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Presented by the author

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DO FLYING FISH FLY?

BY C. O. WHITMAN.

OF all the modes of animal locomotion, none has excited more general attention than that of flying creatures; and this is none the less so now that many of those who believe in the ultimate success of "the flying machine," have discarded the balloon theory, and come to regard nature's contrivances for flight as the true models for aërial locomotives. Among those animals that enjoy the much-envied power of flight, none has elicited such universal interest and comment, from old and young, layman and scientist, as that anomalous member of the finny tribe, the flying fish. Science, poetry and fable have conspired to extend the fame of this little denizen of tropical seas, and philosophy has more than once attempted to find some adequate cause for the enormous development of its pectoral limbs, hoping to find here one more important link between swimming and flying animals.

This fish owes its generic name to a curious belief which is said to have been current among the ancients. They supposed that the flying fish —"sea swallows" they called them—left the ocean at night and slept on shore, to avoid the attacks of their marine enemies. From this habit of "sleeping out," they were called *Exocœti.*

Besides Exocœtus, which includes between forty and fifty different species, there is a genus of flying fish called *Dactylopterus* (finger-winged), from the fact that the fin rays extend, finger-like, beyond the margin of the fins. This genus, popularly named the flying gurnard, is represented by comparatively few species which inhabit the Atlantic, the Mediterranean sea, the Indian ocean and archipelago, and the Japan seas.

To those who may never have had the opportunity to observe

the flight of these fishes, it may seem a matter of no little surprise that it is still an unsettled question whether they fly or skim. The difference of opinion on this point is all the more remarkable as the flying fish has been known, at least, since the time of Pliny, and even of Aristotle, and has always attracted the attention of voyagers. Although its aërial flight, to accomplish which it has to leave its native element, is not at all more remarkable than the sub-aquatic flight of the quillemots, grebes, auks and penguins, all of which are accustomed to exchange temporarily their own element for that of the finny race, to move through the water with even greater rapidity than the fishes themselves, and to remain submerged longer than the flying fish remains above water; and although the modification of the fins for aërial locomotion is certainly not greater than that of the wings of the auks and penguins for flight under water; yet the testimony of able scientific witnesses, in favor of the actual flight of Exocœtus, has been often challenged by equally good observers, and plausible reasons have recently been urged against even the possibility of such flight.

It is maintained by many, perhaps the majority of observers, that the Exocœti are sustained by the parachute-like action of the pectoral fins, which they simply hold outstretched during their passage through the air. According to this view the fins exhibit none of that "poetry of motion" seen in the bird's wing, being capable of only a passive kite-like action, like the membrane-wings of the flying squirrel *(Pteromys)*, the flying lemur *(Galeopithecus)*, the marsupial Petaurists *(Petaurus* Shaw.) or the foot-web of the flying frog of Borneo.[1]

In one of our popular "natural histories" the flight of the flying fish is explained in the following manner: "These fishes possess the power of darting from the water into the air, and by the mingled force of the impetus with which they spring from the surface and the widely spread wing-like fins, to sustain themselves for a short space in the thinner element, and usurp for a time the privileges of the winged beings whose trackless path is through the air."

"The passage of this fish through the atmosphere can lay no just claim to the title of flight, for the creature does not flap the wing-like pectoral fins on which it is upborne."[2]

[1] Described by Wallace in his "Malay Archipelago."

[2] Wood's "Natural History."

The following statement to the same effect is found in "The Ocean World," by Louis Figuier: "Their fins sustain them rather as parachutes than wings."

In Beeton's "Dictionary of Natural History," the author speaks thus: "Although some few naturalists have supposed that these fish possess the true power of flying, that is, by beating the air with their members, it is generally agreed that their large fins sustain them parachute-wise when they have leapt from the water."

In the same place occurs a quotation from Bennett's "Wanderings in New South Wales," which is here given in full, as it contains some statements which have found quite general acceptance among scientific men.

