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Whales, Porpoises and the U. S. Navy

By

Raymond M. Gilmore

The far-flung activities of the U. S. Navy now include serious studies of whales and porpoises.

These studies center on 1) the confusion of whales and porpoises with military targets; 2) the swimming of whales and porpoises in relation to the dynamics of solid bodies passing through water.

Actually, at no time since the start of World War II have the studies ceased; but, at times they have been slow, and in many fundamental aspects have shown little progress. Now, they are more intense than ever.

It is hard to realize that whales are anything more than nautical curiosities to the Navy and an occasional hazard in the course of a ship; but whales may possibly be mistaken for submarines; and the Navy has to learn biology and oceanography, which include whales and porpoises, i.e. cetology.

In World War II, whales fouled up the sonar-gear of Navy search-craft so much, and confused so many visual contacts from surface, or from the air, that the toll of these peaceful, harmless creatures was high. In addition, trigger-happy air-men often used whales as targets even as late as 1958 off Santa Barbara, California, on migrating gray whales close to shore.

A special «Royal Order of Whale Bangers» was issued in the last war to mistaken gunners or to depth-charge officers; and, a Navy brochure on «The Ways of Whales», written by their Intelligence Department, stated that «.... certificates similar to those given to «Shellbacks» and «Blue Noses» were awarded to crews which tracked and fired on whales instead of submarines». With the compulsion of Americans to be joiners, this could have been hard on the whales.

The attention of the world was focused in early 1960 on the difficulty of identifying underwater targets, when the Argentine Navy, aided by specialists flown from the U. S., failed to determine the nature of a mysterious object which they thought was a foreign submarine trapped in the Golfo Nuevo, about 800 miles south of Buenos Aires.

The Russians laughingly said it was not one of their submarines. It might not even have been a military target. It could have been a large basking-shark, 20 to 30 feet long, or a whale-shark, 30 to 40 feet long. It was not a whale, else it would have surfaced often and regularly, which no human observer saw it do, day or night.

Some false alarms of foreign submarines off the coasts of the U. S. recently, however, have been later claimed [illegible] to have been whales; and, in any case, such a matter is no longer a joke to the U. S. Navy. Nuclear warheads on the present anti-submarine torpedo-missiles cannot be wasted as could the 50-caliber machine-gun bullets and even depth-charges formerly; nor, can the risk of massive contamination of the sea be taken lightly. The Navy must be sure, now, before they push the button to fire. Are they? A «homing» torpedo, by the way, built to guide ~~only~~ on a metalic object and finding ~~only~~ a whale which does not attract, could have an interesting course subsequently.

Whales not only resemble submarines in their form as seen from the air by planes, but also in their echo of sound-impulses sent out by surface-craft and helicopters trailing transducers; and also in their own sounds, or vocalizations.

Porpoises can make a variety of sounds; and can swim at, or near, the surface towards a ship frighteningly like a torpedo, especially at night in a phosphorescent sea. Many a bridge-watch in the last war froze at such a sight; and some, before they looked twice, even signaled fullspeed astern, or, hard-over on the wheel — with a strident clanging of bells ringing «battle stations» through a previously silent ship in a false alarm.

Whales, as seen from aircraft, can be distinguished from the *usual* submarine by the presence of horizontal tail-fins; but the new nuclear submarines also have horizontal vanes astern — identical in position and triangular form to the flukes of a whale, and, of course, the new submarines, beginning with the controversial Albacore which was built over the opposition of many Navy men, all have the rounded, blunt fore-end of the whale. The Albacore, by the way, though diesel-powered, had such great speed and acceleration that it could throw the crew off their feet.

Some whales, however, have a narrowly constricted and elongated head, and one, the sperm whale, has an elongated cylindrical head. A second or third look may be necessary to identify the target; and, this look might even identify the species of whale — as one that is expected in the area!

The size of the larger whales approaches that of the smaller subs; and, from a great altitude, accurate estimate is difficult.

Many blue whales attain 80 and 85 feet. Stories of 100-foot blue whales are common, but the animals themselves are elusive.

