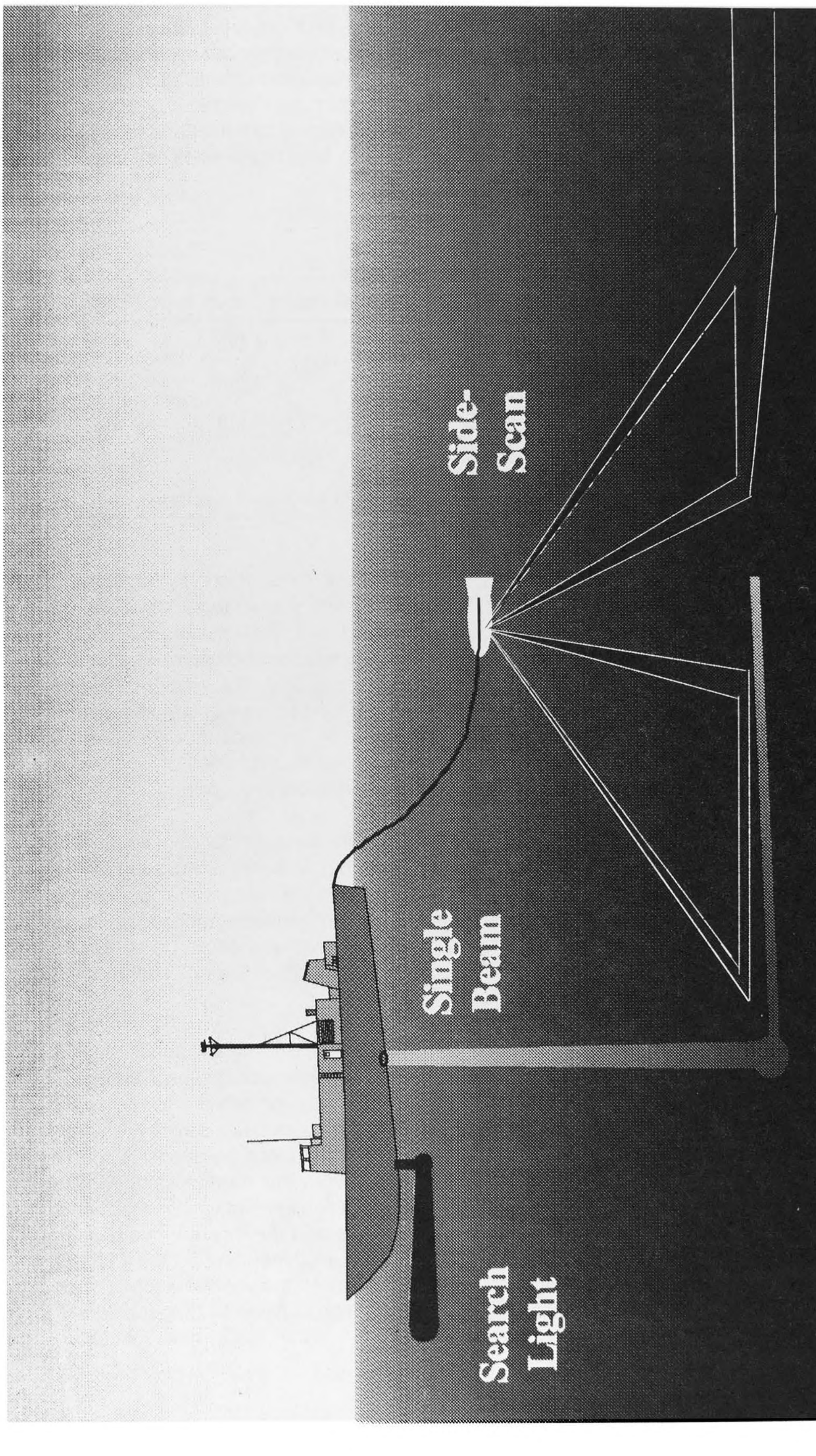


FIG. 5.- Traditional Hydrographic Sensor Suite.

