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Deep towed vehicle for fish abundance estimation, concept and testing

by

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ABSTRACT

A research program was initiated in Norway in 1988 for measuring the abundance of fish resources at depth from 500 to 1000 metres. It was decided to develope a deep towed vehicle, to bring acoustic transducers down to 400 metres depth. The vehicle serves as a stable and quiet platform for the transducer. The attenuation due to air bubbles in the upper water layers is avoided, and the transducer is closer to the fish so that the resolution of single fish is improved. The vehicle has a weight of 500 kg and is designed as a streamlined torpedo with accommodation for the transducer, a depth sensor and inclinometers. A special feature is that the transducer face is in direct contact with the waterflow below the vehicle. This eliminates the need for an acoustic window, and all the well known problems of air bubbles attached to the inner surface of the window. This paper describes the concept of the vehicle and the transducer, and gives test results obtained during surveys in 1990 and 1991.

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INTRODUCTION

Our knowledge of the biological resources in deep waters may be increased considerably by either developing proper observation instrumentation for the purpose or eventually improving existing systems. As for shallow waters, (less than 400 m), acoustic instrumentation and methods are together a strong candidate for such tasks.

During the period 1975-1984, the Institute of Marine Research (IMR) in Bergen, in cooperation with SIMRAD Subsea A/S in Horten, have been working with (i.e. developing, testing, and operating), three different versions of towed vehicles carrying acoustic transducers. None of the vehicles developed in that period were designed to be deep towed. One body was towed at maximum of 150 m, maintaining 8-9 knots, while the other two were operated at shallower depths, less than 60m, at the same speed. It should be mentioned that all these vehicles were torpedo-shaped. V-fins were removed during pre-project phases due operational problems with meeting our requirements.

This project aims to procure a towed vehicle, carrying acoustic transducers, to observe target strengths and estimate fish abundance in the depth range 500-1000 m. This will be achieved by bringing the vehicle down to 300-400 m. The speed of the towing vessel will be moderate to high i.e. 6-10 knots.

The development of the system occurs in two phases. Within the first phase, from which this report presents the results, we have opted for known technology, partly existing systems units and partly improved/newly developed ones. We have achieved promising conclusions at the milestone of the end of this first phase. We will therefore continue to develope dedicated instrumentation and system modules for an optimized deep towed system.

THE CONCEPT

The advantages of towing the transducer

1. The upper water layer of the ocean contains air bubbles, induced by wind and waves. These air bubbles attenuate the sound transmission and reception from a hull-mounted transducer, (Dalen and Løvik 1981). The thickness of the bubble layer may be 5 - 10 m, or more, depending on the sea state. A towed transducer operates below this bubble layer.

2. The transducer is closer to the fish. This gives a better signal to noise ratio, and also the resolution of single fish is improved because the width of the sound beam is smaller. For the study of deep water biological resources - below 500 m - a towed transducer is essential.

3. The transducer is not affected by vessel pitch, roll and heave.

4. The noise is lower as the transducer is a considerable distance below the vessel machinery and propeller.

The vehicle design

As an improved basis of decisions for the vehicle design we ran two simulations, one for the static towing case (Lie 1988, Larsen 1989) and one for the dynamic towing case (Støle-Hansen et al. 1989). The results of these simulations were presented to the ICES at the FAST WG - meeting in 1989 (Dalen 1989).

The final design is for a large towed vehicle which can be used for towing transducers and other sensors at great depths. The body is shaped like a torpedo, and operates on the "dead weight" principle.

The vehicle follows a stable and straight-line course because of its form, and its high and favourable static margin (i.e. the ratio between a) the distance from the hydrodynamic centre of the total vehicle to the tow point and b) the distance from the hydrodynamic centre of the main body to the tow point). The force used to take the body down to the operating depth is the gravity only, there are no depressor wings as used on V-fins etc. During the early stages of the design, the addition of depressor wings was discussed. The simulation model used to analyze the performance concluded that several square meters of wing area would be required to provide a sufficient additional force. Furthermore, a great advantage of relying on gravity alone would be lost - the fact that gravity always acts vertically downwards, independent of the body's pitch and roll. Wings were therefore not recommended, and the body maintains its stable behaviour over the entire range of towing speeds and in rough seas.

One of the main challenges in deep water towing is to get the vehicle down without using an excessive length of tow cable. This is most accentuated at high speed, when the water drag on the vehicle and the cable tends to bring the vehicle up. The solution is to make the vehicle heavy and streamlined and to reduce the cable water drag. The torpedo form has been selected because of its low water drag, and fairing is employed on the lower third of the tow cable to reduce the water drag.

