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Opinion



# Bottlenose dolphin hydrodynamics research

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## Opinion

For decades, physicists and biologists have declared that dolphin speeds of 25 mph were impossible given water density and the amount of muscle dolphins possess. In the 1930s, a colleague of British Zoologist Sir James Gray observed dolphins swimming at 23 miles per hour. Gray calculated how much energy a dolphin needed to do this and compared this with his knowledge of muscles. His calculations revealed that a dolphin requires 7 times more muscle than it has to swim 25 mph. This conundrum came to be known as "Gray's Paradox". Gray concluded the power a dolphin could exert based on its physiology was insufficient to overcome the drag forces in water. He hypothesized that a dolphin's skin must possess anti-drag properties. In the 70 years that followed, the mystery was to figure out how dolphins obtain high speed acceleration with a small muscle mass. For years, I have been interested in knowing how fast dolphins swim, and how they move through the water. I have been fortunate to conduct research working with open-ocean trained, captive dolphins outfitted with comfortable, light-weight vests which house a small, light weight, high definition video camera.

Data collected thus far, including surface photography, and underwater high definition video footage, have provided answers to many initial questions while providing opportunities for further studies, such as, dolphin burst speeds used in catching fast swimming fish and/or avoiding predatory attacks. It's not until looking at images frame by frame, that we see what wonderful examples of natural design dolphins truly are. The information and photographs provided in this article were taken from lecture notes, surface and underwater photography, and isolated video sequence imagery obtained utilizing open ocean trained dolphins. Numerous websites state average dolphin swimming speed ranges between: 3 - 7 and 7 - 8mph. My research findings are provided below.

a. **Average casual swim speed:** revealed dolphins traveling, in the open ocean, at 40 feet every two 2 seconds. This calculates into an average casual swimming speed of 13.6mph.

b. **Fastest casual swim speed:** revealed the same dolphins traveling at 42 feet in 1.8 seconds. This calculates into an average fast casual swimming speed of 16.1mph.

c. **Burst speeds:** at the time of this writing, burst speeds appear to be in the 35 - 40mph range but more testing is required.

### Dolphin fluke shape

As the tail moves up and down, it produces thrust which is then channeled into forward movement. Frank Fish, a biologist at West Chester University in Pennsylvania placed dolphin flukes through CT scans to examine shape and determined that as flukes bend their geometry changes into an arch. This arch is crucial for one split second of every stroke at the exact moment it changes between up and down. Dolphins, therefore, never lose thrust and, thus, can successfully maintain continuous forward momentum. In 2008, researchers from Rensselaer Polytechnic Institute, West Chester University, and the University of California, Santa Cruz used digital particle image velocimetry technology designed for the aerospace industry to measure fluid velocity. This technology is used for solving fluid dynamics problems. By videotaping dolphins at 1,000 frames per second swimming through a section of water filled with hundreds of thousands of air bubbles they were able to measure exerted force. These results showed a dolphin exerts approximately 200 pounds of force every time it thrust its tail and at peak performance exerts between 300 - 400 pounds of force. This is 10 times more than Gray hypothesized in the 1930s.

### Tail flukes

Assuming the researchers from Rensselaer Polytechnic Institute, West Chester University, and the University of California, Santa Cruz are correct that dolphins exert a peak force of 200 – 400 pounds of pressure when swimming, I researched how tail flukes managed this force. I also hoped to answer another question. Have you ever wondered why dolphin tail flukes contain no bones? Dolphin pectoral fins contain remnants of bones like those in the human hand, so how come tail flukes don't contain remnants of bones like those in the human foot? Through high definition photography, I captured how incredibly flexible tail flukes are. In action, tail flukes resemble bird's wings in flight which maintain a high degree of flexibility under extreme stresses, the two shapes in action are similar in shape. When a dolphin exerts 200 - 400 pounds of peak force, flukes must be flexible enough to take advantage of, and handle these stresses. If tail flukes contained bones they would limit movement because bones retard flexibility, and they would complicate the physics of dolphin swimming. When dolphin tail flukes oscillate to provide forward propulsion, fluke muscles allow the fluke to bend because it contains no bone. Simply put, bones would not allow the degree of flexibility dolphins require. Photographs below shows the stress on falcon wings at the end of a stoop, and dolphin flukes during a bow take off (Figure 1).

