WINGS

INSECTS · BIRDS · MEN

BLANCHE STILLSON

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by

BLANCHE STILLSON

Drawings by KENNETH GOSNER

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To

D. L. C.

PRIME MOVER

O to speed where there is space enough
  and air enough at last!

—WALT WHITMAN, *Children of Adam*

Foreword

THE following pages are the outgrowth of random studies instigated by an interest in birds and, more specifically, by the fascinating spectacle of their cyclic appearance and disappearance—the phenomenon of migration. An awareness of the orderly ebb and flow of populations—the waves of transient harbingers of spring and fall, the comforting reappearance of summer and winter residents—casual at first, deepened as years passed and led to the desire to know more about the ways and means of the process. Inevitably the wing, the organ of flight, claimed special attention. Naturally enough, curiosity was aroused about other kinds of wings, about flight in general. This led into an expanding universe. It has been an adventure pursued in the library, the back yard, the countryside, rather than in the classroom; through books and binoculars rather than by laboratory procedures. It has been an unregimented, informal, never-to-be-finished study filled with the delights of exploration through paths branching in all directions from the point of departure.

As the preparation of the material for the press draws to a close, acknowledgment is made of the help of many friends who, wittingly and unwittingly, have contributed to the enterprise, and to the librarians who have ably rendered professional service. Especial thanks are due to Clarence J. Goodnight, Associate Professor of Zoology at Purdue University, for having read the manuscript and made valuable suggestions for the sections on insects and birds, and to Guy A. Wainwright, who rendered the same service for the section on human flight. Above all there remains to be expressed gratitude for and indebtedness to the great naturalists of the past and present whose research has opened up the trails through the vast territory of Natural Science and whose published records have made their findings available for our enlightenment and enjoyment.

BLANCHE STILLSON

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PART I

INSECTS

1

The First Fliers

> Deep in the sun-searched growths the dragon-fly
> Hangs like a blue thread loosened from the sky. . . .
>
> —Dante Gabriel Rossetti, *Sonnet XIX*

Wings were first acquired by the insect. They were one of the great innovations with which, eons ago, Nature was trying to modernize existing forms of life and prepare them for the requirements and opportunities of a changing world. They are one of the most spectacular of all the inventions which she has taken from her inexhaustible store and put at the disposal of her creatures to help them cope with life.

The world in which they made their first appearance is beyond the range of myopic human vision. In spite of the efforts of the scientist to bring it into focus, its blurred outlines merge into the obscurity of the unfathomed past. It seems to stand at the very beginning of things. By geological time, however, the earth was by then really middle-aged. It had already supported life for at least a thousand million years. It was a life that had been, through unimaginable stretches of time, confined to the waters that monotonously lapped harsh and barren shores and that had begun its invasion of the silent wastes with the tentative efforts of the first land plants. By slow degrees moss and lichen had found precarious footholds; reed and fern and forest had come and, with shade and shelter, beckoned to other organisms in the teeming seas. Then

Nature began patiently and relentlessly to coax and force from the water those creatures that could adjust themselves to the now habitable earth and take advantage of its resources; and as she gradually and indomitably transformed fins into legs and swim bladders into lungs, she set in motion also the mysterious processes that endowed the insect with the power of flight.

The sight and sound of wings are such integral parts of our experience that it is no wonder we take them for granted. We accept as a matter of course the varied and ever-present aerial population: the bumblebee that on a May morning bends the mertensia almost to the ground as it probes for nectar, the mourning cloak that wavers along the shrubbery, the flycatcher that snaps its wings as it darts after a passing miller, the chattering swifts that pursue other winged insects in higher zones. We accept casually on August nights the acrobatics of the bat and the presence of the nocturnal moths it hunts, the eerie flight of the owl, the broadcasts of katydid and cricket, the drone of the mosquito. In the fall, migrating birds keep the air aquiver with wings equal to the demands of the changing season, wings that bring back the junco on the appointed day and bear away the thrush; and there are myriads of gyrating gall insects from the hackberry, infesting the air and competing with flies in a last desperate charge against the screens in an effort to escape the cold. Even in bleakest winter the wings of many residents—cardinal, chickadee, crow, starling, and sparrow—are all about, and lacquered ladybugs crawl up window curtains indoors. Over all, at every season, night and day, man-made wings sparkle with a silver sheen or, darkly ominous, threaten in the sun, and at night they blink by turns red and green, red and green, amid the stars. It is hard to imagine what it would be like to have no wings about us, to look out and up into a sky empty, silent, uncharted, unprofaned—a sky devoid not only of stratoliners, sky writers, and bombers, but of birds, bees, gnats, and butterflies as well, a sky arching over a world where the only aeronaut was an anonymous insect making trial flights even more momentous than those at Kitty Hawk.

No one can say just how or why or when the adventurous precursor of all aviators became air-minded and air-borne. The identity of the ancestral aquatic stock from which all insects evolved is still a matter of speculation among the experts, and that of the *enfant terrible* whose unprecedented longing for the skies sets him apart is still the deepest mystery. The earliest fossilized insects that have yet been found are winged insects. The first fliers seem to have sprung, like Aphrodite Anadyomene, full-formed from the waters. Of course they did not do so, for in Nature's academy there is no chance to skip a grade. It is agreed that a period of terrestrial existence must have preceded the first tentative vault into space, that in preparation for this aerial debut the candidates proceeded step by step. However, the records of all their trials and errors, the false starts and new beginnings, the discarded models, are missing—either forever lost or else still locked in unexplored or inaccessible regions of the earth's crust. The soft bodies and rudimentary forms of the individuals that escaped the maws of shark or lungfish or of those preposterous amphibians, the stegocephalians, disintegrated and left no trace. Only when the tough, insoluble fabric of the wing had taken on a definite form was there a chance of its being preserved in the accumulating silt of the lagoons and flooded areas and of being eventually recognized by the paleontologist.

No doubt the accession of wings was a long and tedious process. Although no one knows when it began or how long it took, it was consummated at least three hundred million years ago. Millions of years before there were birds or pterodactyls or flowering plants, while the coal beds of Pennsylvania and Wales, the Urals and the Saar were still dank forests of seed fern and giant horsetail, winged insects were abundant. Exploring the dense undergrowths of the swamps, skimming the surface of the shallow inland seas, they shared the delights and perils of existence with the first amphibians gasping in the mud, with primitive reptiles wallowing on the shores, with scuttling millepedes and scorpions, spiders and silver fish. In the heavy, steamy atmosphere they drifted or flickered over stagnant fens and disappeared into the shadows of forested swamps where slender trunks with tufted crowns of bladelike foliage and tapering reedy shafts, divided vertically by masses of whorled leafage, surmounted the lush layers of fern frond to produce effects which must have been as fantastic and unreal as those in the canvases of Rousseau le Douanier.

The fragments of insects so far retrieved from deposits older than those of the Carboniferous period are rare finds; but the coal measures of the world have yielded many fossils in a variety of forms. Differentiation of the original primitive stock, whatever it was, must have started long before this time, for it had by then progressed so far that a dozen different orders can be recognized. Of these the Ancient Netted Wings (Palaeodictyoptera) are the most undifferentiated and are thought to be the most primitive of all yet discovered. They, as well as most of the others, dropped out of sight during the next period (the Permian), when several orders of modern insects made their appearance. Of these the only two that we might have recognized from their family resemblance to some of our contemporaries were a dragonfly and a cockroach.

If the fact that these pioneers resembled their descendants is an indication that their modes of life also corresponded to those of the present day, it follows that great differences had already come about in ways and means of living. In response to impulse or necessity, each of these had worked out a life pattern adapted to its requirements. The omnivorous roach had become inalienably attached to the land with a taste for vegetable matter as well as for other viands. Hatching from the egg a minute version of its adult self, it scurried in and out of nooks and crannies, growing and molting until mature. The two pairs of wings then acquired were used probably as gliders, as handy means of escape when the harassed creature was cornered by a hungry foe; and they were similar in all respects—shape, texture, and arrangement of the veins—to those of some of its descendants. The roach far outnumbered all other insects in these early days. Its way of life was circumscribed, perhaps, but eminently successful, insuring its survival even amid today's perils of domestication.

The predaceous dragonfly, on the other hand, became pre-eminently aerial in its adulthood, hunting its food on the wing,

DRAGONFLY IN PALEOZOIC SWAMP.

incapable of locomotion on the ground. As if driven by an overweening nostalgia for its primordial home, it returned to the water for part-time residence. If the past can be judged by the present custom, it was to the water that the pioneer mother dragonfly entrusted her eggs, fastening them to the submerged stem of a plant or lightheartedly dropping them on the surface from which they sank into the protecting mud below. There the young hatched, as aquatic nymphs, grew and molted for a year or two until ready for their winged maturity. Scientists say that an insect's return to the water for all or part of its existence is a "secondary adaptation." These words at least label the process, but they do not explain it. They do not explain how the dragonfly came to prefer a watery cradle to a snug, dry crib. Were the young nymphs less palatable to fish than to spiders and thousand-legs? Were their own needs met more easily and bountifully in the water than on dry land? No one knows, and it is necessary in this instance, as in so many others, to follow reluctantly the advice of Henri Fabre: "In the presence of the unfathomable problems of origins, the best thing is to bow in all humility and pass on."

At all events, the dragonfly established its way of life and perfected the techniques of its transition from aquatic youth to aerial maturity. However long postponed, the day finally came when a water-bred creature could at the proper moment confidently forsake its native element, feel its way up the stalk of a reed into the air, shed its outgrown, muddy skin for the last time, and emerge transfigured, an air breather endowed with the miraculous power of flight. Is it too much to suppose that, as it still clutched the swaying support with immaculate feet and waited for the strange new organs to unfold and harden, its tiny spark of being quickened into a brighter glow? Surely its little ego must have swelled (it must still swell) to capacity as, with sails spread, it darted off to explore its boundless precincts. Though still part and parcel of the watery world, it had risen above it. It could cavort in the sunshine, itself "a living rush of light," patrol the dark bogs, rest among the rushes, frisk through the days in gay abandon until, perhaps as it ventured too near the sluggish forms dozing at the water's edge, the snapping jaws of a salamander closed its account. The flight of the first dragonfly may not have been as dazzling, as brilliant as that of some of its descendants, but the general design of the four wings of netted gauze, which it had devised, was evidently a good one. With slight alteration it has served those descendants for at least two hundred and fifty million years.

2

Differentiation

> Thick in yon stream of light, a thousand ways,
> Upward and downward, thwarting, and convolv'd
> The quivering nations sport. . . .
>
> —JAMES THOMSON, *Summer*

ALTHOUGH scientists are not yet able to say with certainty just how wings evolved, they are sure that they are not, like legs and lungs, adaptations of already existing organs. A theory once advanced, that they are modifications of the tracheal gills of the unknown aquatic ancestor, is for various reasons held to be unsatisfactory. Wings are, in fact, extensions of the chitinous body wall of the insect. They are flattened pockets of cuticle, traversed and strengthened by a framework of veins; and they are borne by two of the three sections of which the thorax is always composed. A pair of legs is attached to each of the segments, but only the second and third ever bear organs of flight. Wings are supposed to have started as simple lateral, dorsal projections which, functioning more or less as parachutes, were useful to insects that were in the habit of leaping from one place to another. Presumably the individuals so outfitted escaped oftener, lived longer, produced more of their kind than those not so gifted. The lobes or flaps gradually extended their reach, acquired a certain amount of movement, were reinforced by veins and finally brought under control by the adjustment of already existing muscles in the body wall.

An important bit of evidence in support of this theory is that in some of the earliest fossils two small lobes are actually present on the first thoracic segment in addition to fully developed wings on the other two. It is as if three pairs had started to grow but that the front ones never got beyond an early stage of development. Small lobes that soon disappear still occur in the nymph of one of the termites and are thought to be additional evidence.

There are doubtless good reasons why three pairs of wings are not only unnecessary but also less efficient than two pairs or one. The movements of six legs are easily synchronized, and three clawed feet to a side are valuable adjuncts when it comes to scrambling up and down and around a stem or leaf edge or negotiating the crevasses of the forest floor; but six wings spread to changeable air currents present problems of a complex order. Practical Nature gave up the idea at the start. It is only in the unrestricted realm of the imagination where no limitations are imposed and engineering problems are unknown that six wings have successfully unfolded. Materialized in works of art, they are effective symbols of supernatural potencies. Six-winged chimeras at the tomb of a Chinese emperor confer celestial protection on the relics of temporal omnipotence. In the verses of prophet and poet or in a window at Chartres, six-winged cherubim and seraphim flutter in transports of supernal ecstasies.

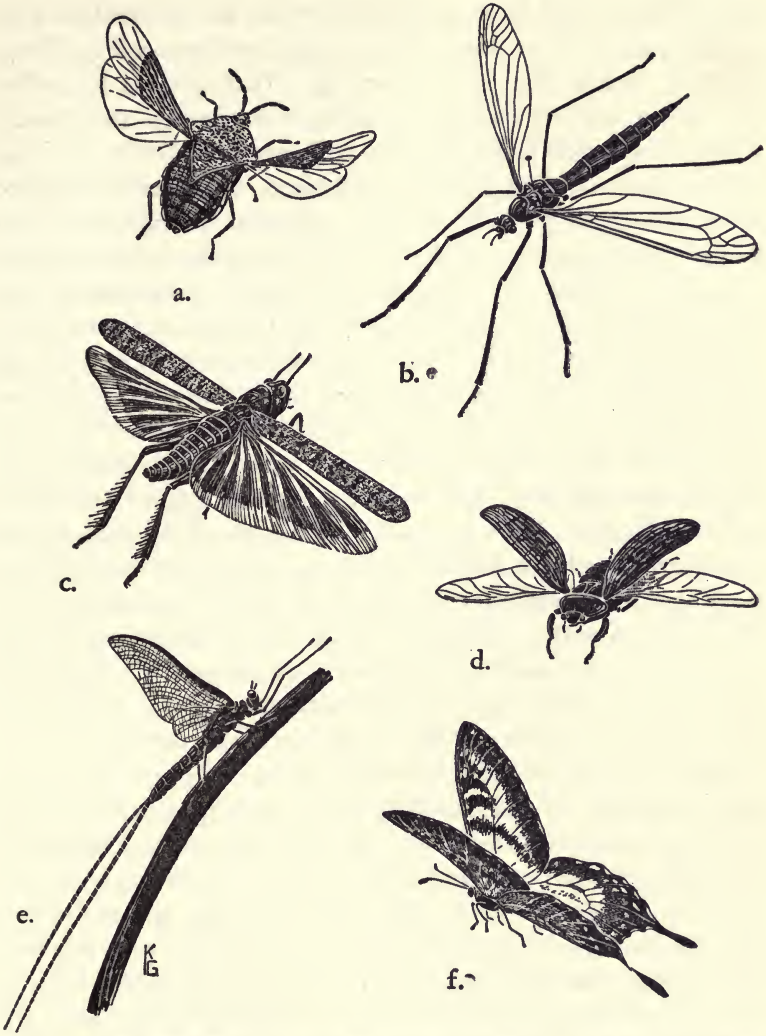
However, if wings were restricted in number, no limitations were placed on their form. Through the devious and inscrutable processes of variation and mutation Nature endlessly experimented with the original design, adapting it to changing needs and circumstances. In the struggle for existence wings were a distinct advantage. Their owners in a sudden take-off could leave an earthbound enemy in surprised incredulity and frustration; they could easily move out of overpopulated communities and stake out claims in ever-broadening frontiers where food shortages did not exist. Except in so far as insects preyed on one another the air was a vast sanctuary. No wonder that their numbers increased, that they spread to all parts of the earth. With the different modes of life necessitated by the changing environments, they acquired different physical needs, different forms, and different kinds of wings to keep them aloft.

The tremendous geologic changes at the end of the Paleozoic era quickened the rate of their diversification. Then the inland seas receded; the great continental land masses emerged; the earth's surface folded into mountain ranges. There were climatic shifts which substituted extremes of temperature and humidity for the warm, moist conditions which had prevailed everywhere, making desert wastes of some regions, ice fields of others. Insects as well as all other forms of life had to meet requirements or die. Many species, unable to face the stark reality, vanished. Others managed willy-nilly to survive and in time the orders of present-day insects were established one by one: lacewings, May flies, cicadas, stone flies, grasshoppers, beetles. With the coming of flowering plants there were new opportunities and a new food supply. The two-winged "true" flies, the "true" bugs, the butterflies and moths with sucking mouth parts appeared and, last of all, only about fifty million years ago, the highly organized branch of an earlier breed—the so-called "social insects," the wasps, ants, and bees.

As a class, insects were able to solve the grim problems imposed by changed and novel environments: they survived. They witnessed the coming of the ginkgo, the conifer, the walnut, maple, ash, the buttercup, and the daisy. They watched the amazing transition of reptilian forms into bird and pterodactyl, the rise and fall of the mighty dinosaur, the portentous advent of the mammal. The family trees of many modern insects were flourishing growths before the whale and the dolphin returned to the sea, before the bat rehearsed its aerial antics, before the ape took up residence in the trees. Long before there were Alps, Apennines or Andes, Himalayas or Rockies, insects were pollinating fruits and flowers, building soil, and in other ways helping to convert the earth into a possible abode for a precocious primate. In and out of ice ages they flitted, amid the vanishing forms of the saber-toothed tiger and the hairy mammoth. Installed in their several domains, they now observe the career of self-styled *Homo sapiens*. Having penetrated into the farthest corners of the globe and populated every region—a small water strider abides even on the open sea—insects today far outnumber in species all other forms of animal life combined. No one really knows how many kinds of insects there are, for thousands of new species are being discovered and described every year. If and when the census is completed for all parts of the earth, the number may reach into the millions. At present there are approximately seven hundred thousand known species, and of these over nine tenths achieve a winged state.

The organs of flight, which are so largely responsible for the remarkable record, naturally reflect the innumerable adaptations that were made. It is not always possible to follow closely the logic of their configurations, which in some cases may be the result not so much of adaptation as of evolutionary trends that, once begun, moved on to their culmination. Also, many of the intermediary stages of a sequence are missing. At all events, in due course the original, unspecialized organs of the early fliers were changed into wings of gossamer, of lace, of leathery stuff, of horny material; they became pellucid, opaque, polished, dull, iridescent, prismatic, fringed, scaled, grooved, painted in grisaille, stained and stenciled in polychrome. They modified their bearing so that in repose they extend horizontally at right angles to the body or stand erect over it, or bend back along the sides, or lie flat over the back. Some rear wings are stowed away in complicated folds, pleats, and overlappings; others, not. The two pairs may be alike or they may differ from each other in size or shape or texture. The number of different combinations of structural elements seems inexhaustible.

The details of the wing's structure, constant for each species (at least relatively constant—constant as far as we are concerned in our mere pulse of time), are dependable guides to the systematist as he traces relationships, and groups like with like, combining species into genera, genera into families, families into orders. It was the great Linnaeus himself who started the fashion of naming the orders of insects according to the general nature of the wings; and his example has been followed, when feasible, by those who came after him. So, stone flies are Folded-wings (Plecoptera); grass-



TYPES OF INSECT WINGS: a. true bug; b. crane fly; c. short-horned grasshopper; d. beetle; e. May fly; f. butterfly.

hoppers and their relatives are Straight-wings (Orthoptera); thrips are Fringed-wings (Thysanoptera); termites are Equal-wings (Isoptera); cicadas and aphids are Like-wings (Homoptera);

squash bugs, stink bugs, and many others are Dissimilar-wings (Heteroptera); alder flies and lacewings are Nerve-wings (Neuroptera); caddis flies are Hairy-wings (Trichoptera); butterflies and moths are Scaly-wings (Lepidoptera); beetles are Sheath-wings (Coleoptera); wasps, bees, and ants are Membrane-wings (Hymenoptera). These orders, and others whose names connote different sorts of physical attributes, make up the subclass of the winged, the Pterygota. Three orders of wingless insects compose the subclass of the not-winged, the Apterygota. Some insects that, by becoming parasites, have forfeited their wings and others that, for one reason or another, have discarded them are retained among the Pterygota. The Apterygota, on the other hand (of which the best known are silver fish and springtails), are those that never tried to fly. The winged and the not-winged are united by important structural bonds into the class of the six-legged, the Hexapoda or Insecta. The seven orders of Linnaeus' original system have increased almost fivefold as later scientists have described an ever-increasing multitude of insects; and there is constant revision of the system as they continue to weigh new evidence and ponder the relative importance of different combinations of characters. Since they do not always reach the same conclusions, the systems adopted by the various authorities differ in minor details.

The absorbing task of relegating a given "bug" or "fly" to an order and suborder and ultimately to a particular branch and twig in the intricate ramifications of a family tree is made possible not only by the general structure of the wing but also by its system of venation. By this is meant the number and arrangement of the veins and of the cells formed by them. The position of a vein and the manner of its branching, the size, shape, location of a cell can be as diagnostic as a Mongolian fold or a Hapsburg lip. They are indelible marks of family, of genus, and often of species.

In an attempt to bring order into the chaotic assortment of innumerable arrangements and to establish a type form to serve as a basis for comparison, scientists have examined the incipient wings of immature insects, the tissues just forming in nymphs and pupae. In these embryonic growths they have traced the paths of the minute tracheae round which the walls of the veins later develop; and, by comparing them, they have mapped out the routes of the veins in the hypothetical primitive wing, from which, supposedly, all other systems of venation have been derived and to which all others, ancient and modern, can be compared. They have given names and numbers to the principal veins and their branches and have added to the basic pattern the cross veins that appear with such regularity in the adults of several orders that they may safely be considered constant elements. As the more specialized types of wing venation are studied, it is not surprising that again opinions differ as to the identity of certain parts, for some are capable of more than one interpretation. Wings became specialized along many different lines and they changed their details accordingly. In the process adjacent veins frequently coalesced; one or more might atrophy and disappear. In such cases the intervening cells either vanished altogether or combined, and the remaining parts often rearranged themselves ambiguously. In some cases "accessory," "intercalary," or "adventitious" veins were added. However, in no case was the number of principal longitudinal veins in the hypothetical primitive type of venation ever increased.

Of these there are typically eight—eight life lines that extend from the base of the wing outward. They are hollow, tough tubes containing blood and the small air passages which are part of the insect's respiratory system. At the time of the transformation of the nymph or pupa into the winged adult, it is by their agency that the expansion of the wing is brought about; and after the two surfaces of the unfolded pockets of cuticle have met and fused, it is the framework of the veins that converts them into effective organs of flight. The longitudinal veins are alternately convex and concave, a fact seen to best advantage in the wings which open and close like a fan (the grasshopper's, for instance), where the convex veins follow the crests of the ridges and the concave veins the furrows. It is less obvious in the higher orders where the wings are flattened. However, the surface of the membrane is seldom, if ever, perfectly flat. It is a complex aggregation of curved areas; and the convexity or concavity of a vein is constant for that vein where-ever found. This fact helps tremendously in the search for homologous forms in the different species. There is usually a concentration of veins at the wing's front edge, where the strain of flying is greatest, especially on the downstroke; and wherever this does not occur, as in lacewings and caddis flies, the insects are poor fliers.

In the most generalized primitive wings an irregular network filled in the spaces between the longitudinal veins; a little later cross veins formed at right angles to the long ribs, to function as struts or reinforcements of them. Variation in the number and distribution of the veins extends all the way from the delicate reticulations in the wing of a dragonfly, which may contain as many as three thousand cells, to the almost total absence of subdivisions, as in some of the small chalcid flies, where a solitary compound vein near the front edge of each front wing supports a clear, undivided tissue, the rear wings being veinless. In another family of minute, black hymenopterous insects both pairs of wings are veinless.

By means of the complex interplay of their endlessly varied elements, the insect's wings are thus, if not the sole, at least an essential means of its identification in its adult state. More than this, they protect, advertise, and adorn. Evolved originally as mechanical devices for aerial support and propulsion, they have become an ensign, a coat of arms, an insigne, a uniform. They are a sort of monogram and sometimes even a signature.

3

Forms and Functions

The myriad things take shape and rise to activity. . . .

—LAO-TZU

THOSE early heralds of aerial conquest, the Ancient Netted Wings (Palaeodictyoptera), were so named because an irregular network filled the spaces between the six or seven longitudinal veins and their simple branchings. The two pairs of wings were alike in all respects and were joined to the body by broad hinges that kept them strictly lateral. Among many primitive traits, these insects possessed on the first segment of the thorax the flaps or lobes that presumably started out to be a third set of wings.

The first known dragonflies, their contemporaries, modifying and refining the details, followed, in the main, the traditional standard—similarity of size, shape, and venation, the fine network, and the broad attachment to the body, which prevented any folding, and limited action to an up-and-down movement. One of them, with a wingspread of over two feet, was not only the giant of its own day but also the largest insect ever known to exist. This colossus, though bigger, was not better than its relatives, for in less than a hundred million years its oversized sails had swept it into the discard; and the responsibility of carrying on the family was left to a collateral branch, small fellows measuring only an inch and a half between wing tips.

In present-day dragonflies the hind wings are usually slightly larger than the fore wings and somewhat different from them in shape. The front edges of both pairs are characterized by a cross vein about halfway between the base and the tip, where a joint or nodus interrupts the continuity of its line. Farther out a thickening of the membrane creates an opaque spot or stigma, which is often pigmented. The number and distribution of the tiny cells of the network vary, according to the species, but a constant feature is the presence of a triangular cell near the base of each wing. Changes in the position of this one cell are enough to differentiate the two suborders of dragonflies: it may occupy the same position in relation to a certain cross vein in both pairs of wings, or it may be closer to the cross vein in the hind wings than in the fore pair. Variations in the shape, number, or location of cell or vein, slight though they may be, are so constant that each genus of the suborder (there are about four hundred and eighty) can be recognized by the venation of the wings alone.

The yoke-winged damsel flies (Zygoptera), close relatives of the dragonflies, similar to them in their general make-up, betray their individuality by their wings. The triangular cell is not present in the meshed gauze; front and hind wings are alike, and they are narrowly attached to the body in such a way that at rest they are brought parallel to it, close at the sides or tilted above. The damsel fly, like its kinsman, has made the long journey out of the trackless past into the man-ridden present, to which it has made an appropriate contribution. It is not a powerful flier, but one of the first French monoplanes was named after it. This was the Demoiselle, designed and flown by Santos-Dumont.

