EFFECT OF SWIMMING ON FISH TARGET STRENGTH

by

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ABSTRACT

The influence of the swimming movement on fish target strength is investigated through a modelling exercise. In this, several gadoid specimens are represented as acoustic scatterers through their triangulated swimbladder surfaces, assumed to be perfectly pressure-releasing. The swimming movement is described as a periodic deformation in swimbladder shape consistent with actual measurements of whole-body movements of swimming gadoids. Results of computations of target strength as would be observed with a vertical echo sounder are expressed through the probability density function. This is found to be nearly identical to that of the same fish with normal extended posture. The inconsequentiality of swimming movement to the target strength in typical echo-sounding applications is thereby demonstrated.

RÉSUMÉ: Influence de la natation sur l'index de réflexion des poissons

L'influence du mouvement natatoire des poissons sur leur index de réflexion est étudiée grâce à une modèlisation. Plusieurs spécimens de gadides sont représentes en tant que réflecteurs acoustiques par la surface de leur vessie natatoire supposée être a pression ajustable. Le mouvement natatoire est assimile a une déformation périodique de la vessie selon les mouvements réels du corps entier observes chez les gadides. Les calculs d'index de réflexion, tels qu'ils devraient être observes au sondeur vertical, sont exprimes grâce à une fonction de probabilité. Les resultats sont sensiblement identiques avec le même poisson prenant des attitudes normales. La non influence du mouvement natatoire sur les index de réflexion dans la détection par echo-sondeur est de ce fait démontrée.

INTRODUCTION

Evidence for the effect of the swimming movement on fish target strength is scanty but conflicting. According to Olsen, the effect on the dorsal aspect target strength is substantial, involving a degree of variation of the order of 3-10 dB for gadoids of 50-70 cm length (Olsen 1976, Nakken and Olsen 1977). Clay has found a similarly distinct effect on the lateral aspect target strength (Huang and Clay 1980, Clay and Heist 1984). This is supported both by measurement and by theoretical computation based on an acoustic model of a fish as a linear array of point scatterers. More recent computations based on another model (Foote 1985) predict only a negligible effect in dorsal aspect. These computations are compatible with Clay's in lateral aspect, and have also been confirmed by direct measurements in dorsal aspect performed similarly to those by Nakken and Olsen in their classic study.

It is the present purpose to elaborate on the new finding of an entirely negligible effect of swimming on the dorsal aspect target strength. Several explanations are offered for Olsen's contrary, disbelieved claim.

MATERIAL AND METHOD

The basic material consists in three swimbladder triangulations. These are associated with the extreme and median lengths of the 15 gadoids whose swimbladder morphometries have already been described in detail (Foote 1985). In particular, the lengths of the three specimens are 31.5, 36.5, and 44.5 cm. The species is pollack (Pollachius pollachius), which has a comparatively simple swimbladder form compared to other gadoids (Hawkins 1981).

According to the new acoustic model, a fish is represented completely by its swimbladder. Thus, geometric description of the swimbladder and use of the Kirchhoff approximation, as in Haines and Langston (1980), allows immediate computation of the target strength. Thus too, description of the swimming movement and relation of this to the swimbladder allows the effect of swimming on target strength to be quantified.

In the absence of specific kinematic data on swimming pollack, data on swimming cod (Gadus morhua) are applied. These were compiled from measurements by Videler and Wardle (1978) on a 42 cm cod. Data gathered at swimming speeds from 92 to 110 cm/s, corresponding to the maximum sustainable speed, were averaged. These were then normalized or scaled to the fish length. Application to pollack was achieved by assumption of coincidence along the fish length of the anterior end of the swimbladder and posterior end of the operculum (Ona, pers. comm.). Relative body dimensions of cod and pollack were established through standard drawings (Wollebæk 1924). The result for the maximum lateral deformation η of the swimbladder inner wall at distance y as measured along the body axis from the tip of the upper jaw is

$$\eta/\ell = 0.063 \ (y-y_a)^2/\ell^2 + 0.015 \ (y-y_a)/\ell \quad ,$$

where ℓ denotes the fish length and y_a the coordinate position of the anterior end of the swimbladder. This equation is used in the model to describe the swimming movement through a pure shearing deformation in the lateral plane.

Also assumed in applying the basic model for fish scattering are uniform probabilities of occurrence and of heading in a horizontal plane in the farfield of the acoustic source and receiver. The transducer beam is assumed to describe a right circular cone of 10 deg vertex angle.

The effect of the swimming movement on the fish target strength is assessed through the distribution function of target strength. This is simulated in each of three ways on the same basis of theoretical target strengths. These were computed at each of 11 detection angles evenly spaced from the acoustic axis to the edge of the beam at 5 deg. At each detection angle the fish was allowed to adopt each of 12 headings spaced evenly over the full 360 deg range. For each heading the swimming movement was simulated by a series of 11 postures spanning the range of shear deformations from $-\eta$ to η. The total number of basic target strength data is thus 11×12×11, of which all 132 computations on the acoustic axis are degenerate.

The theoretical target strengths were assembled into distributions according to the mentioned assumptions of uniform fish behaviour and additional assumptions about the swimming movement. These are enumerated here.

