The Way

~~How~~ Birds Fly

Ever since man first became curious about his environment he has envied birds their ability to fly and has ~~dreamed of~~ imagined learning their art, and of freeing himself from his pedestrian limitations. The Greek myth of Daedalus and his son Icarus concerned the successful mastery of flight by these two mortals who ~~used~~ devised wings to escape from Cretan captivity. But the contrivance was never repeated, perhaps because of the disastrous consequences to Icarus, ~~who, when he~~ becoming over-confident ~~and~~ he flew ~~too~~ so close to the sun that ~~the heat melted~~ the wax melted and by which his wings were attached, he crashed to his death - a punishment for ~~his~~ his importunity ~~of~~ in challenging the gods considered quite just by ~~his contemporaries~~ the Greeks. No explanation of how they managed their wings, which were copied from birds, feathers and all, was ever given. Nor were the mechanics of flight discussed in the Greek mythologies, either for these two experimenters or for the even less probable winged horse Pegasus. Apparently it was believed that ~~to be equipped~~ equipment with wings was the only requirement for flight, and that once this was accomplished the manipulation of them would be self-evident. The gods flew about with the greatest of ease, but since they commanded magic powers their exploits, with or without wings, were taken for granted.

Later in the Christian era angels with wings ~~were~~ made their ~~depicted~~ appearance. Consideration of the efficacy of these appendages was probably ~~considered~~ irrelevant since angels like Greek gods had access to supernatural forces. Angel's wings seem to have served chiefly as a badge of status rather than as useful means of locomotion. Although they too were patterned after the birds and were proportionately ~~correct,~~ a reasonable size, they could not have sustained flight without an adequate working

mechanism which was not provided. In contemplating the Celestial Hierarchy above the angels the symbolic meaning of wings becomes increasingly evident as the top levels are approached where, if wings survived at all, they become vetigial.

Men have always dreamed of flying, ~~but not through the invention of a machine, rather~~ by the mastery of godlike powers to overcome the restrictions of gravity. Who in his sleep has not momentarily experienced the joys of a sudden acquisition of ~~the~~ miraculous powers of flight, as well as the frustrations of their critical failure? Many schemes have been ~~proposed~~ suggested in the past few hundred years to give men the freedom of birds. ~~Many~~ Some of the ~~devices~~ ideas inventions were simple balloons subject to the vagaries of the wind, but from time to time machines with flapping wings in imitation of birds were proposed as means to surmount man's ~~two~~ three dimensional limitations. The most famous of these is undoubtedly the flying machine designed by Leonardo da Vinci in the Fifteenth Century. It had birdlike wings and conceivably ~~could~~ might have flown, had it been built, since it depended for sustained flight on the approximately adequate leg muscles of the operator rather than, as in other ~~schemes~~ devices, on his ~~deficient shoulder muscles.~~ much too weak arms.

Not until the Wright brothers at Kitty Hawk separated the propelling power from the supporting wings was the feasability of the flying machine demonstrated. Their success was assured not alone by abandoning the bird as a prototype but by the invention, in the gasoline engine, of a compact source of power. Except for a momentary return to the bird's wing in a copy of the ~~the design of~~ German ~~German~~ World War I Taube fighter plane, the design of airplanes turned away for good from ~~attempts to imitate~~ an imitation of birds ~~flight~~. Even an elementary analysis of the relations between weight, dimensions, and energy requirements for flapping flight

would have made clear the inevitability of this course of ~~development~~ technology. That birds could ~~not~~ neither also indefinitely increase in size and still sustain flight would have been demonstrated by the analysis. The ostrich and the extinct Moas are birds that exchanged the powers of flight for huge size as they adapted to purely terrestrial life, but it should not be assumed that flightlessness is necessarily a parallel development with massiveness, which results from other adaptations as well. But even among the larger flying birds the ability to remain air born for long periods of time was accomplished through special evolutionary developments, ~~processes~~. Some like the duck have developed ~~large~~ pectoral muscles proportionately larger for their size than are found in less strong flyers ~~far out of proportion for that size to those of smaller birds~~. Others have adopted a soaring type of flight in which they depend on air currents more than on wing flapping to keep them aloft. Among these are some species that experience considerable difficulty in taking off on a windless day and must make a running start like an airplane to get off the ground ~~build up sufficient lift~~. Needless to say, such a bird would be hoplessly trapped if it inadvertantly landed in a forest. In fact cormorants, that ~~xxx~~ rise from water ~~xxxx~~ by a long flapping ~~and~~ paddling runs on the surface, get caught ~~xxxxxxx~~ in fish wiers from which they can escape only by diving under the nets. Probably physical limits for wing-flapping flight were reached in the largest ~~living or~~ extinct birds. A flapping flying machine no larger than a small plane would not be able to carry an engine big enough ~~for~~ to sustain useful flight; and a machine the size of a jet liner would be a physical impossibility.