Ant lions, lacewings, and their relatives also keep to the old-fashioned way with two pairs of netted fabrics that are approximately the same in texture, size, and shape. In repose they slant over the body like a roof. May flies also have netted wings of sheerest gauze, but the hind pair is much the smaller of the two and at rest they are held above the body like a butterfly's. On these fragile, triangular webs the May fly passes its adulthood—a few evanescent, aerial hours filled with the ritual of the strange courtship "dance" and the nuptial flight—a brief culmination of a life cycle for which an underwater existence of a year or more as an aquatic nymph is the necessary preparation.

Grasshoppers, katydids, and crickets belong to one of the lower, generalized orders, but their front and rear wings are not alike. The front ones are leathery or parchmentlike protections for the wider, thinner, rear pair which take over the burden of flight. Opening and closing fanwise, the rear pair expand for action and fold neatly beneath the narrower front covers when not in use. At rest, both pairs lie smoothly against the sides of the abdomen or overlapped on top. Grasshoppers show these characters clearly. The venation of the wing covers—the tegmina, as they are called—follows the generalized plan, but in the hind wings the longitudinal ribs radiate outward from the base, with convex veins on the ridges of the accordion pleatings, concave veins in the valleys. In the male katydids and crickets, the venation of the tegmina is greatly modified for a special purpose.

The rear wings of crickets show a variety of form. In some species they are longer than the tegmina; in others they are wanting. As a rule, they are present but weak and short and ineffectual as organs of flight. Nevertheless, the mole cricket, from which the habit would not be expected, sometimes indulges in nocturnal flight.

The wings of all three cousins are better suited for gliding than for true flight. They progress by leaps and bounds made possible by the extraordinary development of the hind legs. As everyone knows, the grasshopper launches itself into space with a mighty leap and glides or flutters to a near-by destination. Unlike the predaceous, water-bred dragonfly, it is the product of the soil and a strict vegetarian. It does not have to pursue victims or travel far at a time. That its equipment has been sufficient for its needs is obvious, for it has arrived in our summer fields and roadsides straight from the Paleozoic fatherland with undiminishing vigor.

Even the great massed flights of the roving members of the family, the migratory locusts (for the short-horned grasshopper is a locust, according to the terminology established by Linnaeus, and what we call a "locust" is really a cicada), are probably accomplished by the insects' ability to ride air currents rather than by actual flying. During such a raid Otto Lugger described them as "eddying and whirling about like the wild, dead leaves in an autumn storm," and they spread over the region they are about to devastate with a speed that seems to vary with the wind's velocity. Darwin described such a visitation in South America. His party observed a reddish-brown cloud approaching from the south. He wrote:

> At first we thought that it was smoke from some great fire on the plains; but we soon found that it was a swarm of locusts. They were flying northward; and with the aid of a light breeze, they overtook us at the rate of ten or fifteen miles an hour. The main body filled the air from a height of twenty feet, to that, as it appeared, of two or three thousand above the ground; "and the sound of their wings was as the sound of chariots of many horses running to battle": or rather, I should say, like a strong breeze passing through the rigging of a ship. The sky, seen through the advanced guard, appeared like a mezzo-tinto engraving, but the main body was impervious to sight. . . . The swarm having once alighted, the individuals flew from side to side in all directions.

The wings of migratory locusts are, indeed, stronger than those of their more sedentary relatives; they seem to be endowed with latent powers that at intervals and in different parts of the world are called into action by an urgent wanderlust, of which the cause is not yet fully understood.

The modification of front wings into protective coverings has been perfected by the sheath-winged beetles, which have converted them into hard, close-fitting, severely tailored, veinless cases called elytra. Meeting in a straight line down the center of the back, they shelter the filmy hind wings stowed beneath them, not in accordion pleatings but in carefully adjusted tucks and folds. Spots, stripes, and streaks, ridges, furrows, and punctures bedeck surfaces that are enameled, burnished, mat, or clouded. Some have no other embellishment than their own splendid metallic sheen.

Among the more familiar shields are those of the tiger beetles with bands and splashes of yellow on grounds of iridescent bronze or green, of the whirligigs in glossy blue-blacks with lustrous overtones, of leaf chafers in gold and silver, wood borers in copper and brass, of bean beetles in striped enamels, and of fireflies in sedate, dull gray. Ladybird beetles prefer polka dots and use them in different quantities and color combinations. They may be black on a red or yellow ground, or red, yellow or white on a black ground. Two black dots on a yellowish-red field distinguish the small guest that so frequently is seen indoors in late winter, prematurely awakened from its hibernation. Irregular black striations (rather like connected spots) on a red ground characterize the imported Australian ladybug whose passion for the cottony-cushion scale has saved the citrus crops on the Pacific coast. The Mexican bean beetle and the squash-ladybird with sixteen and twelve spots, respectively, are from man's point of view the black sheep of the family (in which there are more than two hundred species in North America) because they are vegetarians and have villainously acquired tastes similar to his own.

There are also seven-, nine-, ten-, fifteen-, twenty-two-spot ladybugs. Like the balls on the scutcheons of the Medici, the spots on their shields vary in number with different members of the family. In the Medici arms, there were at first eleven balls, then nine; and, one by one, the number was further reduced: to eight in the time of Giovanni di Bicci, to seven in Cosimo's day, and finally to six when Lorenzo flourished so magnificently. Can it be that the spots on the ladybird's armor have genealogical significance?

Such a possibility has not escaped the scientist; but how is he to follow the history of a family which flourished for millions on millions of generations before his own? At best he can but collect data from the representatives of his own time, and then sort, compare, and speculate on them. There is a theory that the primitive pattern of the ladybug's elytra—the forward pair of wings—took the form of stripes or bands, that there was next a barred design and that, as the network of this was reduced, the points of intersection remained as spots. Although there is great diversification in the number, size, and distribution of the spots, there seems to be for each genus an underlying "pattern unit" within which the change from stripes to dots took place albeit in varied combinations. Moreover, it is probable that the general trend was toward either a reduction in the number of spots or their confluence. In the case of the two-spotted ladybug and its varieties, its simple pattern appears to be "referable" to one of seven spots. When the attempt is made to trace evolutionary trends among genera, however, the problem becomes too complicated. It is easier to conclude that the set of variations adopted by each genus stemmed independently from the primitive striped pattern. Among species the design of the ladybug's shield may have genealogical significance; among genera it does not.

Elytra originated as near as we can tell with certain remote ancestors of the Coleoptera that had become wood borers, a theory for which the tunnelings discovered in tree trunks of the Carboniferous provide some evidence. Four trailing vestments of gossamer in such surroundings unquestionably presented problems which some insects in similar straits solved by discarding their wings altogether.

The resourceful beetles met the difficulty by ingeniously remodeling their fore wings into smooth, hard coats of armor. A very logical and advantageous adaptation it was, for it allowed them to enjoy the security of a cozy burrow without surrendering the freedom of air travel. It was handed down with surprising uniformity to an ever-increasing progeny. In the two hundred and fifty thousand species of Coleoptera known today (the largest order in the animal kingdom), the general form of the elytra is remarkably stabilized in spite of the great variation in detail. There are, of course, interesting deviations from the typical scheme, such as those seen in the wing covers of oil beetles which are so short that they by no means cover the body and they do not meet in a straight line. They overlap at the base and their inner edges curve away like those of a cutaway coat seen in front view. The elytra of rove beetles are also very short, while the hind wings are often longer than the body. The folding of the hind wings beneath their abbreviated shields calls for skillful management on the part of the beetle, and the insect is often seen maneuvering them into place with a leg or the tip of its abdomen.

The sheaths of weevils and of some ground beetles that have lost the power of flight have fused into a completely unified shell. In such cases the hind wings have altogether disappeared through disuse. Lastly, the females of some species of fireflies are entirely wingless. As yet little has been done in the study of the venation of the hind wings of beetles; interest has centered on their protective coverings.

The large group of "true" bugs, such as squash bugs, stink bugs, water boatmen, and many others, are called Heteroptera—other-winged—because their front wings are of two different textures. They start out as thick and tough as the elytra of beetles, and half or two thirds of the way to the tip they change abruptly into thin membranes. The thickened basal part is made up of two or three areas in which veins are usually lacking, and they are sometimes lacking in the membranous tips as well. In many ways the venation differs so widely from that of all other insect wings that it is only by the study of the branching tracheae of embryonic forms that they are seen to be, after all, but modifications of the primitive plan. There are, of course, many variations of shape and color and also of the arrangement of the veins when they are present. These wings always lie flat on the back with overlapping tips when not in use and the membranous hind pair fold neatly beneath them.

The greatest deviations from the pattern of the primitive wing have been made by the bees, wasps, and flies. With the veins greatly reduced in number and arranged in systems that seem simplified and are actually of the most extraordinary diversity, they represent a high degree of specialization.

The flies, moreover, have reduced the number of wings to one pair, retaining the front wings and replacing the rear ones by two extremely small stemmed knobs called halteres. Rapidly vibrating in flight, halteres act as balancers. They are usually regarded as the greatly modified hind wings, although Dr. C. H. Curran, Curator of Insects and Spiders at the American Museum of Natural History, is convinced that they are separately evolved organs, "developed as a compensation for the loss of wings and to satisfy the need for rapid flight." At all events, in the males of some of the scale insects, members of an entirely different order, the rear wings have shrunk into the same sort of club-shaped appendage. In still another order, in which only the males are winged, an order of small insects that live parasitically inside the bodies of bees and wasps, it is the front pair that has contracted into similar knobbed projections. In these minute creatures the hind wings are comparatively large; they are fan-shaped and they fold along their radiating veins like those of a grasshopper.

There seems to be no limit to the diversification of the wing's elements or to the ways in which their characters combine. In addition, the state of winglessness among adults, resulting always either from degeneration or from relinquishment through adaptation, has arisen independently and sporadically in many orders. Sometimes it is the female of a species that is the confirmed pedestrian, as with the scale insects, the cankerworm moths, the tussock moth, the bagworm, and the firefly. Sometimes it is the male, as with fig insects. Sometimes the loss occurs in both sexes of certain species and not in others of the same family, as with some crickets, roaches, and beetles that have useless or vestigial wings or no wings at all.

Again, wings may be present at one period of the life cycle, to be discarded when that particular stage is passed. Among the underprivileged ants, wings are reserved for those on which the future of the race depends, and to these they are granted for only a brief while. After the nuptial flight the females cast theirs off and withdraw into the dark privacy of underground chambers as their consorts die. A similar system is in force with the so-called first reproductive caste of termites, except that the grooms, refusing to be so promptly expunged, shed their organs of flight also and retire with the queens into the royal apartments. The severance of its wings is an easy matter for the termite, for there is a suture across each membrane not far from its attachment to the body where at the proper time the break is made.

Another extraordinary example of voluntary surrender of functional wings is to be seen in the behavior of a small European wasp that parasitizes the praying mantis. With the welfare of her offspring at heart, she attaches herself to a mantis in some secure spot, usually under its wings, and then, with transportation assured, tears off her own. If all goes well for her, if she has rightly chosen a female mantis searching for a place to lay her eggs, she is present to lay her own on those of her hostess in the nick of time, before the frothy protective covering provided by the mother mantis has had time to harden and prevent such depredation. Confident that her own brood will hatch first in the midst of ample rations, she resumes her place on the mantis and continues her own parasitic existence.

To fly or not to fly seems to have been a recurrent problem among insects, and of all the solutions of it, one of the most extraordinary has been made by the aphids. They seem to be able at critical moments in their life cycle to produce wings at will. The first individuals to appear in the spring are all wingless females that have hatched from over-wintering eggs. There is not a male among them, yet their numbers increase astronomically. Without mating, a process known as parthenogenesis, they give birth to infant daughters which quickly grow up and repeat the process. When the accumulated multitudes threaten the food supply, winged aphids are born. These are also spinsters, and they fly away to fresh pasturage and establish new colonies of wingless females that continue as before. As summer draws to a close and days shorten, winged males intrude into the hitherto exclusively feminine society. Then winged forms of both sexes mate and re-establish the life cycle: the female deposits her eggs in a convenient crevice in a stem or bud, where they will hatch the following spring into a new congregation of "stem mothers" and begin a new dynasty.

The details of the domestic economy of the three hundred-odd different kinds of aphids in the United States vary with the species; but as far as wings are concerned, it seems likely that their appearance is always related to food, temperature, and light. Years ago J. H. Comstock supervised an experiment at Cornell University in which ninety-eight generations of aphids were reared without the appearance of any winged individuals. The experiment was carried on for over four years in controlled temperatures in a greenhouse, where the young of each generation were removed to aphid-free plants as they arrived. In experiments with the potato aphis, A. F. Shull has proved that the number of winged individuals born of wingless mothers is greatest when there are about eight hours of illumination.

4

Tokens of Maturity

> An inner impulse rent the veil
> Of his old husk. . . .
>
> —Alfred Tennyson, *The Two Voices*

An insect's wings are a token of its maturity. They do not unfold for flight until the last stage of development has been reached, beyond which there is no further growth. An insect may begin life resembling its parent more or less and attain adulthood by a series of molts that do not greatly interrupt its active career. Or it may hatch as a larva—for instance, a caterpillar—which, after having grown to its maximum size by successive molts, turns into a quiescent form, a pupa (in or out of a cocoon), from which after days or weeks or months, as the case may be, the winged adult escapes. This is the way of butterflies, moths, wasps, bees, flies, beetles. It is called "complete" metamorphosis. It is a later invention than the "gradual" metamorphosis practiced by roaches, grasshoppers, crickets, and the "incomplete" metamorphosis of dragonflies and others whose infancy and childhood is spent in the water. There are many variations of the processes, but the inactive period as pupa or chrysalis (the term usually applied to the pupae of butterflies) is the feature that characterizes complete metamorphosis. The process of growing up is, therefore, not the same for all, yet all agree in postponing the acquisition of functional wings until the molt that ends all molts, the final transformation. To this rule there is only one known exception: the May fly, after its liberation, fully winged, from the husk of the aquatic nymph, must molt yet once again and pull its diaphanous tissues from diaphanous capsules in preparation for its brief aerial revelry.

Transformation: a-a′, complete metamorphosis of sphinx moth; b-b′, gradual metamorphosis of harlequin bug.

Although they seem to be the outcome of a striking improvisation, wings are produced by a gradual process. Insects that undergo gradual or incomplete metamorphosis acquire small wing pads several stages before the final molt which contain the developing organs and betray their presence outwardly. In those that pass through a complete metamorphosis, wing growth takes place internally. There is no external sign on caterpillar, grub, or maggot that it has begun; it is apparent only after the larval form has changed into pupa or chrysalis. Then wings can be seen close-pressed against the body beneath the pupal skin, ready and waiting for the time to come for the last act.

The crucial process of the final transformation is essentially the same for all. From the outworn husk of a nymph clinging to a stalk or tree trunk, or of an unprotected chrysalis anchored to a leaf or twig, or of a brown pupa bedded in a dark cocoon, the adult winged creature extricates itself. Unerringly groping its way, it finds the right support, the position best suited for the unfolding of the organs on which its survival will thereafter depend. Pale, weak, soft, it rests until its body dries and hardens and its wings expand.

Fabre has given a detailed account of the last molt of the large gray locust whose din in late summer reverberates through the vineyards of the Midi. He records each step of the process: how the immature insect, ready for its transformation, grasps its support; how pulsations of the body split the jacket and lengthen the rent from the head to a spot between the wings; how the back bulges up through the slit, to be followed successively by the head with its antennae, the forelegs, the intermediary legs, the four limp, narrow wings, the hind legs with their sawlike shanks; how the creature, at this point dangling head down, rights itself, frees the rest of its body and assumes a position head uppermost so that the wings hang in their natural position. He describes, at last, the completion of the two wads of crumpled membrane on each side of the thorax: how the unfolding begins imperceptibly as gravitational forces tug at the formless bundles; how vital fluids begin to flow through the longitudinal veins, starting at the juncture with the body and spreading slowly outward; how, finally, each pair of shapeless stumps assumes by degrees its perfect, predetermined form, needing only a further period of rest in which to harden. This description of an insect's coming of age is to be found among the essays assembled in *The Life of the Grasshopper.* Fabre, experimenting with cicada nymphs, found that when they were prevented from taking their normal position—that in which the wings could naturally unfold—they renounced transformation and perished.

Butterflies and moths follow the same general procedure; and the newly invested Cecropia exercising its great sails as they expand and dry is a common sight. Yet this process, as every other, is variable and at times takes place with incredible dispatch. The aquatic nymphs of the May fly do not leave the water when about to transform as do those of the dragonfly. Instead, they merely float to the surface and release the adult without more ado. It has been said that after the nymphal skin first cracks not more than ten seconds elapse before the insect flies away.

The expansion of the wings of one of the caddis flies is even more rapid. It undergoes complete metamorphosis and its larvae live in rapidly flowing fresh water, remaining there after they have changed to pupae. Moreover, transformation takes place entirely under water. When the adult breaks from the pupal skin it rises to the surface and its wings expand instantly. Such an immediate response solves the problem imposed by its perilous situation, for if it could not fly at once, it would be swept away by the current.

A similar pattern of existence has been made by the family of net-winged midges. They also transform under water where, just below the surface, the masses of pupae cling to rocks by means of suckers on the lower area of the body. When they burst the pupal skins and rise to the surface, their wings do not expand as other wings do—they unfold. They are already full-formed and complete before they are pulled out of the wing cases, into the smaller compass of which they have been adjusted by intricate foldings. The network of fine lines, unrelated to veins, caused by the creases distinguishes the adults of this family from all other insects.

The phenomenon of the insect's metamorphosis has always appealed to man's imagination. In the spectacle of the emergence of the moth from the cocoon, the butterfly from the chrysalis he seems to have found vicarious satisfaction for his own vague longing for regeneration and also justification of his hopes for its attainment. At an early day the butterfly became the symbol of immortality. The idea is implicit under many guises. In Greece the word *psyche* acquired a double meaning and the nature myth of Cupid and Psyche became an allegory of the soul's pilgrimage. The early Christians, borrowing from pagan iconography, used the little winged figure of Psyche on sarcophagi and walls of catacombs as an emblem of the soul; and pagans placed the butterfly on their monuments to represent the *animula vagula* freed from its earthly trammels. The French archaeologist A. N. Didron cites a funeral inscription that clearly illustrates this usage: "Also, I therefore command my heirs to entomb my bones so that the drunken butterfly may flutter upon my ashes." This identity of the anima with a butterfly is suggested in an entirely different vein by the often quoted quandary of Chuang Tzŭ, a Chinese philosopher of the fourth century B.C.:

> Once upon a time I, Chuang Tzŭ, dreamt I was a butterfly, fluttering hither and thither, to all intents and purposes a butterfly. I was conscious only of following my fancies as a butterfly, and was unconscious of my individuality as a man. Suddenly, I awaked, and there I lay, myself again. Now I do not know whether I was then a man dreaming I was a butterfly, or whether I am now a butterfly dreaming I am a man.

Nowhere has the beauty of insects or the mystery of their lives been more appreciated than in China, where in early days the cicada was of symbolic importance. The main features of its life history were known from a very early time. The Chinese observed how, at the summer solstice, the dusty nymph worked its way out of the ground and found suitable foothold for its transformation. They watched the winged adult as it struggled out of the discarded jacket and took on successively the colors symbolizing the five elements (metal, wood, earth, fire, and water), changing from white to pale green, to yellow, to brown, and to black. They watched the wings expand and bear it away. It became for them an emblem of resurrection. Therefore, they made carved images of these insects out of precious jade, some of which were worn as amulets by the living. Others were placed in the mouths of the dead as an aid to the struggling soul in its efforts to free itself from its mortal fetters.

In ancient Egypt a similar, though less exalted, service was rendered to the one "going out into the day" by the carved image of the Sacred Beetle. Engraved with the words of a charm beginning "O my Heart, rise not up against me," it was laid on the breast of the mummy beneath the wrappings, and its office was to quiet the reproaches of the uneasy conscience when the time came for the Weighing of the Heart in the Great Balance. The origin of the idea that it could be of such practical assistance, as well as the rest of the elaborate symbolism which developed around that relative of our tumblebug, is, however, another story. It has nothing to do with metamorphosis or wings. Beetles are not distinguished fliers.

5

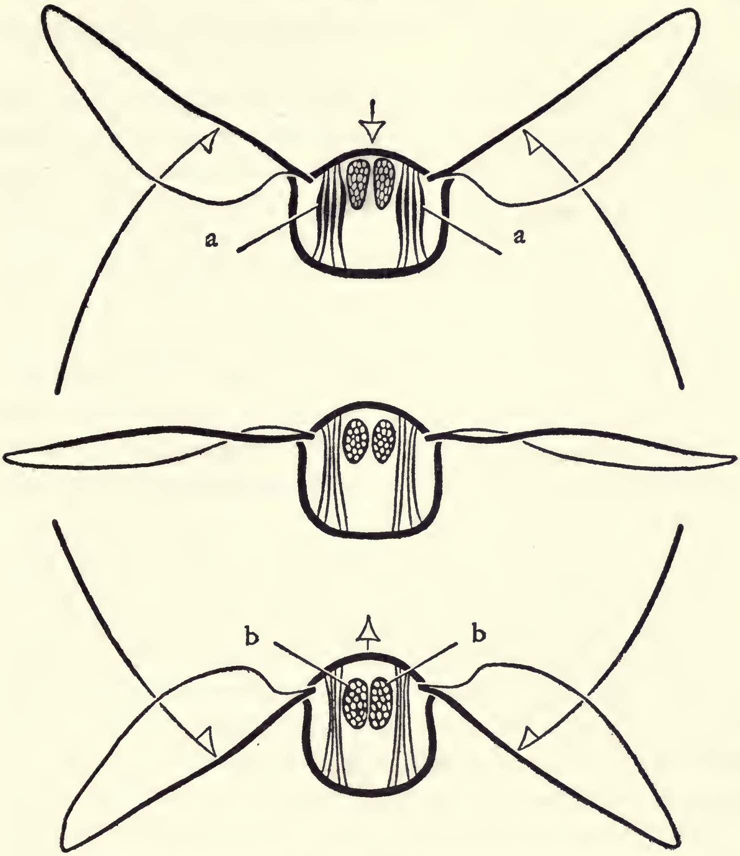
Wings in Action

> The joys of earth and air are thine entire,
> That with thy feet and wings dost hop and fly. . . .
> —RICHARD LOVELACE, *Sonnet*

AS SOON as an insect has completed its transformation, as soon as its wings have dried and hardened, it unhesitatingly begins its aerial career. Without the example or admonition of a parent, without any tentative sallies, it is off and away with complete mastery of a medium into which it ventures for the very first time. Through air that is still or gusty, light or heavy, it makes its way with perfect equanimity, with perfect understanding not only of the eccentricities of that fickle, unstable fluid but of the methods of reconciling them with those of its own structure. Without ever having had a course in aerodynamics, it knows all about lift, drag, velocity. It seems to have a built-in lightning calculator which automatically solves the complicated equations of which weight, wing area, length of wing, rate of vibration, amplitude of motion, angle of attack, air density, direction and speed of flight are salient factors. For horizontal flight all it has to do, really, is to take into consideration the direction and force of the air currents and then so adjust the movements of its wings that air pressures above and in front are reduced as those below and behind are relatively increased in amounts sufficient to sustain and send it forward. At other times it creates and manipulates these and other pressures which send it upward, downward, in loops, spirals, zigzags, or allow it to hover.

The muscles that control the action of an insect's wings are of several sorts, and, strangely enough, those that are responsible for the most obvious effect, that of raising and lowering them, have no direct connection with them. They are "indirect" muscles. They bring about the up-and-down movement of the wings by producing changes in the surfaces of which the wings are outgrowths. There are two sets of them and they are attached to the inner layer of the body wall. One set, extending longitudinally, from front to back, by its contraction forces the upper surface of the thorax to bulge upward. The wings are consequently lowered. A second set, anchored to the walls of the chest vertically, by contraction flattens the top surface and causes them to rise. The alternate contraction of these two sets of muscles thus produces the flapping movements of flight. In addition to these, there are typically four pairs of "direct" muscles to each wing. As their name implies, they do have direct connection with the wing and their duties are to rotate it, shift its position forward or backward, draw it to the body, and fold it.

The wings of the dragonfly are exceptions to this accepted formula. Since they are hinged to the body in such broad attachments that they must keep to a horizontal, lateral position even at rest, there is no folding or shifting in and out. Their movement is almost entirely confined to the rapid up-and-down vibration. Yet, unlike the wings of all other insects, they are controlled by direct muscles only, of which there are no less than eight pairs for each. It is probably because of this unique muscular system that the dragonfly achieves its particular mode of flight, for it vibrates its front and back wings in opposition to each other, the front pair rising as the rear ones dip and, conversely, lowering as the latter rise—a motion that has been compared to airplane propellers turning in opposite directions to reduce torque. The movements are doubtless so synchronized that disturbances in the air created by the vibrating front wings do not impede the action of the rear pair. It



INDIRECT MUSCLES OF INSECT WING: a. vertical muscles; b. longitudinal muscles.

(Redrawn by permission from *Principles of Insect Morphology*, by Robert E. Snodgrass. Copyright, 1935, McGraw-Hill Book Company, Inc.)

is by means of this unparalleled procedure that the insect is able to fly so brilliantly—to halt instantly, to hover as if suspended, to dart and zoom and turn with unexcelled agility and speed. Nevertheless, this very faculty, the attainment of the alternating beat, is thought to be a specialized version of a primitive trait, for in the first fliers the action of the two pairs of wings was supposedly not synchronized. They wavered independently of each other. This is an inference that the imperfect co-ordination of the wings of May flies, ant lions, roaches, and other members of lower orders seems to justify.

The dragonfly is a law unto itself. It provides the exception to the rule that simultaneous action of all four wings is a requisite for strong, swift flight. Refusing to follow the general evolutionary path, it specialized in a way peculiar to itself and achieved a technique and a way of life that harmonized perfectly. Refuting the evidence presented by all other insects, it proved again that Nature is not necessarily bound by her own precepts.