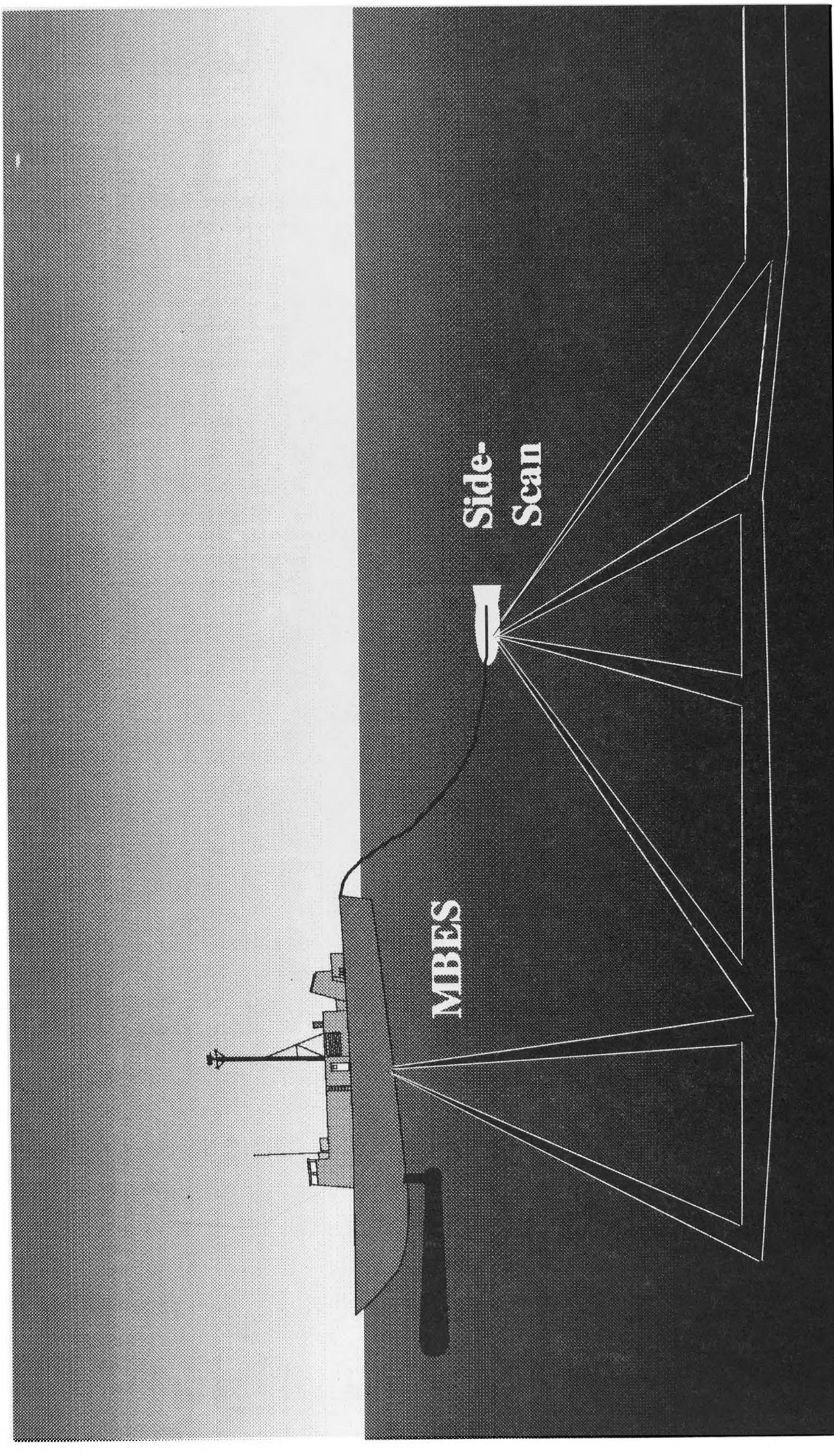


FIG. 6.- Multi-beam Side Scan Hydrographic Mission.

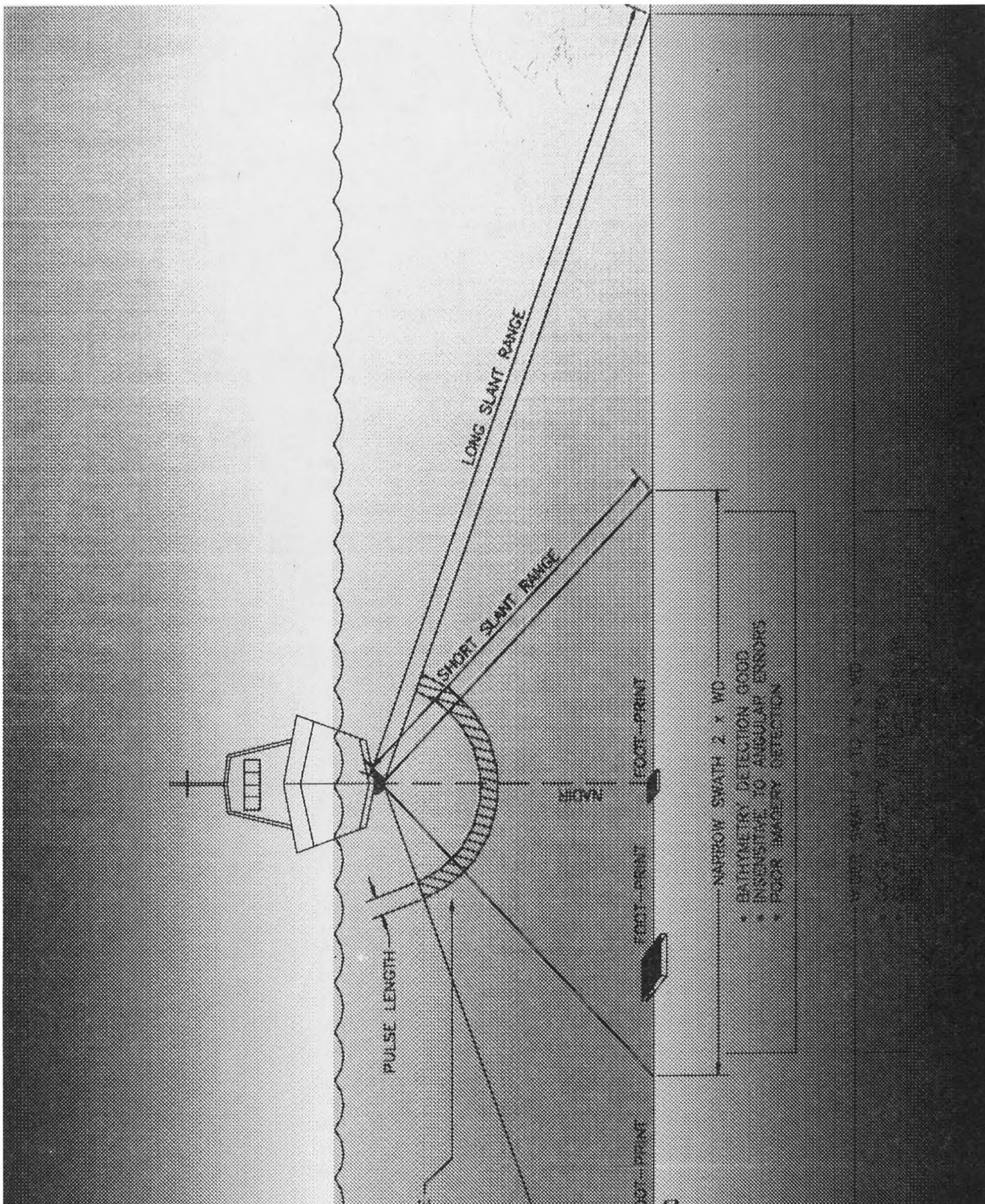
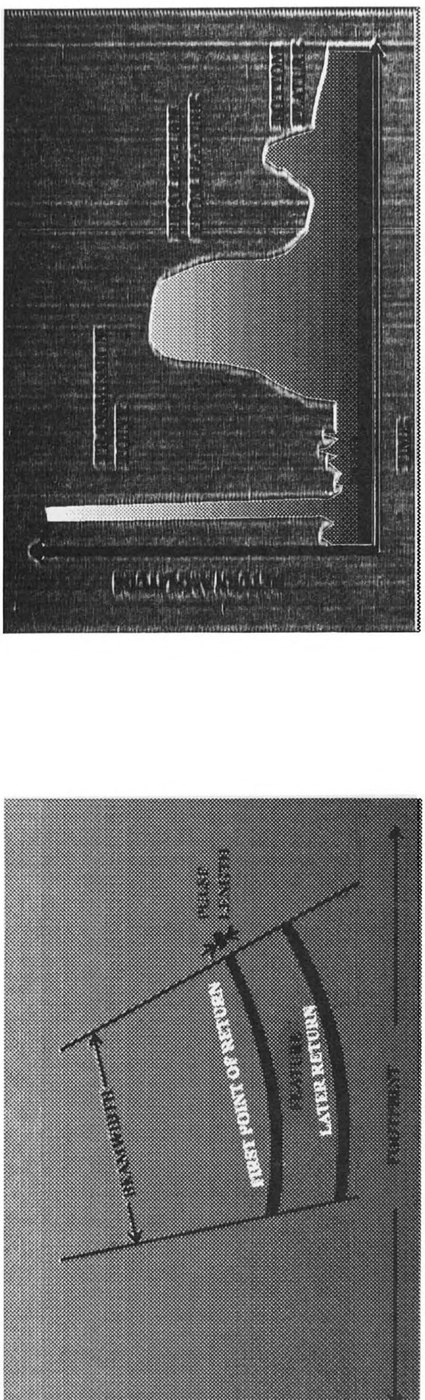


