Comments on "A generalized target strength model for euphausiids, with applications to other zooplankton" [J. Acoust. Soc. Am. 95, 2452–2466 (1994)]

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A major premise upon which this paper by Macaulay was written is flawed as is the formulation (both conceptually and mathematically) of the scattering models. The formulation is actually an assemblage and adaptation of previously published approximate solutions rather than a generalization. The physics of the scattering is blurred through a multitude of empirical parameters. In order for this new "generalized" model to fit the data, the animals are required to change shape as the acoustic frequency changes (for any animal of fixed size, it is required to be a sphere at low frequencies, prolate spheroid at intermediate frequencies, and bent cylinder at high frequencies). The scattering models, as presented, are not only physically incorrect, but in two cases are not even dimensionally correct (terms that are dimensionless are added to terms of dimension area). These and other errors are listed in several categories and commented upon with references given. © *1995 Acoustical Society of America.*

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I. MAJOR ERRORS

(1) The "generalized" or hybrid model is composed of the combination of three models involving three shapes—the sphere, prolate spheroid, and bent cylinder [Fig. 2 and Eqs. (1)–(3)]. Each of the three models is based on simple approximate formulas presented in Stanton.[1] In the Stanton paper, the formulas for the elongated objects (cylinder and prolate spheroid) are based on a general ("deformed cylinder") model presented in Stanton[2] while the approximate equation involving the sphere is based on the exact solution to the fluid sphere presented in Anderson.[3] The approximate equations can be considered to be estimates, at best, and information is lost when using them, such as the structure of the target strength versus frequency patterns. The original general equation [Eq. (6) in Stanton[2]] predicts the complex patterns for elongated shapes such as with the body of euphausiids and can be used to integrate over size and orientation distribution of the animals. Other "simple" equations have since been published that do indeed predict the structure.[4,5] They cover a wide range of frequencies, have been evaluated for different shapes, and have been averaged over size and orientation distributions.

Regardless of the development of simple approximate formulations that have evolved since 1989, it is incorrect to call the combination of several approximate formulas, two of which were based on the same general formula, a generalization. The new general model under question is less general than the deformed cylinder model presented in Stanton.[2] The deformed cylinder model allows a wide range of elongated shapes to be used (i.e., it is not restricted to just cylinders and prolate spheroids). While the deformed cylinder model is less accurate for spherical shapes, that shape is not required to model euphausiids which are elongated. The deformed cylinder model is valid for all ka (where k is the acoustic wave number and a is the cylinder radius). Furthermore, it is not restricted to homogenous fluid material properties such as the model under question.

(2) The hybrid model requires use of a different shape for different ranges of ka, where k is the acoustic wave number and a is the radius of the sphere or cylinder or semiminor axis of the spheroid. It can be considered reasonable to ignore certain features of the target for low ka which allows use of simpler models in that region. However, the three models used are of similar mathematical complexity. Furthermore, it is stated in paragraph 1 of Sec. III that use of all three models was "required" so that the data could be fit over the range of frequencies (this suggests that the model involving the most complex and realistic shape could not be used to describe all data). With this requirement and using the fact that k is proportional to acoustic frequency, an animal of fixed size is modeled as changing shape as acoustic frequency changes—an approach that has no physical basis.

It is worth pointing out that in Ref. 5, a model is presented that compares well with both numerical simulations and the scattering data involving decapod shrimp (an elongated zooplankton) over a wide range of frequencies. Orientation is taken into account in this model, and the (bent cylinder) shape of the animal is allowed to remain as a bent cylinder regardless of the acoustic frequency.

(3) The function in Eq. (9) used to model the directivity pattern of the scattering is not appropriate, even as an approximation. This function was originally derived to describe the radiation from a finite length line source. The difference between the radiation pattern and scattering pattern from line