Notwithstanding the recalcitrant behavior of this individualist, the evolutionary trend was definitely toward the simultaneous movement of the four wings and, further, to their unification into a single pair. It is thought that the first step of the process was the creation of mechanisms which fastened together the two wings of each side so that they functioned as one. In modern insects this coupling is effected in several different ways. In one family of small moths the edges of front and hind wings are intertwined: the rear margin of the front wing overlaps the front margin of the rear wing except near the base where a small lobe (a "jugum" or yoke), stiffened by a vein, reaches underneath it. In the dobson fly and some other insects this lobe projecting from the inner area of the front wing extends not underneath but back over the top of the rear wing where a raised area engages it. It is then called a "fibula" or clasp. In most moths one or more strong bristles spring from the front margin of the rear wing near the base and project under the fore wing, where they slide into a sort of hook projecting from membrane or vein, and latch the two wings firmly together. This organ is known as the "frenulum" or little bridle. There are several variations of this system in different kinds of moths, and the hook is often lacking on the wings of females of species where it occurs regularly among the males. Have these ladies indolently neglected to provide themselves with the means of enjoying a more abundant life, or have they found that they can do very well without the elaboration of equipment so dear to the masculine heart? Have they with mature resolution freed themselves from the tyranny of the gadget?

The larger moths—the Cecropia, Polyphemus, Luna, and others—as well as all the butterflies and the skippers, have simplified their method even more. They have merely greatly enlarged the front area of the rear wing near the base, so that it underlies the front wing to such an extent that no bolts or bars are necessary. As the front wings are depressed they automatically press against the rear pair, and on the upstroke the reversed action works with the same efficiency in the opposite direction. Among bees and wasps the two wings of a side are so closely conjoined that they have the appearance of a single membrane. The rear wings of these insects are much smaller than the fore wings, and each bears on its front margin minute hooks which fit into a groove on the rear edge of each fore wing. Sliding along like hooks on a curtain rod, these hooklets, "hamuli," insure a stable and adjustable coupling, whether the wing is extended in flight or flexed in repose. By this method of joining, the two membranes on each side have been, to all intents and purposes, combined into one.

This tendency toward reduction in the number of wings to one pair culminated in the "true" flies of the order Diptera. However, their highly specialized organs of flight, narrowly attached to the body, with their versatile swivel action, are useless without the stemmed, vibrating knobs behind them, the halteres. If one or both of these organs is removed, flight is impossible. They are the balancers and stabilizers, gyroscopes. From the study of high-speed photographs of the drone fly, some of which are reproduced in his book *Insects In Your Life,* Dr. Curran observed that at rest these knobs are collapsed; that as flight begins they fill with blood; that during flight they have the same rate of vibration as the wings; and that they continue vibrating for a very brief moment, as if dying down, after wing action has ceased. The drone fly, outfitted with two wings and these gyroscopes, and the honeybee, with its four wings hooked together two by two, are said to have identical flight patterns. They could supply further evidence, if it were needed, of Nature's versatility, of her propensity to experiment along different lines in the search for the most efficient and economical means of reaching a given end. The four-winged grasshoppers and beetles are in a sense two-winged fliers, for they are propelled by the rear wings only. It is true that the elytra of beetles probably help to the extent that they function as parachutes; but the tegima of grasshoppers are largely excess baggage until at rest they, like the elytra, justify their presence by becoming protective coverings for the more delicate tissues of the organs of flight.

In spite of her obvious desire for economy, Nature has usually provided insects with more than enough wing area. In most cases she seems to have played safe and allowed for injuries or other contingencies. Many years ago the English scientist J. B. Pettigrew made a series of dismal experiments for the purpose of determining just how much wing area and what part of it was the minimum requirement for flight. He lopped and clipped and pruned and amputated. Eventually he was able to report in regard to the bluebottle fly that two thirds of the rear portions of its wings could be removed without any impairment of its flight; that the rear two thirds of one wing could be taken away, the other being left intact, without loss of balance; that with one half of the wings removed transversely flight was only slightly impaired; that the rear edge could be notched in various ways without inconvenience; but that any injury to the front margin completely destroyed the ability to fly. He found that a dragonfly could still travel when it was deprived of either pair of wings, but that its flight was steadier when the front ones remained; and that a butterfly also could carry on when only its fore pair were left to it. He stated, moreover, that "if portions be removed from the posterior margins of the wings of a buzzing insect, such as the wasp, bee, blue-bottle fly, etc., the note produced by the vibrating pinions is raised in pitch. This is explained," he continues, "by the fact that an insect whose wings are curtailed requires to drive them at a much higher speed in order to sustain itself in the air."

The study of wings in action was of absorbing interest to both Pettigrew and his French contemporary, E. J. Marey; and both men in the late 1860s fashioned mechanical devices in the attempt to duplicate and explain their movements. In a noted experiment

Marey attached a speck of gold leaf to each wing tip of a captive wasp and, by holding it in a sunbeam, observed that the path traced by the sparkling tips was an elongated figure eight. By other means he demonstrated that the plane of the wing changed in each part of the stroke, the front edge turning slightly backward during the upstroke and forward during the descent—changes due, he thought, solely to air resistance acting on the pliant rear portions of the membranes. Dr. Curran, having studied the photographs of the drone fly, is convinced that the apparent figure-of-eight trajectory made by the wings of flies and bees is an optical illusion caused by their rapid vibration and the swivel action at the shoulder, which sends the front edge, reinforced by the heaviest veins, always in advance of the yielding surface at the rear. However it is, the wings do move in a general upward-backward, forward-downward direction and in the free-flying insect trace an undulating path with a backward slant. Their surfaces are never flat but aggregations of ever-changing, reciprocating curvatures that adjust to the stresses of air pressure at every part of the stroke.

The angle at which an insect normally flies is one of the important factors of its flight, and it varies with the species. It ranges from an inclination of about forty-five degrees to the horizon among the wasps, bees, and flies, to the almost vertical undulations of the large sails of the butterfly. As they hover, the wings of bees and flies pulsate horizontally. It is possible that changes in direction of flight are made by altering the angle of the wings. Steering is certainly often accomplished by the slowing down of the beat on the side toward which the turn is to be made. In some cases the insect's legs are used as rudders.

Marey was one of the first to try to determine the rate of vibration of the wings of various insects. He thought that the method of estimating their frequency acoustically by matching the hum or buzz with the note of a tuning fork should be checked by graphic means, and he contrived a soot-covered revolving cylinder near which he held his subjects in such a way that their wing tips scraped against it and left the record of their pirouettes in undulating line or in a series of dots, according to the amount of contact.

Since the cylinder rotated uniformly at a known rate, the number of loops or dots per second could be easily computed. By recording beneath the tracing made by the insects' wings the vibrations of a chronographic tuning fork equipped with a style, of which the rate was two hundred and fifty double oscillations a second, he double-checked them. In this way he fixed the rate of a common fly at three hundred and thirty beats a second; of the drone fly at two hundred and forty; of the bee at one hundred and ninety; of the wasp at one hundred and ten. The wings of the hummingbird moth (hawk moth) vibrated seventy-two times per second; a dragonfly's, twenty-eight; a butterfly's, nine.

Marey realized that the friction caused by the wings' contact with the cylinder possibly slowed down their motion somewhat and that in normal flight where there was no such obstacle the rates might be higher. He realized too that the fatigue of the victim modified results. Surely the frenzy to escape might also have had a bearing on them, although he does not mention this.

On the whole, Marey's data were reliable, although some revision has been made by later investigators using improved techniques. The rate for the housefly has been revised downward to one hundred and eighty beats a second; that of the drone fly, now thought to be one of the fastest fliers, has been raised to three hundred. It is known now that wing power varies greatly among the different kinds of dragonfly and that, consequently, frequencies vary. Some believe that if high-speed motion pictures of dragonflies in flight could ever be taken, they would prove that the most powerful fliers among them, members of the family Aeschnidae, vibrate their wings at a rate that approaches that of the drone fly. However, they move more slowly because they flicker through a smaller arc.

While most insects fly at the moderate speeds of five to ten miles an hour, a rate of ninety has been claimed for one of the dragonflies. In the opinion of A. D. Imms this rate is open to question. Some of the large two-winged flies attain swift flight, and the most extravagant of all claims has been made for the deer botfly. By even the more conservative estimates, some of which grant the possibility of its capacity to fly at the extraordinary rate of four hundred miles an hour, this insect appears to be the fastest of all fliers with the exception of man.

With a few exceptions the humming and buzzing produced by vibrating wings is constant in tone for each species. However, when there is a difference in size—as, for instance, among bumblebees, where the male of the species is smaller than the female—the larger bee will hum on a higher note. Again, the hum of the honeybee on its contented, routine flight, with wings vibrating about four hundred and thirty-five times a second, is in A—the A above middle C on the piano; but that of a tired worker drops to E as the wing beats slow down by a hundred or so vibrations a second. The quality of tone is modified also by emotion, for the trained ear can detect differences between the chant of placid workers, the threnody of a queenless colony, the song of the wayfarers at swarming time, and the call to arms of an irate society.

On his notable expedition up the Amazon, the great English naturalist Henry W. Bates on one occasion watched a large yellow and black mason wasp as it built its nest on the handle of a chest in the cabin of his canoe. He said that it brought in each fresh pellet of moist clay "with a triumphant song, which changed to a cheerful busy hum when it alighted and began to work." In addition to the wing-produced note there is also in some cases a sort of overtone (in the bee an octave higher than the wing tone), which is not yet satisfactorily explained. Some entomologists have suggested that it is caused by the passage of air through the tiny openings along the sides of the insect's body which are part of its respiratory system; others, finding that it continues after these minute spiracles have been sealed, attribute it to the vibration of diminutive scales at the base of the wings.

The tremolo of the female mosquito is likewise produced by vibrating wings, which are, in all American species, fringed with delicate scalelike hairs on their margins and veins. It is different in pitch for each species and the vibrations are intercepted by the plumed antennae of the male, which are adjusted in every case to the frequency emitted by the female of its species and to no other.

So sensitive is this receiving apparatus that by a turn of his head the male can detect the direction from which the sound comes. The refrain of the female malaria mosquito has been recorded and rebroadcast in Cuban swamps to attract the males of the species in the region. Tricked by the irresistible lure, they fly to their deaths against charged screens. The male himself is usually silent. At best he is capable of only a feeble solo, made presumably just for his own pleasure.

In a general way, the rate of the wing's vibration is determined by its size—the smaller it is the faster it must move to carry a given load. The great scaled sails of the butterfly wave comparatively slowly and, due to the inadequate ballast supplied by the light body, produce an undulating and wavering flight, a flight effective, nevertheless, in its way, for it is unpredictable and baffling to birds and other enemies and often long sustained. At the other end of the scale is the bumblebee, whose great bulk is raised and carried by relatively diminutive airfoils. It used to be averred that the bumblebee flew in defiance of all the laws of mechanics. It was often cited by those who sought to inspirit men in their struggles with themselves and other overwhelming odds as an example of what could be done in accomplishing the impossible: unaware that it could not fly, the bumblebee went on flying anyway.

With greater knowledge of the laws of aerodynamics, today's engineers can elucidate the matter. They can write down formulas that are said to prove not only that the creature can lift itself but that, once up, it can fly if it moves its wings fast enough (it takes about a hundred and thirty beats to the second) and at the proper angle. The patient, gallant insect may now go about its business with man's sanction. Its judgment is sustained, its optimism justified, its practice licensed. Perhaps a load is off its mind. However, there is no way to tell, for if it was ever hurt or troubled by the incredulity of its human neighbors, if its confidence in itself was ever shaken, it kept its misgivings to itself and never once let on.

There is still much to be learned about the insect's flight. Perhaps even high-speed photography and other modern techniques will not be able to clear up all the mysteries. The whole question of speed is a great enigma. As Dr. Curran points out, the shape of the wing in itself is an undependable factor, for both slow and fast fliers have long, pointed wings; some fast fliers and many slow ones have broad ones. A large area is not a requisite. Some rapid fliers have light bodies, others have heavy bodies; but a heavy chest for the accommodation of strong flight muscles is certainly essential. He concludes that requisite factors for rapid flight among flies and bees include flexibility of wings (wings that have a heavy front edge and a billowing surface), a rapidity of stroke, a certain amount of weight. The direction of the stroke is also important.

Perhaps the day will come when all the ingredients of an insect's flight will be recognized and tabulated, all the intricate interrelationships resolved into their components. Then, no doubt, an all-embracing formula will be forthcoming. Stated with mathematical clarity, it will, like Einstein's awaited universal equation, explain everything.

6

Sound-Producing Wings

a musical composer
is all puffed up with pride
if he can catch the spirit
of a summer night full of crickets.

—Don Marquis, *Archys Life of Mehitabel*

Of course Nature's chief goal in producing the wing was the creation of a dependable organ of flight; but in the course of converting her six-legged crawlers into competent aeronauts and adapting them to their vocations, she allowed the new appliance to take over other functions as well. One of these was the production of sound.

In the highest orders—the buzzing, humming flies, bees, and wasps—sound is a mere by-product of the wings' rapid vibration. In other orders it issues from specialized mechanisms, which may involve either very slight or very complex modifications of structure. Many beetles are able to make an occasional click or creak by a very simple process. The darkling and burying beetles, for instance, scrape the rear edges of their wing cases, the elytra, against minutely corrugated areas on the dorsal surface of the abdomen. Some of the weevils and ground beetles use a similar method but reverse the relative positions of the smooth and roughened surfaces, the undersides of the elytra bearing the little files which are rasped against the edges of the abdominal segments. Both sexes are provided with such specialized structures, although their positions are not always the same in male and female. The small squeaks produced in this way are probably signals emitted by the insects as they traverse the narrow trails through bark and soil as well as expressions of protest or terror when they are molested. Such simple mechanisms, no doubt fully adequate for a beetle's needs, seem artless makeshifts when compared to the highly specialized appliances used by some of the less highly organized insects. For, curiously enough, it is among the lower orders, those having gradual or incomplete metamorphosis, that the most remarkable sound-producing organs are found.

From evidence in the rocks—a fragment here, a broken remnant there—ample proof exists that Nature's adaptation of the wing for the production of sound began early. In the Devonian formations of New Brunswick—that is to say, in strata laid down more than three hundred million years ago—S. H. Scudder discovered a fossil insect wing with sound-producing mechanisms not very different from those possessed by modern katydids; and more recently a later (Triassic) deposit in New South Wales yielded a fore wing about six inches long similarly specialized. Eons before there were mammals with vocal cords or birds with complicated sound boxes or even reptiles with full-time lungs—before a single roar or snarl, peep or twitter, hiss or croak could be uttered—the trilling of an insect broke the heavy silence. Above the soughing of the wind through the ferns, the lapping of the water at the shore line it shrilled—one of the first of all animate sounds.

What were those first creakings? Were they songs of joy and well-being elicited by the sun's diffused rays, or brave whistlings in the dark made by a confused nomad to reassure itself and relieve the black silence? They might have been signals, serenades, invitations, directives broadcast at random to locate and enchant a fortuitous companion. Perhaps they had no purpose whatever; perhaps they were, at least at first, merely adventitious crepitations born of casual contacts of roughened surfaces rubbing together accidentally.

Whatever they were, they originated in the wings. Strictly speaking, the insect has no "voice." It cannot truly sing or chirp or hum, for in its make-up there are no vocal cords, no larynx. There are no lungs. Those insects that have evolved sound-producing mechanisms are instrumentalists; and their instruments, entrusted usually only to the males, correspond to lyres, lutes, harps, or violins—or, in the case of the cicada, to kettledrums.

The first insect musicians belonged to orders long extinct which appear to have been remotely related to our katydids and crickets. Among the moderns, our contemporaries, it is still in three families of the order of straight-winged insects (Orthoptera)—the grasshoppers, the katydids, and the crickets—that the most accomplished musicians are to be found. To be sure, these three families are not equally talented, and among the members of each one there is as great a diversity in the design and quality of the instruments as there is in the techniques of the players.

The least proficient are the insects we call grasshoppers (Acrididae). More accurately termed "short-horned grasshoppers," to distinguish them from their cousins the "long-horned grasshoppers," these are the insects scientists call locusts, the term "locust" in popular American usage being misapplied to the cicada. They are daytime performers; and they play a sort of second fiddle in summer's orchestra with unobtrusive ticks and whirs and lisps, which are made either by scraping the legs against the tough wing covers, the tegmina, or by the shuffling of the two pairs of wings together during flight.

Most of those that adopt the first of these two methods have a row of small elastic spines (eighty-five or more to the inch) on the inner surface of each hind thigh, and these are drawn, in the simultaneous action of both legs, across sharp-edged veins in the wing covers. Clear areas of membrane on either side of the specialized veins serve as soundboards. In one genus of the family it is the thigh which is provided with a smooth ridge along its edge, while the toothed projections appear on the wing vein and its branches. Either way, it is an undistinguished sort of fiddling that emanates from these instruments, although it must be admitted that the simple motifs are executed with unvarying skill and are constant for each species. Each one consists of a few notes combined into a phrase on a certain pitch, which is infinitely repeated. In tempo the themes are variable, for, like the cicada (whose crescendos are produced by vibrating membranes that have nothing to do with wings), short-horned grasshoppers are devotees of the sun, and they strum more vigorously when basking in its life-giving radiance than they do in the shade. The refrain of one small brown hopper measuring somewhat less than an inch in length has been described as a feeble *tsikk* repeated from nine to twelve times at the rate of fifty-three in fifteen seconds in the sun, forty-three in fifteen seconds in the shade. The graceful sedge locust emits four notes, usually, the first one duller than the others and separated from them by a pause of one-fourth second.

The majority of those short-horned grasshoppers that make only intermittent sounds as they fly have colorful inner wings, conspicuous in flight. They are often yellow or red combined with black and are thought to be useful means of identification or of maintaining communication between individuals. Of these, the Carolina locust with black wings trimmed with pale greenish-yellow borders is one of the best known. Sometimes called the "Castanet Grasshopper," it makes a curious crackling sound, which may be caused by the quick snapping open or shut of the accordion-pleated membranes of the rear wings rather than by the rustling of the wings and the tegmina against one another. Some members of the group, according to W. S. Blatchley, "produce a uniform rattling note during the entire period of flight, which is generally in a straight course. Others make it only during certain intervals of flight. These change the direction of flight at will, and at every turn emit two or three short, rattling sounds."

As usual, it is the males that do most of this sort of stridulation, although in a few species the females are able to make themselves heard. Some short-horned grasshoppers are unable to take the slightest part in August's broadcast. As a result of that extraordinary variation of structure that characterizes all forms of life, the wing covers of some species are rudimentary or even altogether lacking; in others where they are normally formed, the hind legs are so excessively elongated that no contact with them can be made; stridulation is impossible.

The long-horned grasshoppers (Tettigoniidae) constitute a family of which the best-known members are the katydids, the meadow grasshoppers, the cone-headed grasshoppers, and the shield-backed grasshoppers. On the whole they are better musicians than the short-horned grasshoppers. Of course they are not all equally gifted, but their ranks include one of the greatest of all insect virtuosi, the "true" katydid. Known to science as *Pterophylla camellifolia* (wing-leaf camellia leaf), this is the famous soloist who is ready about the twentieth of July (six weeks before frost) to make his entrance on the program of the summer night. It is not the sun that stirs him into action. In its light and warmth he is silent; beneath its ardor he rests concealed among the leaves he so closely resembles. He reserves his energies until the poignant dusk when, taking his stance, he begins to play his familiar air, reiterating its equivocal, ambiguous theme until dawn. In full relief against the accompaniment of the other instruments of the orchestra, the notes of his concerto reverberate in soothing or strident monotony, according to the mood of the human listener; and, barring accident, they continue night after night, unremittingly, until frost numbs the frail members that produce it.

These are strains produced by the wings alone, by the outer pair, the wing covers, the tegmina; and they originate in a triangular area near their base where they overlap. A cross vein on the underside of the left tegmen, thickened, coarsely ribbed, converted into a file, is rasped against a tough ridge on the innermost edge of the right one as, half raised, the two wings are shuffled sideways, in and out against each other. The vibrations thus produced are amplified by areas of clear membrane, tympana, formed in the usual way by the deviation of other veins from their normal courses. Each wing cover is specialized for its particular role, for the file on the right one, if present, is not well developed, and there is no scraper on the left. The left one is always uppermost.

If the wonderful sound organ of *Pterophylla* is in a sense the Strad or Amati of its world, the instruments of other members of the family are scarcely less admirable. They all conform to the same general plan and differ only in detail. However, the slight variations in size, form, and position of the files, scrapers, and amplifying membrane, together with changes in the rate of movement, produce a wide range of effects and account for the differences in the tone poems of the various members of the family. Each has a melody, if such it can be called, characterized by its own pitch and rhythm. Many species are daytime fiddlers; some perform both by day and by night and use a different motif for each occasion.

In the days before the invention of recording machines, entomologists tried hard to describe these sounds. S. H. Scudder even devised a system of musical notation to indicate their rhythms. His verbal description of the pastoral of the meadow grasshopper gives an idea of how carefully and minutely such studies were made. It is quoted by W. S. Blatchley in *Orthoptera of Northeastern America:*

> When about to sing on a hot, sunny day, the male mounts a stalk of grass to about a foot from the ground where it clings with its four front legs, allowing its hind legs to dangle . . . that they may not interfere with the movements of the tegmina. Beginning with *ts* it changes almost instantly to a trill of *zr;* at first there is a crescendo movement which reaches its violence in half a second; the trill is then sustained for a period varying from one to twenty seconds (generally from six to eight seconds), and closes abruptly with *p*. This strain is followed by a series of very short staccato notes sounding like *jip, jip, jip,* repeated at half-second intervals; the staccato notes and the trills alternate *ad libitum*. The staccato notes may be continued almost indefinitely, but are rarely heard more than ten times in direct succession; they ordinarily occur three or four times before the repetition of the phrase, but not more than two or three times when the phrase is not repeated. The night song differs from that of the day in rarer occurrence of the intermediate notes and the less rapid trill of the phrase; the pitch of both is at B flat.

The tegmina of the long-horned grasshoppers are not the stiff leathery affairs that the short-horned grasshoppers carry; they are usually delicate structures, pale green and leaflike, with a system of venation which often enhances their resemblance to the plant forms they frequent. When closed, they slope diagonally downward and outward, rooflike, over the body, at least in the larger forms, and they are often convex. The rear wings, as a rule, are a little longer than the tegmina and their efficiency as organs of flight varies with the species. In some species they are absent; in some the tegmina too are abbreviated.

The so-called chirps of the crickets (Gryllidae) emanate from sound-producing organs which are similar in all essentials to those of the katydids and their kin, except that the files, scrapers, and tympana occupy a much larger part of the wings' surfaces. Unlike the sloping wing covers of the katydids which overlap only in a small triangular area at their roots, those of the crickets lie flat over their backs and the overlapping takes place along the edges in varying amounts in the different species. The sound-producing mechanism spreads over most of these flat surfaces and is equally developed in both. The cricket is potentially ambidextrous. In practice it is, however, usually right-handed like the human artist: the tegmina, lifted to an angle of about forty-five degrees, shift sideways in and out and rub together with the right one almost always uppermost. In the nonmusical female, they sometimes overlap in the opposite way.

Since curiosity springs eternal in the scientific brain, it is not surprising that even the male cricket's predilection for a certain way of holding its wings should be a subject for investigation. In their efforts to probe into the matter, inquisitors have by careful manipulation reversed the natural position of the wing covers of a right-handed cricket and imposed left-handedness on it.

Using field crickets in such research, the late Dr. Frank E. Lutz proved that when the positions were reversed immediately after the transformation, while the tissues were still soft and pliable, and kept in place until they hardened, the insect would later stridulate as if nothing had happened. Apparently it suffered neither physical maladjustment nor emotional conflict. It did not even stutter. However, if the change were made after the wings had stiffened, its discomfort would be manifest and it would wiggle itself out of the unnatural posture.

The same experiment was made by Fabre with French tree crickets, which were found to be uncompromising. They would restore the natural order of things even when the reversal had been imposed in the wings' early, tender stage. On the third day thereafter, Fabre would hear a few brief grating sounds, "the noise of a machine out of gear shifting its parts back into their proper order. Then the song begins," he says, "with its accustomed tone and rhythm. . . . With a painful effort, he has dislocated his shoulders, which were made to mature and harden the wrong way; and in spite of a set that seemed definite, he has put back on top that which ought to be on top and underneath that which ought to be underneath. He laughs at your devices and settles down to be right-handed for the rest of his life."

Lutz intimates that a parallel can be drawn between the cricket's propensity to carry its wings in a certain way and the habit of human individuals to find it natural and comfortable in clasping the hands to keep the same thumb consistently uppermost. Whether it be the right or left is a tendency he found to be inherited. It is inherited at least to the extent, he says, that the chances for a child to clasp its hands with the right thumb, for instance, uppermost are greater if both parents do so than if both parents prefer the opposite way. No doubt the laws of inheritance are impartially applied. They must account for the ways of crickets and katydids as well as for those of man; but will their workings ever be elucidated to the extent that we will know how their forces are marshaled to produce invariably a left-handed katydid and a right-handed cricket?

Among crickets, as among katydids, there are innumerable variations in the construction of the files, in the shape, position, and extent of the tympana, and in the movement—structural, functional differences which account for the sounds that are distinctive of each species. Mole crickets, ground or field crickets, and tree crickets exhibit differences of tone as definite as those of violin, viola, cello, and double bass. More obvious still are the variations in the rhythms.

The bass *churp* of the mole cricket, often compared to the distant croaking of the tree toad, and by Gilbert White to the *churr* of the nightjar or fern owl, is pitched two octaves above middle C and repeated at the rate of a hundred or more times a minute for a varying length of time. It is produced inside the burrow, underground, and it begins about four o'clock in the afternoon, though somewhat earlier on a cloudy day, reaching its climax about dusk. The pygmy mole cricket is no musician. Its tegmina are very short, almost veinless, and without tympana. It cannot possibly make a sound.