FIG. 7.- Typical Swath Environment - Athwartship Systems.

Near Nadir Beam-First return detection time series



58° Grazing Beam-No detection from first return time series

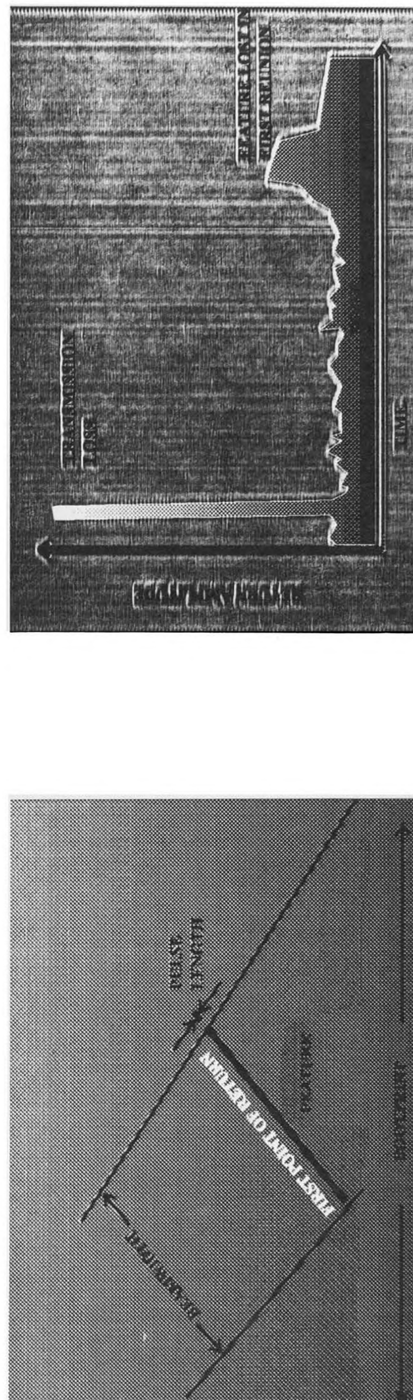


FIG. 8.- Feature Detection by Depth Anomaly.