How birds fly, the detailed elucidation of the mechanics of flight, was not even attempted until fairly recently and is not yet completely worked out. The process is very much more complex than the aerodynamics of the fixed wing soaring flight of gliders or motor driven airplanes because bird's wings are jointed and designed

for both soaring and flapping. In soaring the lift is obtained from rising air currents which the bird takes advantage of; in flapping he generates his own air currents. All birds flap their wings to some extent as in taking off, landing, or maintaining altitude on a still day, and some never soar or glide at all. But even the soaring that birds do is more involved than the most sophisticated glider flight owing to the separate control ~~the birds~~ they have over the ~~different~~ segments of ~~his~~ their wings . But by this very control flapping flight is still more complex and almost defies analysis. No generalizations on the relationship between the type of flight and wing anatomy are without exception. The wide stubby wings of quail are not always correlated with the rapid whirring flight characteristic of these birds, nor are narrow pointed wings always associated with the swift flight of the swallow. The problems of analysis arise from the number of variables involved. The wing of a bird has several planes which can be independently adjusted for lift and propulsion. Thus the proximal part of the wing next to the bird's body ~~supports the weight of the bird and~~ serves as an airfoil to support the weight of the bird; the end of the wing beyond the wrist where the primary feathers are attached can be separately moved to act as the principal propellor. These functions, however, overlap to varying degrees in different species. Some birds, the terns for example, move their wings stiffly, using the whole surface for both propulsion and weight support. The primary feathers play an important role too in determining the type of flight, but infallible relationshipd do not exist. The shape of the end of the wing is ~~also~~ likewise an ~~important~~ important adaptation to ~~the~~ behavior requirements and environmental conditions ~~of the bird~~. Narrow pointed overlapping primaries reduce ~~the~~ eddies at the ends of the wings and allow ~~a smoother~~ flow of air ~~to~~ that cuts down resistance. Separated which

primaries producing multiple slots for ~~the flow of~~ air to flow through ~~the~~ at wing tip do the same thing. Although wide blunt wings with overlapping feathers, as occur in the owls and rails, are not usually associated with fast flight, the rounded wings of the bird hawks,- the accipitors,with primary feathers that separate, are correlated with strong, swift flight.

The way in which wing segments are manipulated to accomplish the kind of flight ~~ø~~ each species has adapted to its life requirements is determined by the boney structure and muscular anatomy of the entire wing. Every bone and muscle in a bird's wing has its analogue and counterpart in all other species. A feature occuring as a massive structure in one species may be represented in another as a vestigial remnant, the function of which has lost its importance during the course of evolution of that species with different flight needs. These differences are also related to body weight. Measurments have revealed an inverse relation between weight and wing surface associated with compensating flight mechanisms. Soaring birds have in general lighter bodies in proportion to wing area than do flapping birds, and their wing anatomies have correspondingly evolved. The soarers do not need the large pectoral muscles of the latter, and since their wing strokes are slower and move through a shorter arc the muscle attachments ~~are not the same in wings designed for these two kinds of flight.~~ to their wings differ from those to wings designed for more active flight. In order to achieve the wider arc and faster rate for flapping flight the breast muscles are attached to the wings at points close to the body. ~~of the bird.~~ But since this arrangement reduces mechanical advantage, a general compensatory increase in the size of flight muscles - proportional to total weight - is found among flapping birds. Nevertheless, within the wide range of size and environmental adaptations that exists in

birds, these relationships are not invariably consistent nor do the anatomical features that relate wing structure to type of flight and body weight remain always distinct between the species.