The vehicle is constructed as a main body and a tail with a rudder on. The main body has 3 sections: nose, centre section and rear section. They are held together with a solid centre bolt, which continues aft to the rudder.

The vehicle is suspended on the tow cable over an arm attached to the centre bolt and a stress relief cup moulded to the armouring of the tow cable. The point of suspension can be moved on the centre bolt to adjust for horizontal orientation with the current pay load. In addition, a number of lead discs may be placed on the centre bolt as balance weights.

The rudder is formed as a thin cylindrical shell. The rudder is normally concentric with the centre bolt, but may be adjusted slightly to an angle with the centre bolt for steering purposes, both horizontally and vertically. A horizontal angle may be used to move the vehicle out to either the port or starboard side of the vessel's wake. A vertical angle may be used to further ensure an exact horizontal orientation of the vehicle during towing.

The centre section contains the transducer. The transducer is mounted in a streamlined blister so that its surface is in direct contact with the water flow. Air bubbles which may be attached to the transducer face after launching are quickly removed by the water flow. The body has ample room for other sensors and electronic units depending on the customer's applications. The centre section has a removable top cover for easy access to interior of the body.

The materials and surface treatments are selected for long term endurance in sea water without corrosion.

For the prototype, stainless steel was used in the centre section. After the successful sea trials of the prototype a new model has been made at SIMRAD named Simrad VD500. For this model the materials are:

main body: aluminum bronze NS16575
centre bolt: steel St52 hot dip galvanized
rudder: steel St52 hot dip galvanized

The VD500 has the same outline dimensions as the prototype. The middle section of VD500 has room for two transducers (38 kHz and 120 kHz) as shown in figure 1.

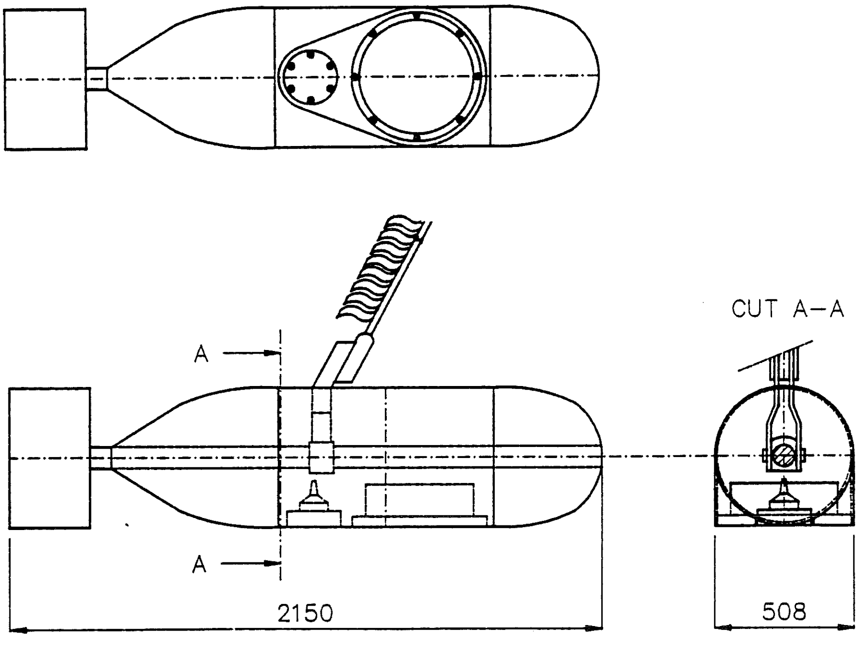

Figure 1. Outline dimensions of the towed body VD500

The transducer

The main transducer frequency is 38 kHz. For the first trials a nickel transducer was installed. Parallel to this a new depth resistant ceramic transducer has now been developed. This new transducer is circular. The outer diameter is 480 mm, and the beamwidth is 7 degrees. A photograph of the transducer is shown in figure 2. It is constructed as an array of 88 transducer elements. The elements are amplitude weighted to reduce the sidelobes. Refer to figure 3 for the beam pattern.

The new transducer is specified and tested to 500 m depth. To withstand the pressure at this depth the interior of the transducer has been filled with a fluorinated liquid FC75. A membrane on the back of the transducer allows for small changes of the volume of the liquid. A well known drawback of the liquid filling is that it tends to increase the back radiation of the transducer. To reduce this effect, an acoustic reflector of syntactic foam has been placed behind the transducer elements.

