Ship wake signatures measured by AUV with upward looking high-frequency sonar

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Abstract:

The Norwegian Defence Research Establishment (FFI) conducted a measurement campaign north of Lofoten in October 2015, studying the signature of ship wakes using a Kongsberg EM2040 high-frequency multibeam echosounder facing upwards on a HUGIN autonomous underwater vehicle (AUV). The AUV sailed with constant course at 100 m depth, while mapping the decaying wake of FFI's 55 m long research vessel H. U. Sverdrup II. The wake had an irregular shape and lasted for nearly 7 minutes, with a maximum depth of 14 m and a maximum width of 60 m.

The configuration was found to be well suited for wake measurements. It is flexible and robust, and the sonar beam was wide enough to cover the entire wake width, also when the wake was drifting. The measurement results are interesting for studies of turbulence, formation of micro-bubbles in the ocean, and ship wake modeling.

Introduction

The wake is an important signature of large ships. Wakes are persistent structures that extend for many kilometers and are visible optically, on radar, on passive low frequency sonar, and on active high frequency sonar. For signature control it is thus important to understand wakes.

On active sonar, wakes are detectible due to the presence of small gas bubbles entrained in the turbulent flow. The strong acoustic response of the bubbles is due to a resonance [1], which implies that wakes are detectible even when the bubble concentration is rather small. However, sonar measurements of ship wakes is practically challenging due to the uncontrolled environment at sea. This means that special care must be taken when configuring the experiments. Previously, several configurations have been applied, such as bottom-mounted sonars [2, 3], sideways-looking multi-beam echo sounders [4], attenuation measurements [5, 6], and downward looking sonar from a small boat crossing the wake [7].

In this work we report results from using an AUV with upward looking multibeam echo sounder, as depicted in figure 1. FFI's research vessel H. U. Sverdrup II (HUS) was used both as an AUV mother ship as well as being the ship creating the wake. HUS is 55 m long, with draft 5.5 m, 13 m breadth and 1387 tons displacement. The AUV is a HUGIN 1000, with length 5.4 m and maximum range 100 nm. The sonar is a Kongsberg EM2040 multibeam echo sounder, with center frequency varying in the range 200 – 400 kHz, and an angular coverage of 130 degrees.

The measurement campaign was conducted by FFI in October 2015, in Andfjorden north of Lofoten, Norway. This fjord is well sheltered