The finback whale grows to an adult size of 60 to 80 feet; the right and Arctic right whale, from 45 to 60, possibly 65 feet. The sei whale is from 40 to 55; the humpback, 38 to 50, the gray whale likewise.

The Soviet coastal-class submarine is only 135 feet, the midget Japanese submarines were only 30.

Rarely, a whale will slide along at the surface barely awash, with a ripple at the dorsal fin like a periscope, or the snorkel, of a sub, with the body-form vaguely seen below. Here it is important to know details of behaviour as well as form.

The most important behaviour of the whale to distinguish it from a sub, is a rhythmical alternation of diving and surfacing for breathing. Most whales dive and stay below the surface 3 to 8 minutes; and, between these deep dives, they surface for a minute or so to blow 3 to 5 times, with a short and shallow dive between blows. This rhythm can continue hour after hour as the animal feeds and moves around, or migrates.

The submarine has no similar short-period rhythm of diving and surfacing.

On the longer and deeper dive of the series, the whale disappears from the sight of an air-patrol; and, it may also disappear momentarily on the short, shallow dives, but, this is by no means always the case. It depends upon the clarity of the water, the angle of vision, and the angle of the sun. However, a whale may often be seen throughout the entire series of its short, shallow dives.

As the whale bends the body and changes the course of its swimming in an arc at the surface on each rise, it often extends the flippers. These may be short and resemble huge ears, or moderately long and spear-shaped, or, even be greatly elongated, as in one species, the humpback, in which their length of 12 to 14 feet and angle to the body make them look like the swept-wings of a jet. But they never are as far forward as are the steering vanes of a sub.

Depth of diving is also characteristic not only

Fig. 1. Gray Whale, seen from the air with blow from exhaled breath drifting behind, but head still peaked for inhalation as muscle bunch to hold nostrils open. Flippers are close to sides. (Gråhval sett fra luften. Hvalen har blåst og dampen driver bakover. Hodet er ennå hevet for at hvalen skal kunne puste inn. Musklene bunter seg for å holde blåsehullene åpne. Sveivene holdes tett inntil sidene.) San Diego.
Photo by Raymond M. Gilmore.

of whales as compared with submarines, but of the species of whales, and is related directly to the time of diving. We are speaking now about the normal feeding, or swimming, dive, not the short, shallow dive as between a series of blows at the surface.

The baleen whales, or whalebone whales have a 5 to 10-minute dive which rhythmically alternates with 3 to 5 blows over a minute at the surface; and, the normal depth of such a dive in these baleen whales is perhaps 200 to 500 feet.

Below 500 feet, of even 400 in upper latitudes where the angle of the sun is low, it is too dark to see food; and the short diving time prevents the whale from going much further down and still have sufficient time for feeding. Luminescence of some planktonic foods could help the whale locate them at these dimly lit levels — and anywhere at night.

The sperm whale and the bottlenose however, dive for longer periods and to greater depths, and stay at the surface for longer periods, breathing more times between short, shallow dives. Thus, underwater, they can be more easily confusible with submarines.

The sperm whale dives to 3000 and even 3500 feet regularly and normally in search of deep-lying, large squid, and stays down an hour, more or less, in the daytime when we can observe and time it. Presumably similarly deep diving occurs at night when, of course, all is darkness below 500 to 1000 feet, no matter what the hour.

The bottlenose whale normally stays down probably 15 to 30 minutes, though I know nothing definite on this matter except for the Pacific bottlenose, *Berardius*, which presumably then goes to a depth of at least 1000 and perhaps 2000 feet. A story of a dive of two hours by the Atlantic bottlenose Hyperoodon, widely, quoted, needs confirmation.

The deep diving of the sperm whale that is also called the cachalot, has been revealed by accidents over the past 30 years in which a sperm whale fouled a submarine-cable and, in its titanic struggles to free itself, broke, or damaged, the cable and interrupted the communication before it drowned. A cable-ship, out to make repairs, then found the dead sperm whale tanglea in the cable at a precisely known depth.

There are four of these records of diving for sperm whales that had fouled cables; and all were made along the steep and deep west coast of South America where the cable lay close to shore, and where sperm whales were abundant.