In dry pastures, low-lying fields, and marshy hollows, along dusty roadsides and in gardens the ground or field crickets flourish, each race happily settled where it may enjoy an existence geared to its particular set of physical attributes. Each wears its own version of the family wings with personalized sound mechanisms from which by day or by night issue the high-pitched trills. These rhapsodies, delivered at the entrance of their burrows, are shrill or feeble, continuous or intermittent, as the case may be. As a rule the pitch and rhythm are constant for each species, although in some cases these are known to vary in different parts of the range.

Many attempts have been made to describe these rustic measures and transpose them into vocal equivalents, but often the sounds are interpreted differently by different human ears and the written reports, valuable and accurate too in their way, are still but diluted transcriptions of the messages broadcast by the vibrating wings. One member of the group, a field cricket domesticated, found in Charles Dickens an interpreter who captured at least the spirit of its musicianship: "Good Heavens, how it chirped! Its shrill, sharp, piercing voice resounded through the house, and seemed to twinkle in the outer darkness like a star. There was an undescribable little trill and tremble in it at its loudest, which suggested its being carried off its legs, and made to leap again, by its own intense enthusiasm."

This English Cricket on the Hearth, now a naturalized citizen of our own society, likes to dwell within doors; and in the old days it sought out the warmth of bakers' ovens and firesides. In these cozy grottoes it dwelt and from time to time, by the shifting of its wings, delivered its sibylline accents, oracles of good or evil import. Said Gilbert White: ". . . they are the housewife's barometer, foretelling her when it will rain, and are prognostic sometimes, she thinks, of ill or good luck, of the death of a near relation, or the approach of an absent lover. By being the constant companion of her solitary hours they naturally become the objects of her superstition."

Tree crickets are still another branch of the family Gryllidae. Of these the best known belong to the genus *Oecanthus* (I dwell in the flowers). The wing covers of the females of these arboreal species are wrapped closely about them; those of the males are firm, semitransparent, flat, with broadly rounded tips which provide large resonating areas. The modified vein on the underside of the right wing that forms the rasp or file is only about one or one-and-a-half millimeters long, according to the species, and in this short extent is divided into from twenty to fifty short teeth. A similar file is present on the underside of the left wing cover, although it is probably never used, for the tree crickets, true to family tradition, keep the right tegmen uppermost as they draw the file back and forth across a fine thickened ridge on the inner edge of the left one. As usual, the rule is not without exception. In the left wing cover of an Italian tree cricket, mentioned by Fabre, the file has developed on the upper, not the lower, surface. And it is functional; for as the diaphanous wings flicker in and out it makes contact with the file on the underside of the opposite wing. The two files move across each other obliquely and by their mutual friction produce a sonorous reverberation.

Of all the tree crickets, the pale ghost known as the snowy tree cricket is one of the most tireless players. Its ivory-white tegmina, tinged with pale green, are held vertically and whisked back and forth so rapidly that they register as an indistinct blur. Their vibratos, as described by Asa Fitch, are based on "repetitions of a single syllable, slowly uttered, in a monotonous, melancholy tune, with a slight pause between . . . *treat-treat-treat* . . . continued without the slightest variation . . ." throughout the night. Only the tempo varies; but it varies so consistently with changes of temperature that it is known as the "temperature cricket." It is said that if forty be added to the number of notes per minute divided by four, the result will approximate the number of degrees Fahrenheit. It has been found that there is a certain geographical variation in the number of "chirps," for in Nebraska these wings shuttle in and out, on the whole, more rapidly than they do in New England, and in Oregon "race A" maintains a faster tempo still. When a number of snowy tree crickets find themselves together on location they play in unison.

SNOWY TREE CRICKET.

The nocturne of the long-winged tree cricket is of a very unusual quality. For H. A. Allard, listening to it in Georgia, where it may be heard on cloudy afternoons as well as at night, it inspired "a weird pathos, unlike any other insect music. The phrase *pre-e-e-e* does not sustain the same uniform pitch, but dies away in a slightly lower key. . . . Each note is a mysterious, momentary wail amid the shadowy foliage of the oaks, and seems like the voice of a complaining spirit interrupting the serenity of the night."

Crickets are able to control the volume of sound easily. Their tegmina, lying flat over the back, make a sharp turn at their outer edges and fit down along the sides of the body like a lid on a box. When they are fully raised the resonating areas vibrate freely and with maximum intensity; but when the score calls for pianissimo the musician mutes the sound by lowering them, by bringing them in varying degrees into contact with his body. Tree crickets are masters of this sort of soft-pedaling; and by its means the snowy tree cricket, especially adept at the art, frequently creates the most puzzling and ventriloquistic effects.

By the wonderful processes of modern sound recording it is now possible not only to register insect music accurately but to analyze it. On examination of the sound track each note made by the sweep of the cricket's wings is seen to be not a single pulse of sound but two or four or more. Each pulse is of such short duration and the intervals between them are so short that they register as one on the human ear. A "chirp" which lasts only a tenth of a second may be composed of three such pulsations, each of which (made by a single sweep of the wings) takes a little over two hundredths of a second, with intervals of somewhat less than two hundredths of a second in between. Moreover, each pulse is not a single note but a slur as perfectly executed as one by Heifetz—an achievement made possible by the fact that the toothed ridges of the file are not equidistant from one another. They are closer together in the central part of its extent than they are at either end, a state of affairs which would naturally produce a lowering of pitch even if the wings did not slow down a bit at the beginning and end of each stroke. The pitch is in the octave beyond piano range, and it as well as the tempo vary slightly both with the emotion of the cricket and with temperature. While the sounds produced by crickets are pure tones, those of katydids are not. These and many other fascinating observations were made by Lutz in his delightful book called *A Lot of Insects,* in which a number of sound tracks of various crickets and grasshoppers are figured.

The tegmina of the female cricket, devoid of files, scrapers, and tympana, adhere to an unspecialized design of several longitudinal veins and a simple network between them. Like her cousin, the katydid, she stands at a little distance from the soloist, slowly and gently waving her antennae with all the appearance of listening in rapt (or resigned) silence. The vibrations pulsating from the wings of her companion are picked up by "ears" consisting of membranes stretched across slots in the shins of her front legs. Transmitted by appropriate mechanisms, they are registered on her consciousness in some strange and to us unknowable form. The auditory organs of katydids are similarly made and located; but those of the short-horned grasshoppers are membranous disks on the first abdominal segment of the body, just behind the third pair of legs. In all three families auditory organs are lacking wherever wings of the males are incapable of producing sound.

The purpose of the male's musicianship has never been explained to everyone's satisfaction. Most of the early scientists seem to have taken it for granted that its object was to captivate and win a mate, but many entomologists now regard this view with skepticism. They point to the apparent lack of enthusiasm of the females for the most assiduous efforts of their suitors (as if feigned indifference were not the universal feminine strategy), and, more cogently, call attention to the fact that the performances continue long after the mating season is over. Some believe that its aim is not so much to charm a prospective consort as to defy a rival, or merely to outdo a competitor in a spirit of sheer bravado and ostentation. However, in China and Japan, where insects are caged and kept as pets like canary birds, the male crickets captured in the fields are segregated from the females to keep them "singing." Perhaps such cloistered outpourings are sublimations of frustrated desires for freedom. It is also possible that there is no ulterior motive in the cricket's trillings, that they are merely a form of self-expression, that they are made, as Fabre suggests, "for the sheer pleasure of feeling themselves alive, 'just as we rub our hands in a moment of satisfaction. . . ." What, then, can account for the males' monopoly of the sound-producing equipment? Is the female grasshopper less stirred by the ardor of the sun? Is the female katydid or cricket less susceptible to the splendors of the August night? Or are these mothers of races so deeply permeated by summer's magic that they are constrained to repudiate an expression of their transports which is so grossly inadequate and to find the only possible medium for the unutterable ecstasy that of deep, enduring, golden silence?

7

Captive Minstrels of China and Japan

> Eftsoones they heard a most melodious
> sound,
> Of all that mote delight a daintie eare. . . .
>
> —Edmund Spenser, *The Faerie Queene*

If the performance of the captive is any criterion, there seems to be ample evidence to support the theory that, at least as far as crickets are concerned, the musician either indulges in art for art's sake or finds in it a means of self-expression. In China, where the custom of keeping caged insects as pets originated, it was a well-known fact that only one of the many species demanded a feminine audience. This was a little black cricket called the "Golden Bell." It was the only one that was unwilling to "nick the glad silent moments as they pass" in monkish seclusion.

The custom of caging insect musicians, practiced at various times and in various places—in ancient Greece, in Italy, southern France, Portugal, Brazil—began in China during the T'ang dynasty (A.D. 618-906). One of the earliest allusions to it is contained in an eighth-century chronicle, where it is recorded that at the approach of autumn the ladies of the palace liked to capture the insects and place them (in small golden cages) near their pillows, where, it goes without saying, the plaintive or cheerful trillings lightened the silence and relieved the monotony of the lengthening nights.

The fashion that began in the palace was imitated by the populace, and by the time of the Sung dynasty (960-1278) it was so widespread that a cricket cult was in full swing. The insects were prized for their pugnacity as well as for musicianship; and both gladiatorial combats and musical festivals were staged. Odes were written in praise of crickets; treatises were compiled describing them and formulating the rules for their care and feeding. This varied according to species, locality, and season. The craze of the amateur became in time a commercial enterprise, and insects were both collected and artificially reared for the trade. The hapless females that were not kept for breeding purposes were fed to caged birds, and the males, as soon as they had reached winged adulthood and had begun to stridulate, were subjected to a screening process in which the more promising musicians were separated from the less talented and given special attention. A thin coating of wax applied to the resonating area of each wing was thought to perfect the quality of the sound. Auditions were held and a connoisseurship developed which not only recognized the distinctive accents of each species but differentiated between the performances of individuals.

Berthold Laufer in his essay on insect musicians describes the elaborate and beautiful homes and utensils that were made for the use of the pampered artists. During the hot months they were housed in round pottery containers with perforated lids, furnished with tiny porcelain dishes for the cucumber and lettuce that comprised their summer diet, and with little boxes of clay for their cool and restful repose. On cold winter nights a bit of cotton padding was provided for them to snuggle into, and their winter fare consisted of masticated chestnuts and yellow beans. In the south they were given chopped fish, insects, and honey as a tonic. For winter residence gourds were used of which the surfaces often bore designs in relief made by the singular process, now a lost art, of causing the gourd to mature inside an earthen mold bearing the design. As the growing gourd filled the mold and pressed against it, its surface received the imprint of the relief modeled on the inner walls of the matrix.

These luxurious apartments were fitted with lids of jade, ivory, metal, or wood, often exquisitely wrought in designs that incorporated flowers and fruits, dragons and lions, and other motifs. There were cages of porcelain also, contrived in openwork design to admit air; and in the Chicago Natural History Museum there is one derived from a walnut shell. The intricately carved all-over design which enriches its surface is composed of pavilions and trees and the figures of the Eighteen Arhats, the holy personages charged with the duty of protecting Buddhist law. Simpler containers were fashioned of bamboo or wood; and these were often carried about by the owner, tucked into folds of his upper garment or suspended from his girdle. As he went about his daily round the blithe creakings of the little occupant provided welcome distraction or cheerful accompaniment to his thoughts.

Among other appointments evoked by the elaboration of the cricket's equipage were traps made of bamboo or ivory rods, and ticklers made of blades of grass or hairs from the whiskers of hare or rat, set into handles of bone or reed. These were used to tease and prod an indolent or weary minstrel into renewed effort.

While all kinds of cricket music found delighted listeners, that made by green and black species was preferred; and the strains created by the delicate wings of the little black Golden Bell *(Homoeogryllus Japonicus)* were among the most popular of all. What Alan Priest has called its "fragile and delicate trill—gold but paper-thin gold" was thought to resemble the tinklings of the little bells used by priestesses in the sacred dances. Far different was the theme broadcast by the "Chickens of the Weaver's Shuttle," as certain mitered crickets were affectionately called because their raspings were supposed to imitate the clicks of the shuttle as it sped back and forth in the loom. Omens of good fortune, these sounds were, in the early days, the signal for the weaver's autumn work to begin.

The appreciation of insect music was widespread in Japan also, where it was an ancient custom for city dwellers to make autumn pilgrimages into the country for the sole purpose of listening to it. There were eleven rural districts, according to Lafcadio Hearn, each famous for the performance of a particular species. It was a delightful custom, but it died out gradually as it became fashionable to keep caged insects and as the breeding and sale of these grew into a thriving business. In Hearn's day twelve varieties of crickets and grasshoppers were sold in Tokyo. Of these, nine could be artificially bred, and three were captured in their native retreats by country people and brought in to the city dealers. The insects and the cages made for their accommodation were distributed by wholesalers to itinerant vendors who hawked them through the streets during summer and autumn nights, particularly in the neighborhood of temples during religious festivals, at prices determined by their rarity and their popularity.

As in China, a tiny "bell insect," the *suzumushi,* was a great favorite. It was said to resemble a watermelon seed—black on the back with a white or yellowish belly; and the quality of the tintinnabulations produced by its fragile little wings were, like those of its Chinese equivalent, exquisitely pure and musical: "If a jewel of dew could sing, it would tinkle with such a voice!" There was a "weaver" in Japan, also, a graceful, bright-green grasshopper, whose movements were thought to resemble those of a girl in the act of weaving and whose clickings echoed those of the shuttle. Among the others, there was a "grass lark" and a "black lark," and the "bridle-bit-insect," the *kutsuwamushi,* which Hearn considered the most wonderful of all the night crickets.

It owed its name to the fact that its notes resembled the jingling and ringing of the old-fashioned bridle bit; but the sound was much louder and more complicated, Hearn thought, than the jingle of one of these. In his essay entitled "Insect Musicians of Japan" in *Exotics and Retrospectives,* he declared:

> Without the evidence of one's own eyes, it were hard to believe that so small a life could make so prodigious a noise. Certainly the vibratory apparatus . . . must be very complicated. . . . The sound begins with a thin short whizzing, as of leaking steam, and slowly strengthens;—then to the whizzing is sud-

> denly added a quick dry clatter, as of castanets;—and then, as the whole machinery rushes into operation, you hear, high above the whizzing and the clatter, a torrent of rapid ringing tones like the tapping of a gong. These, the last to begin, are also the first to cease; then the castanets stop; and finally the whizzing dies;—but the full orchestra may remain in operation for several hours at a time, without a pause. Heard from far away at night the sound is pleasant, and is really so much like the ringing of a bridle-bit that when you first listen to it you cannot but feel how much real poetry belongs to the name of this insect—celebrated from of old as "playing at ghostly escort in ways where no man can pass."

An ancient poem in which this insect figures was written by the Lady Idzumi-Shikibei and translated by Hearn:

Listen!—his bridle rings;—that is surely my husband
Homeward hurrying now—fast as the horse can bear him! . . .
Oh! my ear was deceived!—only the Kutsuwamushi!

To judge from the illustration accompanying the description of the *kutsuwamushi* in Hearn's essay on these elfin musicians of Japan, it resembles a katydid. There are several varieties, the one commonly sold in Tokyo being a green insect with a yellowish-white abdomen.

Long before it became a popular custom to incarcerate these fragile insect minstrels in dainty prisons, their bucolic strains were celebrated by poets in plaintive and haunting measures of their own as one of the chief charms of the autumn season. Usually an overtone of sadness pervades the lines.

Parting is sorrowful always,—even the parting with autumn!
O plaintive Matsumushi, add not thou to my pain!

The *matsumushi* was a very small member of the insect orchestra whose note, clear and sweet, was said to resemble the sound of an electric bell heard from a distance. Its name in its written form signifies "pine-insect," and when pronounced can mean also "waiting-insect." Its "little silvery shrillings" pulsing through the still night inspired many poems. Among the earliest extant verses included in an anthology compiled in 905 are the lines:

> With dusk begins to cry the male of the Waiting-insect;—
> I, too, await my beloved, and hearing, my longing grows.

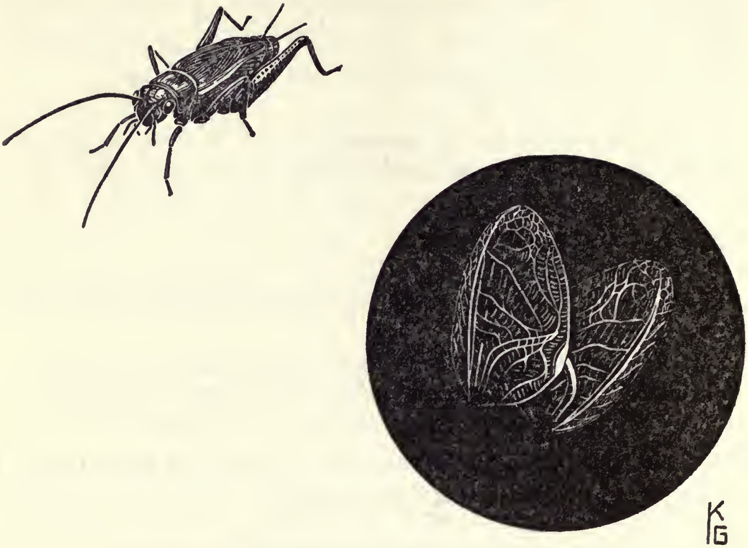
A poem of a later day declares:

> Always more clear and shrill, as the hush of the night grows deeper,
> The Waiting-insect's voice;—and I that wait in the garden,
> Feel enter into my heart the voice and the moon together.

In still another poem, also translated by Hearn, the poet addresses the *kirigirisu,* a short-horned grasshopper:

> O Kirigirisu! cry not, I pray, so loudly!
> Hearing, my sorrow grows,—and the autumn night is long!

The "pictures of the passing world" of the eighteenth-century print makers are full of references to the popular interest in insect life. A color print by Harunobu, for instance, represents two young people in the very act of searching for the serenaders of the night. Against a dark background, indicating the night, a young woman stands holding a lighted lantern while her companion, a little cage of wicker or bamboo in readiness at his feet, prepares to examine the foliage of a shrub. Both day and night hunts for insect musicians had become a popular pastime in the seventeenth century; and the night performers were easily captured because they were attracted by the light of the lanterns. The males were always separated from the females as otherwise they would not only stop their fiddling but die soon after mating. The cages in which they were domiciled were not the elaborate mansions that the cricket cult in China inspired. In the prints by Kiyomitsu, Utamaro, and others the little bamboo cabins in general use can be seen, in the hands of a child, on the floor of a pavilion, or



Cricket and its Sound-Producing Wings.

dangling from the arm of a girl chasing fireflies. The cicada was never caged by the Chinese or Japanese, for the strident reverberations produced by its kettledrums were held in low esteem.

In both China and Japan the insect music which the ear of the populace and the trained sensibility of the connoisseur found enchanting was created by the incredibly delicate modulations of form and movement of the organs of flight. It is improbable that there exists any detailed descriptions of the nature of the files, the patterns of veining, the aberrations of movement which produce these various trills and the often complicated rhythms. It might be interesting to know such things; but certainly any knowledge one could glean about the mechanics of the process would by no means explain it. Even if it were possible to capture the image of the nimble, tremulous tissues on photographic film and to reduce their quiverings to slow motion, we would come no nearer to an understanding of the strange and wonderful performance.

8

Double Duties

> Of sunbeams, shadows, butterflies and birds;
> Of fluttering sylphs and softly-gliding Fays . . .
>
> —WILLIAM WORDSWORTH, *The Recluse*

THE production of sound is but one of several chores occasionally discharged by insect wings in addition to the main business of effecting flight. Those of the honeybee add to these two tasks a third—that of air-conditioning the hive. When days are short and winter's chill settles down on the colony, the interior of its tenement is warmed by heat generated in the bodies of its tenants by the beating of their wings; and in summer when it is filled with stagnant and humid air, circulation is established by the tireless fanning of wings at the threshold. The diligent worker frequently seen at the entrance of the underground nest of the bumblebee with wings vibrating was once thought to be a "trumpeter" sounding a reveille, summoning the drowsy colony to begin the tasks of the new day. It was only in 1868 that an American farmer correctly reasoned that this exercise, like that of the honeybee, had to do with the very practical problem of ventilation.

The wings of some insects that spend most of their adult life in the water while remaining air breathers do double duty as organs of flight and as oxygen tents. By the simple expedient of raising its elytra, the predaceous diving beetle creates air pockets between them and its body for the purpose of carrying along its air supply, rising to the surface to replenish the store as it becomes exhausted. Some of the water boatmen, members of an entirely different order, manage to keep themselves from drowning by the same method. They stow their oxygen supply beneath their wings, where it is available for use by the minute openings that admit it into the air tubes that form an insect's respiratory system.

There are various ways by which aquatic insects propel themselves through the water. Both the diving beetles and the water boatmen do so by means of their hind legs, fringed, flattened, and thus converted into efficient paddles. Very different is the custom of some minute aquatic egg parasites which use their wings as oars and "fly" through the water on their maternal duties. One of these, an unbelievably small thing, only a fraction of a millimeter long, freely swimming, searches out the eggs of the damsel fly in which to lay her own. Inside the host egg that of the intruder hatches into a larva, feeds, grows, and undergoes complete metamorphosis, departing only when its adult state has been reached. Then its pygmy wings, delicately haired, adapted to two elements, propel it upward to the surface and launch it without delay into its aerial life.

The female of the European praying mantis, an insect with an inborn sense of the dramatic, uses its wings to bewilder or hypnotize its prey. Though predaceous, the mantis is a close relative of the grasshopper and has transparent rear wings which lie folded along radiating veins beneath the front pair when not in use and they spread like great fans when unfurled for flight. They are quite adequate at all times for the male, but they are incapable of sustaining his much larger mate for any distance. Since she cannot actively pursue her game, she relies on patience and stealth and sits motionless until it comes to her. One quick decisive gesture is all that is needed then to snatch and overcome the smaller items of her menu; but when an intended victim, one of her large grasshopper kinsmen, say, approaching her in size, seems capable of offering resistance, she brings her wings into play. With an awful flourish she spreads the green-bordered transparent veils in great quarter circles and, with magnified stature, strikes what Fabre calls her "spectral pose." Transfixed by the apparition, her quarry is reduced, by abject terror, to frozen immobility when, by a single leap, it might easily escape. Utterly demoralized, helpless, it is as easily disposed of as any other.

One of the most interesting of all the extra duties that insect wings have assumed is the creation of disguise. It is a twofold service which masks the hunter so that it may the more surely secure the food on which its life depends, and, on the other hand, grants to the hunted the protection for want of which it might face extinction. With colors and patterns and simulated textures infinitely diversified and combined, and adjusted for the backgrounds against which they rest or flutter, such wings wrap the creatures for whom the need exists in cloaks of invisibility.

The American painter, Abbott Thayer, and his son Gerald, in *Concealing Coloration in the Animal Kingdom,* distinguished between two types of concealing coloration: between that which is "mimetic" and that which is "obliterative." Mimetic coloration conceals not by making the wearer invisible, but by making it look like something it is not, as when an insect closely resembles a leaf, or a larva takes on the appearance of a stem. Obliterative coloring conceals by breaking contours of forms with disruptive designs, stripes, or patches of color, and by introducing onto surfaces color notes and patterns of the natural setting so that they merge with their backgrounds. Such is the case with the tiger, the wood duck, the red admiral butterfly.

The true katydid is one of the masters of leaf mimicry. Its wings, in shape, color, and arrangement of the veins, counterfeit the appearance of the plant forms of its dwelling place; and a remarkable gradation of tone heightens the resemblance by creating the illusion that their convex surfaces are flat. By "counter shading," which the Thayers considered one of the most important and universal principles of concealing coloration, the delicate green of the central part of each wing cover becomes lighter in tone as it curves away from the light into the shadow under the body, and it darkens toward the top where, in ordinary circumstances, there is the strongest illumination. Changes in pigmentation thus counteract the effects of light and shadow and produce the illusion of the flat surface of a leaf.

Tropical regions of the Old World harbor one of the most bizarre of the "leaf insects," a winged relative of the wingless walking stick, whose tegmina strikingly reproduce the foliage of its food plant. At rest they lie flat over the back, meeting along a line which perfectly simulates the central rib of a leaf and from which on either side other veins branch. Strange leaflike excrescences on the legs change them also into bits of leafage.

Perhaps the greatest of all leaf mimics are certain butterflies of the tropics. One of them, a resident of Sumatra, richly colored and conspicuous on the wing, becomes instantly lost to view when it alights amid dried or dying foliage. Its wings are then held raised and pressed together above the body with only their undersides exposed, and they duplicate in every way—in shape, color, and markings—the leaves of their haven. The head and antennae, retracted between the fore wings, are completely hidden; elongated tips on the hind wings make contact with the supporting twig in such a way that they emulate a leaf stalk; the illusion is perfect.

A detailed description of this shrewd masquerader has been given by Alfred Russell Wallace, who, during years of collecting and studying the insects and birds of the tropics, arrived independently and simultaneously at Darwin's conception of the origin of species by natural selection. Wallace mentions also the related species of this butterfly found in India, of which he says that "no two are alike, but all the variations correspond to those of dead leaves. Every tint of yellow, ash, brown, and red is found here, and in many specimens there occur patches and spots formed of small black dots, so closely resembling the way in which minute fungi grow on leaves that it is almost impossible at first not to believe that fungi have grown on the butterflies themselves!"

The great naturalists of the nineteenth century—Darwin, Wallace, Bates, and others—used the word *cryptic* to designate those designs that made their wearers inconspicuous or invisible. Brilliant and gaudy markings they regarded as ornaments of display or as warning signals with which the species that are obnoxious to birds and other enemies advertise the fact. While not denying these possibilities, Gerald Thayer declared that the primary purpose of all decoration is concealment and that every sort of coloration tends to protect its wearer "in its true and particular environment, under the typical and appropriate conditions." Even bold and gaudy markings contribute to this end on the principle that "the stronger the pattern appears, the dimmer appear the forms and outlines of its wearer."

