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Swimming Speed of a Pacific Bottlenose Porpoise

Abstract. *Four kinds of speed runs showed a Pacific bottlenose porpoise (*Tursiops gilli*) to have a top speed of 29.9 kilometers per hour (16.1 knots) for 7.5 seconds and a top speed of 21.9 kilometers per hour (11.8 knots) for 50 seconds. These results compare closely with highest predictions based upon rigid body drag calculations, the same power output per unit body weight as for athletes, and a propulsive efficiency of 85 percent.*

Many observations of the speed of porpoises have been made from shipboard (*1*), and analysis indicates unusually high power output or unusually low drag (*2*), or both. Some of these observations indicate various types of assisted locomotion (*3*), where the animal obtains thrust from ship waves. Such field observations are always difficult to interpret in terms of exact speeds, so tests with calibrated instrumentation under controlled conditions are needed.

In 1960, speed tests were conducted on a Pacific striped porpoise (*Lagenorhynchus obliquidens*) in a 97-m tank (*4*). Top speed was only 27.9 km/hr (15.0 knots), which indicates nothing unusual in performance.

On 24 March 1964 a Pacific bottlenose porpoise (*Tursiops gilli*) was captured in Hawaiian waters. This animal (Fig. 1), an approximately 3-year-old male named Keiki, was trained by conditioned-response techniques to swim at high speed in open water and to return upon command (*5*). He weighed 89 kg and was 191 cm long.

Four types of speed runs were conducted from August to December 1964, two in an enclosed lagoon racecourse and two with a speedboat in the ocean. The lagoon runs took place in 3 m of sea water in the 300- by 35-m lagoon at Coconut Island, in Kaneohe Bay, Oahu, Hawaii. The speedboat runs were conducted off Oahu, near Rabbit Island, and in Kaneohe Bay.

Lagoon runs were made by stationing Keiki inside a 9.3- by 9.3- by 3.1-m chain link pen which rested on the bottom of the lagoon. With one side of the pen open, Keiki was stationed under his trainer's hand at the back of the pen. When the hand was lifted, Keiki accelerated toward the entrance. As his snout passed over it, a timer was started and simultaneously an audible "start signal" was projected underwater to the animal. The porpoise raced the entire length of the 61-m course underwater, crossing a submerged finish line. If the run was of acceptable speed, as indicated on a timer at the finish line, a police whistle was blown and a reward of three fish was given. If the run was unusually fast, six fish were given simultaneously. An underwater recall signal returned the animal for another run. If the animal appeared tired, which would usually be indicated by an increased rate of respiration, a rest period of 5 minutes then ensued. Incorrect behavior was punished by "limited hold or time-out periods" of varying length.

The maximum speed recorded for this test was 29.9 km/hr (16.1 knots) on two runs. Several other runs were in the range from 28.2 to 29.9 km/hr (15.2 to 16.1 knots). During such runs the animal swam partly on its side less than 1 m underwater, seemingly watching the nearby buoy line that marked the course. Though its tail never broke surface, each tail beat was evidenced by a discrete boil on the smooth surface. Spacing of tail beats varied from 0.85 to 1.15 body lengths at a beat rate of about 2.5 per second. On fast runs, swimming was continuous without glides and very straight from start to finish.

The next series of speed runs was conducted offshore of Oahu and consisted of Keiki pacing or overtaking a homing signal transmitted from a moving speedboat (*5*). The tests took place along a 320-m course marked by buoys spaced 15 m apart along an anchored steel cable. The same cage that was used in the lagoon tests was moored nearby and used to house Keiki. Data were recorded from the top of nearby Rabbit Island with a 16-mm Bell and Howell motion-picture camera. The camera was held stationary when Keiki entered one edge of the frame and moved quickly to the next position as he reached the opposite side of the frame.

Frame rate was recorded for each run. Walkie-talkie radios were used for communication between stations. The data were reduced, boat length being used as the length scale, frame rate as the time scale, and the numbered buoys as stationary markers. Keiki was difficult, and generally impossible, to see in the data films when he was underwater. Fortunately, he made several jumps in each test run, so most records were taken during these jumps. Average sustained speed was obtained from elapsed time between jumps. Two outboard boats were used, each capable of high speed. The measured speed of the animal was corrected (increased) for jump height to obtain true speed at water exit. The correction varied with speed and jump height, but was normally around 2.8 to 3.7 km/hr (1.5 to 2.0 knots).

