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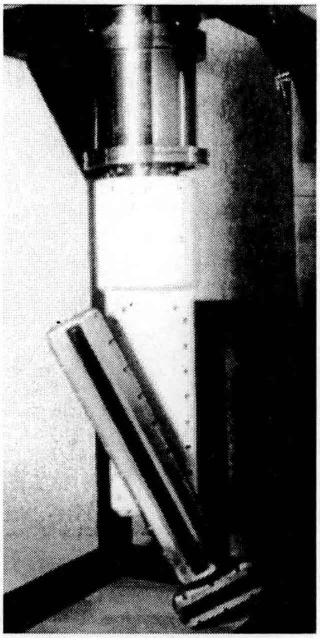
PETREL TSM 5424 THREE DIMENSIONAL SONAR FOR SHALLOW WATER COASTAL HYDROGRAPHIC FEATURE DETECTION

by Colin ELLIS [1]



Abstract

This is a charting hydrographer's perspective on the potential for the PETREL 5424 three dimensional mine avoidance sonar to be exploited as a hydrographic sensor for shallow water 10-100 metre feature detection. It projects the advantages of three dimensional ensonification over athwartship systems and provides an overview of the success of PETREL sea trials conducted in conjunction

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with the Royal Australian Navy in April 1998. The paper further reports on continuing development of a hydrographic variant to the PETREL. In conclusion it proposes that PETREL can revolutionise mission efficiency and safety within the coastal hydrographic feature detection mission by allowing faster vessel speeds, wider line spacing and easier planning. The views expressed are those of the author.

PETREL TSM 5424 SONAR OVERVIEW

PETREL 5424 is a commercially available mine and obstacle avoidance sonar designed to optimise the navigational safety, and therefore tactical freedom of manoeuvre, of modern warships operating in poorly charted, mined and/or shallow waters. The Sonar is unique in that it provides instantaneous ensonification of the volume of water ahead of the vessel including the sea-floor within each transmission. 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 obtained by phase comparison techniques. Beam resolution is achieved by time series in the transmission, thus creating the 3D volume resolution.

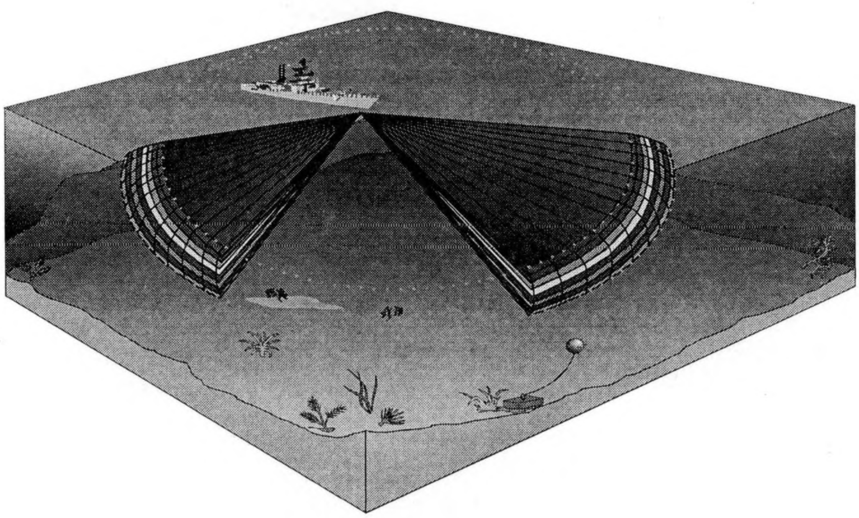

FIG. 1.- PETREL 5424 Sonar.

PETREL is unique in the presentation of the collected three dimensional spatial data in a number of operator selected three dimensional displays. These displays range from plan views exploiting colour depth contouring for three dimensional discrimination, to natural perspective views such as that which would be apparent to the mariner if he or she were to view the sea bed ahead of the vessel with the water removed. This additional data processing includes real time extraction of the sea bed spatial disposition from the volumetric data set, and display this bottom contour on an intuitive three dimensional graphical display. Specific point obstacles are detected and localised in the volumetric set and displayed as icons, overlaid on the three dimensional display in a way which unambiguously conveys the object position and detection confidence.