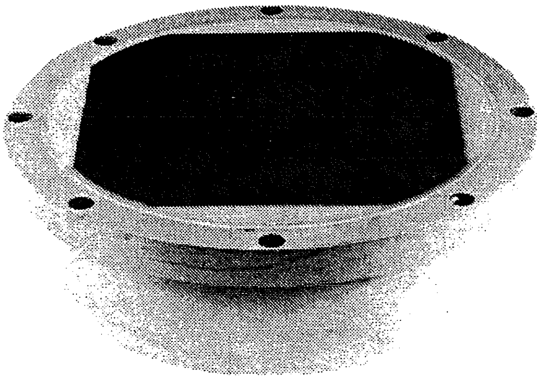

Figure 2. Photo of ceramic transducer 38-7D

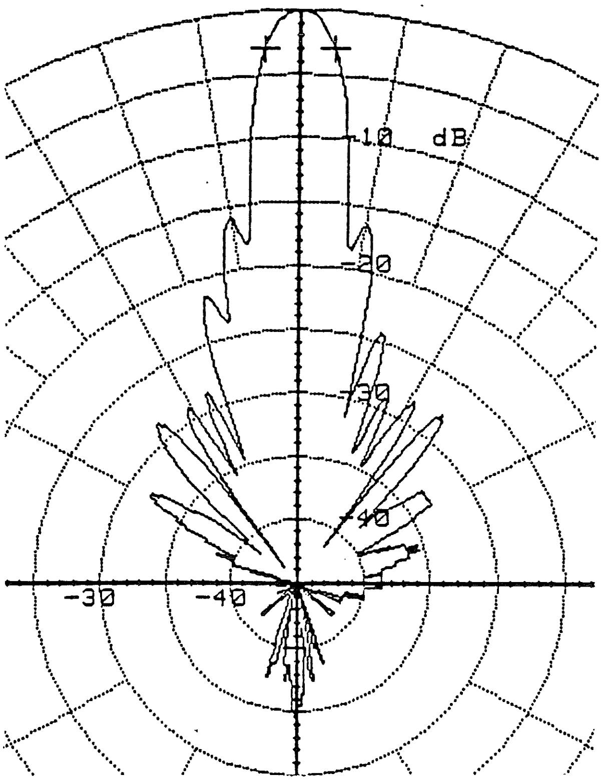

Figure 3. Beam pattern of ceramic transducer 38-7D

Angle and depth sensors

The towed body contains an electronic unit with a depth sensor and two inclinometers, one for pitch and the other for roll angle. The analogue outputs from these sensors are multiplexed and converted to digital form before transmission on an RS422 serial line in the tow cable. A block diagram of the electronics and its functioning is shown in figure 4. The sampling frequency is 5 Hz. With this sampling it should be possible to detect oscillations and instabilities of the vehicle motion that may appear. The power to the electronic unit is supplied on two separate wires in the tow cable.

The serial line in the tow cable has a continuous one way data stream, from the towed body to the surface. Onboard the surface vessel the data stream is decoded and the information is presented on a computer display. A sketch of the surface units is shown in figure 5.