All records were summarized by Heezen (1957). Those that were definitely sperm whales were: 2820 feet (470 fathoms), 3270 feet (545 fathoms), 3360 feet (560 fathoms), and 3720 feet (620 fathoms). The record of 3270 feet first appeared in the New Bedford Standard and later as a reprint in the Nantucket Inquirer and Mirror for 9th April 1932, where it received much attention.

Interestingly, Heezen is a geologist and was searching the records of all cable-breaks and interruptions, for those caused by earthquakes and submarine landslides. William Schevill, the cetologist of Woods Hole Oceanographic Institution, had already started a search on his spare time for breaks caused by whales and the recovery of bodies, but relinquished his priority to Heezen who was subsidized [redacted] and could complete the search without interruption until finished.

Water-pressure increases one atmosphere, or 14.7 pounds per square inch for every 33-feet of depth; and there is one atmosphere of air-pressure at the surface to begin with; so, it is easy to figure out the pressure at each depth given above for diving of the sperm whale.

It is the number of units of 33-foot depth, times 14.7, plus another 14.7 for the air-pressure. At 3720 feet this is 1710 psi, or 122.5 short tons per square foot on the body of the sperm whale.

The great depths of diving by the cachalot probably exceed those of any submarine, though such data are classified. Also a sperm whale swimming along at intermediate depths could jolly well confuse the issue, even though the sperm whale eventually, within an hour or so, must come to the surface to breathe, while the submarine does not.

In echo-ranging, or sonar-searching, for underwater targets, the human operator has difficulty in distinguishing whale from sub.

Despite cases of anechoic whales, that is, those that do not return an echo, whales may do so under favourable conditions, especially at close range. This echo, however, may be faint, or loud and clear, and with or without Doppler effect, which is a shift in intensity according to the movement of the target in relation to the surrounding water. There may be an echo off the wake of the whale, always without Doppler.

Whales not only return an echo at close range under favourable conditions, but they make noises of their own; and porpoises are veritable chatterboxes of the sea.

The hydrophones of sonar at 14 and 31 kilocycles, and even those of echo depth-finders at 18 kc., often pick up vocalizations of porpoises as a cacophony of squeals, whistles, squeaks, creaks, roars, buzzes, grunts and groans, as well as chattering of teeth.

The frequencies of these sounds actually range from 5000 to 100,000 cycles per second; and some have reached 197 kc. Of these, only those below 15,000 to 20,000 cycles are in the human sonic range, and hence heard without special instruments.

For many years, sounds of porpoises audible to a human-ear nearby on the prow of a ship, or alongside a stranded individual, plus the obvious fact that sound was the only possible means of communication under water for long distances, put the finger on vocalizations in cetaceans. However, not until W. E. Schevill and his wife Barbara Lawrence of Woods Hole Oceanographic Institution took a hydrophone and a tape-recorder to the Gulf of St. Lawrence and, among the well-known herds of white porpoises, or beluga, at Tadoussac on the lower parts of a tributary, the Saguenay River, obtained a record of such vocalizations, had anyone measured accurately the frequency and pitch-patterns, or the «melodies» as W. N. Kellogg of the Oceanographic Institute of Florida State University has described similar sounds.

Schevill and Lawrence found this Arctic white porpoise, *Delphinapterus leucas*, to make «. . . .high pitched resonant whistles and squeals, varied with ticking and clucking sounds slightly reminiscent of a string orchestra tuning up, as well as mewing and occasional chirps. Some of the sounds were bell-like, and a few rather resembled an echo-sounder. At times, there were sharp reports, somewhat like a blow with a split-bat, or a slap on the water and trilling which quite justified the name «sea-canary».

The captive bottlenose, porpoise, or shore-bottlenose *Tursiops truncatus,* of Marineland-fame, and found commonly in oceanaria of the U.S., has been the species subject to most intensive and continuous studies for the characteristics and classification of its sounds.