Mr. Bennett says, "I have never been able to see any percussion of the pectoral fins during flight, and the greatest length of time that I have seen this fish on the fin has been thirty seconds by the watch; and the longest flight mentioned by Capt. Hall[1] is two hundred yards; but he thinks that subsequent observation has extended the space. The most usual height of flight, as seen above the surface of the water, is from two to three feet; but I have known them come on board a ship at a height of fourteen feet; and they have been well ascertained to have come into the channels of a man-of-war, which is considered as high as twenty feet and upwards. But it must not be supposed they have the power of elevating themselves after leaving their native element; for on watching them, I have often seen them fall much below the elevation at which they first rose from the water, but never in any one instance could I observe them rise from the height at which they first sprang; for I regard the elevation they take to depend on the power of the first spring or leap they make on leaving their native element."

Burmeister in his "Reise nach Brasilien" (Berlin, 1853, p. 36), declares that he watched the flying fish for a long time, and saw, with certainty, "that they made no kind of movement with their large pectoral fins, but held them quietly outspread like a parachute."

In his well-known work on "Animal Locomotion" (p. 98), Pettigrew says: "Whether the flying fish uses its greatly expanded pectoral fins as a bird its wings, or only as parachutes,

[1] "Lieutenant and Commander," by Capt. Basil Hall.

has not, so far as I am aware, been determined by actual observation. Most observers are of opinion that these singular creatures glide up the wind, and do not beat it after the manner of birds; so that their flight (or rather leap) is indicated by the arc of a circle, the sea supplying the chord."

From a careful examination of the structure and action of these fins, Pettigrew has been able to satisfy himself that "they act as true pinions within certain limits." That this restrictive phrase, "within certain limits," is intended to exclude a flapping motion, is evident from the following: "The flapping and gliding action of the wings constitute the difference between ordinary flight and that known as skimming or sailing flight. The flight of the flying fish is to be regarded rather as an example of the latter than the former, the fish transferring the velocity acquired by the vigorous lashing of its tail in the water to the air."

Pettigrew shows that all kinds of wings, when extended in flight, have a kite-like action, or a "combined parachute and wedge action" independent of any beating movement; and it is to this action alone that he refers when he says the pectorals "act as true pinions *within* certain limits."

According to Pettigrew, "Mr. Swainson, in crossing the line in 1816, zealously attempted to discover the true action of the fins in question; but the flight of the fish is so rapid that he utterly failed." So much for the negative testimony.

In favor of the flapping motion of these fins, we have the testimony of Capt. de Freminville,[1] who says, "I have been able to convince myself that they [flying fish] do actually fly, impressing upon their fins, which serve them as wings, a rapid movement—a species of vibration [frémissement]—which sustains them and causes them to advance through the air."

Speaking of these fish, which he saw on the way from Callao to Lima, U. de Tessan[2] says: "J'ai très-bien vu un poisson-volant battre d'abord des ailes en l'air, et puis les faire vibrer en planant."

In the "Reise der Oesterreichischen Fregatte *Novara* um die Erde" (1857–1859), published by Wüllerstorf-Urbair, 1861, p. 109, occurs (according to Möbius) the following: "Careful ob-

[1] *Ann. des Sci. Nat.*, Vol. XXI, p. 102, 1830.

[2] "Voyage autour du Monde sur la *Vénus*," Paris, 1844.

servation enables one to see that the wing-like pectoral fins of the flying fish are capable of a vibrating movement, like the wings of a grasshopper."

Dr. Kneeland[1] makes the following noteworthy statements as the result of observations made in 1870, on a voyage from San Francisco to Panama: "The ventrals were expanded like the pectorals in the act of flight. They rose out of a perfectly smooth sea, showing that they are not mere skippers from the top of one wave to another; they could be seen to change their course as well as to rise and fall, not unfrequently touching the longer, lower lobe of the tail to the surface, and again rising, as if they used the tail as a powerful spring. While the ventrals may have acted chiefly as a parachute, it seemed that the pectorals performed, by their almost imperceptible but rapid vibrations, the function of true flight."