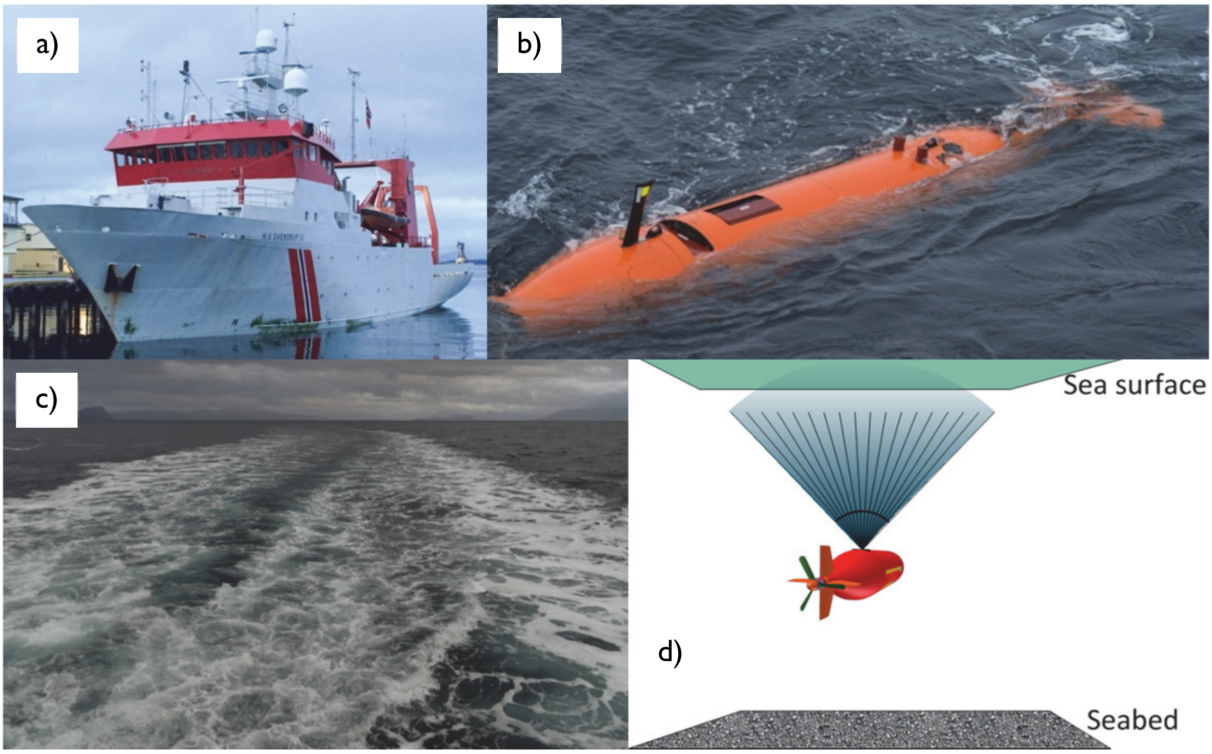

Figure 1 H. U. Sverdup II. b) HUGIN AUV. c) Photo of the wake. d) The AUV wake measurement concept.

from the strong north-Atlantic autumn winds so that the measurements were conducted mainly at sea state two. Also the fjord is around 200 m deep, so the AUV could use the Doppler shift from the bottom-track for positioning. The latter was important since the ultra-short baseline positioning was unavailable while the ship was busy creating a wake. The regular ship traffic in late October is modest so interference from other ships was not a major problem.

During the experiments, the AUV sailed at constant course with a speed of 4 knots and 100 m depth. The ship passed above the AUV with a speed of 12 – 13 knots on a parallel course. After the overpass, the distance to the ship kept increasing. This meant that the AUV recorded the acoustic response of a decaying wake.

Results

The output from the EM2040 is the volumetric acoustic response in dB, as seen in figure 2 a). The AUV is here at 100 m depth and the sonar center frequency is 200 kHz, with a scan width of 130 degrees. The ship has already passed over the AUV, so the wake is about one minute old. As expected, there is a strong back-scatter from the surface, seen as a semi-circle with signal in excess of 20 dB. The pronounced line at 100 m is a side lobe artifact from the sea surface specular reflection. The wake itself is seen between -30 and 0 degrees, near the sea surface. A close up view of the wake after transformation to Cartesian coordinates is in panel b). The wake width is 50 m and maximum depth is 13 m. Roughly, the wake can be viewed as consisting of two parts. First, there is a relatively compact core 10 m wide and 10 m deep. Second, there are quite wide structures on both sides with depth less than 3 m. Presumably the core is created by the stern and propeller, whereas the side structures are the residuals of the hull's turbulent boundary layer. The signal level is strongest in this turbulent boundary layer. This indicates that the bubble concentration is higher there than in the core.

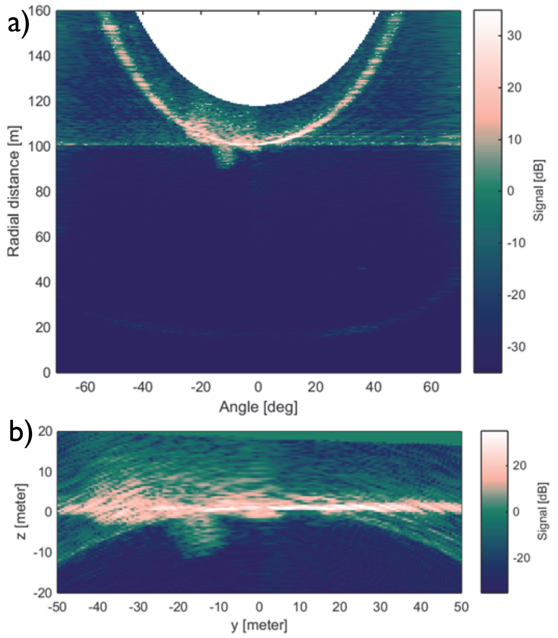

Figure 2 a) The volumetric response for a ping with wake present, in polar coordinates. b) Close up view near the wake, after conversion to Cartesian coordinates.

Above the sea surface we observe an image of the wake caused by the sea surface reflection.

The image of the turbulent boundary layer is an almost perfect replica, which means that attenuation is negligible there. The core, however, lacks a clear image and this indicates strong attenuation, i.e., the signal is reduced at least 10 dB when traveling twice through the 10 m bubble cloud.