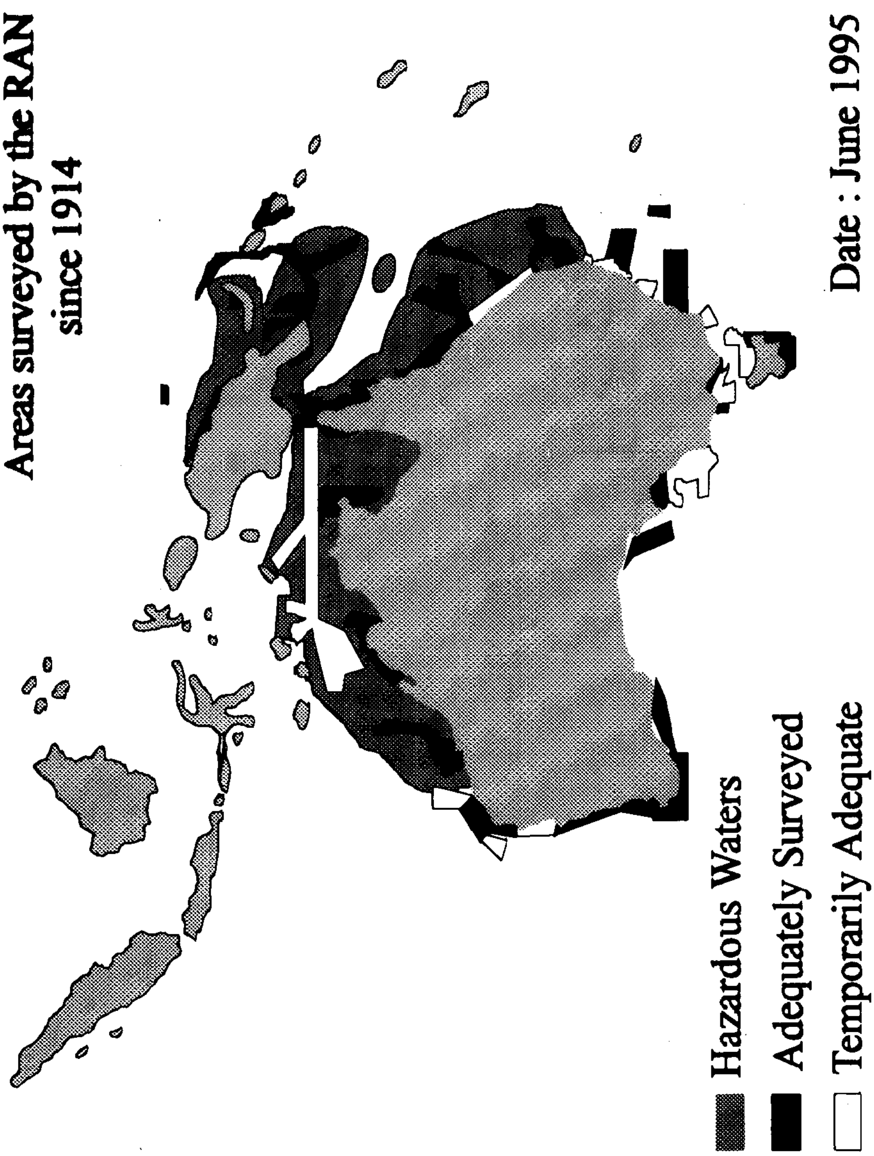


FIG. 9.- Area of RAN Survey Activity and Task.