Various investigators, principally Schevill and Lawrence, and W.N. Kellogg and co-workers, have found such vocalizations to be usually a frequency-modulated whistle from 7 to 15 kilocycles, or clicks and clacks, from 20 to 196 kc.. and in pulses as short as 1 millisecond, 1/1000 sec. — though, many were longer.

Such high-frequency, short-time pulses, were emitted in a series which sounded to the human-ear like a buzz, or a bark, and were clearly effective to the porpoise in detecting, locating, and identifying unseen objects in the water, such as food and obstacles - - - perhaps even each other. This means of course, that echos of the sound-impulses were heard by the porpoise and computed in its brain There was no emission of air from the nostrils at the time of sound-production, yet it was clear by the location of the object detected that the nasal-pockets on top of the head produced the sounds according to a public statement of Kenneth Norris of University of California at Los Angeles, and formerly with Marineland of the Pacific.

The captive pilot whales of Marineland in Florida and California, the *Globicephala* of the zoologist, have also been heard to make sounds in the range of human audition, and these have sounded like whistles, crying and popping, eructations, and moans, or mews like a bird. These animals can even roar, or bellow, into the air, when the head is out of water; and, this latter sound, apparently, comes out of the mouth, though such is not yet clearly established despite investigation by David Brown of Marineland of the Pacific.

Some of these sounds are frequency-modulated and pulsed, according to A. Rechnitzer of the San Diego Naval Electronics Laboratory; but they have not as yet been described technically.

The sperm whale or cachalot, has been heard recently and recorded by L. V. Worthington of Woods Hole Oceanographic Institution and analyzed by him and W. E. Schevill in 1957 as making «strong . . . muffled, smashing» noises, a « . . . grating sort of groan . . .» «a rusty hinge creaking» . . . «sharp clicks».

We have long known that the cachalot will come from long distances to the side of an injured fellow, as if trying to help, or to find out what the danger may be; but, only recently has the mechanism of such calling for aid, or announcing injury and danger, been known.

In 1951, when with the whaling fleet of two catchers off Eureka, California, I heard from each skipper the same story: a rapid clicking, or ticking sound, almost like a buzz, heard from the whales when such an incident occurred and the whale was drawn alongside, still alive.

Captain Gilbert Hunter had *two* sperm whales come alongside an injured fellow, and actually shot the second also, and distinctly heard this «sharp, ticking sound, like that produced by the fathometer . . . ». Captain Bud Newton said that he heard the «rapid ticking sound, . . . almost like a high-pitched buzz . . .» and at the same time saw a stream of small bubbles issuing from the nostrils.

I myself once saw such an emotional incident, but the whales were too far ahead, 200 feet or more, for any of us to hear the sounds through air.

Sonar-men from both submarines and surface-craft have long known and worried about mysterious clicking sounds as if an enemy craft were echo-ranging from afar. Details of such ordeals and experiences have been given by Marie P. Fish in 1949 and William V. Kielhorn in 1951. But, it was not until Worthington and Schevill made the tape-recording of similar sounds in the presence of sperm whales - - - a pure culture of sperm whales - - -, that the association with whales was clearly established.

All the porpoises and whales mentioned so far have been of the toothed group, that is of the suborder Odontoceti; and it is presumed that all odontocetes make similar noises for communication and echo-ranging.

The other whales, those with the fringed horny whalebone or baleen-plates in the mouth for straining quantities of small planktonic food, rarely have made vocalizations detectable by man; and, reasons for this have not been apparent to anyone who knew their social habits and the necessity of communication, as well as the advantages conferred by echo-ranging in finding food and obstacles in dark of night or of depth, or in opaque water.

Whales have also been suspected by the Navy of making sounds like a propellor; and this has led to some false contacts, even recently, with subsequent alleged discovery of a whale. But, with the known, long-range transmission of sound in water, the possibilities of craft over the horizon, either on, or below, the surface, cannot be overlooked as a source.

The mechanism of such a propellorlike sound by the whale has not been described. Presumably it has been caused by the flukes in swimming. Other mechanical sounds by whales can be conjectured, even if they do not sound like a propellor. These are: - - slapping of flipper on the side, snapping and riffling of baleen-plates by the tongue, or by twisting of the mouth, and the striking of flukes on the surface, a sound which, from below, can sound like a muffled explosion, as Robert Dill of the U.S. Navy Electronic Laboratory in San Diego has related to me.