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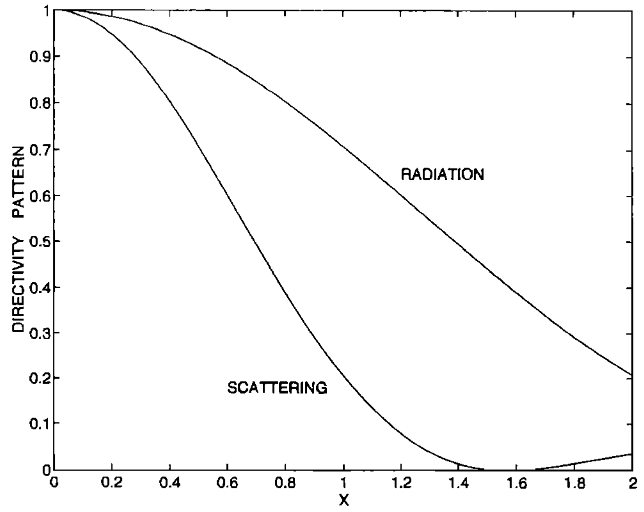

FIG. 1. Comparison between the directivity patterns for the scattering by a finite line object, $[(\sin 2x)/(2x)]^2$, and radiation from a finite line source $[(\sin x)/x]^2$, where $x = \frac{1}{2}k\ L \sin \theta$, k is the wave number, L is the length of each object, and θ is the angle between the direction of the incident wave and the plane whose normal is the axis of the object ($\theta=0$ corresponds to broadside incidence).

objects is significant as the latter has a factor of two in the argument of the sinc function plotted here in Fig. 1. While it is mentioned that the term was used in the work by Kristensen[6] and Kristensen and Dalen,[7] the factor of 2 was inserted into a later paper by Dalen and Kristensen.[8] Note also that the correct forms of scattering by a line object appear in Stanton[1,2] and Urick.[9]

Finally, it is important to point out that the (correct) scattering directivity function for a (straight) line object is not necessarily appropriate for the scattering by these elongated animals whose longitudinal axes are typically bent. The directivity function for a bent cylinder is significantly different from that of the straight cylinder.[5] Variation of floating parameters in Eq. (12) will not produce the correct directivity function for bent cylinders. Rather than parametrizing an incorrectly chosen function to describe the complex body of a euphausiid, a superior approach would be to integrate along the body while allowing the material properties and cross-sectional radius to vary. The deformed cylinder model[2] and distorted wave Born approximation[10] allow such an integration.

(4) One major premise upon which the paper was written involved the (perceived) need to incorporate directivity into various models developed by Stanton. It is stated on p. 2453 that "The models of Stanton[1,2] did not contain orientation as a factor in their formulation." In fact, orientation is incorporated explicitly in those papers for the straight-cylinder geometry [see, for example, Eq. (12) of Stanton[2] and the term s in Table I of Stanton[1]] as well as being taken into account for *all* deformed-cylinder shapes in the dot-product term, $(\hat{r}_i-\hat{r}_r)\cdot\hat{r}_{\text{pos}}$, of the general far-field expression in Eq. (6) of Stanton[2] (where $\hat{r}_i$, $\hat{r}_r$, and $\hat{r}_{\text{pos}}$ are unit vectors describing the directions of the incident and scattered waves as well as position of the integration point along the cylinder axis, respectively). Examples concerning the other elongated shapes in the two Stanton papers involved only broadside incidence. However, the directional properties of the scattering by those shapes can be obtained directly through evaluation of Eq. (6) of Stanton.[2]

Using the broadside-only examples, Macaulay proceeds to incorrectly take directivity into account by using an inappropriate function (see above section).

II. QUESTIONABLE APPROACHES

(1) Equation (5) may represent an attempt to relate density contrast g and sound-speed contrast h. This is not generally supported by data. For example, in Ref. 11 independent measurements involving many live euphausiids reveal density contrasts larger than the sound-speed contrasts, not smaller as predicted by Eq. (5).

(2) In order for the directivity function to fit the main lobe of the backscatter directivity data in Fig. 4, a floating parameter C_1 is inserted in Eq. (9) to produce Eq. (10). The parameter is then varied over the range of angles of orientation for the fit to be satisfactory [discussion after Eq. (10)]. While this practice is sometimes justifiable, it is another indication of the incorrect choice of the directivity function.

III. MISCELLANY

(1) Equations (1)–(3) were incorrectly copied or adapted from Stanton.[1] In each equation, the corresponding ones from Stanton[1] were broken down into a numerator and denominator (part a and b of each equation, respectively). In part c of each equation, the two are combined with the additional division of another term. This latter operation is incorrect because in Stanton,[1] the division is performed on only the second of the two terms in the denominator (third column of equations in Table I of that paper).