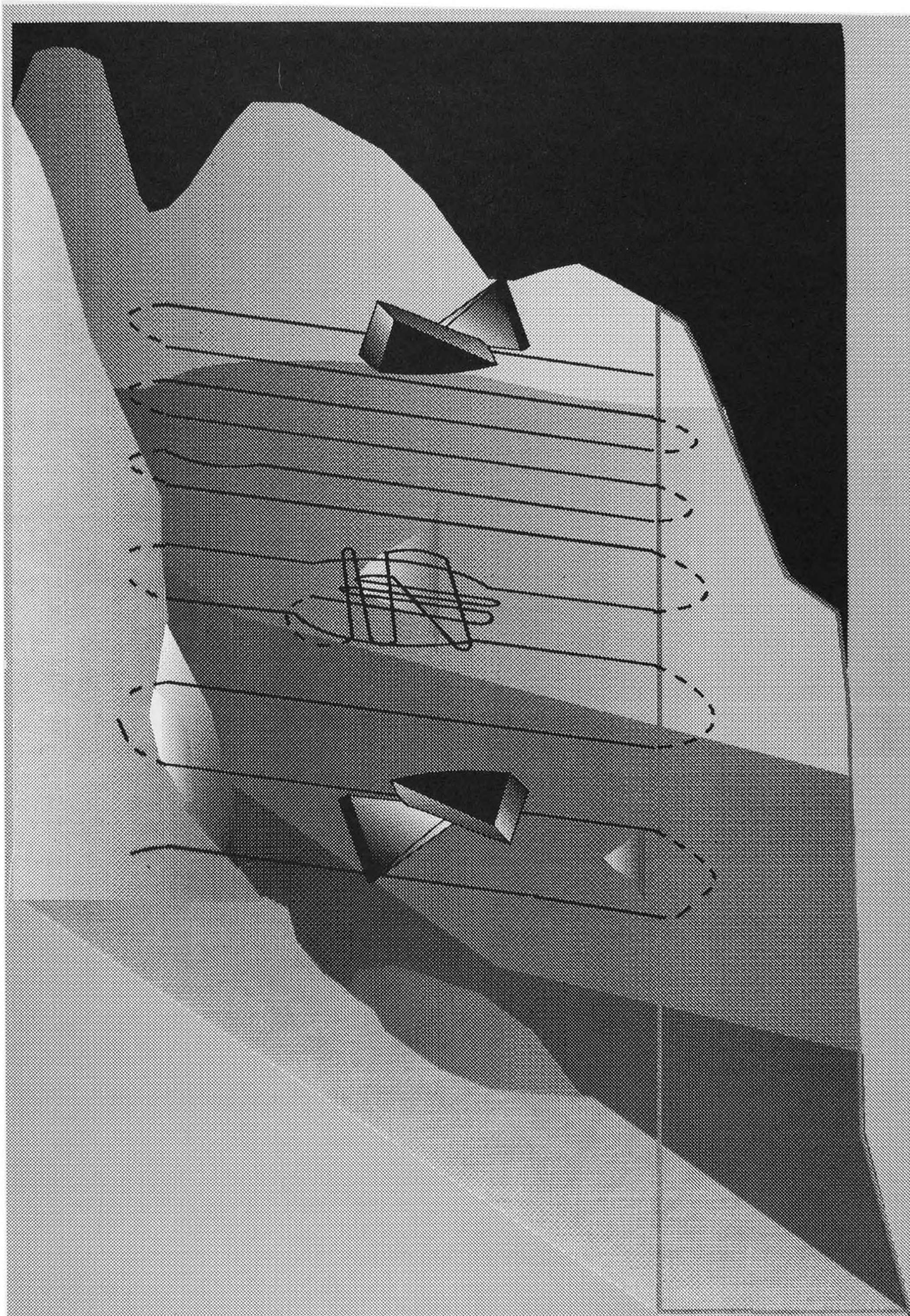


FIG. 10.- Athwartship Sensor Mission Profile.

resolution of the system with respect to the planned target size. The Pulse Repetition Interval will be dictated by the speed of sound in water and maximum slant range in respect to ambient water depth. As sound will not go any faster in the future, the planned slant range will always be a limiting factor on the maximum possible Pulse Repetition Interval again dictating compromises on swath widths to detection capability and vessel speed.

4.5 Athwartships sonar environments are also depth sensitive for their resultant swath coverage. This sensitivity is so marked that swath achievement by multi beam systems are traditionally described in terms of multiples of water depth. This dependency dictates the narrowing of line spacings and subsequently the reduction of efficiency in shallow water. Recent developments of multi transducer side-scan environments exploiting multiple along track beams have, to an extent, alleviated some vessel speed limitations by achieving high resolution within an effectively wide along track coverage. However, they remain sensitive to depth for their resultant swath width and generally as they employ extremely high frequencies and short Pulse Repetition Intervals they have narrow effective slant ranges.

4.6 Multi-beam echo sounders are excellent depth collection sensors allowing the collection of data at rates unimaginable with single beam systems. The functional performance required of a multi-beam echo sounder that is to be used as both the primary feature detection sensor and a depth collection sensor is, however, restrictive and can be contradictory in the shallow water arena where small feature sizes are germane. Swath sizes for reliable multi-beam feature detection of small features by recognition of depth anomaly, will be limited to a grazing angle of approximately two times water depth to ensure the first echo return is that of the feature as shown in Figure 8. Propagation over a wider swath in shallow water using phase comparison type signal processing methods and/or centre of energy methods will achieve the requisite depth accuracy's but may not achieve the required feature detection due to the relative size of the feature to echo foot-print size, the sustainable Pulse Repetition Interval and the slant range limitations. For a multi-beam which is to be used primarily as a depth sounding sensor in conjunction with an alternative shallow water detection sensor, the functional performance becomes less critical and can be optimised to achieve accurate and efficient depth collection.

4.7 A final limiting factor on survey efficiency is vessel safety. Survey vessels by dint of their role, operate in unsurveyed or poorly surveyed areas, this is particularly true for Royal Australian Navy Hydrographic Service operations given our extensive areas of uncharted and coral waters as in Figure 9. Obviously vessel safety will be a determining factor on both vessel speed and the mission profile with compromises made to both to ensure that the surveyor finds navigational dangers with the sonar rather than the hull. Traditionally safety is provided by a search-light sonar. The inherent limitations in detection and resolution of search-light systems results in the ironic situation of the survey vessel navigating on relatively poor data whilst collecting high quality data athwartships. This will dictate, at times, sounding a dangerous area of water very slowly and with the survey vessel closing the dangers in a crab-like manner to ensure the vessel steams through the area ensonified by the last sounding line. This still does not optimise safety and also drastically degrades the over-all efficiency of the mission.

4.8 The combination of the limitations and inherent compromises above culminate in determining a typical shallow water mission profile as is depicted in Figure 10. Line-spacings will narrow as the coast is closed, vessel speeds will slow and in cases where potentially dangerous features are detected ahead, the mission lines may be deviated into previously swept water to ensure safety.

4.9 TDFLS can potentially revolutionise the hydrographic mission due to the inherent advantage of undertaking feature detection, systematically and reliably, in a three dimensional target detection swath ahead of the vessel vide Figure 11. This regime permits low rates of angular change of features relative to the vessel and therefore allows a much larger number of returns to be received from the feature. Given the generic standard of three returns for detection vide Figure 4, TDFLS will at the very least represent a 1000% over-sampling of detection . This over-sampling is possible from a 1 second Pulse Repetition allowing much longer achievable slant ranges which equates to wider swaths. As this swath is layed in the forward plane rather than athwartships it is also far less sensitive to the depth of water for it's coverage. The wide line spacing permits the surveyor the luxury of 200% ensonification for feature detection to ensure features hidden in the shadow of a larger structure in one direction are identified in the next. This is possible whilst still enjoying a significantly wider line spacing and faster vessel speed than traditionally available as depicted in Figure 12.