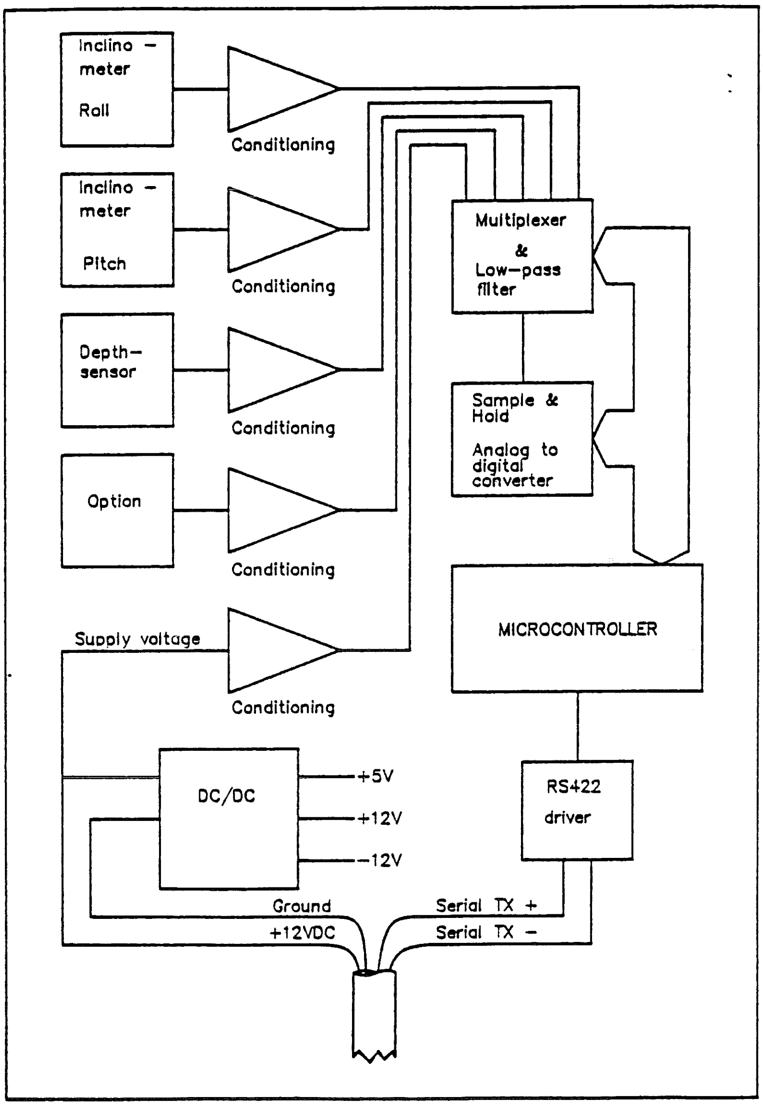

Figure 4. Electronic unit in the towed body

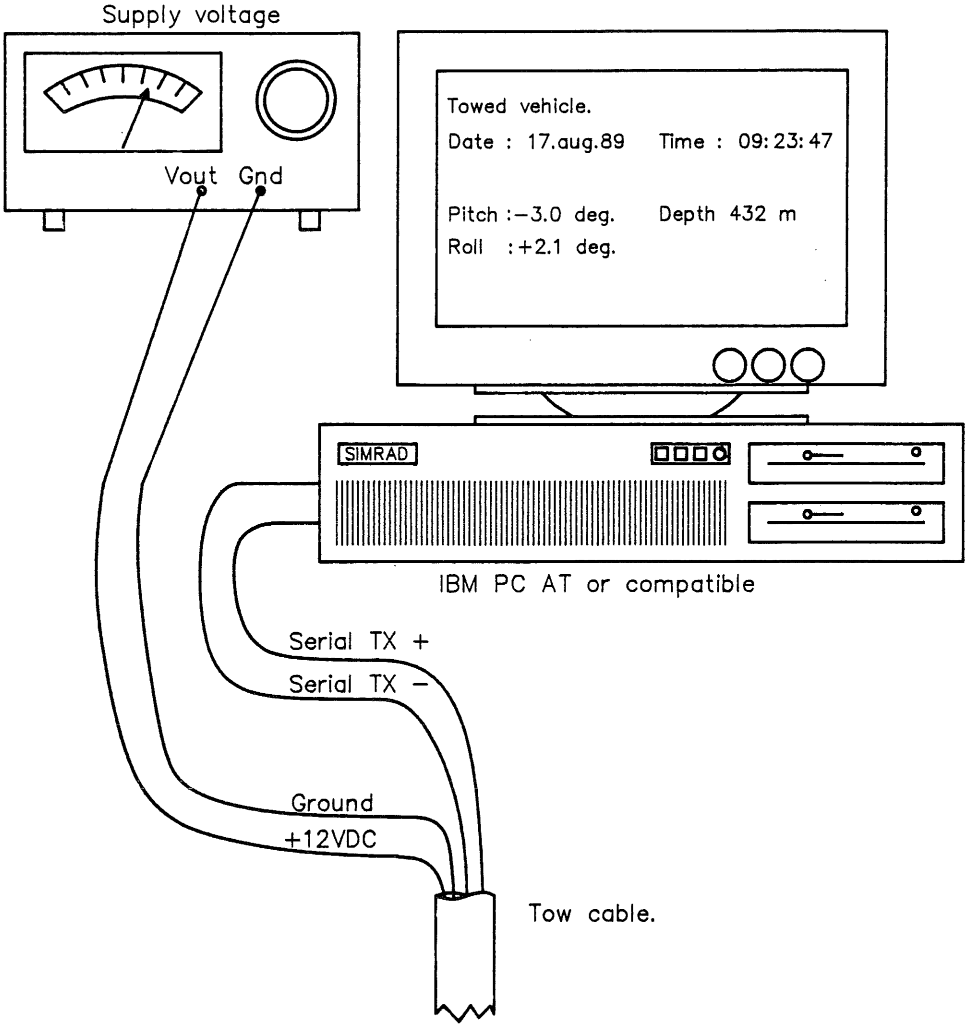

Figure 5. Surface unit for angle and depth sensors

Deck arrangement

The deck units consist of a customer-designed folding-crane with a grab at the end - hydraulicly operated and mounted near the ship's port rail, and a hydraulic winch with a bobbin winder and slip rings. When not in operation and during maintenance activities, the vehicle rests in a cradle by the ship's rail. The cable capacity of the winch is in the range 1200 - 1500 m for a 12 - 10 mm diameter cable. The crane and winch are operated from a control unit by the winch, and the winch operation may also be controlled from the bridge.

The echo sounder and the echo integrator used during testing have been the SIMRAD EK400 and the N10-based Bergen Digital Integrator. From early autumn 1991, the SIMRAD EK500 will be used.

SURVEY TEST RESULTS

Vehicle testing

