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THE SCALING OF AIR GUN ARRAYS, INCLUDING DEPTH DEPENDENCE AND INTERACTIONS: A CORRECTION[1]

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I wish to report a mistake in my depth scaling paper (Ziolkowski 1986), that was found by Brynjulf Owren of SERES A/S, Norway. This mistake is an error in the expression for the work done by an oscillating bubble, and it leads to incorrect expressions for the scaling of the volumes and pressures of airguns in scaled arrays. The rest of the paper remains unchanged. This note explains the original error and the consequent errors in the rules for scaling airgun arrays.

My original expression for the work done by an oscillating spherical bubble was

$$4\pi \int_0^\infty [P(t) - P_w(t)]R^2(t)\dot{R}(t)\,dt,$$

in which $P(t)$ is the internal pressure of the bubble at time t, $P_w(t)$ is the external pressure at time t, $R(t)$ is the bubble radius, and the dot indicates the time derivative. Brynjulf Owren pointed out that this is wrong. The work done by the bubble against the external pressure $P_w(t)$ is simply

$$4\pi \int_0^\infty P_w(t)R^2(t)\dot{R}(t)\,dt.$$

Equation (6) in the paper should then be

$$\eta E = 4\pi \int_0^\infty P_w(t)R^2(t)\dot{R}(t)\,dt. \tag{6}$$

This does not change the argument or the conclusions of the paper, but it does slightly change the way in which the scaling should be carried out in practice.

Appendix A remains the same. Appendix B remains the same as far as (B17), but (B18) and (B19) should now be

$$W_1 = 4\pi \int_0^\infty P_{w1}(t)R_1^2(t)\dot{R}_1(t)\,dt, \tag{B18}$$

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and

$$W_2 = 4\pi \int_0^\infty P_{w2}(t) R_2^2(t) \dot{R}_2(t)\, dt. \tag{B19}$$

Then (B23) becomes

$$W_2 = 4\pi \int_0^\infty P_{w2}(\alpha v) R_2^2(\alpha v) \frac{dR_2(\alpha v)}{dv}\, dv. \tag{B23}$$

Using (B7) and (B14), (B24) becomes

$$\frac{W_2}{W_1} = \beta X^3. \tag{B24}$$

Then the argument continues unchanged as far as (B30). But then using (B30), the energy assumption (B17), and (B24), (B31) becomes

$$\alpha Y^2 = \beta X. \tag{B31}$$

Solving (B16) and (B31) for X and Y now yields

$$Y = \beta^{2/3}, \tag{B32}$$

and

$$X = \alpha\beta^{1/3}. \tag{B33}$$

Thus (B34) and (B35) now become

$$R_2(\alpha t) = \alpha\beta^{1/3} R_1(t), \tag{B34}$$

$$P_2(\alpha t) - P_{w2}(\alpha t) = \beta^{2/3}[P_1(t) - P_{w1}(t)]. \tag{B35}$$

The remainder of Appendix B stays the same. In particular, the dimensionless quantities are defined in the same way and the dimensionless equation of motion remains the same.

However, this now changes Appendix C and Appendix E. Appendix D and Appendix F remain the same. In Appendix C – The Initial Conditions of Two Scaled Bubbles – (C1) becomes

$$R_2(\alpha t) = \alpha\beta^{1/3} R_1(t). \tag{C1}$$

Therefore, when $t = 0$,

$$R_2(0) = \alpha\beta^{1/3} R_1(0), \tag{C2}$$

and since

$$V = 4/3\pi R^3, \tag{C3}$$

$$\frac{V_2}{V_1} = \alpha^3\beta. \tag{C4}$$

This is the new expression for the volume scaling. Equation (C5) is the same as the new (B35), and (C6) now becomes

$$P_2(0) - P_{H2} = \beta^{2/3}[P_1(0) - P_{H1}], \tag{C6}$$

or

$$P_2(0) = \beta^{2/3}[P_1(0) + P_{H1}(\beta^{1/3} - 1)], \tag{C7}$$

which is the new expression for the pressure scaling.

In Appendix E the only changes are to (E14) and (E15) which now become

$$\frac{V_{si}}{V_i} = \alpha^3\beta \tag{E14}$$

and

$$P_{si}(\alpha t_i) = \beta^{2/3}[P_i(t_i) - P_{Hi}(\beta^{1/3} - 1)]. \tag{E16}$$

In the main text of the paper (12) and (13) now become

$$\frac{V_2}{V_1} = \alpha^3\beta \tag{12}$$

and

$$P_2(0) = \beta^{2/3}[P_1(0) + P_{H1}(\beta^{1/3} - 1)], \tag{13}$$

because these are the same as (C4) and (C7).

The conclusions of the paper remain unchanged, including all the geometrical relations. The revised way in which the volumes and initial pressures of the guns should be scaled, as described by (12) and (13), is presented here.

Reference

ZIOLKOWSKI, A.M. 1986. The scaling of airgun arrays, including depth dependence and interactions. *Geophysical Prospecting* **34,** 383–408.