

HF SONAR PERFORMANCE IN WHITECAPS AND WAKES

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1 Introduction

Small air bubbles present in the near the ocean surface are well known to interfere with the operation of High Frequency (HF, > 10 kHz) active sonars. These bubbles are naturally created by breaking surface waves (whitecaps) [1] and also generated by propeller and hull effects in a ship wake [2]. In both cases these bubbles are predicted to limit the performance of horizontally-oriented HF sonars operated from a ship [1,3]. Such sonars have been previously utilized for forward-looking obstacle avoidance and in-harbor surveillance purposes. There is renewed interest in such sonars for close-in ship defence purposes. In order to specifically assess HF sonar performance in the vicinity of a ship a sea-trial was conducted on the CCGS Vector April 8 to 14, 2015 in BC south coast waters.

2 Experimental Description

The CCGS Vector is 40 m length overall with displacement of 515 tonnes and top speed of 12 knots. These sea-trials took advantage of a retractable sonar strut on the ship's starboard side, allowing use of a HF multibeam sonar at a depth of 3.5 m in either a forward- or aft-looking horizontal orientation.

The forward-looking sonar tests examined the detectability of drifting near-surface targets at low and medium sea states. The targets were hollow steel spheres, 0.9 m diameter, ballasted to submerge them either 1 or 4 m below the surface. Sonar data was recorded as the ship made a series of close passes by the targets at differing approach headings relative to the wind/sea. The typical ship speed during these approach runs was 3 to 5 knots under sea state conditions ranging from 0 to 5. These tests were conducted in both Saanich Inlet and the southern Strait of Georgia in water depths of approximately 200 m.

The aft-looking sonar tests were designed to test target detection in the vicinity of the ship wake. In this case a newly designed acoustic target was towed at distances between 20 and 500 m behind the ship at speeds of 6 to 7.5 knots. The aft-looking sonar tests were conducted under calm conditions in Saanich Inlet.

A Kongsberg Mesotech SM-2000 system operating at 90 kHz was utilized for these sea-tests. This sonar provided 128 overlapping 1.5° beams covering an angular aperture of 90°. The vertical beam-width was 13.5°. These tests utilized sonar range settings between 200 m and 800 m, pulse lengths between 0.5 and 1 ms, and pulse intervals between 0.5 and 1 s. Ship position (GPS) and heading (gyrocompass) were recorded along with the raw sonar data. The present

results are based on successive snapshots (images) of single ping data.

In order to provide *in situ* bubble density measurements, two acoustic resonator devices were deployed at 1.2 m and 4.7 m depth from a surface following float. These devices (described in [4]) were capable of detecting bubbles with radii between approximately 2 and 250 microns with a 1 s update rate.

3 Sonar Detection Performance

Based on a review of the sonar imagery there were a number of qualitative observations which apply to both the forward- and aft-looking sonar tests, specifically:

- Targets were generally detected and followed using their ping to ping consistency. On a single-ping basis targets were generally difficult or impossible to detect due to the presence of background clutter with similar intensity and spatial scale.
- The images exhibited significant small-scale variability from ping to ping. This might be best described as *fluctuations* or *scintillation*. Both target echoes and the background reverberation exhibited this variability.
- On occasions when the ship accelerated, significant acoustic interference attributed to propeller cavitation was observed. This disappeared when the ship speed reached a steady-state speed.

It was also found that the receiver bandwidth used in the SM-2000 was tightly coupled to the sonar pulse length; presumably set at minimum values in order to minimize electronic noise interference. Unfortunately in moving ship operations some parts of the sea surface backscatter reverberation or wake scattering were shifted out of the receiver band by the Doppler effect, reducing their apparent amplitude. This Doppler limitation was seen with the 600 m and 800 m sonar range settings at ship speeds above 5 knots.

3.1 Forward-Looking Drifting Target Tests

Forward-looking sonar data were collected in Saanich Inlet under relatively calm conditions on April 9th and 10th, and under medium sea states in the Strait of Georgia on April 11th and 12th. The targets were observed at significantly greater ranges in Saanich Inlet, due to the calmer wind conditions. Figure 1 shows an example target detection (small red dot) at 530 m range. This target could be clearly tracked inwards over a period of roughly 7 minutes as the ship approached. The large intense scattering features on the right side of the image is the remnant bubbly wake from a previous pass by the ship. While in this particular image the target has high signal strength relative to the local

background, there are other regions of higher sea-surface backscatter in the image against which the target would not be detectable. At higher sea states there was often a region of higher reverberation in the near-field zone, up to 180 m.