The first prototype of the vehicle was tested during a cruise in May 1990. We then discovered that we had a hydrodynamically unstable vehicle with which it was impossible to reach a stable, forward directed, straight-line course.

The upper part of the centre section of the main body was rebuild from a quasi-rectangular shape to a semi-cylindrical shape. This changed the position of the hydrodynamic centre of the main body, improved the static margin of the vehicle and yielded a stable, predictable towing behaviour. This was tested and verified during a cruise in July 1991.

The on-line monitoring of the depth, and pitch and roll angles of the vehicle was very useful for quick and reliable testing and for surveying purposes.

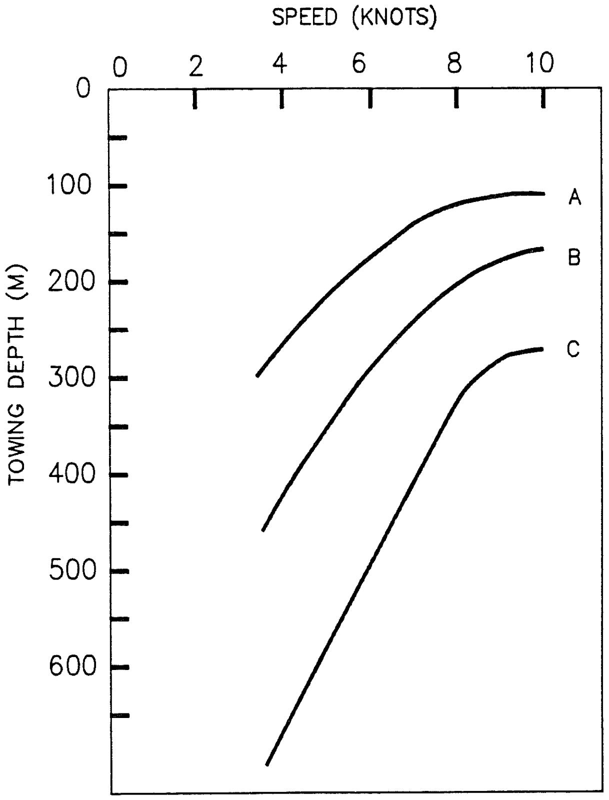

Figure 6. Towing depth versus towing speed for three different cable length - the prototype (RV."G.O.Sars")
A: 550 m (observed)
B: 800 m (observed)
C: 1200 m (estimated, Lie 1988)