With the most lavish display of her creative energies, Nature has covered the wings of butterflies and moths with patterns which are illimitably varied and distributed with nice regard to whether the habits of the insect are predominantly aerial or sedentary. In flight many butterflies, making their undulating way against an ever-changing background, are served best by wings which pick up both the lights and darks and the colors that are likely to be found there. Against a dusky ground, approximating the average color and tone of the shadows of the forest, bands, streaks, and flecks of color occur, distorting shapes and disrupting the continuity of surfaces. The iridescence of the wings of high-flying tropical butterflies blend them with the sky; the velvet blacks and brilliant greens of such marvels as the great bird-winged butterflies bind them to the rich shadows of the jungle; the transparency of the clear-winged species confer invisibility on them. One of these last, admired by Bates, has but one opaque spot—violet and rose—on the hyaline surfaces of its wings. This "is the only part visible when the insect is flying low over dead leaves in the gloomy shades where alone it is found, and it then looks like a wandering petal of a flower."

Though they are not obliterative, even the strange elongations of the wings of some species, trailing behind them, are probably protective devices, for in case of attack they divert the attention of the predator to an area far removed from the vulnerable body. With its rear wings torn and broken, the butterfly can still live out its days with reasonable comfort.

When it is the nature of the butterfly to alight with its wings spread, obliterative effects are obtained in many ways. With white, yellow, or crimson bands or patches the wings repeat the color of the petals whose company they keep. Spangles of saffron and gold transmit to their surfaces the hue of a blossom or the effect of sun-flecked foliage. Cerulean and turquoise notes bring down a bit of sky. Lustrous blacks and bronze and purplish areas sink them into the luminous shadow. To the casually wandering predator opalescent eyespots are indistinguishable from beads of glistening dew; and small dark dots on white or yellow wings, trimmed to a petal's contour by dusky tips, are stamens which augment their resemblance to a flower.

When the butterfly rests with its wings held vertically above the body and their under surfaces exposed (its usual posture), these surfaces, duller in their coloration than the upper sides, mirror the surroundings. If the favorite haunt is on the ground or near it, they usually bear streaked and mottled patterns which picture the confused litter of the woodland's floor, or of pebbles or rocks. When a perch among leaves and flowers is the habitual resting place, they bear other kinds of appropriate cryptic designs.

The need for protection for both butterflies and moths is greatest, of course, during the daylight hours; but while at such times butterflies are awake and active, moths, with few exceptions night fliers, rest. Quite at the mercy of diurnal foes, the moth's only chance of surviving until the return of dusk depends on concealment; and each species selects and clings to a resting place where it knows instinctively that its wings provide protection. Wrapped about its body, or held rooflike over it, or (as is usually the case) extended at the sides horizontally, they blend it with its background. Among the most perfect of all cryptic designs are those which so accurately reproduce patterns of bark and lichen that the wearer is as invisible as Perseus in his helmet of darkness. Thayer mentions a certain moth of Trinidad that, contrary to the usual custom, always arranges itself with body crosswise of the tree trunk and with wings spread flat lengthwise against it. A "secant" stripe which crosses the insect transversely from tip to tip on the

DAZZLING AND CRYPTIC COLORATION OF UNDER-WING MOTH.

front wings and which, when applied to the tree vertically, counterfeits a bark ridge explains the performance.

The brightly colored rear wings of some moths, visible only in flight, are "dazzlers" which an insect, startled out of its daytime slumbers, flaunts before the eyes of its pursuer. When they suddenly disappear beneath the grayed front wings as it lands and sinks again into its background of oak, hickory, or beech, the enemy is left baffled at the complete and instantaneous disappearance of its game. The same ruse is used by those grasshoppers whose rear wings are bordered with gay and lively colors. The abrupt eclipse of the bright object the pursuer has been following renders the dull wing covers under which they are so quickly hidden even less conspicuous than they would ordinarily be.

Even the great wings of the larger moths, which to us appear conspicuous objects of striking beauty, are doubtless protective mantles. Their ground colors are usually those of the woodland floor, and the motifs which are added to the otherwise too monotonous canvas are appropriate details of the surroundings which disguise or distort. One of the most wonderful and beautiful of the markings, to be seen in full glory on the wings of the Cecropia and the Io, is the ocellus or eyespot, a round dark area surrounded by concentric rings of contrasting hues. Its presence in the wings of moths puzzled Darwin, for since it is developed alike in both male and female it could not be explained on the basis of sexual selection. It may therefore be considered part of the obliterative design—a detail of the background which disguises. The resemblance of the ocellus to the watchful eye of a vertebrate is undeniable.

The wonderful color effects which convert the wings of butterfly and moth into the drab or gorgeous vestments originate in minute scales which cover the clear membranes and differentiate them from all other insect wings. Structurally, the scales are modified hairs, and they are shaped and distributed differently in different members of the order. Those on moths' wings are, as a rule, long and slender; and in some of the more generalized forms they are scattered over the surface of the membrane in what seems to be a haphazard sort of way. Those on the wings of butterflies are broad and flat, and in the higher forms arranged with great regularity in overlapping rows. In some species their arrangement on the front wings is different from that on the rear pair; but they seem always to be thickest and most regularly spaced where the strain of flying is greatest. Sometimes small areas are left uncovered by scales, like little windows of clear membrane; and the reduction in the number of scales in some species produces large transparent areas. Some small clear-winged moths closely resemble bees and wasps because their wings have no scales at all. By another variation of evolutionary processes, the wings of certain hawk moths are fully scaled at the time of transformation; but many of the scales are loosely anchored, and they fall off during the first flight, except along the veins and the outer edges.

Under the microscope the surface of each minute scale is seen to be grooved longitudinally into numerous fine ridges. In some cases there are transverse furrows between the longitudinal ones. Scales may be richly pigmented or they may be utterly lacking in coloring matter. Absence of pigmentation of the scales, however, does not prevent the production of gorgeous color effects. They produce color as a dewdrop produces color; light falling on the thin, chitinous walls is reflected, refracted, and diffracted to create all the hues of the spectrum. There is no pigmentation in the wings of some of the most brilliant of the tropical butterflies; but their innumerable scales, striated at the rate of thirty-five thousand ridges to the inch, act like refraction gratings breaking up the light rays into their component parts and sending back the vibrations that the human retina and brain interpret as the most intense and iridescent blue. When a pigmented tissue underlies the outer transparent film, metallic sheens and opalescent effects result.

The spots, stripes, grooves, the many sorts and combinations of color, and the various markings on the elytra of beetles and the wings of other insects are also thought to provide protection in one way or another. Bars and spots on the transparent wings of wasps and dragonflies are disruptive designs which, by breaking the continuity of margins and shapes, tend to make their possessors less conspicuous than they would otherwise be. The principle of counter shading is often used and has been carried out in an unusual way by a relative of the water boatman, the back swimmer. As its name implies, this aquatic bug reverses the usual position of the swimmer. Its body, much deeper than that of any insect that swims in the conventional way, backside uppermost, is boat-shaped, and the submerged elytra are almost white. The under parts, turned skyward, are dark. To an aquatic predator approaching from below, the color of the elytra supposedly merges with that of the sky; and to one hunting from above, the darkened tone of the underside of the abdomen blends with the color of the floor of the pond.

At least this is the way it appears to man. All the dazzling hues and the cryptic patterns are effects that he recognizes and names. But how do insects look to one another? How do we look to them? After all, the world revealed by human faculties is not the whole world. It is, of course, the only world we know; and it is not easy to investigate a realm so far removed from ours by vast differences of structure in the organs of sight. We can be sure that all insects are nearsighted, for in neither their compound eyes nor in their ocelli is there provision for a change of focus. It appears likely that for mutual recognition they rely on a mysterious faculty more like our sense of smell than anything else we can imagine. Their color sense? We can no more conceive what it may be than we can apprehend the nature of their response to sound.

It has been demonstrated many times that the gamut of color perceived by butterflies, ants, bees, and wasps does not coincide with our own. The range of vibrations to which they respond is shifted toward the violet end of the spectrum. In other words, they are color-blind to red, but they see the ultraviolet, which is beyond the capacity of the human retina to register. When we learn that the butterfly's wing as well as the petals of the flowers it visits are often so made that ultraviolet is reflected from either the entire area or from part of it (a fact revealed by photographing insects and flowers through appropriate filters), we are brought up sharp at the threshold of a world of color into which we cannot penetrate. When we are told that the red-blind bee can nevertheless make distinctions between different kinds of red blossoms if they reflect ultraviolet in different amounts, we are bewildered anew at the scope and complexity of natural processes.

What bearing these and similar discoveries have on the subject of concealing coloration remains to be seen. A certain yellow spider supposedly securely protected as it lurks in the blossom of its yellow primrose has been found to be distinctly visible to an eye sensitive to ultraviolet light, for it is only slightly ultraviolet and the primrose is strongly so. If it is not concealed from its prey or from its insect enemies, does it possess some other quality that confers immunity? A whole new set of values must be in force in this indescribable world. Perhaps these are equivalent to those recognized by man but expressed in different idioms. As for birds, although we cannot take for granted that they see worms, beetles, butterflies, the earth and the sky, their fellows and human beings as we see them, still their eye, the eye of the vertebrate, is not greatly different from our own; and it may respond to light from the sun in a way that makes the theory of protective coloration as valid for thrush or owl as it is for man. We really do not know.

The opinion hazarded by Thayer that "the butterfly's wing, at the present stage of its development, seems almost to be a *mask* which is also used for action" nicely summarizes his arguments, yet the fact that the scales on the wings of Lepidoptera, even when casually arranged, are thickest and most regularly placed where the strain of flying is greatest suggests that the function of the scale is to strengthen and protect the membrane as well as to mask or decorate it.

Among the estimated one hundred and forty thousand species of the order now known to exist, there is great diversification in the size and shape of these scaled organs of flight and also in the relative size and shape of the rear and the front pair. Naturally the power of flight varies greatly. It ranges from that of the hawk moth, the strongest flier in the order, which personates the hummingbird, to the darting sallies of the skippers and the lazy, vacillating progression of many of the larger species. Although usually wavering, the flight of the butterfly is often long sustained, a fact confirmed by the migratory flights of several species. The painted lady leaves its breeding place in Africa in early spring, crosses the Mediterranean, continues over Europe, and arrives in England in late May or June. The mourning cloak reaches the British Isles in autumn from Scandinavia. Ten miles off the coast of northern

Patagonia, Darwin witnessed a massed flight of white butterflies that extended as far as he could see, so that the crew of the *Beagle* cried out that "it was snowing butterflies." William Beebe witnessed several great massed flights of butterflies heading out to sea from islands of the Galápagos.

In our own country we have the astonishing annual migration of the monarch. The southward trek of northern residents begins in September, and it follows certain well-defined routes. As they casually drift over fields, through orchards and city suburbs, singly or in scattered groups, the paths of the monarchs converge as night comes and they congregate at certain long-established lodging places along the way. Year by year, by tens of thousands, they roost in specific trees along their line of march. In the spring they make an unobtrusive return and reappear in their northern haunts. While it is certain that the southbound butterflies of the autumn are not the same ones that came north the previous spring, it is not definitely known whether or not those that reach their southern goals outlive the winter and start the return journey. It is possible that the spring migrants which arrive in the north are successive generations of offspring bred along the way. The success of their unusual undertaking can be attributed at least in part to what amounts to their lifetime immunity to the attacks of birds to whom they are distasteful. This happy circumstance allows them to float through life in comparative security and accomplish probably the only migratory flight among butterflies that is a round-trip affair ordered, seasonal, and purposeful.

One of the unsolved enigmas pertaining to it is the ability of the travelers going south for the first, the only, time to find the identical lodgings that have been used by successive generations of their ancestors. Is the answer to this riddle supplied by still another function of certain specialized scales on the wings? In several families of butterflies such modified scales serve as outlets for scent glands, which emit subtle essences perceptible to members of each particular clan and to no others. On the male monarch they form a small black patch on the upper side of each hind wing. It has been conjectured that these sachets, of which the admitted purpose is to make the male a seductive suitor, help also with the problems of the long migratory flight by so impregnating the roosting places with their odor that these become olfactory beacons which attract the wanderers from considerable distances. On the other hand, there is a record that to the empty site of a "monarch tree" destroyed by a hurricane the butterflies returned for several years at the usual time, fluttering about as if in search of it.

The monarch butterfly makes no attempt to conceal or disguise itself. On the contrary, the light ruddy-brown wings with their white-spotted black borders on which it nonchalantly makes its way are plainly visible at all times. An instance of what is called warning coloration, their very visibility is a protective device announcing to its world that it is unpalatable. Even as larva and chrysalis the monarch is undisguised. Indeed, all conspicuous coloration and pattern among insects is held to be an indication that they are undesirable articles of food. Those that are relished by bird or lizard do their best to evade detection; those that are unpalatable or possessed of stings or other unpleasant attributes advertise the fact and remain in full view.

From this relative immunity to attack of insects endowed with warning coloration has sprung another sort of mimicry—that whereby a creature lacking distasteful or loathsome attributes imitates one that is so provided and consequently shunned by its enemies. There are many instances of this sort of mimicry among insects: defenseless flies that imitate bees and wasps, innocuous beetles that have elytra patterned to simulate those of the unsavory ladybug, and numerous butterflies (especially abundant in the tropics) whose wings have taken on the form and color of inedible members of their order. Among the butterflies we know best the viceroy is the outstanding imitator. It is not repellent to birds but pretends to be by imitating the monarch, which is. It is smaller than the latter; the venation of its wings is different; but its coloration almost duplicates that of its model. Whether such resemblances are the results of chance—occasionally a human being is supplied with a "double"—or whether they have come through logical and well-ordered progression we do not know.

If all the different stages through which each insect species has passed to reach its present form could be known and arranged in proper sequence, if all the extinct forms could be retrieved and placed where they belong in the vast array, it would be possible to settle this question and many others. It would be possible to start with the monarch or the viceroy, or any other butterfly or grasshopper or beetle, and follow its line to where it branched from a parent stem, then to follow the stem to where it had budded from a larger branch, and so on back to the primeval common stock from which the multitudinous, ramified growths had sprung. It would be like tracing the lineage of Eskimo or Hottentot, Bushman, Indian, or Celt back through Ham, Shem, or Japheth to Noah himself. Or, proceeding in the opposite order, it would be possible to start with a primitive insect with a yen for flight and trace its conversion through multifarious forms into the endless variety of highly specialized winged creatures that we see and hear. And as for the wings themselves, it would be possible to see just how the generalized sails of the Palaeodictyoptera (or of some other remote hexapod) underwent all the diverse modifications of shape, size, and texture and by slow degrees took on the characteristics of the wings of dragonfly, cricket, ladybird, mourning cloak, bumblebee, and the rest. Each variation or mutation would fall into place in logical alignment with all the intermediary forms, bound together within the framework of the stupendous evolutionary scheme.

PART II

BIRDS

9

The Feathered Wing

> Birds, my sisters, much are you beholden unto God, and you ought always and everywhere to praise Him for the free flight that is everywhere yours. . . .
>
> —Saint Francis of Assisi, *Sermon to the birds*

In the feathered wing of the bird, Nature contrived another version of the organ of flight, multifarious in form, versatile in function, an eloquent testimonial of her inexhaustible resources. It is different from all other wings. It is not an accessory organ, a supplementary expansion of the body wall, nor is it an extension for which arm or hand lends support. It is the arm itself—the arm and hand with an outgrowth of feathers, those highly specialized features which are, as F. A. Lucas observed, "the exclusive prerogative of the bird" and its most distinguishing character. It evolved from the foreleg of the reptile, which, in turn, budded from the fin of a fish as cartilaginous membranes slowly hardened and arranged themselves into a generalized pattern that, like a theme with variations, was elaborated and in time transformed into such mechanisms as those which allow the turtle to paddle, the mole to burrow, the bird to fly, and man to hold a book and turn its pages.

Having with slow and patient effort produced the design that answered the needs of the bird, Nature then began to modify its elements and adapt them with economy and logic to the requirements of each set of changing circumstances. Adjusting bone, muscle, and feather, lengthening here, shortening there, emphasizing, rejecting, reshaping, she made for each species the instrument that enables it to compete for life wherever its lot is cast—in the dooryard, in the forest, on the shore or plain or open sea. Hummingbird and partridge, egret, hawk, and albatross bear witness to the amazing scope of the harmonious diversification of the basic formula.

The bones of the bird's wing correspond to those in the human arm. In the upper arm there is the humerus; from the elbow to wrist, radius and ulna. From there on the resemblance falters, for, in the bird, wrist and hand are considerably altered. Omission of some bones and fusion of others have consolidated and strengthened this section which must bear the greatest strain of flight. Two digits have entirely disappeared. Whether these tally with man's thumb and little finger or with the little finger and the one next to it seems to be still an open question. Those who hold the latter view base it largely on the fact that the hand bones of the first-known bird correspond closely to those of certain three-fingered reptiles in which the fourth and fifth digits are unquestionably the discarded ones. If this is the case, it is the metacarpals of the index and middle fingers that have fused and the remaining digit, a mere stump, is the thumb. The effect of this simplification was to make a strong, tapered shaft for the attachment of the feathers. No avian hand has ever been known to possess more than three fingers, and in that of the cassowary, the emu, and the kiwi there is only one.

The articulation of the joints is also different from man's. The changes in bony structure make rotation at the wrist impossible. The advantage of such rigidity is obvious, for if the hand section with its stiff feathers could be turned like man's, palm up or palm down while the rest of the arm is stationary, it would be at every gust twisted out of alignment with the rest of the wing. Its movement is limited; it can be bent only sideways back against the forearm so that when the wing is folded its three sections lie in a compact Z formation against the side of the body. Ligament and tendon and membrane do their part to stabilize this framework and fortify it for the austerities of flight. The extended wing presents an uninterrupted, continuous edge to the wind. Its area is modified by flexing of wrist and elbow; the angle at which it meets the air current is regulated by rotation at the shoulder.

BIRD'S WING SHOWING BONES, PRIMARY AND SECONDARY FEATHERS.

The three sections of the wing, working together as a closely integrated unit, are nevertheless separate entities. Each bears a set of feathers that differ in shape and quality from those of the other two. Those attached to the hand are called primaries; those belonging to the forearm are the secondaries; and together these two groups constitute the so-called flight feathers. The role of the primaries is to propel, and since they move through a wider arc than any of the others, they have become stiffened to bear the strain of the greater resistance. The secondaries, less rigid and of different shape, function largely as a sustaining area or parachute. At the elbow and from the upper arm other systems, tertiaries and scapulars, increase the sustaining area and fill in the gap between wing and body. Still other series of smaller feathers, coverts, whose function is, as their name implies, to cover, overlap the main groups on both inner and outer surfaces and reinforce the leading edge. A tuft of four small feathers springs from the diminutive thumb, forming the alula or bastard wing, an organ hardly perceptible in many species but prominent and of the greatest utility in others.

The three sections of the wing—hand, forearm, upper arm—thus specialized, vary their relative lengths and shapes according to the kind of flight that answers the need of each species. In birds that depend on vigorous, flapping flight the hand section dominates the design and the upper arm is comparatively short. For gliding and soaring flight, where sustaining power is all-important, upper arm and forearm lengthen. Such shifts of emphasis, occurring in all possible combinations and correlated with changes in the size, shape, and quality of the feathers, produce wings of every description.

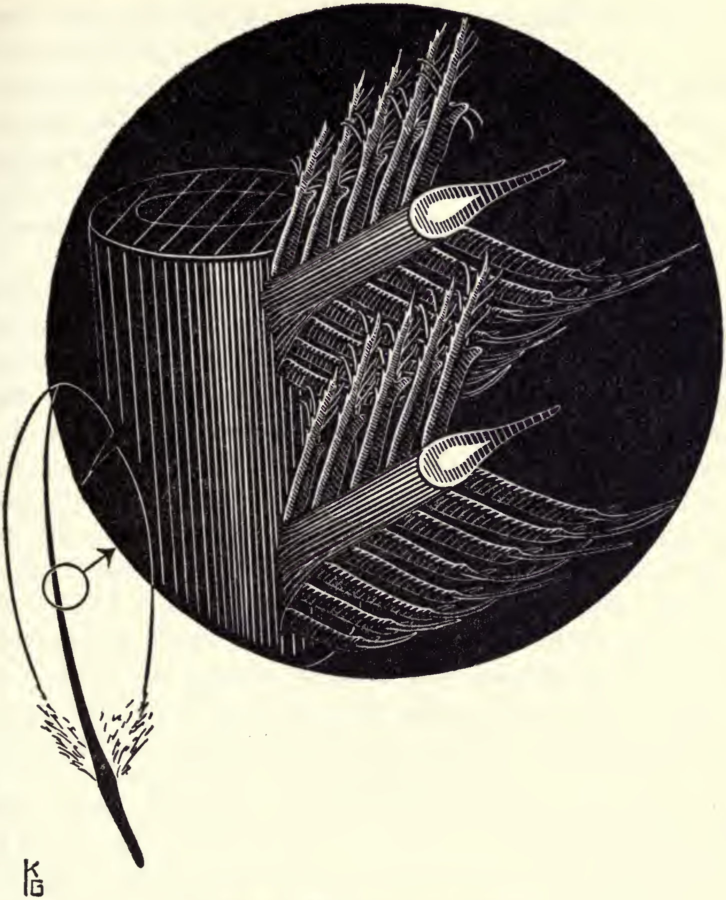
Yet in spite of the fact that the wing is one of the bird's salient features and that it is so varied and so versatile, its qualities do not, like those of an insect's wing, supply the labels for the twenty or more orders into which the Class Aves is divided. The modern systematist in establishing these major groups stresses internal structure and relegates to second place superficial likenesses that arise from similar habits. The bony structure of the bird's wing is more or less irrelevant because, when compared, for instance, with the highly variable breastbone or palate, it is virtually constant. In spite of changes in proportion and minor adjustments, the underlying pattern is essentially unchanging. The outward form is a variable thing that develops in response to the use to which the wing is put, and though it is of great value, when correlated with shape of beak and foot, in uniting families and defining genera and species, it is not in itself a reliable criterion of relationship. Birds of widely diverse lineage may have wings that bear a resemblance to each other if they are used the same way. The outward aspect of the wing, evoked by the way of life, is due mostly to the number, shape, size, texture, and color of the feathers.

The total number of flight feathers varies greatly—there may be sixteen or fifty—but the variation occurs only in the number on the arm sections. Irrespective of the size of the bird, or the shape of the wing, or how it is used, the number of primary feathers on the hand section is fixed: in all modern birds, with very few exceptions, it is either ten or nine. The hummingbird has as many primaries as the albatross—ten; but whereas it has only six secondaries, the albatross has forty. In a few waterfowl lagging behind on the lower rungs of the evolutionary ladder, an eleventh primary is occasionally present; and it is only among the highly evolved families making up the highest order of all, that of the perching birds, that the number is ever reduced to nine. The reduction is thus an indication of higher specialization and of an additional step away from the primitive ancestral form. It is an important item when it comes to assigning a bird to its proper niche in the intricately gradated ranks of the avian aristocracy. There was a time when the English sparrow was thought worthy of a place among the Fringillidae, the very first family of all in the top-ranking order Passeriformes, the perching birds. From this enviable perch with the élite finches (among which are found the song sparrow, the field sparrow, the chipping sparrow, various other sparrows, and the buntings) it was torn by the unflinching hand of the taxonomist all because—or largely because—he could not disregard a spurious first primary which increased to ten the total number of feathers on the hand section of its agile wing.

A "spurious" first primary is one that is very short, not more than a third as long as the second or the longest primary. Many of the perching birds are embarrassed by this abbreviated quill and are in a sense at a halfway point between the ten and the nine primary state. The first primary is, in some wings, the longest of all. In fact the relative lengths of the ten—or nine—primary feathers vary endlessly, and out of each combination there results a particular shape of wing tip. The shapes of the individual feathers are subject to great variety also: they may taper gently and smoothly to the end, or they may be abruptly narrowed or notched on one or both webs in various ways. In any one wing no two primary feathers are exactly alike. The feathers on the arm sections also change size and shape in the different species and bear different relations to those of the hand section. In short, the relative proportions of the several parts of the wing and the composition of each of the parts are indescribably complex and in each case the logical result of Nature's attempt to supply the best implement for a given duty.

The feather in itself is a masterpiece of mechanical efficiency, a work of art worthy of all praise. It is the distinctive character of the bird: everything that has feathers is a bird and all birds have feathers. In all probability feathers constituted the first outward sign of the bird's differentiation from the reptile. They are not merely the gadgets with which it learned to sustain and propel itself through the air; they are the covering which protected and insulated, the means by which, in the early stages, the heat of its body was maintained, conserved, augmented. With the rise in temperature, circulation and respiration quickened, activity increased, and chemical changes occurred which transformed a cold- into a warm-blooded creature. With the body temperature ranging from one hundred and four to one hundred and twelve degrees, birds have now the highest temperature and metabolic rate of any member of the animal kingdom.

The feather is comparable to the reptile's scale and to mammalian hair, and like them develops from a follicle in the skin. It consists principally of a shaft (in itself an extraordinary structure, firm yet elastic, in cross section changing from base to tip, and also varying according to function) with a web or vein on either side. The web is composed of parallel fibers called barbs, each of which is a miniature feather in itself fitted with smaller filaments which overlap and, by means of still smaller processes, interlock to create an elastic yet tough fabric which, if torn apart, will readily recombine. There are many modifications of the general design adapted for specific duties—contour feathers, down feathers, and plumes of all sorts. They grow either uniformly over the surface of the body or, as is usually the case, in definite feather tracts. Their modification in quality and color with age or season is another one of Nature's inimitable processes; and the molt in its varied man-



DETAIL OF FLIGHT FEATHER.

ifestations in different kinds of birds offers more food for thought and wonder. Except in the case of waterfowl, most of which lose the flight feathers all at once and withdraw into obscure retreats until replacements are fully grown, flight feathers are shed symmetrically, two at a time, one on either side, and at intervals, so that flight is not impaired.

The outer primaries, which strike the air edgewise, are in cross section streamlined. The outer web is narrower than the inner one and both are thicker where they join the shaft than at their free edge. The barbs that compose the webs not only grow from the two sides of the shaft at different angles, but vary these angles from base to tip. The shafts withstand great pressure from below, yet they bend in other directions in response to the forces they encounter. During every stroke there is continuous change of size and shape as the air pressure widens the webs or molds them into shapes that respond to such strains.