In the past, sonar systems have provided raw sonar data in flat plan formats such as the common Plan Position Indicator. The traditional type displays have required significant training and data interpretation skills to be effective. This situation is further exacerbated as modern sonars are capable of providing vast amounts of data well beyond the operator's ability to assimilate exploiting traditional non intuitive displays. The PETREL sonar solves this problem by providing intuitive data presentation formats to allow the operator to use the data assimilation skills learnt since birth.

Using this display, the operator or untrained observer can readily recognise detected obstacles and easily interpret object characteristics such as depth below the surface, height above the sea bed and object position relative to own-ship. The display allows the operator to easily keep up with the sonar. This format has the additional and critical advantage of making the presented data instantly recognisable to the operator, minimising the time required to look at the sonar prior to undertaking effective avoidance of detected dangers. Finally, by allowing the operator to view the data intuitively, training burdens are reduced. This is further enhanced by exploitation of standard X-Windows^{TM} Graphic User Interfaces for system control.

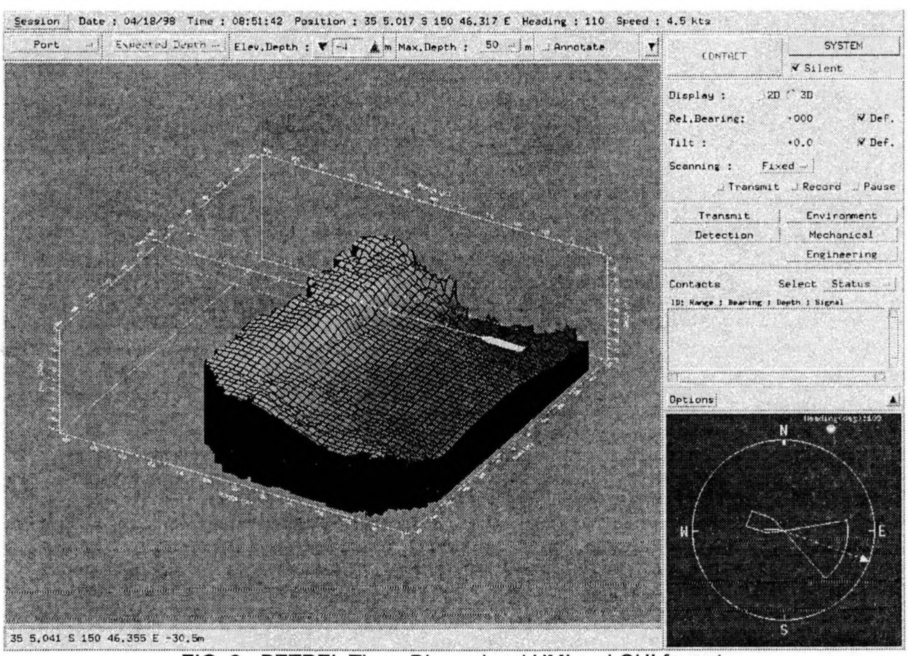

FIG. 2.- PETREL Three Dimensional HMI and GUI format.

As the Sonar was developed for littoral warfare roles in mine and obstacle avoidance and for optimised navigation in poorly charted waters, there was a significant emphasis on robust performance in dynamic conditions and in providing a high level of detection probability with a low false alarm rate. PETREL delivers extremely robust sonar performance, that is, its Signal to Noise Ratio (SNR) increases rapidly as the target range decreases. This is significant because it means that a change in environmental parameters such as background level, target strength, bottom type, water depth or multi-path will only cause a small change to the maximum detection range of the sonar. This gives the operator the confidence in real world performance, critical in shallow/coastal/warm waters which are regions of dynamic environmental conditions.

The PETREL sonar provides both a high probability of detection and a low false alarm rate. PETREL can therefore be safely operated without the need for a dedicated operator. The design features include:

a) The resolution of target height and separation of water column contacts from sea-bed allows for intelligent monitoring and instant classification of moored mines;
b) Orthogonal transmit and receive beam-forming to enhance the SNR by reducing the effect of both surface, bottom and volume reverberation;
c) The use of automatic detection and tracking (ADT) algorithms to reduce the number of echoes due to clutter and/or bottom reflections;
d) The use of beam stabilisation to ensure accurate obstacle localisation, and to facilitate ping to ping integration and tracking; and
e) The generation of real time assessment of Closest Point of Approach and alarm only when operator pre-set conditions are exceeded.