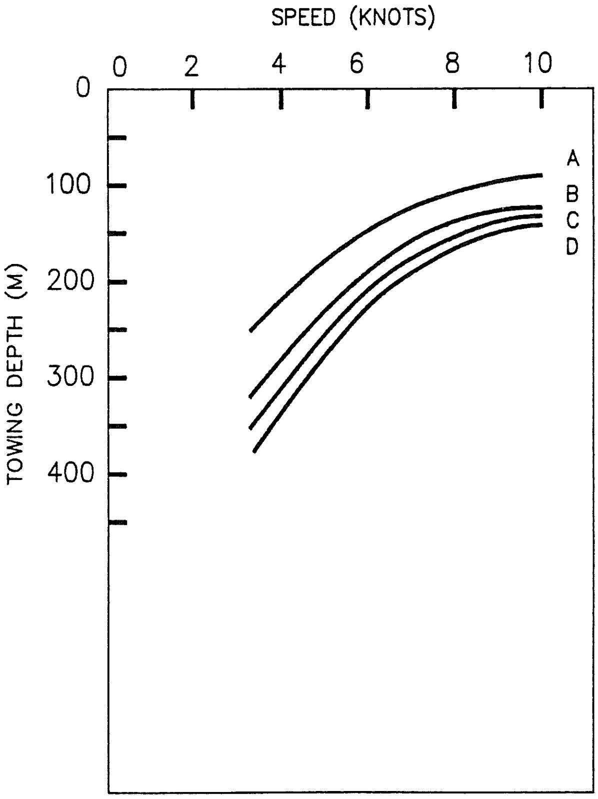

Figure 7. Towing depth versus towing speed for four different cable lengths - the VD500 (RV."Johan Hjort").
A: 300 m,
B: 550 m,
C: 650 m,
D: 735 m.

To demonstrate the deep-towing ability of the vehicle, we observed towing depths versus cable lengths and towing speed. figure 6 presents the towing depth versus speed of the prototype version for cable lengths of 550 and 800 m, and an estimated curve for a cable length of 1200 m (Lie 1988). The cable is faired for a length of approximately 280 m. The cable diameter is 12 mm.

The commercial version of the vehicle (VD500) mounted onboard RV. "Johan Hjort" was similarly tested in March and June 1991. The cable diameter here was also 12 mm. The cable was faired for approximately 85 m. The results are displayed in figure 7.

The VD500 has a slightly improved hydrodynamic design compared to the prototype version and it is approx. 40 kg heavier. This, together with the different faired cable lengths of the two systems, is expected to cause the VD500 sink deeper than the prototype for shorter cable lengths and high speeds. On the other hand the prototype should go deeper for longer cable lengths and high speed. These considerations are confirmed by the figures.

Comparative acoustic testing

Acoustic testing of the towed transducer itself is not of great interest in this context. What is of interest will be further comparisons of simultaneous acoustic data from the towed transducer and the hull-mounted transducer. The relevant data could be echo abundance, or target strength distributions, or both, from the two systems observing the same fish distributions / depth layers.

Comparative acoustic measurements of the echo abundance of fish, i.e. echo integration data, took place along the slope of parts of the shelf off western Norway during a cruise in May 1990. The depth in the area varied between 780 and 950 m. The vehicle traveled at a depth of approx. 275 m, at a speed of 6 knots, with a cable length of 650 m. The integrator recordings were logged every 1 nautical mile over a distance of 18 nautical miles, of which 12 nautical miles were accepted for the comparative analysis. The echo sounder and transducer of the towed system were not calibrated for the survey, therefore we put the instrumentation factor for this system equal to 1,0. In this case, this will yield 3 - 4 times higher integrator recordings from the towed system than from the hullmounted one (i.e. after correction for bubble attenuation) for the same fish distributions. In this context this will produce no problems for the analysis.

The wind conditions in the area were a north-easterly to northerly, moderate to strong breeze, of wind force 8 - 10 m/s. With the ship's heading of 90°, the wind therefore came in on the port side of the ship (the same side where the hull-mounted transducer was located). This produced additional noise and bubble attenuation to the data from the hull-mounted transducer compared to other relative directions between the ship's heading and the wind directions. The estimated correction factor for the bubble attenuation under the prevailing weather conditions would have been approx. 1.8 (Dalen and Løvik 1981).

Due to the noise affecting the hull-mounted system data, the comparative analysis is only of significance for depths less than 500 m. Equivalent analysis for greater depths will merely demonstrate how this information is degenerated. Table 1 displays some statistical parameters from the analysis of corresponding echo integrator recordings from the towed transducer, Mt, and the hullmounted transducer, Mh. The latter are raw data i.e. not corrected for bubble attenuation.

Compa-rative layers	Statistical parameters								
	$\overline{Mt}$	$\overline{Mh}$	sMt	sMh	sMtMh	a	b	r	n
A	1115,5	167,6	1251,2	177,6	$1,64x10^5$	5,20	244,1	0,74	24
B	76,5	54,3	58,9	58,9	$-5,32x10^2$	-1,08	135,4	0,41	12
C	42,1	102,1	19,8	19,8	$-4,12x10^2$	-0,12	54,5	0,36	12
D	498,3	226,2	81,6	81,6	$-4,06x10^3$	-0,28	561,1	0,41	12
E	270,2	164,1	240,1	112,2	$1,26x10^4$	1,0	105,4	0,47	24

Table 1. Some statistical parameters from the comparative analysis of the echo integrator recordings from the towed transducer (t) and from the hull-mounted transducer (h).