To the same effect speaks A. v. Humboldt[2] when he says, "Notwithstanding the astonishing swiftness of their movement, one can convince oneself that the animal beats the air during its spring, *i. e., that it alternately opens and closes its pectoral fins.*"

In his work "On the Origin of Species" (p. 175), the great naturalist remarks: "It is conceivable that flying fish, which now glide far through the air, slightly rising and turning by the aid of their fluttering fins, might have been modified into perfectly winged animals. If this had been effected, who would have ever imagined that in an early transitional state they had been the inhabitants of the open ocean, and had used their incipient organs of flight exclusively, as far as we know, to escape being devoured by other fish?"

Without attempting to make this bibliographic sketch exhaustive—an infeasible undertaking with the libraries at my command—I will now pass to my own observations on the flight of flying fish, made during a voyage from San Francisco to Yokohama, on the steamer *City of Peking*, reserving till the last the consideration of the recent elaborate paper of Prof. Carl Möbius.[3]

Of the nearly twenty-three days that elapsed between departure and arrival (Aug. 1 to Aug. 24, 1879), at least ten were favorable for the study of the question under consideration.

[1] Proceed. Boston Soc. Nat. Hist., Vol. XIV, p. 138, 1872.

[2] "Reise in die Aequinoctial-Gegenden des neuen Continents," I, Stuttgart, 1815.

[3] "Die Bewegungen der fliegenden Fische durch die Luft." *Zeitschrift für Wissenschaftliche Zoologie*, Supplement to Vol. XXX, p. 343, 1878.

Aware that these fish are now generally regarded as skimmers rather than flyers, notwithstanding the testimony of very trustworthy observers to the contrary, I determined to satisfy myself, if possible, on this one important point.

I found the most favorable place for observation to be the bow of the steamer, and the best hours to be in the morning from five till eight or nine o'clock, and in the afternoon between three and six o'clock. Observations made when the air was quiet and the sea perfectly smooth, so that the fish could often be seen before they left the water, were the most satisfactory and conclusive. A stiff breeze, a billowy sea, a tossing ship and an easy chair are not conditions which facilitate accurate observation, and to such conditions, doubtless, is to be attributed the ill-success of many who have undertaken to decide this question.

It has often been stated, especially by those who deny the wing-like motion of the fins, that flying fish are seldom seen above water when the air is still, and Burmeister even goes so far as to say that "they fly *only* when there is considerable wind, since it is the wind which supports them."

That Burmeister "never saw a flying fish by still air," proves only his misfortune, either in having no opportunity to see, or in not improving the opportunities which he did have. I have often seen great numbers of these fish when the air was almost motionless—so still that not a ripple could be discerned on the glassy surface of the water—and it seemed to me that they were not much, if at all, less numerous on such occasions than when there was a moderate wind.

Under the favorable conditions before mentioned, it is by no means difficult to determine whether the fish executes any flapping movements with its pectoral fins. As I have seen them come out of the water directly under my eyes, I have been able to see distinctly the individual flaps of the large pectorals, while the ventrals were held in quiet expansion. The flapping movement, which is quite regular and rapid—so rapid that it is not easily recognized at any great distance until experience has sharpened the eye—may be continued for the whole, or a part of the flight; but is *generally* discontinued after the first few rods, and the course completed by a pure skimming or sailing movement. In some cases I have seen the flapping of the fins renewed once or twice after short intervals of the sailing movement. In

the case of young fish, from a-half to one and a-half inches in length, many of which I saw leave their native element to essay the rarer medium, the strokes of the fins are continued throughout the short flight; and the resemblance between these tiny fin-flyers and flying insects is most striking.

The course of the flight is generally in a straight or curved line; but on several occasions I have seen it abruptly changed, apparently by the aid of the tail, the lower lobe of which was brought for a moment into contact with the water.

In one instance I saw the course thus changed three times, at intervals of only a few seconds. The fish came out of the water only a few feet from the steamer, flew outward and backward, then, suddenly turning, came toward the steamer, striking the crest of a wave within a few feet of the same, it darted alongside, and again dipping its caudal lobe in the water, wheeled directly away from the boat and plunged into the ocean. In the majority of observed cases, where the tail was made to touch momentarily the water, the course was not changed, the tail appearing to act, as Dr. Kneeland has already remarked, like a spring for raising the fish.