The Navy's underwater listening stations called SOFAR at Hawaii and Bermuda have recorded loud, low-frequency moans and attributed them to humpback whales. But, W. E. Schevill and B. Lawrence failed to record such sounds at close range when actually among migrating humpbacks at Bermuda, as noted by them in a special report to the Office of Naval Research.

Fig. 2. Gray Whale breaching at momentary «escape velocit of perhaps 20 knots. Cruising speed, for hours, 3 to 5 kno Sustained high speed, for an hour or two, 8 and possibly knots. (Gråhval som kommer opp av vannet mens den f en kort stund flykter med toppfart på kanskje 20 knop. Mars fart som kan holdes timevis er 3 til 5 knop. Stor fart so kan holdes i en time eller to er 8 eller muligens 10 knop Baja California, Scammon Lagoon.

Photo by Raymond M. Gilmore, courtesy of U. S. Fish and Wildli Service.

The California herd of gray whale has been an ideal and much used subject for such investigatio off San Diego where it concentrates during mig tion south and north, to and from the breedi and calving grounds of Baja California. On recently, however, has the Navy announced throu A. R. Rechnitzer to newspaper reporter Gene Fuso that this gray whale has produced a sound on tl recorder through the hydrophone as a «... bee beep noise, ... something like a child hammerir an empty cub on the table». However, another scie tist, James Snodgrass, together with Martin Joh son of Scripps Institution of Oceanography, we unable to get any sounds through the hydropho alongside cows with calves in San Ignacio Lagoo of Baja California in 1951, even at almost oar length, and without any background noises. Th gray whale, and other baleen whales are undoub edly silent most of the time, and vocal only rarel if at all.

The whole matter of cetacean sounds — ket phonics, a word apparently coined by W. E. Schevi —, is complex and little understood; but, it is clea how the Navy can be fouled up with suc endogenous sounds. Also, be it from active nois or passive echo, a tense sonar-man in time of wa blindly and nervously probing the enveloping worl of water from his claustrophobic quarters mus often come to a rapid and agonizing decision: What was that sound? Who made it? Who's there? Friend, or foe, or whale?

A final attribute of whales that enters Anti-submarine Warfare, is their distribution and concentration by season, by locality, and by species.

Each species has its summer feeding and its winter breeding and calving, grounds, usually separate. In summer, along with the food, concentrations of whales are common.

In winter also, with some species, concentrations are the rule for breeding, usually close to shore; though other species scatter widely in the open ocean.

However, knowing the species and their habits of distribution will pin-point areas of multiple contacts where there is much confusion in the detecting gear. I can think of few places better for a submarine to hide in the open sea, than in an aggregation of whales, at a few hundred feet depth, just below any thermocline, the sharp change in temperature, that may exist. Should the water be shallow, and should small islands and reefs be present, as around the Farallones off San Francisco, the combination of whale, bottom, and rock would be ideal for concealment and for the creation of conflicting sounds and echoes in the sonar gear.

This whole discussion leads to the conclusion that the identification of whale as distinct from submarine, is a multiple observation — a complex pattern of form and behaviour, of time and place — as a «gestalt».

The fallibility of man and the legimate confusion in identification of contacts, have encouraged the thought that an electronic machine could be built to select the proper signal from a submarine and reject that from a non-military object, including whales.

The matter of coding the information into a dualistic 0-or-1 situation, a yes-or-no, off-and-on, etc., has not yet been solved; and, the human operator with ability to improve his performance by adding to the instructions in his memory and thus be able to improve his selection, remains the best operator for submarine detection. The next step is to acquaint the operator with as many of the «gestalts», or patterns, of the common non-military targets as possible

For example, an unidentified contact deeper than 500 feet, that remains steady, though not necessarily stationary, for more than an hour, is certainly military. Anything at 100 to 300 feet that remains steady on course for more than 10 minutes is strongly suspect. Large basking sharks in cool waters, and large whale-sharks in warm waters, could, however, confuse the situation.