SYSTEM BACKGROUND

The system was designed and developed in Australia by Thomson Marconi Sonar Pty Ltd of Sydney (TMS Pty) in a joint project with the Australian Department of Defence. PETREL was designed as a mine and obstacle avoidance sonar for the Royal Australian Navy (RAN). The development programme benefited from direct RAN Navigation and Underwater specialist advice on performance objectives and with the Human Machine Interface (HMI) design and format. Subsequent to this activity, TMS Pty have also investigated the potential of PETREL in fulfilling the shallow water, coastal hydrographic feature detection mission. This investigation grew out of the initial vision of the RAN Hydrographic Service (RANHS) in the system's potential hydrographic role."

SEA TRIALS RESULTS

Long-term Sea Trials were conducted in and around the Jervis Bay NSW area from March to May 1998. The purpose of these trials was to develop detailed base-line capabilities for the system, validate the modelling of sonar performance and demonstrate the capability of the system to RAN specialists. The trial was very successful in demonstrating that the three dimensional display concept is operationally ready and it was the preferred display of RAN specialists whom witnessed the trials. The trial was conducted onboard the Australian Department of Defence trials vessel, MV *Kimbla*.

FIG. 3.- MV Kimbla at HMAS Creswell.

The sonar was able to generate high resolution vector maps of the sea-bed ahead of the vessel at the nominal 1 second ping rate. When compared against the onboard echo sounder, the difference in depth estimates were better than +/- 0.5 metres. This result was encouraging given that the PETREL depth estimates are based on measurements several hundred metres ahead of the vessel in comparison to the immediate measurement below the vessel. The PETREL sonar was evaluated in all the bottom types and depths available within the Jervis Bay from sandy seabed in depths of 5 metres to rock strewn seabed at depths approaching 100 metres east of Bowen Island.

To demonstrate the strength of the sonar it was used to navigate MV *Kimbla* through a narrow and shallow passage between the Bombora Rock and Longnose Point on the north side of Jervis Bay, aspects of this passage are pictured below in forward, quarter and navigation (contoured) views. The images clearly show both the extent and least depth positions on the ridge structure and the deeper water at 26 metres beyond the structure. This image is possible because of the good shallow water performance of the sonar looking through the passage. The shadow effect created by the ridge immediately outside the passage is dramatically visible in the navigational view.

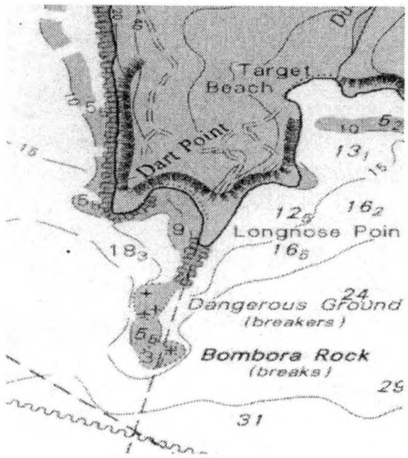

FIG. 4.- Chart segment showing the Bombora Rock.

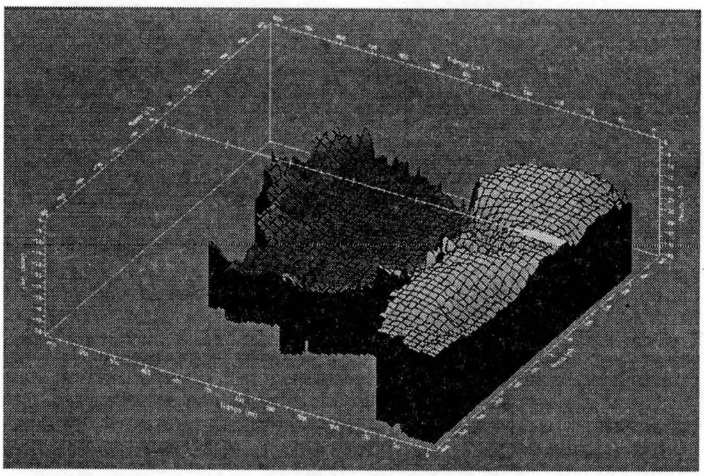

FIG. 5.- Port Quarter view through the Bombora passage.