4.10 The low pulse interval also results in lower data rate burdens on the associated visualisation and logging environment. Given the high data rate pressure implicit in the latest multi-beam and also multi-transducer side-scan environments, this represents a significant advantage. The low rate of angular change also reduces the time pressure on the system operator to make decisions on detected features in comparison to athwartships systems whilst providing a lot more data with which to make that decision. Finally forward ensonification permits the TDFLS to be co-exploited as the mission safety and management system. TDFLS means that potentially the hydrographic surveyor can navigate on the same quality of data as he collects thus optimising vessel safety and survey mission planning and management. Additionally this dual use offers a cost off-set for the surveyor in the number of sensors required onboard.

4.11 The exploitation of TDFLS within the hydrographic mission will require its integration within a sophisticated hydrographic data logging, processing and visualisation environment. This integration would include a suite of sensors comprising the TDFLS as the primary shallow water mission safety, mission visualisation and feature detection sensor combined with a multi-beam echo sounder for depth collection and augmentation of feature detection within the deeper and subsequently less stringent depths beyond the limit of the TDFLS. The TDFLS will need integration with appropriate attitude sensors and sophisticated multi-dimensional sound velocity observation and modelling. The TDFLS integration must include dedicated operator manning on a separate interactive control and display console. It is envisioned that this display will be a multi-window environment including the same three dimensional display as the navigation system and additionally, rectified backscatter intensity (imagery) displays, water-fall displays, automatic target detection algorithms and track-ball operator target designation. The various displays must be translational with track-ball movement in one being mirrored within the others. Finally a capability for data logging will be essential for post

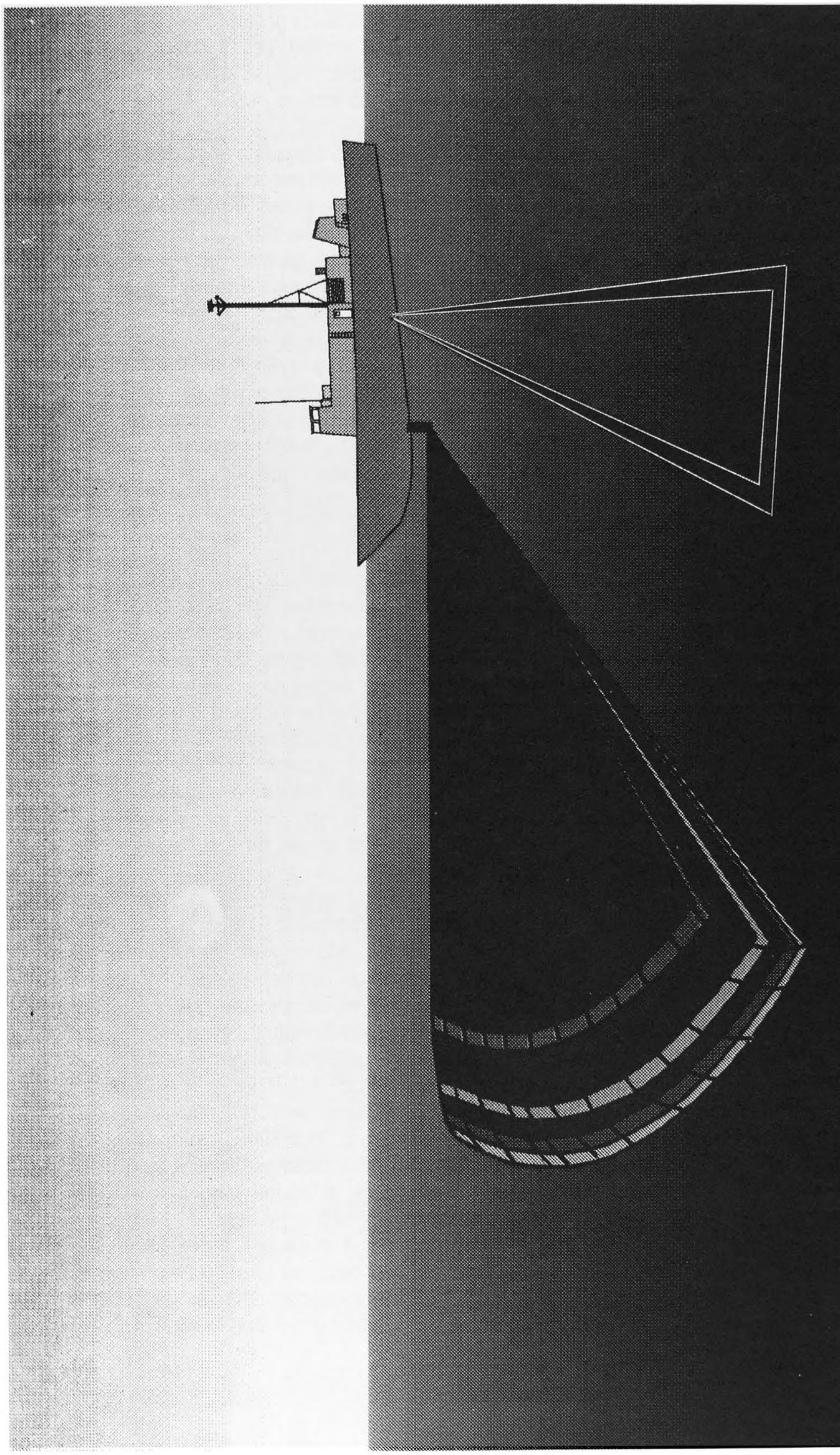


FIG. 11.- Three Dimensional Forward Looking Sonar Mission.