As man is a visual animal, relying heavily on sight for orientation and decision, and as the sonar-detector gives an audible beep, or ping of characteristic nature, as well as a visible blip, or pip, on a screen, a blind operator might be able better to distinguish non-military from military pings than a man with normal vision, and both might work well together.

Recently an instantaneous photographic technique has helped the visual identification of submarines, on the sonar screen, but has not replaced the human operator.

Finally, the Navy has shown a recent and intense interest in the swimming dynamics and the body-form of whales and porpoises, and has taken thousands of feet of high-speed motion-picture film of swimming porpoises and pilot whales in the larger oceanaria, and in special towing tanks.

That which makes porpoises and whales so interesting to marine architects and engineers in their swimming and form, is their high speed without excessive turbulence.

Turbulence would not only prevent such high speeds at the power capacity of mammalian muscle, but it would create background noise and negate the animal's own echo-ranging except at the highest frequencies, which, however, require great energy-input.

There has been a considerable amount of speculation and theoretical engineering analysis of this problem, but most of the conclusions have been contradictory, or vague.

This has been the result of 1) lack of agreement as to the exact speeds of whales and porpoises, which are difficult to determine and identify as to species; 2) confusion between bursts of speed and sustained speed, that is, maximum steady-state; 3) inexact determination of amount of muscle used in locomotion and the energy produced by this muscle and its physiological limits; 4) lack of analyses of specializations in body-form of the different species; 5) lack of study of the flow-patterns over such bodies during swimming; and 6) disagreement as to the actual mechanics of swimming itself.

The situation has also been overlain by a blanket of highly technical terms, formulas and concepts, such as those of laminar flow, turbulence, friction, Reynold's number, critical Reynold's number, Gray's paradox, etc.

There are few subjects in cetology which are more subject to error than speeds in swimming — unless it be speculations on diving.

Try as I may, on the ocean, or in the books, I am unable to find solid evidence that a whale or porpoise can swim faster than 18 to 20 knots; and, I have never seen a porpoise sustain a steady speed of more than 10. Mostly it is less.

It appears to me now that all porpoises and whales are capable of about the same short bursts of speed, 20 to possibly 25 knots; but that only three and possibly four species can *sustain* a speed of 15 knots or better for hours. These fast whales are the blue, finback, sei and killer.

The high velocity attainable by all species enables any to jump free of the water, that is to breach — the porpoises, several times their own length. This speed may be called the «escape velocity», but I would not want to draw the analogy with missiles projecting satellites, too closely.

The fastest sustained swimming I have seen was that of a blue whale, or a finback, which came up on the port quarter of a Navy fleet-oiler doing 16, well-calibrated knots in calm Antarctic seas, 17 February 1947. The whale, unfrightened was swimming slightly faster than the ship — say 18 knots. Other whales in the Antarctic that same summer swam 15 to 16 knots, and though most