### Tail fluke flexibility

Images reveal a 500-pound dolphin's tail fluke flexibility at peak force during a tail walk (Figure 2).

**Figure 1** The stress on falcon wings at the end of a stoop, and dolphin flukes during a bow take off.

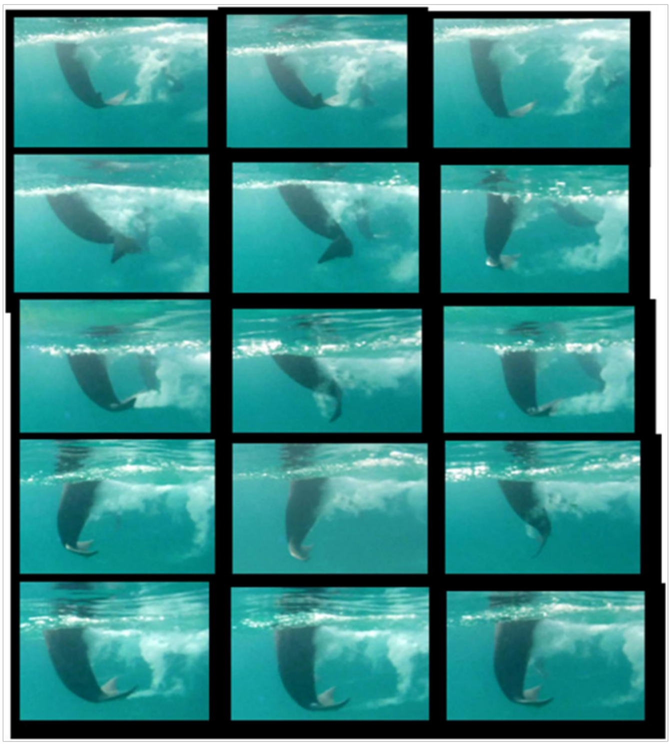

**Figure 2** I believe these images support claims made by Rensselaer Polytechnic Institute, West Chester University, and the University of California, Santa Cruz.

## Dolphin Skin

Scientists know dolphins evolved streamlined bodies to reduce the pressure of water against their skin (known as form drag) as well as reducing friction drag. Until recently no one knew that soft flaky dolphin skin, which is shed every 2 hours, plays a vital role in reducing drag allowing dolphins to travel faster and further. In 1977 a Russian experiment was conducted with a group of women who volunteered to be dragged naked through the water to see if ripples caused in soft human skin would smooth water flow. It did not! It's not clear exactly what they hoped to accomplish? I can only assume this experiment was an attempt to compare the drag properties of human and dolphin skin?

In 2004 to understand the role of dolphin's soft, flaky skin, Professor Yoshimichi Hagiwara from the Kyoto Institute of Technology in Japan devised a detailed computer simulation to model water flow over a dolphin's skin. This model examined every individual flake of skin and the way it peels off. The results found the shedding of skin reduces friction drag by disturbing the tiny whirlpools of water called vortices that occur in the water flow around the surface of a fast swimming dolphin which would otherwise slow it down. With migratory species like dolphins the goal is not go faster but to go further while expending the least amount of energy (Figure 3).

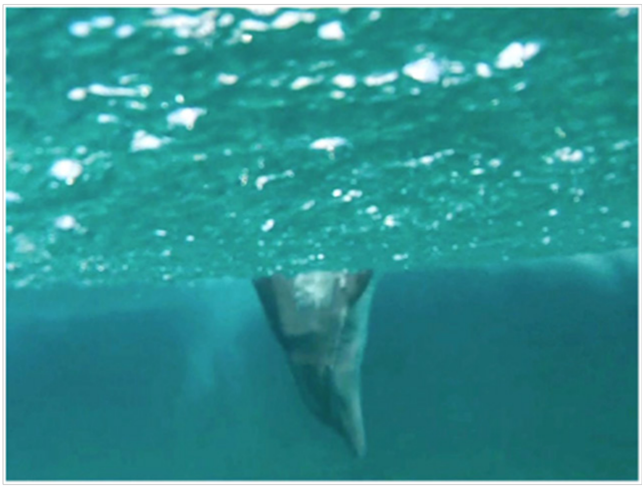

**Figure 3**

## Shedding Skin Diffusing Turbulence and Reducing Drag

The following images provide excellent examples of Professor Hagiwara's research (Figure 4).