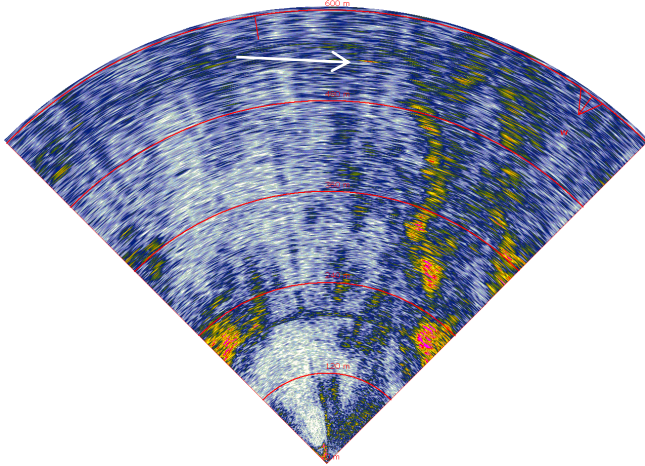


Figure 1: Forward-looking HF sonar image to 600 m range, 1011h April 09th in Saanich Inlet. Range rings are in 120 m increments. Arrow denotes location of target sphere.

Through visual examination of the sonar imagery, the target maximum detection ranges were extracted from the various runs. There were no cases where the targets were not detectable, although in higher sea-states the targets became difficult to track inside of roughly 100 to 150 m range. The average detection ranges were (mean \pm standard deviation) 503 m \pm 50 m and 274 m \pm 85 m in Saanich Inlet and Strait of Georgia, respectively.

3.2 Aft-Looking Towed Target Tests

The aft-looking sonar tests were all conducted on April 13th under calm conditions in Saanich Inlet. Figure 2 shows an example of the towed target detected at approximately 150 m range. The sonar was inadvertently mounted with a 9° counter-clockwise heading offset, so that in the images the wake is apparently rotated 9° clockwise of the ship track. The ship speed at this time was 7.3 knots.

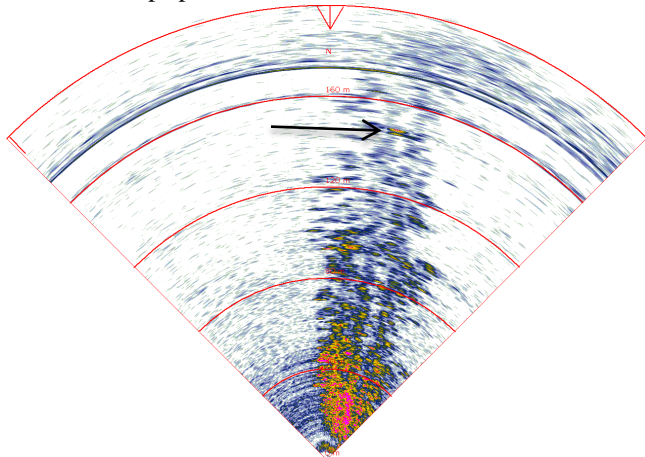


Figure 2: Aft-looking HF sonar image to 200 m range, 1128h April 13th in Saanich Inlet. Range rings are 40 m increments. Arrow denotes location of towed target.

At the time in Fig. 2 the towed target was located at a depth of roughly 12 m, well within the vertical aperture of the sonar beam but likely below the wake bubbles. In a reference frame fixed to the ship the wake backscattering appeared to translate away at the ship speed. The target was detectable by its apparent inward motion relative to the moving background. While the ship wake backscatter can be clearly seen in the *near-field* (< 50 m range), it generally faded in intensity at greater ranges presumably due to acoustic extinction by the near-field wake bubbles. This fading allowed relatively straightforward target detection at ranges from 50 m up to approximately 450 m. The target was often lost in the strong wake scattering in the near-field zone (< 50 m).

4 Summary Discussion

The HF multi-beam sonar functioned well in both the forward- and aft-looking target detection tests, producing a valuable data set covering a variety of sea states and near-surface sound-speed conditions. In the forward-looking tests targets were routinely observed at ranges up to 600 m in low sea-states, but the detection range was greatly reduced in higher sea states. While this suggests wind speed was the dominant factor in target detectability, the effect of near-surface sound speed gradients cannot be discounted. During the aft-looking sonar tests the towed target was detectable up to 500 m behind the ship at speeds from 5 to 7.5 knots. While this result is encouraging, the ship wake at the maximum speed (7.5 knots) was relatively weak. Greater wake width, depth, and densities have been previously observed with this same ship at speeds up to 12 knots [2]. If opportunities arise, further aft-looking wake tests should be conducted at higher ship speeds.

The next step in this work is to extract quantitative target Signal to Background Ratio (SBR) data from the various sonar tests. Here the acoustic background includes the combined effects of sea-surface reverberation, wake backscatter, and sonar self-noise. The variation of this SBR parameter against wind speed and measured bubble densities can then be used to validate sonar performance models. Acoustic calibration of this sonar will be required.

References

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