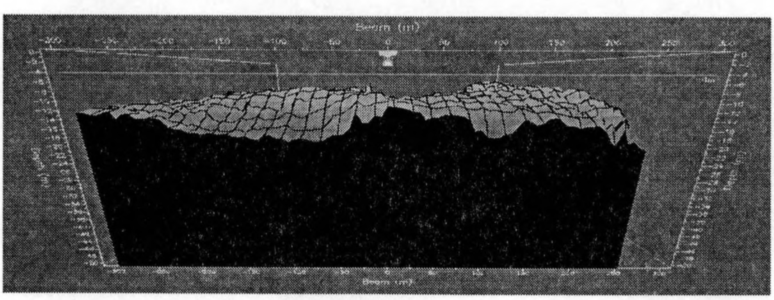

FIG. 6.- Forward view through the Bombora passage.

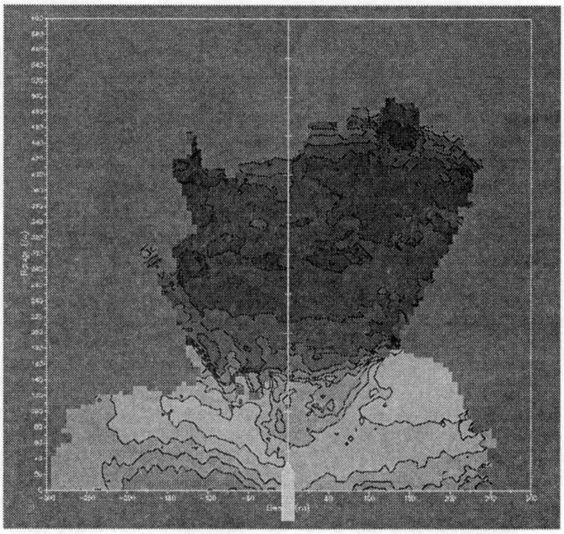

FIG. 7.- Navigation view through the Bombora passage.

The systems dynamic performance was also tested. The objective for stabilisation was to achieve a 0.45 degree roll error relative to the sensor. During the roll stabilisation tests at sea, the vessel was manoeuvred to achieve maximal roll conditions. At sea the roll stabilisation was verified against a ±10 degree roll at a period of 2.6 sec. The results indicate a RMS value of 0.1 degree and typical peak to peak performance of ±0.2 degree.

Punctual performance was also proven in a series of alerted detection trials in varying depths, sea-bed types, seas and swell conditions against moored and sea-bed targets ranging from -12dB to -18dB. Unalerted detection's were also documented with detection of a training sea-bed mine laid in Jervis Bay by the RAN prior to PETREL's sea trials. These trials have proven performance in the obstacle avoidance role and validated the robust modelling used to project PETREL's performance.

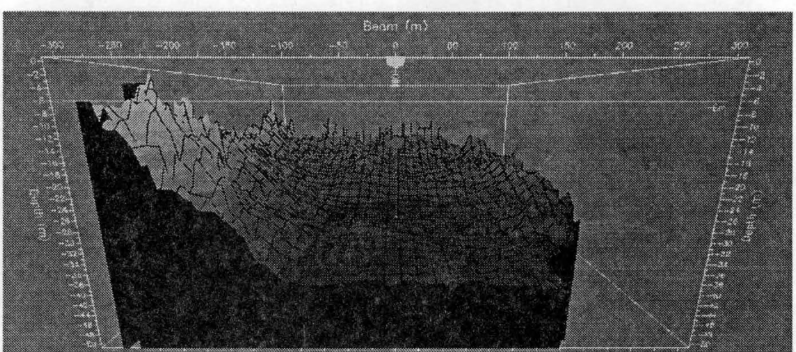

FIG. 8.- Punctual detection moored –15dB target seaward of Bowen Island NSW.