In the case of a breeze, the direction of flight, as a rule, was either against that of the wind, or formed a more or less acute angle with it; not unfrequently, however, the flight is with the wind, or at right angles to it.

The longest flight observed lasted not less than forty seconds, and its extent was undoubtedly over eight hundred feet, and may have exceeded twelve hundred feet. This remarkably long flight began near the right side of the steamer and was performed in a long curve, which formed, at first, nearly a right angle with the boat, then moving directly against a gentle wind, but gradually turned backward, so as finally to coincide nearly with the direction of the wind.

While the average flight does not perhaps exceed fifteen seconds, nor extend above four or five hundred feet, yet I have observed numerous cases in which it was continued twenty to thirty seconds.

That this flight, executed in a horizontal plane, which, according to the concurrent testimony of all observers, is seldom raised above the surface of the water by more than two or three feet, continued for ten to thirty or forty seconds, and extending a dis-

tance of one to eight or more hundred feet, can be due to the impetus gained by a single spring combined with the parachute-like action of the fins, seems to me, aside from the oft repeated testimony of my eyes, quite incredible.

It is maintained, however, by Carl Möbius, professor in Kiel, in the article before mentioned, that the pectorals of the flying fish execute no flapping movement during flight; and this view is based not only on the author's observation of the flight of many Exocœti and one Dactylopterus, but also on anatomical and physiological grounds.

No one, so far as I know, has undertaken so elaborate a discussion of this question, and approached it from so many different standpoints as Prof. Möbius; and his conclusions will, on this very account, undoubtedly command the assent of many naturalists who have had no opportunity to settle the question for themselves. It is not, therefore, surprising to find that Prof. Bardeleben, in his review of this paper, in Hofman and Schwalbe's "Jahresberichte über die Fortschritte der Anatomie und Physiologie" (Vol. VII, part I, p. 129), appears to accept as conclusive the opinion so ably maintained by Prof. Möbius. Had I not seen many times, with my own eyes, under circumstances so favorable as to forbid all manner of doubt in my own mind, the flapping of these fins, I might have accepted the conclusions of the German naturalist and overlooked the assailable points of the arguments adduced in their support; but with the positive assurance that he is in error on the main question, I have been led to question the validity of some of his interpretations of facts. That I have fairly stated the position of this author in regard to the function of the pectoral fins of the flying fish, will appear evident from the following citations:

"If during the entire flight the pectoral fins of flying fishes actually made motions similar to those of the wings of bats, birds and insects, one would be able to perceive them quite as well as the strokes of equally large wings of bats and birds" (p. 353).

This statement is open to the objection that it entirely ignores the fact that the color of the fins, the rapidity and sweep of their vibrations have a vast deal to do with the question whether the fin-strokes would be as easily recognized as the wing-strokes of the bird or bat.

"Flapping movements of the large shining pectorals would

make themselves visible by the alternate appearance and disappearance of the light reflected from them. They would escape no accurate observer who viewed the fully expanded pectorals from the height of a steamer. But as often and as long as I have been able to follow with my eyes flying fish, which came out of the water near our boat, I have never seen light reflected in this manner from the pectoral fins as from the wings of birds and bats" (p. 353).

That these movements have escaped Carl Möbius is then evident from his own testimony; what application then is to be made of the statement that "they would escape no accurate observer?" This author first attempts to account for the fact that many good observers have affirmed the wing-like movement of the fins on historical and psycological grounds, asserting that this "false notion" had its origin in a fancied resemblance of these fishes to swallows, and that it has been handed down from the times of Aristotle and Pliny to the present time, simply on authority; and afterward, as if aware that this was not altogether a satisfactory solution of the question, admits that these observers may have had some grounds for their statements, but thinks they were deceived by appearances, which they did not understand, into the belief that the fins behave like wings. He is very frank in telling us just what these appearances are, although no one, not even Möbius himself, has ever observed such phenomena in a living Exocœtus.