We present the full spatial extension of the wake and calculate the wake depth in Cartesian grid in figure 3. The AUV sails with constant speed of 4 knots in positive x direction, at y = 310 m. When it reaches x = 350 m, the ship passes over it on a parallel course, with speed 12-13 knots. The echo from the hull is so strong it affects most beams, with the consequence that the ship hull appears to be much wider and deeper than it actually is. After the overpass, the AUV records a decaying wake; the labels indicating the wake age at the given position. The wake depth is extracted from the water column by a signal level excess threshold of 12 dB at each depth. Panel b) shows that the wake extends 1200 m, lasts for 7 min, and has a

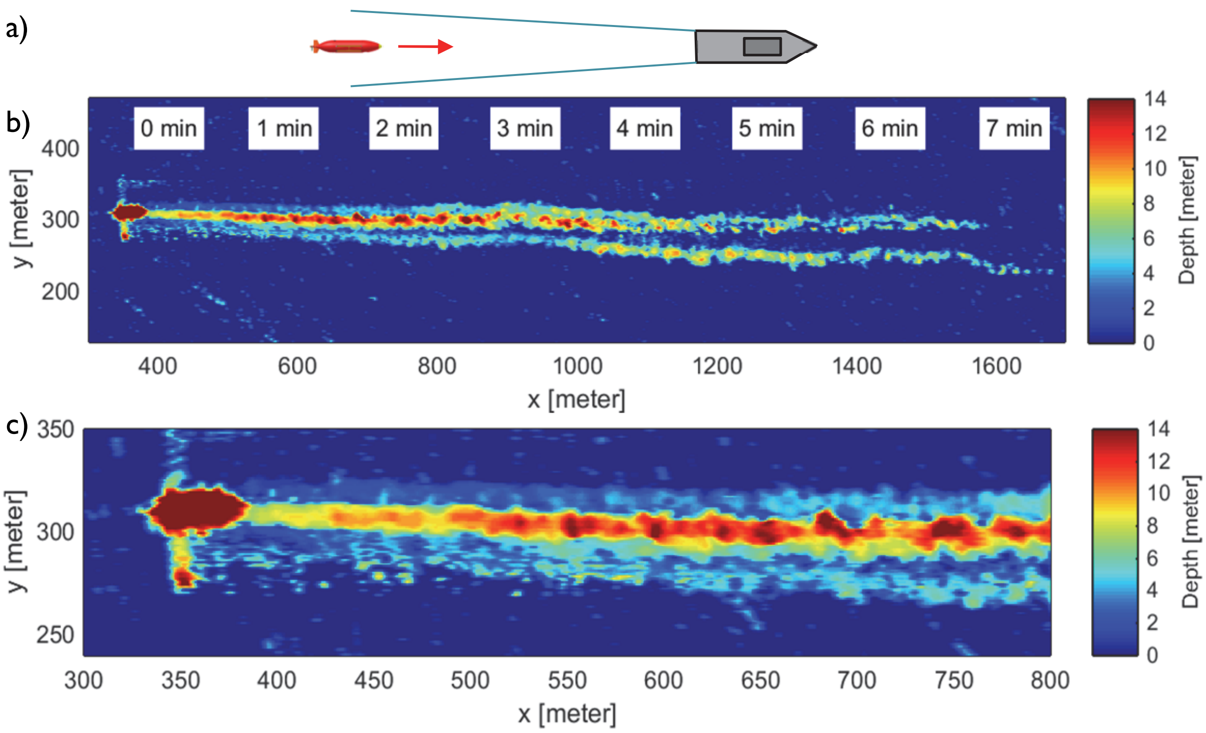

Figure 3 a) HUGIN and HUS after the overrun. b) The wake depth in xy. b) Same data, closer to the ship overrun.

maximum width of 60 m. The wake core is seen as a compact and deep trail of width 10 m and depth up to 14 m, lasting for 4 min. The two residual turbulent boundary layers are initially just 2-4 m deep and last for almost 7 minutes. In the entire wake they appear to drift apart and create a characteristic split in the wake. There is also a notably drift in the wake, most likely due to current. The drift of 50 m in 7 min is consistent with the reported current of 10 cm/s. Panel c) shows details of the wake just after the overpass. Here the initial core depth is about 6 m, matching well the ship draft. This further strengthens the notion that the wake core was created by the stern and propeller. The shallow and wide part of the bubble cloud is initially much wider than the hull and we thus again concludes that it originates in the hull's turbulent boundary layer.

Summary

The wake of a medium-sized surface ship was measured using a HUGIN AUV with upward looking Kongsberg EM2040 multibeam echosounder. The experimental setup enabled us to map the whole decaying wake of the ship passing over the AUV on a parallel course at 12-13 knots. The wake had a complex structure, with a pronounced deep core lasting for 4 minutes, and shallow side structures, originating from the hull's turbulent boundary layer, lasting for up to 7 minutes.

The measurement concept was proven to be an efficient way to map the acoustic response of ship wakes. Also, since the measurement concept is quite flexible it allows for further experiments with more complex arrangements, such as mapping the wake of maneuvering ships.

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