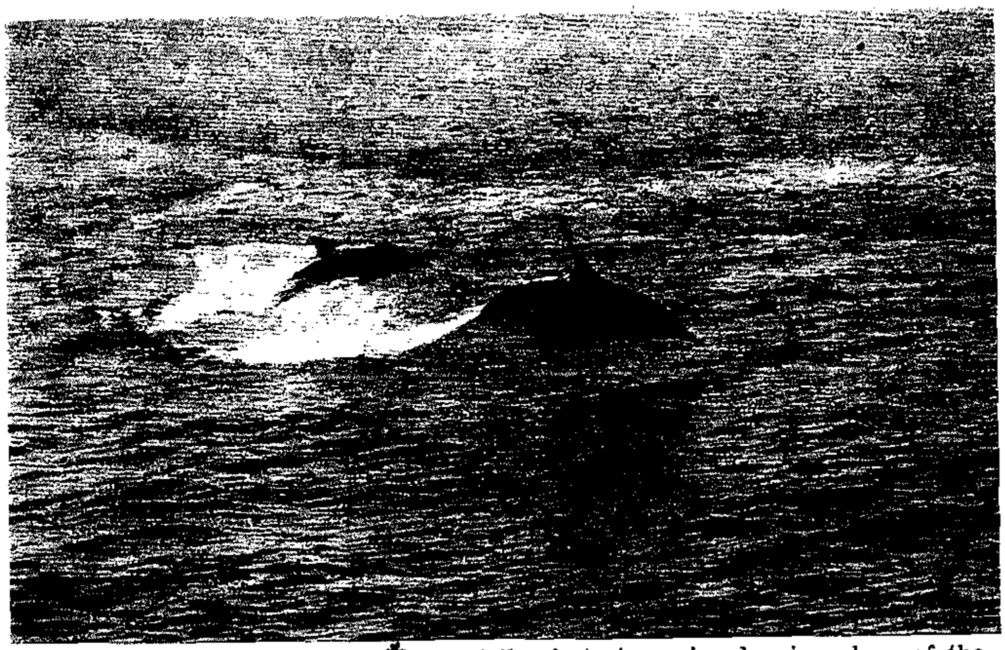

Fig. 3. White-belly porpoise,* one of the fastest species, leaping clear of the water at a momentary escape speed of perhaps 20 knots. Ordinary cruising speed for hours, 2 to 3 knots. Sustained high speed for quarter to half hour, perhaps 10 knots. (En delfin, en av de hurtigste artene, hopper over vannet med en hastighet som for et øyeblikk kanskje er oppe i 20 knop. Vanlig marsjfart som kan holdes i timevis, er 2—3 knop. Stor hastighet som kan holdes i et kvarter til en halv time er kanskje 10 knop.) Baja California near Cedros Island. Photo by Raymond M. Gilmore.

*Delphinus bairdi

were certainly finbacks, a few could have been blues, and once they appeared in the distance as humpbacks: though I could not confirm the latter.

The sharp difference between short bursts of speed and steadily maintained speed is the result of the law of surface and volume. The larger the whale, the more is the volume of muscle, that is the engine, in relation to the surface where friction occurs. Consequently, the larger whales, especially the blue and the finback, can sustain higher speeds longer than can the smaller whales and porpoises. The same principle applies to aircraft-carriers and destroyers.

The volume of swimming-muscle of whales and porpoises has not accurately been measured. Even though a number of whales have been weighed in pieces, the figures have not separated swimming from non-swimming muscles, and in many cases do not include an estimate for loss of body-fluids. The result is that, as only a rough order of magnitude, 40 % of the total weight of the body is taken to be muscle, and all of this is considered as swimming power.

The smaller species of cetaceans afford an opportunity for accurate documentation of these data; but few if any investigators have expended efforts in this direction.

Nor has the power from a unit-weight of muscle of whale or porpoise been tested, though it is possible in both. Instead it has been arbitrarily taken as that of man, or dog, that is, at about 0.01 horse-power per pound.

This is the basis of Gray's Paradox. James Gray, an early English worker on the swimming dynamics of porpoises and whales, stated that 0.01 hp.lb. of muscle was insufficient to push a porpoise through the water at 15 knots if turbulence was equal to that of a similar rigid body towed at the same speed. Hence, there must be no turbulence.

But, if the common porpoise, either *Phocaena*, or *Tursiops*, cannot *sustain* a speed of 15 knots, as I contend, but which Gray and most others have believed they could, the matter is academic; and, the power is simply insufficient for such speed against resistance of the water — turbulence or not turbulence.

The larger whales that can sustain speeds of 15 knots or better for hours, have sufficient volume in relation to surface to enable 0.01 hp/lb of muscle to produce the necessary power — but, this does not explain why they have so little turbulence at such high speeds. Strong turbulence would effectively prevent such speeds. The wake of a whale leaving the surface for a dive has apparent turbulence; but this may be more a temporary transport of bubbles by surface disturbance, than eddies that drag on the skin.

In this connection, one can remember that the cetacean body is unencumbered with hind-legs, and that all the muscles of the tail and trunk, aided by the thick abdominal muscles, are applied to the narrow peduncle at the base of the flukes, above and below, through great tendons like wire cables, with resulting great concentration of power. Only the muscles of shoulder, flipper, and ribs, are not involved in swimming.