The following plots show system performance as signal to background ratio, modulated by colour, as a function of target depth and range for worst case scenario conditions for the coastal trials operations of PETREL. Dynamic coastal conditions are modeled with multi-path reverberation, surface scattering based on bubble layer, high water column back-scatter, spreading loss calculated from ray theory and high sea-state. The plots are produced by combining predictions for each vertical beam so that the signal to background ratio over all the vertical beams is shown.

To assess potential hydrographic feature detection performance, trials included both alerted and un-alerted detection of small punctual sea-bed features. Alerted detection trials were undertaken against a 0.8 cubic metre target deployed on the sea-bed in 22 metres of water. These trials were run on three separate occasions in variable sea-states from calm seas to seas of 1 metre, coupled with a swell of 2 metres, confirming the reputability of detection. During the course of other trials, a number of punctual targets were detected on the sea-bed. Subsequent inspection by diver found these targets to be natural structures ranging in size from approximately 0.5 cubic metres to 5 cubic metres. The success of the sea-bed feature detection was significant, as it encourages the potential use of PETREL as a hydrographic feature detection sensor.

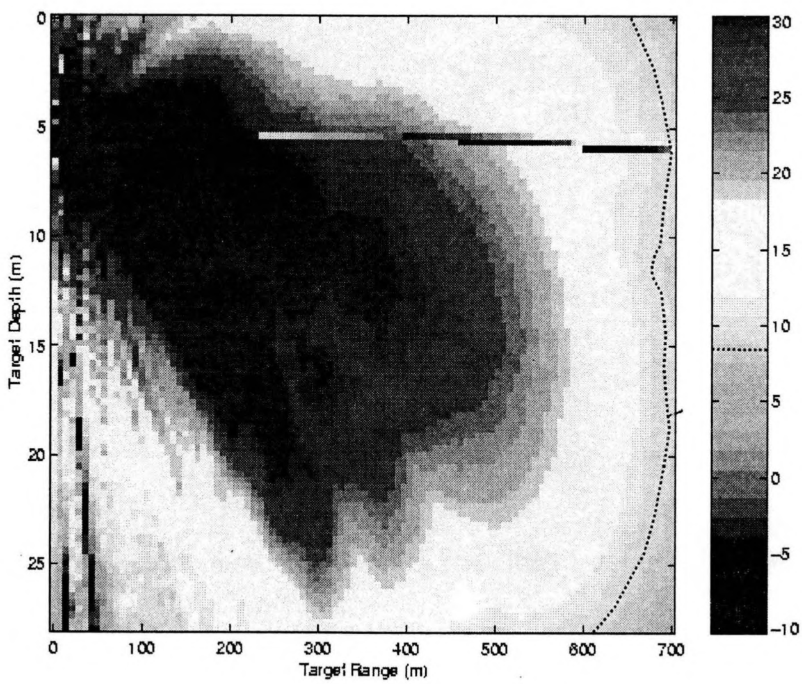

FIG. 9.- Trial Performance Punctual targets (-15 dB) Water depth 30 metres.