So far I have not really explained how birds fly; I have merely described flight and discussed a few of the factors involved, and shown how complex the process is. Only the exceptionally curious wonder about the causes of events and the working of natural processes. Consistant with their tendency to accept the usual regardless of the measure of ignorance ~~in their understanding,~~ men have long been conditioned to take the ability of birds to fly for granted because birds have always been part of their experience. The commonest kind of flight, by wing flapping, was questioned least, although it still is the more difficult to explain, whereas the less usual and less complex soaring attracted earlier attention. Soaring flight is now an established art founded on experimentation with many devices, large and small, that were built and flown, some with outstanding success. On the other hand practical flapping flight has never been imitated. Its mysteries were not even begun to be unravelled until the invention of photography made possible a detailed examination of the process. At first photographic methods of investigation were crude, but with the introduction of various high-speed photographic techniques a clearer picture of the mechanism of flapping flight began to emerge. Other tools have also been used to investigate flight such as radar, wind tunnels, and airplanes. Nevertheless, a great deal remains to be learned owing to the immense variety of rhythums and rates and speeds that occur within the patterns of the common flight types. ~~the wing motion~~ of a few species of birds has been studied in great detail, but ~~of the~~ about the great majority little is known.

It is perhaps quite natural that people would compare flight with rowing a boat, and some points of similarity between the two kinds of locomotion exist despite the differences of the media in which they take place. One might be tempted to draw a closer analogy between flying and swimming, but the validity of the comparison is only convincing for animals equipped with flippers as are the seals, sea turtles, and a few specialized species of birds belonging to the penguin and auk families. Among all of these the front limbs have evolved into paddlelike swimming appendages, poorly adapted to other uses. Seals are capable of short excursions only onto land where they settle down inertly near the water, the cows basking and nursing their pups, the bulls somewhat less lethargically guarding their harems and roaring at interlopers. Sea turtles retain a tenuous and hazardous link with their heritage on land, which is leading to their undoing. Long ago sea turtles began ~~to renounce the accomplishments of~~ their amphibious ancestors returning to the sea from which they had painfully and tentatively crept hundreds of millions of years before in exchange for an uncertain future on a hostile continent. Like their later mammalian contemporaries the cetaceans and the still more recent seals, they are renouncing an ancestral experiment by following a path that leads back to a complete dependence on the medium of their origin. Today only the female sea turtle has retained a temporary and perilous dependence on the land, which the male has finally deserted. She still, in response to genetic dictates, comes ashore onee every few years to bury her eggs in the sand above the reach of the waves. Her purpose is accomplished in a few hours on successive nights, but during this short time she stakes her life on this means to perpetuate the race of sea turtles. Her most determined predator is recent, and it

may not come as a surprise to learn that the responsibility for her extinction, if it comes, will rest in the hand of man.

Penguins use their specially adapted wings almost exclusively for swimming under water in search and pursuit of food. In the water penguins move with great swiftness and when seen from above look like birds flying through the air. The auks are pelagic birds of the arctic seas capable of rapid but not sustained flight. They seem to be progressing towards the flightless condition of the penguins. They too dive from the surface and use their wings exclusively in pursuit of fish under water.

Thus the similarity of swimming under water to flying is not too far fetched if applied to the higher acquatic animals, but is not valid with fish. Even a man in a row boat uses many of the same techniques to push himself along as does a bird. He dips his oars as far forward as convenient and pulls against the water, then he raises and returns them in the air to the starting point, perhaps feathering the blades to reduce air resistance. A bird does much the same thing except that the driving stroke is obliquely down and back ~~in order~~ to produce lift and forward thrust simultaneously. The up stroke of the wing is much faster than the down stroke, ~~in which respect the same relationship holds as~~ a situation which holds as well for an oarsman who returns his oars ~~more~~ quickly in the air ~~than he~~ after pulling ~~them~~ hard against the water. At the end of the down beat for many common birds the wings are in a nearly vertical position. As they are raised they are folded in close to the body to reduce air resistance, and then brought forward with the planes of the wing rotated edgewise to the direction of flight, for the next beat. At the same time the ~~primary feathers~~ the terminal feathers, the primaries, may separate

to further reduce ~~xxxxxxx~~ drag. The expression "to feather" ~~oars~~ derives from ~~the~~ turning ~~of wing~~ feathers ~~in flight~~ edgewise in direction of motion to lessen resistance. In relation to the bird's body its wing tips describe a figure 8 curve, but to the ground they follow a wavelike undulating path similar to the path made by the blade of an oar in ~~relation~~ respect to the water surface.