"Just as a sail begins to slacken and vibrate the moment the wind blows parallel to its surface, so the more flexible and elastic distal and ventral parts of the pectoral fins are thrown into rapid vibrations when the air-current moves parallel to their surface" (p. 370).

As a simile, this will do very well, but how is it as a matter of fact? We are assured that this comparison is fully justified by the following simple experiment. A specimen of Exocœtus shriveled, distorted and stiffened by long soaking in alcohol, was suspended and its pectorals exposed to a swift current of air in such a manner that the current swept along both surfaces. The fins thus exposed "made directly under my eyes the same rapid quivering movement that various good observers of flying fish have regarded as a flying movement" (p. 370–371). It is important to observe that Möbius has here affirmed an identity without any authority whatever. He shows his deference to the statements of "good observers," by undertaking to sweep all their

testimony out of court by the mere breath of his private opinion. Surely this is a most facile mode of reconciling contradictory testimony!

If Möbius merely announces it as his *opinion* that the tremulous movement observed in his experiment is identical with the movement that has been so often interpreted as a true flying movement, then we have simply to raise objections.

There are three questions here to be considered: First, whether the fins probably exhibit such movement; second, whether such a movement, if made, would be probably recognized; and third, whether, if recognized, it would likely deceive "good observers."

It would seem that the wings of a sailing bird, such as a gull or a hawk, would be quite as likely to exhibit such motion as the fins of the flying fish; and it would be much more easily recognized in the former than in the latter.

With reference to this point, I watched the long-winged gulls that were seen almost every day of our voyage. These birds were often circling about the stern of the boat, on the watch for waste bits of food, and were remarkably good skimmers, moving the most of the time without flapping the wings. I very rarely saw any vibratory movement that could be attributed to the wind alone, and *never* anything of the kind that was of more than a momentary duration. It is very evident that, under conditions that would render possible a continuous movement of this kind, the bird, as well as the fish, would inevitably fall to the water.

Is it probable that a momentary quiver in the comparatively small fin-wings of a swiftly-moving flying fish would be noticed? The fact that no naturalist has ever affirmed anything of the kind except Möbius, who bases his assertion on an experiment with an alcoholic specimen, is sufficient answer to this question.

As to the probability of any one being deceived by such motion, I cannot, of course, judge from experience, as I have never been so fortunate as, in the first place, to detect it, and, in the second place, to discover that I had erroneously interpreted it. I cannot persuade myself, however, that any "good observer" would be likely to make such an egregious blunder.

That Möbius does not regard this hypothetical quivering as in any sense a true flying movement, he states in the most unequivocal manner, and goes on to ask, "how, then, are the Exocœti able, without touching the water, to rise over the waves? For

this also they make no fin-strokes. They do not raise themselves, but are passively raised by the ascending currents of air, which are caught in the grooves on the under surface of their pectoral fins" (p. 371). Notwithstanding the oft-repeated affirmation that flying fish do not actually fly, our author seems, in one place, to admit the possibility of the flapping of the fins during flight. "These explanations of the movement of the flying fish do not imply that an Exocœtus or a Dactylopterus cannot make powerful and plainly recognizable movements with its tail and pectorals during its ascent (out of the water), and even occasionally in the middle of its course, if prompted thereto by a strong wetting of the body by the waves" (p. 372).

This statement, interpreted in the light of the context, cannot be said, however, to involve a contradiction; the author simply means that the fins and tail may be used in getting out of the water, and that these movements may possibly be recognized just as the fish rises. But he still maintains that the wing-like movement attributed to them by many observers, "arises not through muscular action, but through the elasticity of the out-spread fins and the pressure of the air, which act alternately against each other" (353–354).

Passing on from these explanations, which presume to reconcile conflicting statements by pronouncing all that will not be reconciled, fallacious, and by substituting others of a less obstinate but of a purely hypothetic nature, which seem to admit of a quasi-explanation, we have next to notice the arguments urged from an anatomical and physiological standpoint.

"I believe then," says Möbius, "that I have refuted on anatomical and physiological grounds, the opinion that flying fish use the pectoral fins as wings" (p. 368).