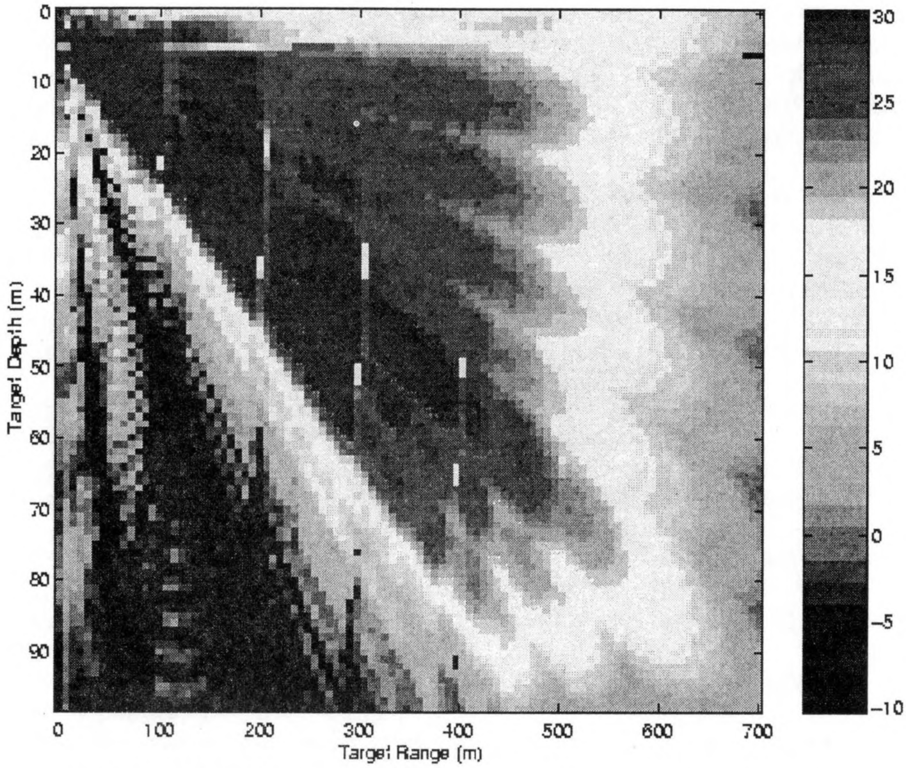

FIG. 10.- Trial Performance Punctual targets (-15 dB) Water depth 100 metres.

PETREL'S PROJECTED ROLE IN COASTAL HYDROGRAPHY

The primary requirement for charting Hydrographic Surveys within coastal waters (0-200 metres) 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/her 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. The term "navigationally significant" is qualitative and has a broad usage, for example a feature that would be seen as significant in a navigational channel or harbour may not be significant if lying in an unvisited area of coast. Generally, features are viewed as significant with respect to their relative dimensions against the surrounding depth of water in keeping with national or international guidelines.

The coastal charting 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) co-incident with collection of depth data and other navigationally relevant data to present the form and nature of the sea-bed. 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. Traditionally the sensor suite will comprise Single Beam or Multi Beam Echo Sounders (MBES) coupled with imagery detection by the MBES or by Side Scan Sonar (SSS) ensonifing within an athwartship swath.

Athwartship ensonification results in 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. The reported performance of PETREL in detection and spatial portrayal of seabed punctual targets means it has a potential use as a hydrographic shallow water feature detection system, concurrently with its designed role as a vessel navigational safety system.

In considering this potential, it must be stated that the author does not propose PETREL as a alternative to the MBES but as an augmentation sensor for the coastal hydrographic mission. MBES are excellent depth collection sensors, however the functional performance required of a MBES that is to be used as both the primary feature detection sensor and a depth collection sensor in waters less than 100 metres is restrictive and dictates compromises in vessel speed, line-spacing, Pulse Repetition Intervals (PRI) and swath widths to ensure detection of small but still significant sea-bed features.

Swath sizes for reliable MBES feature detection of small features will be limited by grazing angles and resolution. Propagation over wide swaths in shallow water, dictates the use of phase comparison signal processing methods to ensure the angular resolution requisite for depth accuracy. These methods optimise MBES accuracy but will prevent small feature detection due to the relative size of the feature to echo foot-print size. The sustainable PRI must also be reduced to achieve the slant ranges required for such wide swaths, resulting in the need to slow the vessel to ensure along track over-sampling for detection is maintained. If the MBES is used for depth sounding in conjunction with the PETREL as an alternative shallow water detection sensor, the functional performance becomes less critical. MBES along track over-sampling is not required, the sonar foot-print size is less relevant and slant ranges can be optimised for depth accuracy at faster vessel speeds and wider swaths.

PETREL's can undertake feature detection, systematically and reliably in a three dimensional target detection swath ahead of the vessel. This regime permits low rates of angular change of features relative to the ensonified area and therefore allows a much larger number of returns to be received from the feature. Conservative swath analysis of PETREL indicates that given the generic standard of three returns for detection the system will provide a 500% over-sampling for 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 projected in the forward plane rather than athwartship, it is also far less sensitive to the depth of water for it's coverage meaning shoaling water will not dictate narrowing of line-spacing like an MBES.