In connection with turbulence at high speeds, it can also be noted that the *Tursiops* porpoises at Marineland of Florida have been shown by F. Essapian to have transverse speed-induced skin-folds, which certainly do not indicate laminar flow but, on the other hand, indicate turbulence preventing high speeds.

There are however, several specializations of form which may enable certain whales and porpoises to attain high speeds. One is the vertical keel on the tail-stock of some species. This certainly helps in vertical movements for transmitting power to the flukes; but, the porpoise with the greatest development, the white-bellied porpoise, *Phocaenoides,* of the North Pacific Realm, is unable or unwilling to stay with a boat travelling at 12—14 knots — and I have checked this a number of times.

The keel is also pronounced on the sperm whale, which is a slow swimmer; but, on the other hand, both the blue and the finback whales have high keels.

Perhaps the most striking specialization, however, on the body of whales, aside from the blunt fusiform shape, is the extensive series of deep, longitudinal grooves and prominent ridges covering the entire throat, chest, and anterior belly for 45 to 60 % of the ventral surface of the swiftest whales, the Balaenopteridae: blue (sulphur-bottom), finback, sei, little piked whale, and humpback. All but possibly the humpback and the pygmy finner are fast — capable of 15 knots and better, for sustained speed.

It has been suggested that these ridges and grooves aid in breaking turbulence at high speeds; but, this has also been denied on the basis of the increased surface, and thus the friction, they could produce.

The ridges and grooves are entirely of blubber, but a layer of muscle several inches thick on the chest and almost a foot thick (in large whales) on the anterior belly where the abdominal muscles are located, underlies them, and may be able to move them to perhaps adjust their shape and pattern to that of water flowing over the surface, and thus break turbulence.

The grooves can, also, it seems certain, function as cooling fins, like the fins on an air-cooled motor, and allow radiation of heat in stress — a difficult act with the body sheathed in blubber to prevent just such radiation. The muscles that underlie the ventral grooves are highly vascularized.

The traditional explanation of the grooves, it is fair to mention, is for expansion of the throat and mouth in feeding; but, suction cannot take place behind the mouth, else water would enter the stomach, which it does not do; and, the ridges and grooves cover 45—60 % of the under-surface of the body, far behind the mouth.

The ridges and grooves are permanent as are the lands and grooves of a rifle-barrel; but, they may be expanded, or separated, and moved considerably, exposing the bottom of the grooves where the muscle and blood vessels lie close to the surface.

The use of special models incorporating such structures, and the use of dyes in the water for both the models and live subjects, might throw much light on swimming dynamics.

The actual movements of the flukes and tail are also points of disagreement.

Early belief in a twisting, sculling motion to the flukes was shown false by the detailed study of D. A. Parry of Cambridge, England in 1929. Parry also showed that the vertical oscillations of the flukes and tail were hinged at two points, so that the animal could vary both the angle and amplitude of the stroke to attain impressive efficiency. Schevill and Lawrence confirmed this. Both parties studied anatomical dissections and moving pictures of swimming porpoises in tanks, and the results seem conclusive.

I can add that the efficiency of the swimming movement is aided by the fact that every stroke of the flukes is both a power and a recovery stroke and the flukes are essentially hydrofoils, cambered like the wing of a plane, when in action.

A recent development in the mechanics and dynamics of swimming in porpoises is the belief that elastic flexibility of the skin reduces turbulence. As a result, an attempt has been made to provide some sort of elastic skin to the hulls of ships, with promising developments, but without successful application as yet.

It will be interesting to see how the engineers can adapt the features of whales and porpoises to different techniques and materials. So far, they have used little except the form of the whale in the design of the hull of the submarine, and then only with the Albacore and even more recent nuclear types.

A British Naval captein once suggested, semi-seriously it seems, as recorded by E. E. Prince, a Canadian, that man domesticate whales to tow the sailing ships of that day, and to ram enemy ships in battle — I seem to recall that Hannibal used elephants in the Carthaginian War. Today, however, the concern of the U. S. Navy with whales is much more sophisticated.

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