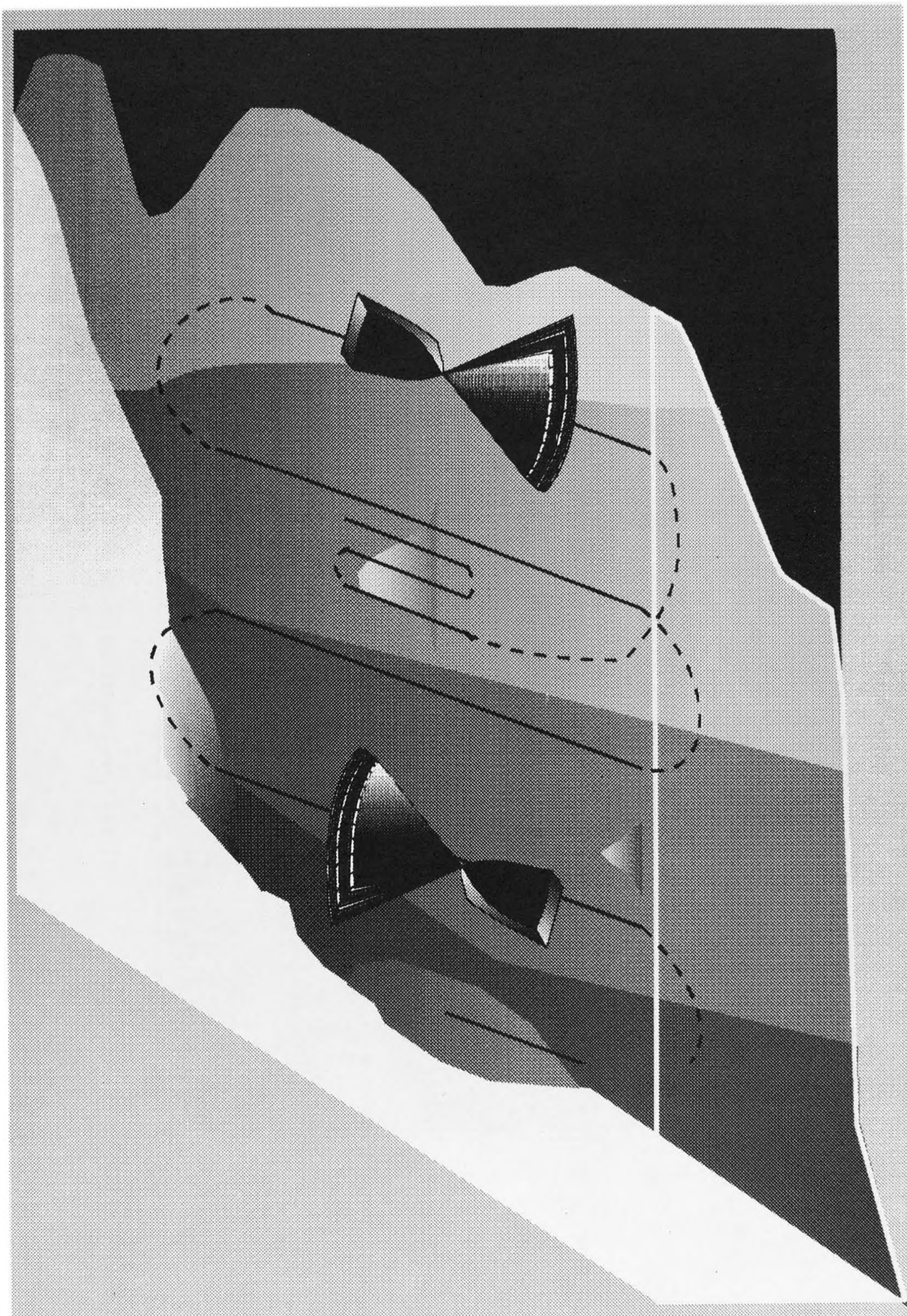


FIG. 12.- Three Dimensional Forward Looking Sonar Mission Profile.