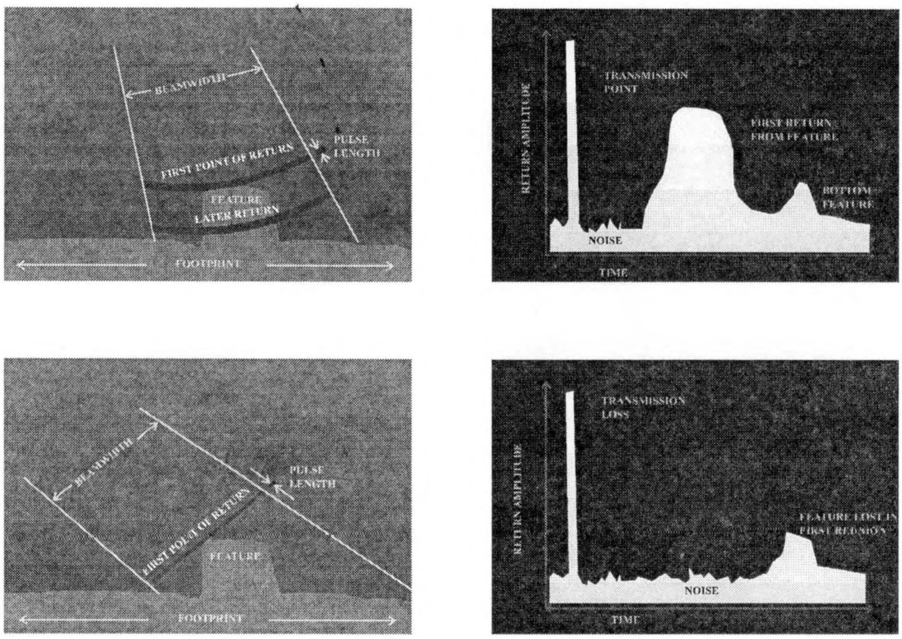

FIG. 11.- Top figures show scenario and time series for a near Nadir Beam, allowing First return detection of target feature. Bottom figures show same target feature at 58° grazing angle, no detection from first return time series and target rejected in return by phase comparison/centre of energy event selection required for depth accuracy.

The low PETREL 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 MBES, 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 athwartship systems whilst providing a lot more data with which to make that decision. PETREL can be co-exploited as the mission safety and management system. This means that potentially the hydrographic surveyor can navigate on the same quality of data as he/she collects, optimising vessel safety and survey mission planning and management.

The potential of the PETREL will only be realised by development of relevant operating doctrine for use of the system in the Hydrographic role. The inherent punctual detection capability will raise operational issues, as detection of punctual targets is prompted by icon with only larger structures being portrayed with shape and extent. Without appropriate detection thresholds, PETREL will detect and portray sea bed features smaller than the surveyors requirement, and therefore "insignificant", mixed with the "significant" features. This problem can only be resolved by appropriate operational doctrine developed by the systematic 'ground-truthing' of PETREL performance in differing water, sea-bed and sea-state conditions. This will allow the adjustment of PETREL sensitivity for differing conditions to ensure only objects equal and/or larger than requirement are icon prompted to the operator. Ground-truthing will require operational optimisation trials.

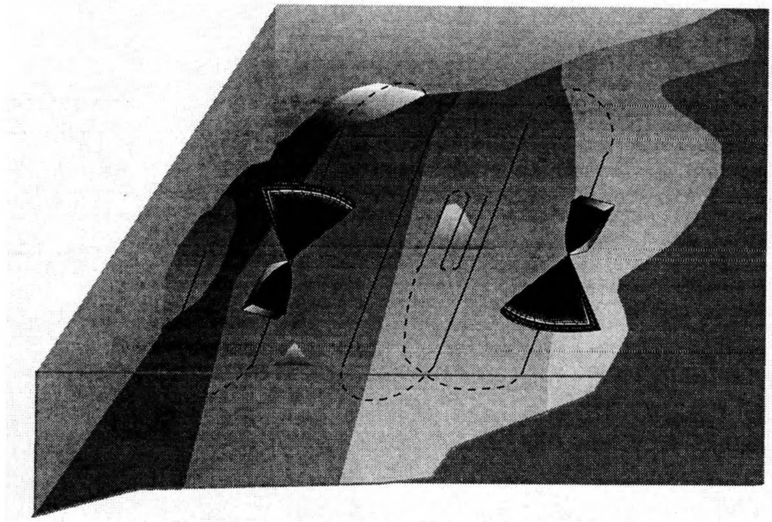

FIG. 12.- Potential charting mission employing PETREL 5424.