In this entire discussion, Möbius tacitly assumes that there can be but two opinions on this question, namely: his own opinion, which he shares with many others, and the opinion attributed, with more or less justice, to A. v. Humboldt, Kneeland and others, *that the fins are flapped with great rapidity throughout the entire flight.* While the claim to have refuted the latter opinion seems altogether too pretentious, it may be freely admitted that the reasons adduced have much more force against it than against the view here maintained, that the flapping movement is *generally* continued for only a part of the flight.

The frequency of the fin-strokes is made the first point of attack. Referring to the number of revolutions made by the bird's wing per second, which, according to Marey,[1] are for the

Sparrow	13
Wild duck	9
Pigeon	8
Moor buzzard	5¼
Screech owl	5
Buzzard	3

Möbius remarks: "If flying fish make a still larger number of fin-strokes per second, then the fin-muscles must be able to contract even more rapidly than the pectoral muscles of birds and all other vertebrates." Then follows a comparison of the muscles of certain fishes with those of mammals, birds and frogs, in respect to the time required to execute a muscular contraction—all with a view to showing that the muscles of Exocœtus are incapable of making very rapid contractions. The strength of this argument is impaired by two facts; first, the duration of a muscular contraction has never been determined for Exocœtus; and second, the number of fin-strokes per second has never been estimated, much less experimentally ascertained.

Furthermore, it does not follow, as Möbius asserts, that if the flying fish make more than thirteen fin-strokes per second, its fin-muscles must be able to contract more rapidly than those of birds. That they would be more rapid than those of *some* birds under *some* circumstances, can be safely asserted, and nothing more. The number of revolutions made by the sparrow's wing in a second is greatly exceeded in the wing of the humming-bird; and the figure given by Marey does not represent the maximum number of strokes of which the sparrow's wing is capable. A complete "muscle-curve" consists of a "*latent period*," a *contraction* and a *relaxation*, as every tyro in physiology knows, and the last two phases may vary much in duration according to circumstances.

Again, the size of the fin-muscles is said to be incompatible with the theory that the fins execute true flight.

The average weight of the entire bird, as determined by Harting for thirteen birds belonging to different orders, is 6.22 times that of the pectoral muscles. In the case of Chiroptera, according to the Dutch physiologist, the body weighs 13.6 times

[1] "Animal Mechanism," p. 228.

as much as the pectoral muscles; and the relation between the same in Exocœtus was found, by Möbius, to be as 32.4:1.

If the work performed by the muscles of flight be proportional to the weight of the body, then, as Möbius observes, the pectoral fin-muscles of Exocœtus must develop about five times as much force as the pectoral muscles of birds, and about two and one-half times as much as the same muscles of the bats.

The objection from this point of view has been greatly over-estimated by Möbius. As flying fish generally move their pectorals during only a part of their flight, which is at most short, they do not need to expend so much muscular energy as birds and bats, which take long continued flights. Small muscles may perform, for a brief period, work which only larger muscles would be able to perform for a long time. Möbius seems to have overlooked the fact that *time*, as well as size, is an element of this problem.

Perhaps also the large air-bladder may, as Humboldt supposed, have something to do with lightening the work of the muscles, while serving as a store-house of oxygen.

The experiment of Humboldt, by which he determined that the fin-rays of Exocœtus move with five times greater force than the rays of other fins, would seem to favor the opinion here maintained.

Admitting that in form, size, length and structure the pectoral fins of Exocœtus are less well adapted to flight than the wings of most birds, there is still ample room to believe, on anatomical and physiological grounds alone, that they are capable of executing true flight.

In regard to the personal observations of Prof. Möbius, it may be said that they can lay no claim to the right of deciding this question. Whatever evidence they afford is of a purely negative character; and of this fact Prof. Möbius seems to be fully aware, if we may judge from the stress which he lays upon other considerations.

That Möbius and others may not have been fortunate enough to recognize the wing-like motion of the pectorals, establishes at most only a probability, which weighs very little against the positive evidence afforded by the testimony of those who have actually seen flying fish fly.