Water currents along the course were measured with a Price current

Fig. 1. Side view of Keiki. The measure at the top of the photograph is a yardstick.

meter at low and high tide. Typically the current ran 0.5 knots from SSE at high tide, and the same from ESE or ENE at low tide, both tidal currents tending to quarter across the course. In view of the small magnitude and the direction, no corrections in ultimate speed were made.

Highest recorded speeds were 26.8 km/hr and 26.9 km/hr (14.4 and 14.5 knots), with several other values ranging from 23.8 km/hr to 24.9 km/hr (12.8 to 13.4 knots). Maximum sustained speed between jumps was 19.0 km/hr (10.2 knots) for 6.6 seconds. During all runs Keiki spent some or most of his time swimming in the bow wave, or aft in one of the spilling waves of the wake, doubtless obtaining some thrust from the pressure field of the boat or from the wake.

In view of the many subjective impressions of porpoise swimming speed that have been recorded, it is worthwhile to note that observers of these open-sea runs, including participants, guessed Keiki's speed to be more than 20 knots. The rough sea and the buffeting of the crew as the boat crashed from crest to crest added to the impression of speed. The porpoise was often outpaced by the boat, so recorded speeds may be near maximum for these conditions.

The third test series was run in Coconut Island Lagoon. A homing signal was transmitted from an underwater speaker about 89 m downcourse from Keiki's pen, and a stopwatch was started when he reached a point 4.0 m downcourse. Keiki received a reinforcement that varied from one fish for slow runs to six fish for the fastest runs. The top speed recorded for the 61-m racecourse was 23.2 km/hr (12.5 knots). Moving pictures taken at the finish line from a 3.7-m tower indicated a slowing of about 3.7 km/hr (2 knots) near the end of the run. Further training might have achieved better overall times, but it was decided, instead, to try a fourth and more promising technique.

For the last series of tests, a speedboat was equipped with a calibrated speedometer, and Keiki simply swam with the boat at various preselected speeds until he fell behind. Visual observations of Keiki's position and of boat speed were recorded on a portable tape recorder. The tape speed was accurate within 1 percent and the boat speedometer was calibrated by running each way at various speeds over a measured course. Keiki could remain with the boat for extended periods at a speed of at least 11.1 km/hr (6 knots), for 50 seconds at 21.9 km/hr (11.8 knots), and for 10 seconds at 25.2 km/hr (13.6 knots). In general, he swam under the bow of the boat or in the first stern wave. Obviously he obtained some assistance from the boat until he could no longer keep up. Although there is no way we could be sure that he did or did not exert maximum effort, he appeared to be strongly motivated to stay with the boat, much like a dog chasing an automobile. Keiki blew much more frequently after the faster runs, so he was given a rest period between runs until respiration rate appeared normal.

A detailed analysis of Keiki's body and appendage drag was conducted with methods applicable to conventional rigid bodies (*6*) in which the boundary layer is predominantly turbulent and the surfaces are smooth. Numerous measurements of Keiki were taken and photographs obtained to aid in the hydrodynamic analysis. Corrections were included for interference drag at the intersection of the body and the appendages. The calculated drag-area coefficient (drag/dynamic pressures) was 0.0644 at 29.9 km/hr (16.1 knots) where the length Reynolds number is 14.2×10^6. If his power output per unit body weight was the same as that of athletes (*7*) and his propulsive efficiency 85 percent, Keiki could travel 26.8 km/hr (14.4 knots) for 7.5 seconds, 25.8 km/hr (13.9 knots) for 10 seconds, 21.4 km/hr (11.5 knots) for 50 seconds, and 12.8 km/hr (6.9 knots) for a 24-hour day. The experimental results showed a top speed of 29.9 km/hr (16.1 knots) for 7.5 seconds, 25.2 km/hr (13.6 knots) for 10 seconds, 21.9 km/hr (11.8 knots) for 50 seconds, and at least 11.1 km/hr (6 knots) for an indefinite period. Consequently the experimental results compare closely with predicted turbulent values for this animal.

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