FUTURE HYDROGRAPHIC OPERATIONAL EMPLOYMENT

To facilitate the development of appropriate operational regimes, TMS Pty and the RANHS will install PETREL onboard a RAN PALUMA Class Survey Motor Launch in 1999 for long-term operational evaluation. The configuration for this evaluation is detailed below, and exploits PETREL's inherent modular assembly for ease of installation into existing vessel formats. The HMI will be a standard Workstation environment with track-ball and keyboard input, located within the Survey System Operators (SSO) area. This unit will control all Sonar functions and provide all standard PETREL three dimensional and two dimensional displays. A separate Officer of the Watch (OOW) display will be provided near the primary conning position using commercial flat-screen technology. Positional reference will be provided by a commercial roll, yaw, heave and pitch sensor.

This configuration differs from the envisioned production system in that the OOW display does not have stand-alone control functions nor will the SSO system be integrated within the SML's Hydrographic System Suite. The production PETREL Hydrographic variant will also include new and modified display formats optimised for the SSO feature detection role. This will include data mosaicing and semi real-time data fusion of historic data-sets to PETREL data.

The PETREL architecture separates the sonar processing electronics from the HMI application via a documented TCP/IP socket interface. One of the benefits of this separation is a more robust system. A failure in the HMI application will not disrupt the sonar processing chain. The second advantage being a optimal PRI for punctual target tracking and sea-bed extraction performance. The PETREL wet end will be installed between Frames 47 and 49 of the SML's Port Demi-Hull. The installation plan provides an elegant sea-chest solution which minimises the impact of installation on the SML and is appropriate for a large number of vessel type configurations including both mono-hull and catamaran formats.

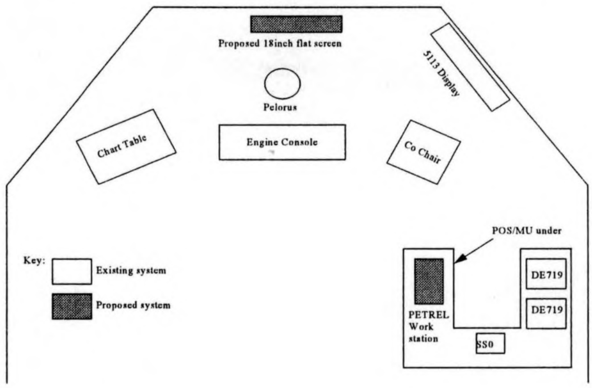

FIG. 13.- System Configuration SML.

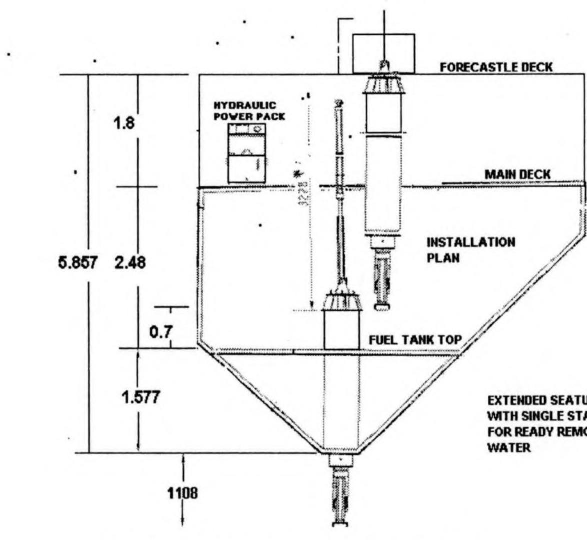

FIG. 14.- Sea-chest Configuration SML.

Summary

PETREL 5424 three dimensional forward looking sonar is a unique system in both the nature of its ensonification and its display. PETREL was designed to significantly enhance the navigational safety of all vessels, particularly warships operating in minefields. The inherent high resolution and real-time spatial discrimination of the system means PETREL also has the potential to augment shallow water coastal hydrography in terms of mission safety, mission efficiency and mission quality. TMS Pty and the RANHS are actively seeking to optimise PETREL for this role. If this potential is realised PETREL will augment, not replace, the MBES within the survey sensor suite.