The efficiency of the wing as an organ of flight depends, naturally, not only on the design of its parts but also on the manner in which they are assembled and controlled. In all wings each of the flight feathers is overlapped by the one next to it, the narrow web of one partially covering the wider web of the one in front, so that on the downstroke they are forced together into a compact, airtight mass. On the upstroke the wing is partly flexed and the primaries automatically turn slightly edgewise and separate. The air then slips through the slots of the decreased surface with lessened resistance. The bird's momentum contributes to the ease of the upstroke, which is accomplished with far less exertion than the downbeat when the extended wing meets the maximum air resistance.

The muscles which control these two movements in flapping flight are anchored to the breastbone and connect with the upper armbone by means of tendons. Attached to the under part of the bone, the "depressors" pull the wing down by direct action. The "elevators" are called on to raise the wings from a position below them, a feat accomplished by the detour of the tendons up and over the humerus at the shoulder joint, so that they function like pulleys and, as Elliott Coues said, "work like men hoisting sails from the deck of a vessel." This is another instance of Nature's logic, for such an arrangement helps to concentrate the weight below the supporting areas and to center it, preventing a top-heavy condition or imbalance which might at times make it difficult for a bird to keep right side up. To accommodate the flight muscles the flat breastbone of the bird's reptilian ancestor (still retained by the flightless ostriches and the kiwi) developed a keel, a ridge of varying depth and length, which affords attachment and leverage for them. It is a general rule that power of flapping flight is related to depth of keel.

In good fliers the pectoral muscles account for a large part of the total bird. In the pigeon, for example, they amount to about half of its weight. Perhaps their position and magnitude can be best understood when they are identified as breast of chicken and the white meat of the Thanksgiving turkey, of which the top slices with grain running from the keel diagonally forward toward the wing constitute the muscle that pulls it down. The elevator is that smooth smaller portion lying in the angle of the breastbone between the keel and the flatter area. The shape of the breastbone, which varies in other ways than in the depth and length of keel (it may be short and broad, long and narrow, entire along its rear margin, or notched and "fenestrated" in various ways), influences the character of the muscles attached to it and consequently the mode of flight. The amplitude of a stroke depends on the length of the muscle governing it; the power, on its thickness; and since any muscle can contract at most about a third of its length, the deeply keeled, short breastbone (like that of the swift) will harbor short, thick muscles that will produce a powerful stroke but a short one; while the long, flattened model will support a long, thin muscle which will pull the wing down through a wide arc laboriously, as may be observed in the duck.

Just why the pectoral muscles should so burgeon in the domestic hen, which can scarcely flap to a low roost, whose wings are being deprived of their sole remaining task of brooding chicks, seems strange until it is remembered that all domestic breeds of *Gallus* trace their descent from the jungle fowl of India which really used its wings, and that on evolution's dial not enough time has yet elapsed for a change to be registered. Moreover, artificial conditions and selective breeding have upset the whole course of events and fostered the conservation of the profaned muscles of flight. The double-breasted turkey, also the product of man's insatiable edacity, descended from the wild turkey of virgin American forests, whose flight to the roost trees was said to have been powerful and silent. Ordinarily the wild turkey did not fly far at a time and it depended a good deal on volplaning. Ducks and geese, primarily water birds, which use their wings intermittently, have (as any woman who has bought, basted, or tried to carve one knows) long, flat expanses of breastbone and, compared to a chicken or turkey, much less meat.

The unerring logic with which the many elements of the bird's wing have been assembled in bewildering diversity and correlated with other physical traits to offset the limitations and utilize the advantages of every way of life is glimpsed more clearly now that man himself has tried to solve some of the same problems. The manner in which the three sections of the wing co-ordinate to produce the intricate movements that constitute flight, for so long matters of conjecture, are now explained at least in part; and it is evident that as the wing is raised and lowered, as it extends and contracts, billows and straightens, adjusting to both direction and force of air currents and to the direction of flight, every detail of the design contributes to the formation of the perfect instrument for the specialized action required by a particular mode of life.

For such mastery of its medium the avian wing groped its way by trial and error through countless millions of years. The initial stages of the process are matters for the imagination to deal with, for the first tentative efforts of a reptile's paw to find support in insubstantial air have left no trace, and the records of its subsequent faltering progress are also missing. The earliest feathered wing that has come to light so far was already well on the way to its present form.

It belonged to a contemporary of the flying reptile, which had followed a different evolutionary course in developing its organ of flight. Neither bird nor reptile, it had characters of both: a short, blunt bill with teeth in both upper and lower jaws, a long tail of twenty vertebrae from which feathers grew on either side in pairs, and feathered wings with claws at the ends. It was about the size of a blackbird. To what extent it flourished, how far it ranged, we do not know. Our acquaintance with it is limited to the fossilized remnants of two individuals who carried on their activities on the land masses that bordered the shallow inland sea which in their day extended over what is now central Europe. By lucky chance they escaped the usual fate of feathered creatures: they were not seized and crunched by a hungry predator; they did not fall among the seed ferns and early conifers to be disposed of by the usual processes of decomposition and decay. Instead they dropped into the still water of the inland sea and sank to the bottom unnoticed by teleosaur, plesiosaur, or other aquatic prowler. Layers of silt covered them before they could disintegrate; and more silt accumulated, which, under ever-increasing pressure as ages drifted by, packed in denser masses and hardened into stone. Continents rose and fell and rose again in rhythmic response to the forces of erosion and upheaval; stresses and strains wrinkled the crust of the earth to create mountain range and plain.

For a hundred and fifty million years the fossil forms, crushed, dislocated but almost entire, lay locked in their impervious matrix, to be, at last, uncovered in quarries near a Bavarian village where acquisitive man delved for lithographic slate of a particularly fine quality. The first specimen was found in 1861 near Solnhofen and was named by the scientist who described it *Archaeopteryx* (Old-wing). The second was discovered sixteen years later not far away, in the same Jurassic deposit. Since certain slight structural differences led to the conclusion that they were not of the same species, the latter was christened *Archaeornis* (Old-bird). *Archaeopteryx* is now housed in the British Museum; *Archaeornis* is in the Natural History Museum in Berlin.

From comparison of the two fossils, it is obvious that a working model for the feathered wing had been achieved. The bony structure of the hand was essentially the same as it is today except for the facts that the two fingers had not fused, that the thumb was almost as long as the fingers, and that a claw grew from each. That it was a wing more suited for gliding than for true flight seems probable, for there was inadequate provision for the attachment of muscles. However, the feathers were constructed and shaped as they are in modern birds; and they were arranged and attached to the three sections of the arm in the usual manner. If the pattern of their imprint is correctly interpreted, there were twelve primaries; and the ones on the outer edge were short, so that they did not interfere with the claws. A relic of this primitive trait persists in a South American bird, the hoatzin, which, as a newly hatched chick, has two claws on the disproportionately large hand. It uses them as well as its feet and beak to climb about among the branches until its wing feathers have grown out sufficiently to sustain it, at which time the forearm develops rapidly, the claws gradually disappear and a normal wing results. The swan, the osprey, and the turkey vulture still retain a skin-covered claw; and in the embryos of several other species vestigial claws occur.

The presence of claws is but one of many proofs that the bird evolved from the reptile. Just why its unidentified forebear forsook the earth to seek its fortune in the air and how it began its adventure are matters of speculation. It is generally agreed that the remote ancestor from whom its line diverged was one of the smaller dinosaurs that had learned to stand partially erect and walk on its hind legs. This hypothetical progenitor, a pseudosuchian (an "imitation crocodile"), having assumed the position that freed its forelegs for other purposes than locomotion, was next attracted to arboreal life. Perhaps it was to escape the jaws of *Ornitholestes* that it first scrambled up the trunk of a cycad to take refuge in its branches. Perhaps it found among the fronds and leaves cicadas and other insects to appease its hunger. At all events, it next acquired the habit of leaping from branch to branch and from tree to tree until, at length, its scales, adapting to new stresses, frayed and became feathers. Finally, it was able to launch itself boldly into space and in gliding flight pursue dragonfly and beetle. Once on the ground, it was doubtless faced with the necessity of crawling back into the branches before making another sally.

William Beebe some years ago proposed a four-winged or "tetrapteryx" stage for the evolving bird. He did so on the basis of his observation of certain stout feathers sprouting from the thighs of young squabs and some other birds which he thought might be vestiges of "pelvic wings." Supposedly such feathers extended at the rear and added to the sustaining surface. They lost this function as the fore limb and its flight feathers took on its definitive form and the rear legs continued to provide locomotion on the ground. Until more archaeological evidence is obtained, there can be no confirmation of this or any other theory.

All is supposition. What really happened we do not know. The wing of *Archaeopteryx,* like that of the insect and many man-made masterpieces of the unrecorded past, such as the monuments of the Mayas (which must have been preceded by wooden tablets), seems to have sprung unannounced from the soil that produced it. It may be that, like the human products, the first verisons of the bird's wing were embodied in fragile materials that quickly sank back into "the receiving earth." On the other hand, it could be that in some recognizable form they still lie deep in the rock waiting to be released by the quarryman and scrutinzed by the paleontologist.

10

Discontinued Models; the Bat

> 'Tis strange, but true; for truth is always strange. . . .
>
> —BYRON, *Don Juan*

GENERATION after generation, through age after age, descendants of *Archaeopteryx* and *Archaeornis* heroically persevered in their attempts to fly. Remodeling themselves bit by bit to comply with specifications imposed by the properties of the air and the pull of the earth, they found ways to reconcile and utilize these exacting forces. Their progress cannot be followed step by step, for there is another great gap in the record. The routes they took as they logically and ingeniously circumvented the obstacles on the way are obliterated as completely as are the tentative moves of the adventurous reptile that started on the journey. The story is resumed only after the goal had been reached, when the reptilian background was all but forgotten and birds were birds unequivocally.

For the next recorded stage the scene shifts from Bavaria to North America, where in 1870 fossil birds were recovered from Cretaceous shales of western Kansas—deposits laid down about a hundred million years ago when the future sites of Wichita, Topeka, and Kansas City were still being formed beneath the waters of an inland sea that stretched from the Gulf of Mexico to the Arctic. Two distinct species were found, curious mixtures of the primitive and the modern that differed widely from each other in most ways while yet retaining one character in common, a toothed bill, the last outward token of their origin. One with keeled breastbone and fully evolved wing bones was a competent flier about the size of a pigeon. It must have been more or less like a gull; and it is known as *Ichthyornis,* the Fish-bird. The other was an all but wingless water bird. The construction of its legs and feet as well as other traits stamped it as an expert diver rather like a loon but very much larger. Its wing was rudimentary. Without hand, without forearm, it had withered until there remained only the tapered stump of the bone of the upper arm, which may not have been visible externally. The name bestowed on this swimmer was *Hesperornis,* Western-bird.

A wingless bird, even a flightless bird, seems a contradiction in terms. Surrender of the power of flight appears at first glance an unaccountable action on the part of any creature that had ever learned to fly. It would seem that when once the primitive wing of *Archaeopteryx* had been transformed into a wonderful mechanism for sustained flight it would have been kept at all costs by the one that had sacrificed its forelimbs to acquire it. This is, of course, to overlook the effects of changing circumstances, the creation of new problems and the removal of old ones, which bring about corresponding changes of one kind or another in the forms of life subjected to them. After having adjusted its frame and all its members to the exacting requirements of flight, the bird has found it now and then advantageous or tempting to forfeit the object of its agelong striving.

So it must have been with *Hesperornis,* the earliest flightless bird of which there is any record. During the fifty or sixty million years that separated its day from that of *Archaeopteryx,* it had won its wings, tried out aerial life, and for some reason found it desirable to make a "secondary adaptation." Its flat breastbone betrayed the fact that it had never been an expert flier; but such power as it had managed to develop it relinquished entirely. It turned its back on the sky in favor of life on and in the water and allowed its wings to atrophy.

It is to be hoped that *Hesperornis,* competing as best it could with the aquatic reptiles that dominated its realm—mosasaurs, plesiosaurs, and ichthyosaurs—was satisfied with its destiny and did not cast a regretful glance skyward to watch ruefully the antics of the comrades from whom it had parted company. The wings of fish-birds, and of others whose presence is known from scattered fragments in the rocks, were not the only ones to cross its horizon. Occasionally enormous dark sails bore grotesque bodies in great gliding circuits overhead. Coasting low, they might suddenly obscure a large part of that expanse and send monstrous shadows sliding over land and water, beneath which *Hesperornis,* intent on fishing expedition or incubating its eggs along the reedy shore, might well have crouched apprehensively. The largest of these dark sails belonged to *Pteranodon.*

This fantastic being was the largest and one of the last of the flying reptiles, the pterosaurs, of which the first representatives so far discovered were contemporaries and neighbors of *Archaeopteryx.* Those whose bodies were embedded in the slate at Solnhofen, along with dragonflies and other insects, were small creatures, about the size of sparrows and robins. There were two kinds, both of which had toothed beaks and tails, the tails of some being short, of others, very long with a rudderlike web at the end. It is obvious that since there was by Jurassic times this much differentiation, a common ancestor preceded them in an earlier age, just as the precursor of *Archaeopteryx* was assuredly the product of a previous day. Their appearance may have coincided with the great expansion of the insect population. It would be rash to infer that birds and pterosaurs made their aerial debuts in the same season, yet they may have worked on their projects simultaneously if independently.

Evidently when the conquest of the earth by the reptiles had reached a certain stage, as they pushed into all quarters, expanding through terrestrial, aquatic, and arboreal zones, there came a time when the air beckoned. Perhaps it was in frantic haste to escape or in urgent need to pursue that some of them developed a habit of leaping out of a ginkgo and pawing the air as they descended. The reptile that was to become a bird having already lost two fingers began to trade its scales for feathers and convert its arm and hand into a reliable support for them. The other, with its lizard frame intact, fabricated a wing by extending the smooth skin of its body.

It was a very different sort of wing from that of the insect's, which is also an extension of body wall. From the vertebrate's point of view the insect is made inside out. Like the lobster, it wears its skeleton on the outside of its body and its wings are made of the same horny, almost indestructible chitin that protects and frames its soft interior. The wings of flying reptiles, which, like all vertebrates, have built-in skeletons and a pliable outer surface, were outgrowths of its skin, and were, as far as can be judged from very scanty evidence, thin, firm, and without scales or other features. They extended along the sides of the body between the fore and hind legs and were supported at their front edge by one enormously elongated finger, the outermost of the four that composed the hand. The other three fingers were of normal length and clawed. According to H. G. Seeley, the wing finger was bent backward when the creature alighted on the ground. It appears to have been sometimes as long as the entire vertebral column and in *Pteranodon* was more than five feet in length.

Pterosaurs inhabited various parts of the earth—central Europe, Africa, England, and North America. All of those whose bones were taken from the Kansas shale and many of those found in England belonged to the short-tailed branch of the family (the pterodactyls) in the last phase of their development. Of these, *Pteranodon* is the most renowned. In the course of its evolution it had lost not only most of its tail but its teeth as well, and in this respect it was a grade ahead of both *Ichthyornis* and *Hesperornis*. It had a most extraordinary backward elongation to its skull, and in some cases wings measuring twenty-five feet or more between the tips.

There are many bones and pieces of bones scattered through the shales and chalks of the localities where pterosaurs once abounded; but complete specimens are rare finds. Even in them there is unavoidable dislocation of parts, breakage, obliteration of tendon and tissue so that there is ample room for disagreement among those who try to conjure up from them the living creature. In a few cases the imprint of the wing membrane is discernible, but there is little to indicate how the wing really worked. Certainly the hollow bones, the keeled breastbone, and other details helped to make *Pteranodon* airworthy. Yet the great expanse of continuous membrane with only a front-edge control must have been a very unwieldly sort of sail and one likely to be made useless by injury to any part. Tremendous muscles would have been needed for flapping flight, and there is no proof that such muscles existed.

Samuel W. Williston, who made an extensive study of American pterosaurs, believed that the wings of *Pteranodon* were given additional support by some of its ribs, and in behalf of this theory he cited the case of the "flying dragon" of the present day. In this small tree-living lizard of the East Indies, five or six ribs on each side grow out laterally and support the outgrowth of skin that forms a sort of parachute on which it glides from one branch or tree to another. Since the rear ribs of *Pteranodon* were very slender and only slightly curved, he thought it quite possible that instead of enclosing the abdomen, as ribs ordinarily do, they might, like *Draco's,* have extended outward into the wing's fabric. Another supposition is that the great backward-projecting crest of the skull might have provided anchorage for flight muscles. However, it is quite unlikely that the muscular system of the pterosaur could compare with that of modern birds.

All in all, it is probable that the scythe-shaped sails of the flying reptile were not the best of all possible wings and that they were better suited for gliding than for true flight. Nevertheless, on them the various members of the family continued their struggle for existence for fifty or sixty million years, which is about two thousand times as long as *Homo sapiens* has been a guest on this planet. Skimming the sea for surface-feeding fish, perhaps, or (as seems more likely for the toothless species) pursuing giant dragonflies or searching for fruit, they found their wings useful. On them under favorable conditions they were able to glide and soar for great distances. On them as the Cretaceous period and the Mesozoic era drew to a close, as a shift of scene was readied and the curtain fell on the Age of Reptiles, *Pteranodon* started on the longest flight of all and quietly accompanied its near relatives and its more distant kinsmen, the dinosaurs, into oblivion.

The flying reptile went the way of all reptiles—all except those that managed to continue into the present as turtles, crocodiles, lizards and snakes. Its wings could not save it from the general debacle; neither could they be blamed for its failure to survive. Though they had their limitations, they also had inherent possibilities, which Nature did not overlook. Even before the last pterosaur started on its glide into limbo she had begun to recast them for the use of a small mammal. Working out an improved version of the design, she revised the proportions, strengthened the surfaces, perfected the control, and in time made a bat.

As usual, the beginnings of the process are unrecorded. Once more there is a break in the geologic record, so that a finished product seems to have appeared suddenly and without notice. The first known bats were in all respects similar to those of the present. Most of them were taken from coal and limestone deposits in Germany and France formed when the Age of Mammals was in full swing.

During the uncounted millenniums through which their ancestors had been making uncharted progress toward bathood, the earth was being again reconditioned. At the end of the Cretaceous period its crust had buckled into Rockies, Andes, Alps, and Himalayas. Submerged areas were drained; climates changed. Beeches, maples, oaks, and elms advanced among the magnolias, walnuts, and willows that had already relieved the monotony of the evergreens. Plants, having learned to make blossoms out of leaves, solicited (with pollen and nectar) the aid of insects in the production of fruits, nuts, and seeds. Those insects that developed sucking mouth parts took advantage of the new fare, and partnerships were sealed. Grasses and grains appeared and created plains and prairies.

The hitherto insignificant mammals, active, warm-blooded, subsisting on little, had been able to withstand the shock of lower temperatures and other emergencies in a way the cold-blooded,

BAT: a Flying Mammal.

sluggish, small-brained reptiles could not do. Freed from their domination, mammals came at last into their own and, in their turn, began a cycle of growth, dissemination, and differentiation. Different habitats and foods necessitated modifications of teeth and means of locomotion; and they began to transform themselves into rodents, carnivores, grazers, hoofed runners, clawed predators, four-handed climbers. In time, as all available areas were populated and as pressures increased, the ancestors of the whale, evidently tired of terrestrial life and, following the precedent of the ichthyosaur, resumed the form of a fish and life in the sea. The progenitor of the bat, like the ancestor of bird and pterosaur, was shoved or enticed into the air and, so far as we know, was the only one of all the competing multitudes to follow their example. Except for man, who, fifty million years later, learned to make for himself artificial wings, the bat was the only mammal that ever learned to fly.

It seems reasonable to suppose that it became air-minded through a series of adventures that paralleled those attributed to the ancestor of the bird. In all probability its precursor, a small shrew-like, insect-eating creature, was first a terrestrial forest dweller, then an occasional refugee in the trees, next a convert to arboreal life, living on the insects that visited the blossoms and later on the fruit. Vaults and capers through the boughs, which were at first adventitious, became purposeful and lengthened into glides and swoops as it leaped out to pursue an insect or tried to elude attack.

The so-called flying squirrels that are found in many parts of the world today and the East Indian flying lemur are among the modern mammals given to such brief aerial excursions. The squirrels have lateral outgrowths of skin between the fore and hind legs that spread out as they leap and help to sustain them. The flying lemur has a similar extension of skin which, in its case, is continued from the forearm to the neck and from the rear legs to the tail. Moreover, its hands are webbed and moderately lengthened. All such membranes are essentially sails and parachutes, not wings; yet they possibly give a clue to the way in which the bat's ancestor began its aerial career. As Glover Morrill Allen explains in *Bats,* the extensions of skin at the sides were probably acquired first, and, next, the additional membranes which joined the rear legs to the tail and the lower part of the neck to the forearm. Then the fingers became longer and more slender with webbing in between. The bat's thumb was not included in the webbing, as was the lemur's; it remained free and diminutive and clawed. Allen suggests that at first the glides were made with flutterings of the webbed hands, the rest of the membrane acting as support. With the development of strong breast muscles and the further refinement of the various parts, the potentialities of this sort of wing were fully realized.

One of the greatest improvements in the bat's wing over that of the pterosaur was the growth of the connecting membrane between all the bones of the hand; for the control, instead of being vested in a single finger at the front edge disproportionately lengthened, was now shared by four sets of elongated hand bones fanning out from the wrist through the membrane to its very edge, like the ribs of an umbrella. In modern bats the bony pattern of the vertebrate forearm is considerably modified. Of the two bones (radius and ulna), one is greatly lengthened; and the other, diminished into a mere shred, is in some cases joined to it not far from the elbow.

The whole framework of the bat's wing is in interesting contrast to that of the bird. In the bird the two bones of the forearm are quite as they are in other vertebrates, while the bones in the hand have not only been reduced in number but fused to make a base for the flight feathers. The bat, on the other hand, spread and lengthened the bones of the hand and fingers (though it discarded some of their joints) and immersed them in a connecting membrane with whose subtle manipulation they are entrusted; and it simplified the forearm which bore a heavier share of the burden of flight.

In the different species the details of construction vary. Of the four fingers, the first is the only one that ever bears a claw; and in many cases this telltale relic is missing as well as a joint or two. Cartilage replaces bone always in the last section of the fourth and fifth digits and usually in the tip of the third. While the relative proportions of the fingers vary, the middle one is always longest. The leathery membrane is strong, smooth, pliant, sensitive, and bare except for delicate hairs that enclose nerve fibers.

One of the fruit bats has a wing cut to a most unusual pattern, for its membranes begin to project from the very center of the back instead of at the sides—an arrangement which gives a great increase of supporting surface. A smaller insect-eating species of the American tropics has a similar arrangement.

By the articulation of the many joints—those of the fingers at half a dozen places in the membrane, and those at wrist, elbow, and shoulder—this wing is capable of the most delicate adjustment. Its extent, its angle, its movement can be regulated in every part. As might be expected, it is unsurpassed in maneuverability. Leonard Dubkin, describing in *The White Lady* a rare variant of the common little brown bat, an excellent flier, gives interesting accounts of its agility. He tells how the mother of his White Lady whisked away her baby as it hung from his finger with instantaneous action; and how the White Lady herself, later, took insects from his hand with the same incredible dexterity. The most amazing performance of all came when she flew straight through an electric fan rotating at the rate of eight hundred revolutions a minute. Less spectacular was the flight of a horseshoe bat observed by an English naturalist which, searching for a way out of a room, fluttered in and out of a gap on a shelf left by the removal of a book without apparently touching anything.

As daylight fades and the bat begins its eccentric wandering in search of night-flying insects, it flitters in weird circumambulations through the sky. It is a sort of flight that has suggested the "unsettled and chaotic state of the unhappy, restless human consciousness." It is often compared to that of the swift, which also feeds on the wing; but the bat is able to check and vary its course in a way that is unique. Emitting supersonic squeaks which bounce back from reflecting surfaces and register on its receptive inner ear, it is able to avoid collisions and make split-second changes in its course. Steering, for which the bird mostly uses its tail, is in the bat accomplished entirely by action of the wings, either by the adjustment of their surfaces or by the regulation of the beat. In ordinary flight the direction of the stroke is, like that of both bird and insect, an upward-backward, forward-downward motion.

Powers of flight naturally vary in different species. Among the fastest is the free-tailed bat of the tropics whose wings are relatively long and capable of a rapid beat. The small brown bats are rapid but erratic fliers. Some of the still smaller kinds—pygmy bats whose wings are relatively short and broad—flutter about with short, quick strokes like large moths. The great fruit-eating bats, or flying foxes, of which the largest is a Javanese species with a wing spread of more than four feet, are, on the other hand, steady fliers with a fairly rapid and well-sustained flight. It is not known how long bats stay on the wing either in their nightly foragings or in migration. The hoary bat wintering in Bermuda must necessarily cover about six hundred miles nonstop, but only it knows how long it had to fly to get there.

In one of the experiments Dubkin made to test the White Lady's homing instinct, he released her ninety miles from her grotto and found her hanging in her usual place when he arrived there two and a half hours later. Her speed on her return trip through unfamiliar territory approximated that of starlings, bronze grackles, and robins. These have been clocked from an automobile running parallel to their flights at thirty-five miles an hour in the case of starlings and grackles, thirty-six for robins. However, the White Lady may have made the trip in much less time and reached home long before her observer.

Some claim for the bat unsurpassed powers of flight; certainly it has unrivaled powers along certain lines. With no help from its weak legs on which it can scarcely crawl, it can take flight from a flat surface, a truly remarkable achievement. Some species are able to hover after the manner of hummingbirds with body erect and wings moving horizontally. Although they can glide for short distances, bats do not soar. Perhaps their bodies are too light to provide the necessary ballast. Perhaps the night air is seldom soarable. It does not matter, for they do not need to soar: their nocturnal affairs call for unremitting action and not for a deliberate survey of the field below. When the night's flight is over and it flutters into its cavern or to an arboreal setting, the bat makes a landing with the help of the claw at the tip of its tiny thumb. Then, hanging itself up by its feet, upside down, it settles to rest. In many species the wings then enwrap it like dark coverlets. Behind them it composes itself to await the coming of another night.