(1) Swimming with sinusoidal time dependence. The deformation in swimbladder form from the normal posture is assumed to be proportional to the sine function of time. The actual fraction of time thus spent by the swimbladder in passing between deformations η_1 and η_2 in the same cycle is $\left| \cos^{-1}(\eta_2/\eta) - \cos^{-1}(\eta_1/\eta) \right|/\pi$.

(2) Swimming with uniform time dependence. The fraction of time spent by the swimbladder in passing between deformations η_1 and η_2 in the same cycle is assumed to be $\left| \eta_1 - \eta_2 \right|/2$.

(3) Non-swimming. For comparison purposes the effect of swimming on deforming the swimbladder is completely neglected. That is, the normal posture is assumed to be the essential posture adopted by the fish. In η-language the time dependence is $\delta(\eta)$, where δ denotes the usual delta function (Lighthill 1964).

RESULTS

Target strength distributions have been simulated in each of three ways for each of three fish triangulations. For each of these combinations the probability density function of target strength has been computed for both dorsal and ventral aspects at each of the four frequencies used during the original data collection.

When comparison is made between the respective distributions representing swimming modes with the non-swimming mode few if any sizable deviations are observed. In fact, the total number of discrepancies in excess of ±2% is 21, which is to be compared with the total number of non-zero target strength classes for the 48 combinations of fish, swimming mode, aspect, and frequency. If ten 2-dB-resolved target strength classes are allowed for each combination, then the number 21 is to be compared with 480.

A more significant measure of the effect of swimming movement on target strength lies in the mean target strength. This is presented in the table for the dorsal aspect data at 38.1 and 120.4 kHz. Because the averages were identical in the several cases for both the sinusoidal and uniform time dependences, the two are considered together.

Table. Mean target strengths for dorsal aspect and two frequencies according to the swimming and non-swimming simulations.

Fish length (cm)	Frequency (kHz)	Simulation type	
		Swimming	Non-swimming
31.5	38.1	-33.7	-33.6
31.5	120.4	-31.8	-31.8
36.5	38.1	-29.9	-29.9
36.5	120.4	-27.1	-27.0
44.5	38.1	-27.1	-27.1
44.5	120.4	-25.6	-25.7

Comparisons made at other combinations of frequency and aspect show a similar agreement. In no case do respective mean target strengths differ by more than ±0.1 dB.

DISCUSSION

The conclusion is immediate: the swimming movement does not significantly affect the dorsal aspect target strength.

In the context of the scattering model the conclusion has a simple explanation. The geometry of ensonification is near-pure dorsal aspect, and the kinematics of gadoid swimming indicates only slight deformation of the swimbladder. Thus the phases of small surface elements change very little in the course of the swimming movement, and the backscattering amplitude, hence target strength, remains nearly constant in value to that at the so-called normal, extended posture.

This explanation seems to be confirmed by an extensive series of acoustic observations on encaged swimming fish in 1980. In the subsequent

analysis it was found that the use of single-immobilized-fish measurements of target strength, together with behavioural observations in the form of the tilt angle distribution, could explain the direct encaged-swimming-fish measurements quite adequately without any specific account being taken of the swimming movement (Foote 1983).

The new-model computations are also compatible with those of Clay in examining the effect of swimming on the lateral aspect target strength. The corresponding target strength distribution does distinguish different degrees of swimming activity. Again, the reason is simple: the geometry of horizontal ensonification is most favourable for sensing the effects of lateral swimbladder deformation in all azimuthal aspects except the frontal and caudal.

What remains to be explained is Olsen's contrary measurements. It is speculated that more than just the dorsal aspect was involved. Given the size of subject fish, from 52 to 69 cm, and inverted posture, maintained by a small float attached to the belly, and lightness of the tethering and suspension apparatus, at least several measurement scenarios are possible, if not likely. (1) The fish changed its tilt angle in uncontrolled fashion during the measurements. A movement of only a few degrees could easily explain the observed 3-10 dB variation in dorsal aspect target strength, cf. Nakken and Olsen's measurements of the directivity functions of gadoids (Nakken and Olsen 1977, Foote and Nakken 1978). (2) The fish changed its roll angle. The normal tendency to righting was thwarted only by the small float attached to the belly, which would have permitted at least some rolling from the unnatural upside-down posture. (3) The fish movements were sufficiently powerful to set the entire suspension system into oscillation. The fish could then have been carried away from the axial position, rendering its echo a composite effect of beam pattern and target strength.

Interestingly, Olsen noted the correlation of target strength variations with the whole tail-beat cycle, and not the half-beat cycle, as would be expected from considerations of symmetry. This observation is entirely consistent with the present postulation of an untoward behaviour. Conscious fish constrained in a awkward position can be expected to resist or attempt to restore a normal posture. Correlation of the resulting movement with the powerful propulsive mechanism of tail beating is therefore not implausible. The further correlation of uncontrolled pitching, rolling, or swaying movements, or combination of these, with the whole-beat cycle is quite reasonable.

In summary, the case for a significant effect of swimming on the dorsal aspect target strength appears weak. Theoretical evidence, supported both by measurement and by comparison with an independent model of fish scattering, predicts a completely negligible effect. The validity of work based on the kind of immobilized-single-fish target strength data collected in abundance by Nakken and Olsen is therefore not expected to be affected by considerations of swimming movement.

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