The remarkable studies on mallard flight by E. M. Queeny published in "Prairie Wings" clearly illustrate this pattern of wing action. They show how the end of the wing twists ~~in relation to~~ on the proximal segment, as it moves up and forward on the return part of the stoke, to bring the plane of the primary feathers parallel to the direction of motion. During this phase of the wing beat the primaries separate to permit a smoother flow of air past the wing tip. Ducks in general are rather heavy bodied birds with short wings and powerful pectoral flight muscles. They exemplify the relationship that heavy bodies are associated with relatively small wings surface, and a rapid wing beats with thick muscles attached ~~xxxxx~~ to the wing close to the body. But even among ducks differences ~~xxxxx~~ in flight capacity, as well as in feeding habits, reflect adaptations to a great diversity of environments. Pond and river ducks are able to rise vertically from water or land by a strong upward ~~leap~~ bound in which the wings are primarily involved. The first stroke hits the water with a loud slap thrusting the bird away from the surface in a shower of spray. The duck will continue to rise straight up on powerful, rapid wing beats until the top of encircling vegetation, even ~~when~~ of tall trees, is cleared. Sea and diving ducks on the other hand are unable to take off this way; they must usually run along the surface, paddling with their feet and flapping their wings, for some

distance to get up enough speed for clearing.

The mode of life of birds, their feeding habits and food requirements, determines or is determined by the way they fly. Hawks and vultures, who obtain food by searching from the air long distances over land, have acquired a soaring type of flight in which they depend on air currents for support rather than the power of their wings, and thereby ecomonize on muscular energy. The wings of these birds have a larger supporting surface in proportion to body weight than have the wings of birds that do not soar. ~~All predator~~ Hawks with different hunting habits, however, are not adapted to flight like this. The accipators or bird hawks, that strike their prey swiftly from a lookout perch have smaller shorter wings intended more for bursts of speed than for long periods of search from the air. The falcons too, with pointed narrow wings, are better adapted to pursuit of prey on the wing than to soaring.

Soaring has attained its greatest refinement in oceanic birds. The Wandering Albatross, ~~that~~ which breeds on barren islands in the antarctic seas, does not return to land for six months after deserting its fattened offspring ~~when~~ at the beginning of winter ~~begins.~~ During this lonely wandering down the perpetual westerlies of the Roaring Forties, the albatross may circumnavigate the globe. Seldom resting on the waves, he lives on squid picked from the sea ~~on the wing~~. Wandering albatrosses are the largest of all pelagic birds with a wing spread of eleven and a half feet that exceeds even tht Condor, and they are aerodynamically constructed for a life on the wing. With long narrow wings perfectly adapted to take advantage of ~~all the variations of~~ the gales that pile up the mountainous seas of their home latitudes, they glide along close to the water, rise on currents behind a wave, turn and coast down into the next trough. They follow the waves around the world, responding invisibly, unconsciously to the ever shifting forces of the wind.

The Man-o-war or Frigatebird, which inhabits oceanic islands and tropical seas the world over, has adapted even more perfectly than the albatross to a landless existence. It breeds every two years on remote tropical islands, and between these periods may also never come to land. Nor does it alight on water. Its feet are unwebbed, small - almost vestigial - not suitable for swimming, and its plumage is not waterproof. Its food consists of squid and flying fish which it snatches from the surface of the sea with its long hooked bill. But it also pirates food from the boobies returning from a fishing trip, scaring it into disgorging by harassment. With extraordinary speed and maneuver the frigatebird retrieves with ease the disgorged fish before it strikes the water. The wings of frigatebirds are long and pointed, but wider in proportion to length than are the wings of the Wandering Albatross. They are better suited to sailing on the light breezes of the tropics than are the thick narrow wings of the latter adapted to the gales of the Forties. Frigatebirds have evolved the most favorable ratio of wing area to total weight of any bird. Lightness was attained by the evolution of minimal body tissues, oilless feathers, and a skeletal structure of thin walled, internally strutted, hollow bones of surprising strength. These features equip the frigatebird for an air-born existence; its intermittent attachment for the land occuring only out of the necessity to reproduce its kind.