One is not apt to think of bats as colorful objects but as dark, drab creatures of monotonous and nondescript hue, for those that flutter across an open space between the trees or occasionally stray into the house belong to groups not distinguished for color. But these represent only a small fraction of the bat population. Among the two thousand or more species that exist in various parts of the world there are many that exhibit subtle and often beautiful color patterns. In many cases the wings with contrasting tone and hue play a large part in the creation of striking effects. In a general way a bat's color is related to climate and to its habits. Allen describes a number of species, many of them tropical, in which color seems to play as important a part as it does in other flying creatures. Among those with contrasting wings are the great-eared bat of East Africa, whose yellow-orange webs are a foil for the pearl gray of the furred body, and the pygmy canyon bat of our own country, whose black membranes create a tonal contrast to its pale form.

In an Indian relative of our little brown bat, the hoary bat, and in an Oriental painted bat black wings have orange markings along the fingers, which repeat the orange and brilliant rufus of the body and spread it through the webbing. This painted bat, according to Allen, takes on the appearance of a russet leaf when it hangs at rest amid foliage. The widely distributed little brown bat has, in the drier regions of Arizona and southeastern California, trimmed its dusky wing with a white edging; and one of the pygmy bats of Europe and Africa has a similar marking, especially in the more arid parts of its range. Several tropical species have eerie white membranes. In the Celebes and other parts of the Malay Archipelago a tube-nosed fruit bat has round yellow dots on the wing's dark ground; and one of the most interesting of all the variations of wing decoration is that of the butterfly bat of West Africa—a network of dark lines which follow the veinings of a pale membrane. This species also sinks into its leafy background.

As a rule, such variations and contrasts of color occur among those species that rest for the day among foliage and find protective coloration desirable. Cave dwellers, on the other hand, constant companions of the dark, are clad in unobtrusive costumes; yet even in these apparently neutral shades there is often delicate modulation of tone and subtle beauty.

11

Flightlessness

> And this shall be the forfeyture: of your own fleshe a pounde.
>
> —Thomas Percy, *Reliques*

While the bat was in the process of disengaging itself from terrestrial and arboreal restrictions and feeling its uneven way through the night air, millions of years rolled by. The volant mammal was a comparative newcomer into a territory through which the insect had long, long before blazed a trail, to which birds had acquired inalienable rights, and from which the transient flying reptile had vanished never to return. The insects, once they had charted their aerial courses, never for one eon canceled their flights; and from the time of *Archaeopteryx* onward there were birds constantly aloft. *Hesperornis* and *Icthyornis,* and many others, it is true, had disappeared at the end of the Cretaceous period as completely as had *Pteranodon* and the dinosaurs, but birds as a class had been able to survive the end of an era (the Mesozoic) and help with the rehabilitation of the next. Active and warm-blooded, they could cope with colder climates and dislocated environments, caused by geologic crises, and vie with the emancipated mammals in exploiting the possibilities of the remodeled scene.

New difficulties, new opportunities, new conditions of all kinds encouraged specialization along many lines. By the time the first recorded bats were flitting through Eocene twilights, hawking for early varieties of moth and mosquito, most of the existing orders of birds had been established. There were ostriches and eagles, partridges, herons, sandpipers, and swifts: water birds, shore birds, land birds of various sorts, and raptorial species. There was even a new version of that curious anomaly, a flightless bird. Its name, *Diatryma,* was coined from the Greek *dia* meaning "through" and *tryma,* "a hole," and referred to the openings in some of the bones of its feet.

It had little in common with *Hesperornis* except its inability to fly. It was a land bird, and from the time of the discovery of its bones in 1916 in northern Wyoming it has held two records, that of being the first of all known ground species and that of being the largest bird ever known to have existed in North America. The sight of a bird six times as tall as a horse would surely create a sensation even among today's wonders, but it was nothing out of the ordinary in *Diatryma's* time, when little *Eohippus,* the remote ancestor of our Percherons and pacers, was about the size of a cocker spaniel (though of different build) and actually not even knee-high to this mammoth beachcomber that towered six or seven feet above it.

Diatryma probably looked like a monstrous fowl; it had strong legs and feet, a powerful neck, and a huge head with a great hooked, toothless beak. Among a queer company composed both of archaic creatures, which were, like it, about to suffer the penalty of being misfits, and of the more fortunate ones with a future, those beginning to diverge along lines which allowed them to hold their own in the unfolding scheme of things, *Diatryma* stalked. On some of these it no doubt fed. Its keeled breastbone was unmistakable evidence that it had descended from an ancestor that had been able to fly, but its own wings were rudimentary. It ranged over areas which are now part of Wyoming and New Mexico, and though it supposedly had little to fear from any of the small mammals that had developed a taste for meat, it did not fulfill the requirements for survival. In modern classification it has been placed between marsh and shore birds, but it was not ancestral to any living form.

What is thought to have been a relative of *Diatryma,* not a close kinsman but one connected through an unknown common ancestor, roamed the pampas of Patagonia during the Miocene, twenty million years later. It was a carnivorous giant even larger than *Diatryma* and the greatest of all known birds of prey. Its skull was almost two feet long and the vertebrae upholding it were five inches across. It too had an enormous hooked beak and large, strong legs. It had wings, but they were too small to be of any use for flight. It was related to the heron family and is known to science as *Phororhacos* (*phor,* "thief"; *rhakos,* "tattered garment").

Colossal flightless birds have not been confined to any one period, locality, or order. The American species were the earliest so far discovered, but in succeeding ages others, quite unrelated to them, appeared in scattered and isolated sections of the Old World, some of them persisting into historic times. In New Zealand, Australia, and Madagascar there were flat-breasted tribes akin to the ostrich which seem to have reached their heyday about the time that man was beginning to make his presence felt and when great blankets of polar ice periodically reached out over large sections of Europe and America to blot out life in the regions it shrouded.

The New Zealand birds were the moas, of which there were numerous species. The smallest one was about the size of a turkey; the largest, ten feet in height, was the tallest of all known birds. All were flightless and some had not even the vestige of a wing. Inhabiting riverbanks, swamps, and lakes, where they supposedly fed on water plants, fern roots, or possibly fish, they were able to maintain themselves, though perhaps in diminishing numbers, until the colonization of their island by the predecessors of the Maoris, which tradition places about the middle of the fourteenth century. Then their extermination began. It was completed before Captain Cook set foot on their shores in 1771. Their small distant relative, the kiwi, escaped their fate and illustrates the general rule that whenever there is a critical situation the largest members of the group confronted with it are the first to succumb to its influence. The great moas fell; but the little kiwi, no bigger than a hen, flightless, with its useless, stunted remnants of wings concealed beneath its feathers, still manages to keep a precarious hold on life. Its nocturnal habits no doubt help, and it is now occasionally domesticated.

In Madagascar lived *Aepyornis* (Tall-bird), another land bird which grew to enormous size and allowed its wings to degenerate. It almost equaled in size the largest of the moas, and it may be that the legends of the fabulous, mythical roc, so widespread in the East, had their origin in vague memories and distorted reports of this giant. However, the roc, or rukh, had, as every member of Sinbad's audience knows, powerful wings. Although its existence could never be proved or its presence traced to anyone who had ever actually seen it, popular belief vouched for its reality. Marco Polo was assured by Arabian mariners whom he questioned on the subject that it was very like an eagle but incomparably larger, with a wingspread of sixteen paces. He was told that at certain times of the year it arrived on Madagascar from the south and that it was strong enough to lift an elephant in its talons. Thinking that "these creatures might be griffons, such as are represented in paintings, half birds and half lions, [he] particularly questioned those who reported their having seen them as to this point; but they maintained that their shape was altogether that of birds, or, as it might be said, of the eagle." He was told also that messengers sent to the island by the grand khan to investigate its wonders brought back a feather of the roc that was said to measure ninety spans, the quill being two palms in circumference.

About seventy-five years after Marco Polo's journey, in 1346, Ibn Battúta, a Mohammedan gentleman from Tangier who liked to be known as The Traveller of Islam, all but encountered a roc on one of his voyages when he was on the way from China to Sumatra in a Chinese junk. One day at dawn there appeared in the far distance what looked like a mountain projecting out of the sea, toward which the wind was driving the boat. The following day as the wind calmed and the sun rose, the supposed mountain ascended into the air. The consternation that had already existed on board increased and the crew began to weep and bid farewell to one another. When Ibn Battúta asked why the lamentations continued, he was informed that what had been mistaken for a mountain was really the rukh and that if it chanced to see them all would be lost. "We were at that moment," he related, "less than ten miles away from it. Just then God of his mercy sent us a favorable wind, which turned us in another direction, so that we did not see it and could not learn its true shape." The roc had again eluded direct observation.

There was no doubt about another fabulous bird, the dodo. It was an actual, bona-fide resident of the island of Mauritius, where it was found and used for food by the early Dutch voyagers. It was a thickset, ungainly forest dweller as large as a swan but structurally related to the pigeon. Although it still possessed wings, they were much too small to lift its bulky body. "It is of a melancholy visage," wrote Thomas Herbert, who saw it when he stopped at Mauritius on his return from Persia in 1629, "as sensible of nature's injury in framing so massive a body to be directed by complimental wings, such indeed as are unable to hoist her from the ground, serving only to rank her amongst birds." He goes on to describe its head, hooked bill, eyes, and tail that "like to a China beard is no more than three or four short feathers," its thick, black legs and talons. Its stomach, he said, was fiery, "so as she can easily digest stones—in that and shape not a little resembling the ostrich"; and he made a drawing of it which his engraver translated into an image of a Gargantuan chick with an enoromus head and beak.

There was also a flightless rail on Mauritius, and on the neighboring islands of Rodriguez and Réunion lived a near relative of the dodo, the flightless solitaire. All of these birds disappeared in comparatively recent times; and the few large flightless species that exist today waver on the brink of extinction—the emus of Australia, the rheas of South America, the cassowaries of New Guinea and various parts of the Malay Archipelago. Their wings, though present, are stunted and useless. The wing feathers of the cassowary of Ceram are so modified that they resemble, according to Wallace, "black spines like blunt porcupine quills." The cassowary has only two primaries.

It would be interesting to know just how and why these birds became earth-bound. Wallace believed that an insular habitat was responsible for the modifications that brought about a flightless state; and he explained the process by applying the same reasoning that Darwin used to account for the unusually large percentage of wingless beetles on the island of Madeira—namely, that where there was danger of being picked up by the wind and carried out to sea and lost, it was an advantage not to fly. "Bad flying," said Wallace, "was worse than not flying at all. So, while on such islands as New Zealand and Mauritius, far from all land, it was safer for a ground-feeding bird not to fly at all, and thus the short-winged individuals surviving, prepared the way for a wingless group of birds; in a vast Archipelago thickly strewn with islands and islets it was advantageous to be able to migrate, and thus the strong-winged varieties maintained their existence longest, and ultimately supplanted all others, and spread the race over the whole Archipelago."

In *Animals of the Past,* Frederic A. Lucas said absence of enemies was primarily responsible for loss of the will to fly—the absence of enemies combined with a plentiful food supply and isolated or restricted quarters that kept together the individuals or races in which the tendency toward smaller wings manifested itself. Since the wing's great value lies in providing its owner with the means of escaping from its enemies, of searching for food, and of coping with change of climate, its use could be conveniently dispensed with by a ground-feeding species living where there was nothing to fear, and where food and climate presented no problems. He calls attention to the fact that in Tasmania, an island near to Australia geographically as well as in the character of its fauna, there are two carnivorous animals and no flightless birds. The African ostrich, the Australian emu, and the rhea of South America, though not island dwellers, nevertheless support the theory inasmuch as they live in isolation on wide plains where there are few, if any, beasts of prey and where a fleet foot effectively replaces the wing as a means of escape. Further evidence is supplied by *Phororhacos*. Increase in size usually accompanied loss of power to fly, for "the larger the bird the less the necessity for wings to escape the four-footed foes." Moreover, the larger the bird the more difficult flying became. A huge body and a diminished wing were thus interacting and mutually determining factors.

By whatever influence or combination of influences the oversized islanders arrived at their flightless state, they had, either because of it or in spite of it, come to pleasant terms with life in their respective Edens. They were in a fool's paradise, however, wholly at the mercy of environment, subject to disaster at the least change in the delicate balance of their situation. Their great size was not an unalloyed asset. On the contrary, it was an indication that they had strayed into an evolutionary blind alley, a portent that the curtain had risen for the last act, when the slightest shift in scene would force an exit. So while these Antaean figures went about their tranquil pedestrian ways, unaware of the possible consequences of the denial of their birthright, fearing nothing from beasts of prey, they were utterly unprepared for the advent of the greatest of all predators. They could as little foresee or forestall his arrival as evade its consequences. What could strong legs and speed avail against the egg hunter, or the purveyor of the spear, the arrow, the boomerang, the bullet? Although in some cases their population had already ebbed through natural causes, their final irrevocable doom was usually sealed by man.

The charred bones and eggshells of the moas have been found in the kitchen middens of the aborigines of New Zealand, where legends of moa hunts and moa feasts were handed down among the Maoris. The disappearance of *Aepyornis* from Madagascar seems to have begun with the arrival of primitive man. The dodo was liquidated by European settlers in 1681, a little more than a century after Dutch navigators first reported its presence on Mauritius. Its fellow countryman, the small flightless rail, met the same fate, as did also the solitaire on Rodriguez and Réunion. What man himself did not destroy his importations did. "It had no creatures in it save birds," wrote Herbert when describing Réunion, "till our captain sent his longboat with some hogs and goats of both kinds ashore, that by a happy multiplication the future passenger might be relieved." Rats were added to the hogs and goats and the eggs of the ground-nesting birds were at their mercy.

Emus, rheas, cassowaries have been able to parry man's attack and continue their existence into the present, though in reduced numbers. The ostrich would certainly have been exterminated but for the turn of fortune that made the feathers from its wings and tail valuable products and led to its domestication. In the hunt the ostrich was not easily overtaken, for its grotesquely small wings were not altogether useless. Held out at the sides as it ran, they acted as sails which helped it to attain extraordinary speed, a fact observed by Xenophon when he marched with Cyrus' army through Arabia and saw the horsemen who tried to run down a bird so outdistanced by it that they gave up the chase. By primitive man it was captured by ruse, led into ambush by the hunter disguised as one of its own kind. There are rock paintings made by the Bushmen of South Africa that illustrate this procedure, and there is a carved rock near Fezzan in the north which possibly records another usage. It represents six ostriches enclosed within a circle. It is possible that the likenesses of these birds were made, as were the portraits of bison and deer on cave walls of Altamira and Font-de-Gaume, in the practice of sympathetic magic and in the interest of the hunt, and are tokens of the widespread belief among primitive peoples that the creation of the image gave the hunter power over the creature portrayed. The ostrich escaped from this slowly tightening noose as well as from the later threat of the bullet, not by any clever work of its own but by a capricious turn in ladies' modes.

Ostrich, emu, rhea, cassowary, and kiwi are all flat-breasted (ratite) birds, as was the moa before them, and consequently their power of flight was never flawless and so all the more easily discarded. *Aepyornis,* the dodo, the solitaire, and the flightless rail, however, with keeled breastbones, were in a sense truants and backsliders. A modern instance of this tendency on the part of some birds to sink into flightlessness in an island retreat is seen in the flightless cormorant of the Galápagos. It is the only flightless member of a family of aquatic birds and is found only in one small area of the archipelago, where it is gradually fading away in spite of the fact that conditions seem to be favorable and that the human being descends on it only at intervals. Its wing has shrunk until, according to Dr. Beebe, it is smaller in proportion to its body than was that of the extinct great auk, and it is not used in any way. In this respect the flightless cormorant differs from other members of its family as well as from the auks, which use their wings as oars in the underwater pursuit of fish.

The lamentable fate of the great auk is the classic example of what can happen to a flourishing flightless species when it is exposed to man's senseless rapacity. It was the largest of a family of Arctic marine birds, expert swimmers and divers, competent fliers, but extremely awkward pedestrians, owing to the posterior attachment of its legs which forced it into an ungainly upright posture. In the course of differentiating itself from its fellows it relinquished flight; but in doing so it did not, like *Hesperornis,* allow its wings to become useless. They helped to propel it as it swam for great distances. Helpless on land, these birds were taken in considerable numbers by the Eskimos, who used their flesh as a stable article of food and their thick plumage for making clothing. This was a thinning of their ranks that they could cope with; but as soon as their colonies on the islands and coastal regions of the North Atlantic were discovered by Europeans a wholesale carnage began. Incredibly wanton and wasteful, it never abated until the last two survivors of what had been an immense population of these inoffensive creatures were killed off the coast of Iceland in 1844.

In the Antarctic, the penguin adopted an aquatic way of life that corresponded to that of the great auk of the north, surrendering the power of flight and bringing to a climax the adaptation of the wing for swimming. After having made the long evolutionary trek from fin to forelimb to wing, the penguin's organ of flight became to all intents a fin again. Since evolutionary processes can never be reversed, it did not retrace its steps to become a true fin, but it underwent adjustments that, as in the case of the seal's flipper, made it one functionally. It became perfectly rigid at wrist and elbow and acquired a thin, flat, broad surface. Its feathers,

Flightless Penguin.

transforming, became short and scalelike with small veins and broad shafts. Wing action is the sole means by which the penguin propels itself through the water, the feet being used only for steering. The penguin still inhabits its outposts, fortunately saved, at least for the time being, from the persecution, if not extinction, which threatened it when a project loomed to institute mass slaughter and convert into soap grease the fat that insulates its body.

It is interesting to speculate on the different approach to an exclusive aquatic existence made, on the one hand, by *Hesperornis* and, on the other, by the great auk and the penguin. *Hesperornis* lost all use of its wings as well as its ability to fly; the others kept theirs and used them as paddles. The explanation offered by Lucas is based on a principle some are now unwilling to accept—that of use and disuse. He thought it likely that if the ancestors of *Hesperornis* equaled it in size—it was about five feet long—their wings were too large to be anything but a hindrance under water.

Swimming could best be accomplished by paddling with the feet and keeping the wings closely packed against the sides to lessen resistance. By the time these wings had dwindled through disuse to a size small enough to make them usable as oars, their muscles were too weak to move them. The only road open was toward further degeneration. The penguin and the great auk, on the other hand, had short wings provided with muscles strong enough to keep them moving as they transferred their allegiance from air to the denser medium.

All in all, the bird and its wing are seldom parted. Flightlessness is an exceptional state; and even when the wing no longer serves the purpose for which it was fashioned it is seldom altogether useless. The underlying framework for which *Archaeopteryx* reached has been handed down to all succeeding generations and kept inviolate by all except a few. Outwardly the wing has lent itself to endless variation.

12

Bird Flight

> O Soul, come back to watch the birds in flight!
>
> —Ch'ü Yüan, *The Great Summons*

Bird flight has always been one of the admitted miracles; and it remains a source of wonder even when the science of aerodynamics undertakes the explanation of the physical laws that govern it, even when modern photographic methods record all phases of the wing in action. Mathematical formulas which set forth the relationships of mass, velocity, resistance, and so on, are all very well in their way. So are the slow-motion picture and the stroboscopic photograph, which disclose unsuspected truths. What eluded even the keen and concentrated observation of Leonardo da Vinci as he tried to follow the flutterings of small birds bought in the Florentine market and released, or as he watched the soaring hawks slowly wheeling over Tuscan hills, is now indelibly fixed on strips of film for all to see. The mystery is to some extent resolved, and yet the delicate blend of the innumerable elements of which each sort of wing is composed, the perfect correlation of form and function, represent processes that are as inexplicable as ever. The way of the eagle can be charted and the wings of the dove can be analyzed; but there is still no graph to plot a curve for the subtly varied and often inscrutable refinements that occur with such endless profusion and complexity to make of each wing a perfect mechanism for a particular purpose.

Nevertheless, the physical forces having to do with flight are now understood. The knowledge of what they are and how they work came gradually and only when man made slow headway in his own attempts to fly. Nothing but failure had come from his first efforts. In these he had concocted flapping appliances with which he sought to counterfeit the action of the bird's wing when he knew as little about its actual structure and the energies it utilized as he did about the properties of the air it mastered. When, centuries later, he took the kite instead of the bird for a model and started to fashion stationary wings, the way opened. By that time a machine was at hand to help him and a motor-driven mechanism could be added to his glider. Then as he experimented with the devices that at last raised him from the ground he began fully to comprehend the nature of the medium into which he was venturing. He learned as the insect and the bird had learned—by actual contact with its forces. Not by conjecture and supposition but by firsthand and tragic experience were its ways revealed and its forces harnessed.

By trial and error he found the way to shape his wings and the blades of revolving propellers to comply with its demands. The ingenious methods he finally evolved seemed at the time to have little in common with those of the bird whose performance he was then able to emulate. Yet strangely enough, in the light of present knowledge, it is clear that the airplane and the bird function in the same way. The chief difference is that the airplane makes use of two separate appliances for the attainment of flight—wings for support and propellers for propulsion—while the bird combines the two functions in a single structure. The inner section of its wing corresponds to the wing of the airplane and supports; the primary feathers of the hand section correspond to its propellers.

As far as man is concerned, flight is still a matter of consciously applied, intensive effort. For the bird, as for the insect and the bat, it is an instinctive art. The bird has been flying so long that its knowledge of its medium is intuitive; its responses to it are automatic. It knows without being told that the air has weight, mass, density, inertia, that it exerts a pressure on every surface it encloses and that this pressure (which by man's measurement is about fourteen and a half pounds to the square inch at sea level) changes with altitude. It senses the air's incessant movement and the strength of the ever-shifting currents that change both direction and velocity in their ceaseless ferment. It takes for granted that horizontal currents near the earth's surface are slowed down by friction and it knows that over land they are far more variable than they are over water where there is no comparable interference and where velocities increase rapidly with altitude. It plays with those horizontal currents that suddenly change into upward-moving masses of air when they bounce off an obstruction and are deflected upward, and it understands the possibilities of other vertical movements of heated air, called thermals, that develop here and there under favorable conditions. The bird has an inborn comprehension of this inconstant medium in which whatever flies must find the energies that lift it and send it on its way. Gliding and soaring, it takes advantage of the ready-made forces. On flapping wings it creates them for itself.

The most obvious of the many extraordinary powers of the bird is its ability to flout gravity, to stay up. Although not at all different from that of the moth or the bat, or more wonderful, this faculty has been the object of far more speculation, probably because the bird can be more easily seen. The human eye, hopelessly inadequate in catching the rapid vibrations of the wings of the insect and the night-flying bat, could more nearly follow the larger and more slowly moving wings of hawk or gull. That the bird's wings flapped generally up and down was clear enough. Their sustaining power, it was reasoned, depended entirely on the force of the beat, on the reaction created by the downward thrust against the air's resistance. While this reasoning seemed to explain flapping flight adequately, the fact that birds often floated about for hours on motionless wings was baffling, to say the least.

Nevertheless, the theory that the reaction to the downward thrust was the sole cause of lift persisted for a long time. It persisted until a long-known principle having to do with the relation between the velocity at which a fluid moves and the pressure it creates was seen to be applicable to air's action on surfaces moving through it. Formulated by the Swiss mathematician Bernoulli about two hundred years ago, this law asserted that the faster a fluid flows the less pressure it exerts round about. This was the clue that revealed the true nature of the forces that keep the bird (or the airplane) in place. It led to the discovery that the resistance of the down-pressed air beneath the wings of the airplane (or bird) accounts for less than a third of the total force that holds it up. The rest of the lift is due to what has been called "negative pressure," a sort of suction produced by faster flowing air over the upper surfaces.

In cross section the supporting area, the inner half, of the bird's wing is streamlined like the wing of the airplane. Its front, or leading edge, is thickened both by the bony framework enclosed in it and by the short feathers that, as a sort of binding, curl back over it and lie smoothly overlapping the lesser secondary coverts of the wing's upper surface. This upper surface is gently convex, sleek, and longer than the concave underside; and as the bird pushes forward, the air stream, dividing to let it through, flows over the polished convex top more rapidly than it does past the shorter hollow interior. Flowing faster, it exerts less pressure there than it does beneath; and the net result of the difference in the rate of flow over the two surfaces is the creation of a partial vacuum over the upper one. This suction, or lessened pressure, can account for as much as seventy-five per cent of the total lift. It, as well as the relatively increased pressure from below, is regulated by the angle at which the wing is held in relation to the air current. This is known as the angle of incidence or angle of attack. Up to a certain point the "negative pressure" increases as the angle of incidence is widened. That is to say, as the wing uptilts, pressure continues to diminish on the upper surface and to increase on the underside. However, there is a limit beyond which the angle of incidence cannot be widened. This is the stalling point. When it is reached, the supporting air stream breaks away from the surface it has been following. Disruptive eddies form;

lift is destroyed. The angle at which the stalling point is reached varies, naturally, with the type of wing. It is said that an airplane produces maximum lift when an angle of about sixteen degrees is reached. Birds do better. A slowly gliding vulture tilts his wings at an estimated angle of twenty-eight.

Widening of the angle of incidence, or angle of attack, is not the only way to increase lift. It is the method necessarily followed by the slow fliers; but a far more effective measure is to augment speed. If speed be doubled, the amount of lift is increased not two- but fourfold. The fast flier, having attained its desired altitude, will then need to decrease the angle of incidence if it wants to keep a level course. The angle at which the wing is held and the rate at which the bird flies are thus interrelated factors in producing lift. The size of the wing also has a bearing on it; everything else being equal, lift will increase in proportion to area. It is a simple matter to compute the amount of resistance met by the uniform and measurable surfaces of the airplane. That encountered by the bird cannot be accurately estimated. Its wings have different textures at different parts of their surface, and these surfaces vary their flexibility and modify their extent. Nevertheless, the underlying principle holds for both. The mathematician definitely asserts that the total amount of resistant force used by the bird to keep itself up varies approximately as the square of its air speed—and by air speed is meant speed in relation to the air, not the rate at which it covers a certain distance relative to the earth below.

Although the bird's wing is an integrated whole of which each part participates to some extent in the work of the other, the hand section is the specialized mechanism that, in flapping flight, propels. The primary feathers that compose it produce, with all the efficacy of revolving propeller blades, the forces that pull and push it onward.