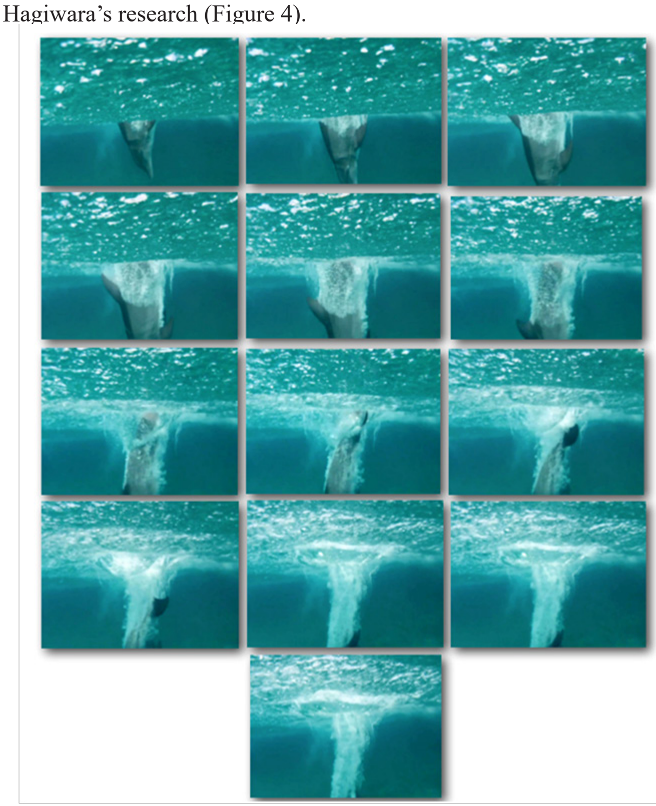

**Figure 4** Examples of Professor Hagiwara's research.

## Boats and Dolphins

Anyone working with dolphins is well aware of the common question, why do dolphins follow boats? Research revealed a possible answer to this question. It has everything to do with hydrodynamics, the physics of swimming, energy conservation, and less to do with dolphins swimming alongside a boat to say hello!

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The easiest way to explain this is, the movement of water around the hull of a moving boat, creates lift and push at the bow, slipstreams along both side and a strong following pull at the stern. Dolphins have learned to harness this "free" energy and take advantage of the opportunity to rest while being either pushed or pulled, depending where they locate themselves, by the movement of water created by a boat in motion. What I discovered when motoring at 20 - 25 mph is that dolphins have no problem staying in the sweet spot where the least drag exists. When speeds approached 30 – 35 mph however, they found it either uncomfortable, too much effort, or both and would break off and fall behind. When I reduced speed they would quickly regain their position in the sweet spot.

## Three contributing factors

1. Pressure drops in areas of high speed resulting in an attractive force between a dolphin and a boat.
2. Boat motion creates a displacement effect by causing water at the bow to move forward and outward, while water behind moves forward to replace boat mass.
3. The larger the boat equals greater the mass.

Dolphins learn to harness this phenomenon known as "drafting" at an early age, the ability to recognize and use a slipstream is critical to calf survival. Drafting enables adult dolphins to help their young by reducing the forces required of the young for swimming. Those of us that have observed calves swimming alongside mothers have witnessed this. Several separate hydrodynamic effects combine to produce this interaction. Under ideal conditions, drafting counteracts a large part of the drag experienced by neonate calves.

Dolphins have proven to be positively hydrodynamic. During my ocean research experiments, I observed natural hydrodynamics combined with aerodynamics originally discovered by

Professor Hagiwara.

## Any moving object - bird or dolphin - splits the medium through which it passes

### Bow Riding

These images reveal a dolphin comfortably drafting at 20 mph with little effort other than to make minute adjustments to stay in the "sweet spot" near the bow. They will travel miles on end in this manner, it's all about conserving energy (Figure 5).

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## Acknowledgements

None.

## Conflicts of interest

None.