Depth layers:
A: t: 320-410m and 410-510m, h: 300-400m and 400-500m
B: t: 510-610m, h: 500-600m,
C: t: 610-710m, h: 600-700m,
D: t: 710-810m, h: 700-800m,
E: t: 610-710m and 710-810m, h: 600-700m and 700-800m

$\overline{Mt}$,$\overline{Mh}$: Mean values of the integrator recordings from the towed (Mt) and the hull mounted transducer (Mh) respectively, pr. nautical mile of the actual depth layers.

sMt,sMh: Sample deviation of the integrator recordings from the towed and the hull-mounted transducer respectively.

sMtMh: Sample covariance between Mt and Mh.

For the regression equation Mt=aMh+b, a is the regression coefficient, b is the intercept of the corresponding regression line with the Mt-axis, r is the correlation coefficient between Mt and Mh, and n is the number of integrator recordings per comparative depth layer, i.e. the number of samples.

The numerical values of the means, the deviations of and the covariance between the integrator recordings, and the regression coefficient of the regression equation between the Mt's and the Mh's, together confirm what was previously expressed: It is only for depth layer A that the comparative analysis has any significance. For the depth layers B-E, we may conclude that under the prevailing weather conditions (often occurring conditions during surveys) the quantitative fish abundance observations using the hull-mounted transducer were useless for depths greater than 500m. However, the results were of high quality when using the towed transducer. The echo integrator system, EK400/N-10 Integrator, connected to the towed transducer has a limited functioning range of 580m, (TVG-limitation). This results in incorrectly presented integrator recordings for the depth layers near to the bottom (i.e. for relative depths of the vehicle >580m) and for the bottom channel of extent 10m, for 10 out of the 12 nautical miles surveyed. However, from the echograms of the two systems we can conclude that the fish recordings at the bottom are far better and qualitatively more significant for interpretation with the towed transducer than with the hull-mounted transducer.

During a test cruise in June 1991 we collected comparative target strength recordings by means of the "Johan Hjort" system, i.e. the vehicle VD500 and EK500. The observations were done on a mixed fish layer (mainly lantern fishes, blue whiting and hake) at depths of 250-400m in a deep fjord in Western Norway. The weather conditions were excellent, i.e. totally calm sea.

Figure 8 shows two target strength distributions from the same depth layers. The upper one is from the hull-mounted transducer and the lower one is from the towed transducer. The instrument-settings were equal for both systems. Please note the slightly different scalings of the vertical axes.