Evolution of flight has taken quite a different course in the hummingbirds, the smallest of all birds, from that followed by the largest. As one might guess the unusual flexibility of hummingbird flight corresponds to a wing development not found in other birds, in which the wings, considered analagous to our arms, are jointed at the shoulder, elbow, and wrist, and rotate at these joints during various flight maneuvers. In contrast the only movable joint in the hummingbird's

Evolution of flight has taken quite a different course in the hummingbirds, the smallest of all birds, from that followed by the largest. Crawford Greenewalt elucidated the dynamics of hummingbird flight by an ingenious adaptation of high speed motion picture photography to the study of the dynamics involved. Hummingbirds fly entirely by flapping their wings - they never soar or glide - and can fly straight up, forward, backward, sideways, or hover with equal ease. As one might guess this unusual flexibility corresponds to a wing development not found in other birds, in which the wings, considered analogous to our arms, are movable at the shoulder, elbow, and wrist joints during various flight maneuvers. In contrast the only movable joint in the hummingbird's wing is the shoulder, and the bones reflect this difference. In the common birds the lengths of the wing bones are roughly proportional to those of the human arm, but in the hummingbirds the humerus, radius, and ulna are much reduced and immobile in relation to one another, whereas the bones corresponding to the wrist and hand are proportionately greatly enlarged. Thus the hummingbird literally flies with his hands as opposed to arms with most birds. Another unique feature of hummingbird flight is that lift is produced both on the up stroke and down stroke, not just on the down stroke as in the usual type of flight. This feat is accomplished by a free rotation of the wing at the shoulder. This respect hummingbirds resemble helicopters, each wing a separate but synchonized rotor. They are thus able at will to direct the air thrust for any desired direction of flight.

The smallest North American species is the Calliope weighing less than three grams, and the smallest of all, a Cuban species, weighs only two grams. The wing beat rate of hummingbirds varies considerably from a high of 80 per second for a few of the

smallest species to a low of 10 for the largest. Among the medium size hummingbirds, whose weights range around seven to eight grams, a flapping rate of 25 is not notably different from that of other common small birds. What is different in Hummingbirds, however, is the ratio of flight muscle weight to total body weight which is greater than for any other birds. With ordinary strong flyers this ratio may reach 25 per cent, while with hummingbirds a top value of 30 per cent is found. An explanation for this high ratio resides for the most part in the flight mechanism, but to a lesser degree in the adaptation of hummingbirds to a ~~mode of locomotion~~ dependence entirely on wings for getting about - they cannot walk or hop. With ordinary birds the down stroke of the wings beat alone sustains flight; i.e. the up stroke contributing nothing to either lift of propulsion. This state of affairs is reflected in the muscular distribution of the wing muscles in these birds in which the depressor muscles are many times larger than the elevator muscles. In hummingbirds, on the other hand, with the acrobatic ability to fly in any direction because the up and down strokes play an equal ~~are equally~~ Part in flight ~~important~~, both sets of muscles are of comparable size and so together make up a larger proportion of total body weight than in birds, less agile ~~with less well developed aerial agility.~~

Hummingbirds are a family that occur only in the New World. The great majority are non-migratory and tropical in distribution. ~~birds~~ They ~~feed~~ on the nector and small insects ~~they~~ extract ed from flowers. The development of this foraging habit was accomplished by a parallel adoption ~~of~~ of a type of flight which permits these birds to obtain their food on the wing. Their acrobatics ~~at which they are do~~ proficiency gives them the ~~facility~~ ability to probe the contents of any blossom however oriented; ~~they~~ it also bestows a means of quick escape from danger. In these adaptations, specialized as they are, hummingbirds are no more highly evolved to fit a

particular way of life than are the frigatebirds, the albatrosses, or even the penguins and auks. In the end evolutionary processes have provided birds with the kind of wings that serve best the mode ~~to~~ of life to which they have concomitantly adjusted.