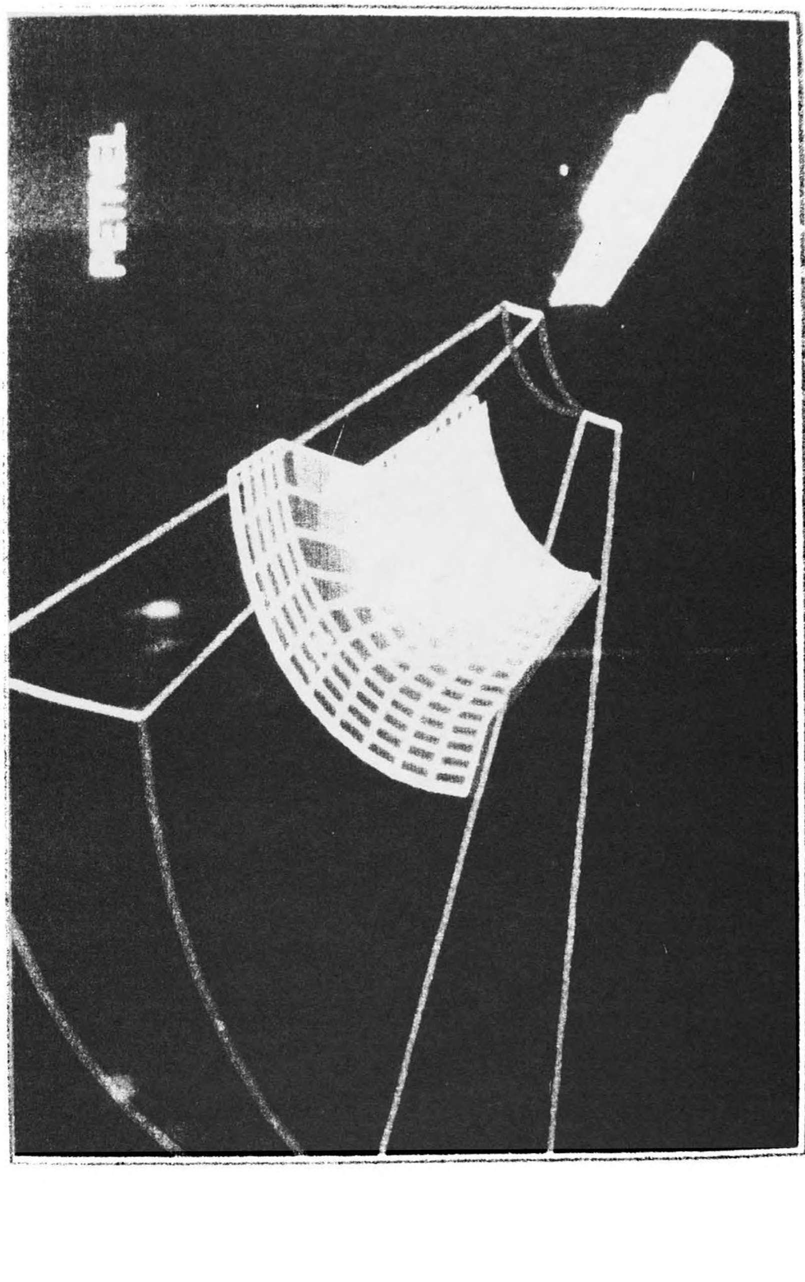


FIG. 13.- Three Dimensional Display of Tests Data.

mission review and quality assurance. This post mission capability should include the capability for TDFLS data manipulation into three dimensional mosaics for optimised feature examination planning, as is currently undertaken with side scan data.

4.12 Once features are detected the Charge Surveyor will undertake separate feature examination missions on the significant ones to establish feature position and least depth to prescribed absolute accuracy's. The multi-beam echo sounder has optimised such missions in comparison to traditional time consuming measures such as wire sweep and/or single beam saturation sounding at slow speeds and narrow line spacing. The significant over-sampling achieved during the detection mission by TDFLS will augment the multi-beam, inevitably reducing the subsequent examination burden due to the extra data permitting informed decisions for the examination strategy, particularly if a three dimensional mosaic of the data is available. Given the high over-sampling possible from TDFLS, a TDFLS with high internal precision and accurate depth assessment may potentially permit the feature examination mission to be undertaken, in cases, during the feature detection mission. Such a capability may prove possible by phase comparison of the co-incident frequencies in the forward plane allowing the depth to be estimated in much the same way as that undertaken within a wide-swath multi-beam echo sounder. This would represent another significant reduction in surveying effort made possible by TDFLS whilst maintaining or indeed enhancing qualitative standards.

5. RECENT AUSTRALIAN DEVELOPMENTS

5.1 A TDFLS is currently being developed in Australia in a project jointly funded by the Acquisition and Logistics Office of the Australian Department of Defence and Thomson Marconi Sonar Australia. Trials of a development system in 1995/1996 have provided data which has enabled further investigation into methods of information presentation to the operator. Commercial scientific visualisation software has been used to create a Three Dimensional Human Computer Interface (HCI) which addresses the requirement for an intuitive, rapidly interpretable and hands free presentation of navigation data. The latest variant of this three dimensional display is shown in Figure 13.

5.2 Sonar developments todate have also been promising, the pre-production sonar has undertaken static field trials in which -18 dB targets moored close to the sea-floor have been reliably detected at ranges up to 350 metres within the raw data without any processing enhancement. The capability to undertake high resolution mapping of the sea-bed terrain within the instantaneous vector data has also been successfully demonstrated. Figure 13 depicts a three dimensional display of actual field tests data.

5.3 Conventional signal processing techniques (i.e. normalisation) have also been successfully employed to enhance the detection of point like contacts in the sea bottom reverberation noise. In a TDFLS these contacts can be identified to lie either in the water column or on the bottom surface. The bottom reverberation noise has also been exploited to provide an indication of sea-bed texture. This ability leads to several possibilities for displaying the resultant information including resolution of resultant amplitude imagery onto the real-time three dimensional display.

5.4 Australian developments todate, have concentrated on realising a capability commensurate with the military requirements for detection ranges and resolution within highly manoeuvrable warships and survey vessels at a base frequency of 100 Khz. Future analysis is required and intended within the lower frequencies required to provide longer detection ranges for navigational safety onboard large unmanoeuvrable, commercial vessels.

6. SUMMARY

6.1 TDFLS has the potential to significantly enhance the navigational safety of all vessels. TDFLS also has the capability to enhance warship safety from random sea-mines and diver attack as well as significantly improving the efficiency of amphibious operations. Commercially the concept complements the significant advances in Electronic Charting presently under way world-wide.

6.2 The TDFLS concept has the potential to completely revolutionise shallow water hydrography in mission safety, mission efficiency and mission quality. If this potential is realised, TDFLS will represent the most significant improvement in holistic shallow water hydrographic capability since Airborne Laser Depth Sounding technology was successfully implemented by the Royal Australian Navy Hydrographic Service in the late eighties. TDFLS will augment the multi-beam echo sounder within the survey sensor suite.

6.3 Advances in the development of TDFLS are being made within Australia including the development of three dimensional displays to optimise the superiority of TDFLS over traditional search-light sonar. The explosion of three dimensional and virtual display systems in the general computer market will inevitably lead to mariners and surveyor alike demanding similar capability within their systems. The Australian TDFLS concept now allows such capability to be a reality.