hull-mounted H1

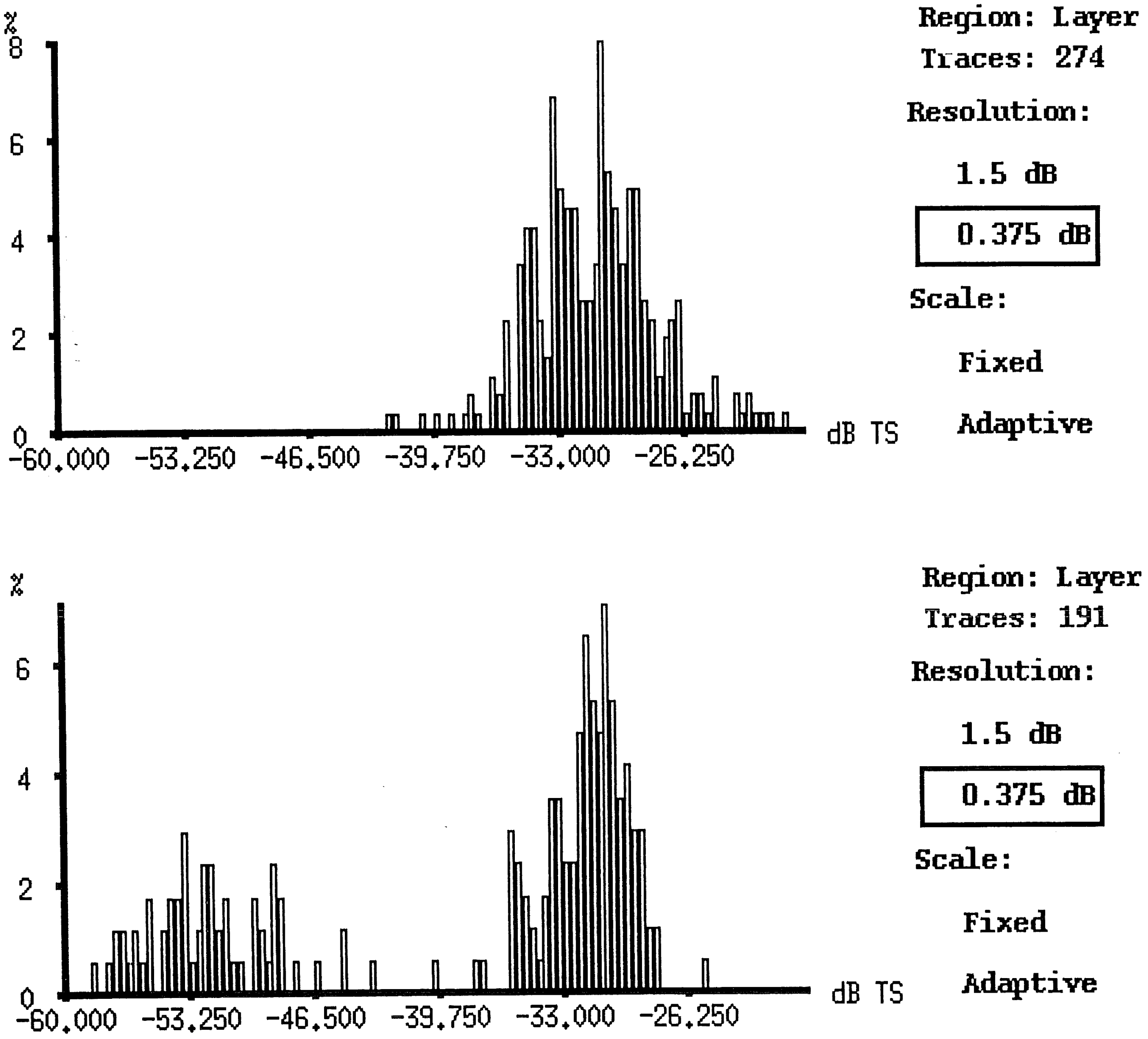

Figure 8. Target strength distribution from the hull-mounted transducer (upper) and the towed transducer (lower).

Due to the improved spatial resolution obtained by the towed system we also observe more correct data from the smaller specimens. When recorded by the hull-mounted system, several of these specimens are often lumped together as one greater specimen, or they may be rejected as multiple echoes.

Altogether, the towed system demonstrates an improved ability to obtain target strength data of higher quality from mixed fish populations containing small specimens, and of fish populations at greater depths.

CONCLUSION

A deep-towed vehicle, carrying an echo sounder transducer, has been developed and successfully tested. Simultaneous measurements with the towed transducer and a hull-mounted transducer show that the towed system is superior with regard to reliability of the abundance estimation of deep sea fish resources. Also, the target strength distribution obtained with the towed transducer is more correct and more detailed than the distribution obtained with the hull-mounted transducer. Being closer to the fish, the towed transducer has a better capability of resolving single fish.

As a result of the successful tests, IMR will continue to use the towed vehicle in acoustic surveys, for mapping deep water resources, and also as a general purpose tool, especially in bad weather. The vehicle is now in production at SIMRAD, and will be available to other users.

REFERENCES

Dalen, J. and Løvik, A. 1981. "The influence of wind-induced bubbles on echo-integration surveys" J.Acoust.Soc.Am.69(6),June 1981.

Dalen, J. 1989. Deep towed vehicle for assessing deep water fish stocks. Concept and operation simulations. FAST WG-meeting 26-28 April 1989, Dublin, Ireland.

Larsen, K. 1989. Statisk analyse av tauet instrumentfisk - utvidet simulering. (Static analysis of a towed instrument-fish - extended simulations) (In Norw.). MARINTEK rapport 511158.00, Trondheim, febr. 1989.

Lie, H. 1988. Statisk analyse av tauet instrumentfisk. (Static analysis of a towed instrument-fish) (In Norw.) MARINTEK rapport 512054.01, Trondheim, mai 1988.

Støle-Hansen, K., Ødegård, O. og Hallset, J.O. 1989. Analyse av tauet instrumentfisk. (Analysis of a towed instrument - fish).(In Norw.). SINTEF rapport nr. STF48 F89008, mai 1989.