Because of this error, the low ka limits of the scattering cross sections result in the product of $\alpha_{\pi s}$ or $\alpha_{\pi c}$ and R which are related to the low and high ka limits of the correct expressions, respectively. [Note also a misleading change of notation of $(\alpha_{\pi s},\alpha_{\pi c})$ in the list of symbols to $(a_{\pi s},a_{\pi c})$ in these equations.] Hence terms specific to two different limits are mixed equally in the same expression. Further illustrating the invalidity of these equations is the fact that the second terms of Eqs. (2b) and (3b) have dimension area which are added to the corresponding first terms ("1") that are dimensionless—an operation that is not mathematically valid.

In conclusion, any calculations using these equations for scattering cross section will result in incorrect scattering predictions. It is no comfort that the predictions using these equations in the paper in question fit the data, because the vast array of floating parameters used in the fitting process could have obscured the errors.

(2) Equation (6), which is intended to relate the radii of a cylinder and sphere of equal volume, is incorrect. The factor 1.5 in the equation should be replaced by the factor 0.75.

(3) In the list of symbols, σ_{bs} should be referred to as the backscattering cross section, not "volume backscatter."[12] Volume backscattering is a term which is used to describe the

scattering by a collection of targets in a given volume, while the backscattering cross section involves an individual target.

(4) Some discussions where object size is compared with the acoustic wavelength are misleading or incorrect. For example, in paragraph 1 of Sec. III, the geometric scattering region is identified as that where "...the ratio of wavelength to target size...approaches or exceeds 1...," where it would have been correct to state that this region is characterized by a very small or vanishingly small ratio.

(5) In describing sound-speed contrast values in Sec. II, comparisons are made to Kristensen and Dalen[7] and Køgeler *et al.*[13] It may be noted that the equation given in Køgeler *et al.*[13] for determining the longitudinal-wave sound speed in krill by a time-of-flight measurement is erroneous; every occurrence of sound speed should be replaced by the reciprocal, as already observed in Ref. 11. (The same criticism applies to the corresponding equation given in Kristensen.[6]) Any connection made to Ref. 13 should be qualified accordingly.

(6) Diel effects, mentioned in Sec. V paragraph 10, were neither compounded nor confounded in the measurements by Foote *et al.*[14] They were combined in the analysis presented in the cited work. Notwithstanding visually observed day–night differences in behavior, which followed the general pattern of aggregation at day and dispersion at night, there was no discernible pattern of diel variation in backscattered energy in these (encaged animal) experiments. The period of darkness was short for the measurements, which were made during the austral summer. At the latitude of South Georgia, about 54°S, the sun remains above the horizon for about 15–17 h during the period late December to early February, with only two hours of nautical twilight at the beginning of the period and five hours at the end.[15] Data were nonetheless recorded as time series, as for investigation of dependencies on extrinsic and intrinsic variables, for example, both light level and behavior or number density.

(7) That the data in Foote *et al.*[14] "are 3–4 dB too low" according to the particular hybrid model, or any other arbitrary model, commented on in Sec. V final paragraph, is hardly remarkable. Use of the fluid-sphere model[16] in Foote *et al.*[14] gave a fair agreement. Application of a finite-length, deformed-fluid-cylinder model[2] to the underlying time series data in Foote *et al.*[14] gave an excellent agreement when the best fit to the two-frequency data pair was used for each time interval, assuming a range of values for the unknown mean and standard deviation of the presumed normal distribution of tilt angle.[10]

(8) A "helpful review by K. Foote" is made reference to in the Acknowledgments section. In fact, K. Foote sent an informal review of a manuscript by Macaulay entitled "A generalized euphausiid target strength model," to the author on 18 September 1990. This review was solicited by a member of the U.S. delegation to CCAMLR. In it, specific comments were made about the "generalized" model, including the inappropriateness of using a radiation model from Kristensen[6] to describe scattering. The comments were evidently ignored in preparing the new manuscript for this Journal. K. Foote did not otherwise see or review the manuscript until after its publication in May 1994.

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