# MATTERS ARISING

## Leaping dolphins

THE analysis of leaping dolphins by Au and Weihs[1] has some shortcomings. The expenditure of energy during shallow high-speed swimming is presumably correct, although one wonders why a dolphin would not spend at least some time at greater depths if a 4.5-fold decrease in drag can be obtained by going down a metre or so. However, the computation of energy loss during a leaping manoeuvre seems to be at fault. Neglecting spray effects initially, the extra energy required for jumping is given as $WH$ which is the energy required to raise a dolphin of weight $W$ to a height $H$. However, the energy expended in raising the dolphin against gravity is not lost, but is partially transformed into potential energy at the high point and back to kinetic energy on returning to water-surface level. The dolphin has the same total energy throughout the leap and re-enters the water with the same speed as it had when it emerged. The total loss of energy is zero.

The spray effect, for which an energy loss of $mWH$ is given, has also been computed incorrectly. A dolphin of weight $W$ carries along with it an additional weight of water $mW$ and on leaving the water it leaves this behind in the form of spray. This does not in fact concern the dolphin until it re-enters, when it has to accelerate a similar mass of water up to its swimming speed ($U$), and so experiences a brief retarding force and a loss of kinetic energy. The loss of energy is clearly $\frac{1}{2}mWU^2/g$, where $g$ is the gravitational constant, and is independent of the angle of the leap. Thus the total energy lost is $\frac{1}{2}m\rho_d VU^2$, where $V$ and $\rho_d$ are the volume and density of the dolphin, respectively, and not $\frac{1}{4}(1+m)\rho_d VU^2$ as the authors claim. They seem to have overestimated the energy loss by a factor of $(1+m)/2m = 3$.

Further, there are more general considerations which could significantly affect the result. It seems unlikely that the dolphin would swim close to the surface between leaps, one reason being the difficulty of launching itself upwards at an angle of 45° from this shallow position. This would require the application of large vertical forces by the fins, of a magnitude several times its own weight. It is more likely that the dolphin follows a sinuous path consisting of leaps out of the water interspersed by dives under the water of a similar shape, thus achieving a clean exit and entry, greatly reducing drag by going deeper while submerged, and presumably breathing while out of the water. It is this total 'flight path' which should be compared with steady shallow swimming in the no-leap case.

Finally, it is unlikely that a dolphin would leap at an elevation angle as great as 45° because of the resulting loss of speed. A dolphin leaping and diving at this angle reduces his forward speed to about 70% of his speed through the water. Reducing this angle has a small effect on the length of leap, which varies as $\sin 2\alpha$ where $\alpha$ is the elevation angle, but gives a significant improvement in forward speed, which varies approximately as $\cos \alpha$. A better compromise seems to be about 30°, and this is more in accord with my recollections of leaping dolphins.

C. N. GORDON

*General Research Corporation, Santa Barbara, California 93111*

1. Au, D. & Weihs, D. *Nature* **284**, 548–550 (1980).

### Matters Arising

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AU AND WEIHS' REPLY—Gordon's comments on the calculation of energy consumed during the leap, as well as the manner of leaping, are well taken. We originally considered a model such as his symmetric parabola, but adopted our model because we observed shallow, brief swimming between long leaps after the dolphins shifted to the running mode. Therefore, we treated the problem of comparing the cost of shallow swimming with a jump from and to a shallow depth. The potential energy of the leap would not be useful to the dolphin trying to maintain a shallow swimming depth and must be dissipated in the re-entry splash and turning forces necessary to maintain that depth. Our energy loss $J$ is exactly that required to keep the animal from plunging deeper. We suggested that the shallow swimming was due to requirements of increased respiration. Gordon's treatment of the overall problem is relevant to the case of sinuous motion whereas our treatment is based on our observations of saltatory motion.

Gordon's approach to calculation of energy loss due to added mass is more accurate than ours. It would result in a 5% increase in the crossover speed $U_c$ at most.

We believe the centre of mass during the leap approximates a parabola with 45° exit angle that maximizes leap length, both because of the great increase in leap length over that occurring during cruising speed and because photographs often suggest a 45° exit. There is often a steep rise out of the water followed by a flattening-over of the body angle once exited that may give the appearance of a lesser exit angle. The difficulty of leaping from, and returning to, a shallow subsurface depth is acknowledged, but we have not seen the kind of motion Gordon postulates. Perhaps the constant extension of the dolphin's pectoral fins during the entire leap, from exit to re-entry, is explained by the manner of locomotion we describe. The pectoral fins probably act as diving planes to redirect the body angle between leaps and this must contribute greatly to the characteristic splashing. We agree that our differences should be resolved with more careful observations and measurements of this difficult-to-observe behaviour.

Finally, we apologize for an error in the last equation of our letter[1] which should read: $U_c^2 = 65.3V^{1/3}$.

D. AU

*Southwest Fisheries Center, NMFS, La Jolla, California 92038*

D. WEIHS

*Technion, Haifa, Israel*

1. Au, D. & Weihs, D. *Nature* **284**, 548–550 (1980).

## Climatic warming of the West Antarctic ice sheet

IN our paper on the "Effect of climatic warming on the West Antarctic ice sheet"[1] we included an analysis of the state of equilibrium of the Pine Island and Thwaites glaciers, which drain the northern part of the ice sheet. Our conclusions concerning these glaciers were the result of our own analysis of available data, but we should point out that attention was first drawn to the Pine Island and Thwaites glaciers by Hughes[2,3]. Moreover, hypothetical Eemian collapse of the West

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