The primary feathers, firm yet resilient, adjustable in both shaft and web, are continuously reshaping themselves during flight, continuously modulating their shapes in response to the resistance of the air. Just as the blade of the airplane's propeller is fashioned with changing curvature, or pitch, from hub to tip, so that it may strike the air with equal force throughout its length, each primary feather in the bird's wing is twisted by the resistance it meets into a comparable mechanism with the same function. The rigid airplane blades move, of course, through a circle. The wing's path is an arc; and the primary feathers automatically reverse their pitch at the end of each stroke and continue to make minor adjustments throughout its course. As a consequence of these reciprocating movements, a forward impulse is produced by the upbeat as well as by the downstroke. The two forces are not of equal power, however, the former being the weaker.

The propulsive power of the hand section of the wing is due to the fact that its feathers are streamlined. An indispensable element of design for all swimming and flying creatures, streamlining plays its vital part in the shape of the bird's body and in the wing as a whole, as well as in the form of the primary feathers. In cross section these repeat the plan of the wing's inner, supporting area: they are slightly convex on the upper surface, concave below, and their front edges are thicker than the rear margins, for the webs on either side of the shaft are never of equal width, as they are in the other flight feathers. The web in front of the shaft is narrower and relatively heavier than the trailing edge. The principle which accounts for the suction formed on the upper surface of the supporting section of the wing (that as velocity of a fluid increases its pressure diminishes) applies with equal relevance to the primary feathers. The air moves more rapidly over their smooth, convex tops than it does over their undersides and, therefore, exerts less pressure. Due to the angle they make, the suction forms in front of the bird instead of above it. Augmented by the positive pressure on the undersides of the feathers, it pulls the wing, and the bird, forward. It is in all respects the equivalent of the force produced by the airplane propeller. The pectoral muscles supply the power.

Modern photography now catches the wing's action in all its phases and reveals unsuspected subtleties, such as the play of individual feathers as they twist and turn at different stages of the stroke and the co-ordinations of the two specialized sections as they so deftly complement each other. In normal flapping flight the wing sweeps through the downbeat fully extended and, at the end of it, a flexing of the wrist inaugurates the upward swing. The whole organ then starts up, the inner half pulling along after it the hand section with primaries partially separated. At the end of the stroke the hand section, in a sudden powerful throb, flaps up and out and resumes the position for the next downward drive. The speed at which the final flip is made is such that in a camera shot in which all other parts are perfectly "stopped," the wing tip often registers as a mere blur. As might be expected, the upbeat requires less time than the downswing.

The direction of the stroke is forward on the downbeat, upward and backward on the return, a fact established by the same E. J. Marey whose study of insect flight produced such interesting results. With a slight variation of the method used in tracing the path of a wasp's wing, he attached bits of white paper to the wing tip of a crow, released it against a black background and obtained a photographic image of the course made by the white tip. It was a series of loops and undulations that swept forward and downward, made a loop at the bottom, and traveled upward and backward until it curved again to make the next descent. This evidence was indisputable. It quite refuted the theory then generally held that birds used their wings as boatmen use oars, pushing backward and downward and making a forward-upward return.

Even Leonardo had been misled. "The birds which fly swiftly, keeping at the same distance from the ground," he wrote, "are in the habit of beating their wings downwards and behind them, downwards to the extent necessary to prevent the bird from descending and behind when they wish to advance with greater speed." Marey's crow, agitated and frightened as it was, made with half a dozen flaps of its wings the first recording of the true trajectory of the bird's wing in flapping flight. Perhaps only in strictly horizontal flight in still air is there an exception to the rule: then the stroke is more nearly up and down.

Interesting side lights are thrown on the nature of the wingbeat when the bird can be observed from above. Then the vertical movements are less obvious, while those of the forward-backward direction are emphasized. A description of the flight of the swan from such a viewpoint has been given by Harald Penrose, who on a flight over the Dorset beach spied two of these great birds far below him. Dropping down until he was about a thousand feet above them and throttling his engine to obtain the slowest speed of which his plane was capable, he was able to follow the swans and observe their slow powerful strokes plainly visible against the deep blue of the water. He observed in *I Flew with the Birds:*

> The root-portions of the wings gave the impression that they had little movement—were, in fact, like an aeroplane's wing—and that propulsion was derived from the stroking tip. Looking intently, it was possible to see that, at the wrist in the plan-form, a distinct angle was formed between outer and inner wing portions, and although there was horizontal movement of the wing as a whole, the greater part of this movement was due to the outer half swinging from the wrist. At the bottom of the downward and forward stroke the primary feathers showed their emarginations very clearly, the wing-tips becoming rounded and blunted—but at the top of the stroke they flexed to more pointed form. In phase with the beats was an indrawing and extension of the wing laterally, due to the method of raising the articulated wing: first the tips were left depressed, whilst the wrist moved forward, and then they were lifted with a flicking and twisting motion, preparatory to the full extension on the down stroke.

On some occasions the bird throws its body into an almost upright position and vibrates its wings more or less horizontally—back and forth instead of vertically. This is the method used by many species in making a sudden take-off, and it is the technique of hovering, when the wing's action is comparable to that of the helicopter. The vigorous movement that is necessary at the commencement of flight moderates once the bird is under way. Often altitude and speed can be maintained with only a slight wave of the hand section, the inner half remaining practically motionless.

The direction of the stroke is, however, only part of the story of the wing's action in flapping flight. Another factor is the angle of attack. Rotation at the shoulder allows the heavy, leading edge to travel in advance of the rear margin, so that in horizontal flight the wing's inner surface, especially that of the supporting area, faces backward a little on the downbeat. The air beneath is pressed downward and backward, and the force of the reaction against this resistance is resolved into two components, one of which contributes to lift, the other to the forward motion.

The speed at which a bird flies is the product of many interrelated factors—the shape of the wing, its size in relation to weight carried, the rate of its beat, the angle of attack. It is to some extent variable, for air speed, the speed which the bird makes in relation to the air, can be very different from the rate at which it covers a certain distance. Moreover, there is a difference between how fast a bird can fly and how fast it naturally does fly under ordinary conditions. However, for every bird there is a speed below which flight is impossible. There is a "minimal velocity" which it must maintain merely to stay up. It must fly fast enough to create lift enough to counteract its weight. From this it follows that, everything else being equal (which it never is), the heavier the bird is the faster it must fly. This is the principle that allowed Harald Penrose to follow the flight of the swans. They were flying at a rate that approximated the lowest speed at which his plane could safely function. He was never able to "keep station" with smaller birds—gulls or lapwings, for instance—except in a helicopter, because they flew too slowly. Using the linear dimensions of the sparrow and the ostrich and the estimated minimal speed of the smaller bird, Sir D'Arcy Thompson, the eminent British scientist, made a theoretical calculation and proved that if the ostrich could fly at all, it would have to do so at the rate of a hundred miles an hour at least. The average minimum speed of birds is supposed to be five meters or sixteen and one-half feet per second.

Shape also helps to determine speed. A long, narrow, flat wing is faster than a broad, cambered one of the same area. "Camber" is the term used to express the arching of the wing—the arching from front to back. It is greatest in the slow fliers and in birds that glide and soar over land. Deprived of the "negative pressure" above that is engendered by speed, the slow-flying bird must obtain lift by increasing the "positive" pressure from below. Like a bellying sail, the wide, arched wing captures the air currents and holds them to satisfy this need. A powerful eddy forms under the fore edge of the cambered wing, which contributes to the forward drive, especially when it is caught in a feather pocket that sometimes opens up in the under-wing coverts.

The relation of the wing's area to the weight carried, its "loading," is still another item to be considered; and it is a curious fact that area does not increase in direct proportion to weight. On the contrary, the wing of the heavier bird is usually relatively smaller than that of the lighter species. It is thus in a sense more efficient than the comparatively larger wing of the smaller bird. This discrepancy is probably caused by the fact that the rear edge of the wing is its least efficient area, disruptive eddies often forming there. In small wings this margin is relatively large in proportion to the total area and so the disturbance is relatively greater. It is, indeed, probable that a number of the smaller birds have more than enough wing for ordinary purposes. This was proved, at least as far as the sparrow was concerned, by J. B. Pettigrew, who trimmed and clipped its wings as well as those of insects in his attempt to learn just how much area was essential for flight. The sparrow, he found, could still fly when its flight feathers were shortened to half their length. It would take very little trimming to ground a bird whose wings had a higher loading or a different shape. A French scientist, M. de Lucy, was the first to formulate the general law that the larger the volant animal is the smaller in proportion are its flying surfaces. In commenting on it Pettigrew expressed himself as being greatly encouraged, "for it shows that the flying surfaces of a large, heavy, powerful flying machine will be comparatively small, and consequently comparatively compact and strong. This," he adds, "is a point of very considerable importance, as the object desiderated in a flying machine is elevating capacity."

It is generally true that the larger the bird is the more difficult flight becomes. The larger it is the more work the wings have to do, yet they have increased in only two dimensions as the body has increased in three. In mathematical terms they have increased as the square of the linear dimensions, while weight has increased as the cube of the linear dimensions. This is the mathematician's explanation of why the larger birds depend less on wing action than on sailing flight (thus taking advantage of the "negative pressure" which helps to sustain them), and why there is a limit beyond which flight is impossible.

Some years ago Earl L. Poole published in *The Auk* (Volume 55, Number 3, 1938) the results of his study of the "Weights and Wing Areas in North American Birds," and the comprehensive table in which his findings are summarized is of extraordinary interest. It reveals the truth of the general rule that there is a "normal diminution in relative wing area with the heavier species," as well as the fact that there are exceptions to it when other factors come into play. The little golden-crowned kinglet, weighing less than six grams, has over fifteen times as much wing per gram as has the heavy loon; a sparrow has more than an eagle. When birds of the same weight are compared, it is found that their wing areas do not necessarily agree unless they have similar habits. The turkey vulture's weight is practically the same as that of the loon (it is only sixteen grams less, according to Poole's data), but it has over three times the wing area of the water bird. It needs more sail, for it floats above its territory slowly on motionless wings, while the loon is a bird of direct flight with rapid wingbeat.

Again, wings of different species may have the same loading, yet differ widely in shape and function. For instance, the loading of the wing of the crow, a little less than two and a half square centimeters per gram, is practically the same as that of the herring gull, and the range of speed of the two birds is about the same; but the crow's wing is broad, with a fair amount of camber and deeply slotted tips—a design suitable for flapping flight over the wide and variable countryside. That of the gull is long, slender, pointed, flattened, designed for gliding over water.

Among the larger birds, the owls seem to be prominent exceptions to the rule that prescribes diminution of area with increased weight, for they have larger wings than other birds of comparative bulk. But owls are silent hunters of the night; and silent flying is the product of wide, pliant, softly fringed flight feathers which strike the air with less force than the stiff primaries of, for instance, a duck. A greater amount of surface is needed to offset the pliancy; and, in addition, the owl's wing must carry the weight of prey.

Among the smaller birds, the ground feeders seem to have a lower ratio than those which feed in the air and use their wings more constantly. Of the one hundred and forty-nine North American species listed, Leach's petrel far outdistances all others in amount of sail. It has about nine and a half square centimeters of wing for each gram's weight. The highest loadings are those of the old squaw duck, the common loon, and the mute swan, where in each case there is only slightly more than half a square centimeter of wing area per gram.

Of all birds the tropical frigate bird has wings that are longer in proportion to bulk than any other; but this does not mean that their relative area is greatest. It is said that for the size of its wing the South American tinamou is about as heavy as a bird can get and still rise, but specific figures are lacking.

In general, the smaller the wing is in relation to the weight carried (the greater its loading), the faster it must beat. The sparrow has a faster wingbeat than the swift, although the latter attains far greater speed. When it comes to mere size, the larger the bird is the slower the wing moves. This is necessarily so, for even if breast muscles were developed sufficiently to do the work that a rapid wingbeat requires, the armbones could not stand the crushing strains. The duck vibrating its wings nine times to the second to the pigeon's eight appears to contradict this precept, but its wings are short enough to bear up under the pressure. On the whole the large bird moves with a slow wingbeat or else depends on gliding and soaring flight.

Each bird, in its perfect adaptation to its way of life, thus seems to be a law unto itself. In each case the shape of the wing, its size, texture, direction and rate of beat, the weight carried, the speed attainable, are integral parts of an equation that as yet no mathematician has formulated. How can the flexibility of a feather be measured, or the degree of its gloss or roughness? Who can appraise the effect of the notched or emarginated edge, the ever-changing curvatures, the imperceptible movement? Who can say how such intricately varied combinations came about? One is ready to agree with Alfred North Whitehead that "all things in nature are equally incredible." "And yet all the while," according to Sir D'Arcy Thompson, "with no loss of wonderment or lack of reverence, do we find ourselves constrained to believe that somehow or other, in dynamical principles and natural law, there lie hidden the steps and stages of physical causation by which the material structure was so shapen to its ends."

13

Take-off and Landing

> We are flying like thistledown, each to a different distance.
>
> —Li Po

Although there is the greatest diversity in avian wings and in the manner of flight, there is one inescapable necessity confronting all birds when they start to fly. By one means or another, every bird at the commencement of flight must attain a velocity greater than that of the air through which it moves. This is a law which sends the boy running across the field with his kite; and it applies with equal force to the taxiing airplane.

As the first would-be human aeronauts discovered, it is one thing to construct an appliance that will glide for a short distance when launched from a height, and it is something else again to devise a way by which the mechanism can lift itself. This was a problem that for a long time presented insuperable difficulties and for the solution of which many looked only to the lighter-than-air craft. There were those who could not account for the bird's knack of overcoming the force of gravity without vesting it with the properties of a balloon, and they proposed a "heated-air theory." The air contained in the bird's body, in its air sacs and hollow bones, they held, was much lighter than the surrounding atmosphere because it was warmer; therefore, it helped the bird to overcome gravitational pull. It did not take much to disprove this idea. The decrease in weight due to the higher temperature of the small amount of air in such cavities is so little that it is not worth considering. The nine air sacs with which birds are normally provided have other purposes. They are auxiliaries of the lungs, carrying reserve oxygen supplies. They probably contribute to temperature control, for birds, like dogs, perspire through their air passages. They contribute also to buoyancy and are of particular service to some water birds, such as the loon, which can deflate itself and all but sink from sight to elude danger. Additional air-filled pockets between the skin and the breast are shock absorbers for the gannet and the pelican. They cushion the impact as these divers crash into the water.

As for aeration of the bones, there is such lack of uniformity, such conflicting evidence even, that it seems safe to infer that it has no direct bearing on flight. In all birds certain bones in the skull are pneumatic, and in most the upper armbone is aerated; but otherwise there is the greatest disparity. Of the good fliers, some have in addition to these many other air-filled bones; others have few or none. All the bones of the albatross except the shoulder blades and one or two others contain air, but in the swallow and the tern even the humerus is solid. In water birds, as a rule, there is little aeration; in the flightless ostrich and its relatives, a great deal. The explanation of these incongruities appears to be that pneumaticity is a structural feature related to size, the bones that are highly pneumatic being of larger girth in proportion to their length than those having little aeration.

As the engineer knows, tubular construction is well adapted for supporting weight and it is equally valuable where bending strains are to be resisted. The principle that makes of the hollow column a reliable prop, that is seen in the stem of the wheat plant and in the reeds, is applied no less to avian needs. Wherever indicated, pneumaticity develops and relieves a bone of excessive weight and endows it with great strength at one and the same time. While the aeration of the bird's frame has nothing to do with flight, strictly speaking, it does considerably lighten its body. The white pelican's twenty-five pounds are borne by a skeleton weighing twenty-three ounces; and the bones of the frigate bird, the most completely pneumatic of all, are said to weigh less than its feathers. Still, no matter how much a bird's specific gravity is lessened by aeration of its bones, there is always weight to be lifted when it starts to fly.

One of the most diverting of all the explanations of the ability of the bird to lift and carry itself through the air was one promulgated by an unidentified theorist who reasoned that since a full-fledged, twenty-pound wild goose loses the power of flight if deprived of its feathers, which weigh about a pound, it is clear that one pound of feathers can pick up and carry nineteen pounds of goose. He explained:

> Now my theory is this, and it applies to all birds. Notice any bird when he suddenly starts to fly, and you will notice a lightning-like quiver of his feathers. I believe that this quiver causes the production of a negative force of magnetism, or some kind of force which pushes the bird from the earth—just the reverse of the loadstone. He then has only to use his wings to propel the body, for the magnetic earth-force does the lifting, and that is all produced by the feathers. If it were not, then the bird ought to fly when divested of his feathers. This is the force which should be looked for; whoever discovers it will make a fortune.

This explanation was a curious mixture of the true and false. The flight feathers do, indeed, help to lift the bird and propel it; their action by manipulating air pressures creates forces which sustain. However, this was not the sort of force the originator of the theory had in mind.

Most birds accomplish the take-off by a quick upward spring into the wind and rapid, vigorous wingbeats. With an expenditure of energy much greater than that put forth at any other time in flight, they try to reach in the shortest possible time the higher levels and the stronger currents where momentum can be maintained or increased with least effort. It has been found that if a pigeon, one of the really strong fliers, be forced to make repeated starts at very short intervals, it will remain on the ground as if exhausted after five or six trials—so great has been its effort. In the first few seconds wings move through their widest arc and at maximum speed. They sometimes snap together over the back on the upstroke, and the whir caused by the rush of air through the flight feathers is always audible.

In a take-off from the ground the broad, rounded wing or the one which, though pointed, has a relatively wide sustaining area has, on the whole, the advantage over the one that is very long, narrow, and tapered. With rapid beats it accomplishes the critical and heroic feat of the initial uplift into the air. The small, rounded, broad wing of the quail, incapable of sustained flight, can be so effectively used that full flight is attained almost the moment the bird leaves the ground.

The upward spring with vigorous flapping is the method of ground species, of all small birds, and of egrets and cranes and other shore birds whose long legs raise them sufficiently from the ground to allow the large wings to swing into action. The dabbling, surface-feeding ducks, such as the mallard, black, pintail, and baldpate, are able to leap up directly from the yielding water of pond or marsh and gain altitude with remarkable dispatch. The primaries of the duck's pointed wing are very stiff and, when in the upward spring the heavy body is thrown almost upright, they take on the helicopter action of the horizontal beat.

The diving ducks of the more open waters—the redhead, goldeneye, old squaw, ringneck, canvasback, and others—are unable to do this, for in adapting them for diving Nature has cast them in a slightly different mold. Their legs are attached farther back on the body, and this shift of weight not only makes them awkward waddlers on land but places an extra burden on the wings in the take-off. Consequently, they must patter over the surface of the water with wings flapping until they gain the momentum that will lift them. Some mergansers, swans, the heavy-bodied coot, the grebes, and loons follow the same procedure. Grebes and loons are even more highly specialized for diving and swimming under water than the diving ducks. Having the legs placed rearward and, in addition, encased to the heel beneath the skin, they strike a more or less erect posture on land from which they are unable to take flight. Completely off balance when they try to walk, they lumber along slowly and awkwardly and, if hurried, tilt forward and flounder to the water on all fours, using wings as forelegs. From the water they take wing only after they flap and patter for some distance into the wind. Once they are up, their short, moderately pointed wings beat rapidly through a small arc and carry them in swift flight.

The guillemot is another diver that rises from the water after the preliminary pattering and on land stands in the typical upright diver's posture, with the entire foot extended on the ground. From this position its short, rounded wings cannot raise it. Thomas Bewick, the English wood engraver and naturalist who produced the illustrations and most of the text for one of the first illustrated manuals of British birds, gives in his *Water Birds* a charming description of a lesser guillemot found stranded among the rocks at Tynemouth. It was brought to him and he made a drawing of it.

> While the drawing was making, it sat under the table trimming its feathers, and appeared perfectly at ease, and not the least alarmed at the peeping curiosity of the children who surrounded it. When this business was finished, it was taken and set down upon an open part of the shore, whence it began to waddle toward the water, with the whole leg and foot extended on the ground; and as soon as it reached its beloved element, it flapped its wings, darted through the surge, dived and disappeared.

In modifying the wing so that it can be used for diving and swimming as well as for flight, Nature was confronted with the problem of reconciling conflicting requirements. Under water the wing's sustaining powers are not needed, and yet when it is used as an oar for swimming it meets far more resistance than it does in the air. When it is not so used, when webbed feet take over the entire job of propulsion, it is carried along as so much baggage. If it is large and heavy, it may be a positive handicap. The short wing with either rounded or tapered tip, and, above all, flattened and equipped with strong primaries, is the logical answer to a swimmer's needs; but these very qualities which make of it a good oar subtract from its lifting power, especially when they are combined with that other characteristic of the true diver, the posterior position of the legs.

The great auk and the penguin evidently found aquatic life so satisfactory that they gave up trying to keep their wings doing double duty and lost the power of flight. Other swimmers and divers have struggled to keep their aerial franchise and by rapid wingbeat compensate for the relatively small wing area. They fly well once they are under way. Some of them—murres, puffins, dovekies—have solved the difficult problem of the take-off from land by establishing their colonies on cliffs and ledges along the coast, from which they launch themselves into space and glide until they gain the necessary momentum.

The diving petrels, small oceanic birds of the southern hemisphere, have little or no difficulty in the take-off. They are able to rise from the water after a preliminary pattering over the surface and fly swiftly for a moderate distance. Differing in many ways from other members of their order, they have a superficial resemblance to the little auk and the dovekie of northern seas. Their wings are comparatively short and are used effectively for swimming and diving. It has been claimed for these birds that they have developed underwater flight as far as it is possible to do so without sacrificing aerial flight.

Yet just as some birds have learned to crack seeds without having the specialized bill of the true "seed eater," so others can dive and even swim under water without having the wing form of the typical "diver." The brown pelican and the gannet, for instance, dive for their living and are able to do so with great wings that are wonderful organs of flight. The former dives with the wind, its long, broad, slotted wings partly flexed and set at the proper angle. It plunges beneath the surface with a great splash and on emerging takes wing again into the wind. The gannet's wings are long, slender, tapered, and its dives are accomplished in much the same way.

On account of its prowess in both sky and sea, the gannet is often referred to as a master of two elements. Its prestige vanishes on land. Like murres and puffins it congregates on rocky ledges and for the same reason. Like them, it is unable to rise from a flat surface unless there is considerable wind, and it hurls itself headlong into space to begin its flight. Its inability to rise, however, does not result from an awkward stance and wings that are too short. On the contrary, its wings are too long. They are too long in relation to its height, for the stout legs, though placed near the center of its body, rather like the gull's, are too short to produce the upward spring needed for the wings (six feet between the tips) to function. Plunging from a cliff, it gets under way and then it travels in strong and long-sustained flights along the coast and out toward the open sea, its wingbeats alternating with periods of sailing and with spectacular dives. Grebes, loons, and ducks dive from the surface, cormorants often from low perches, but gannets start from heights that vary and seem to be determined by the depth at which the fish are swimming. Sometimes from near the surface, sometimes with a hundred-foot vertical drop, the white forms strike the water with the black-tipped wings partly flexed, and they disappear to a depth of forty feet or more, the wings helping to propel them.

In his Labrador journal Audubon tells of throwing live fish from his boat in order to observe the actions of the birds closely. "Two fluttered on top of the water for twenty yards or so, then dove, and did not rise again for fully a hundred yards from the vessel. The third went in head-foremost, like a man diving, and swam *under the water* so smoothly and so rapidly that it looked like a fish with wings."

On regaining the surface, gannets take wing again with no difficulty. This extraordinary display of strength and skill is possible, however, only under favorable conditions. The prerequisite, the indispensible requirement, is wind.

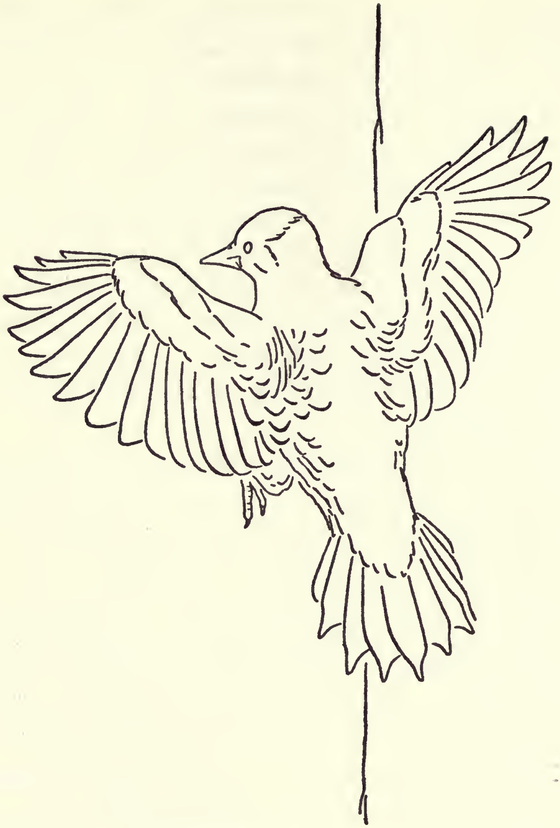
The tragic story of what can happen when the wind suddenly fails is to be found in *The Land's End* by W. H. Hudson. The incident happened at Sennen Cove in Cornwall many years before Hudson's sojourn there and was told to him by one who had been a witness. It was to the effect that a large number of gannets, intent on following a shoal, came gradually in toward land in a strong wind which was blowing into the bay. They became helpless prisoners of the water when the gale very suddenly died away and was followed by perfect calm. The birds on the surface of the water could not rise, and their struggles to do so were unheeded by those overhead. One by one these also descended still in pursuit of the fish until, at last, all were down. The townspeople stood about and watched as they were borne slowly, inexorably toward land by the still incoming waves. "Then the waves began to fling them out on the flat sandy beach. . . . There was no escape for the birds, for their wings could not lift them and they were slaughtered without mercy. . . ."

The albatross that can outride the hurricane and sail for days on end with no visible movement of the wings is in the same predicament when it is caught on becalmed waters or in obstructed quarters such as a boat deck where there is no runway.

The frigate, or man-of-war, bird, whose wings are of greater extent in relation to its bulk than those of any other bird, and whose flight has been described by Arthur H. Howell as "perhaps the most marvelous example of perfect adjustment to aerial conditions to be seen in the bird world," has great difficulty rising from its nest. It can, once up, turn to account the faintest breeze, but its legs are so short and weak, its wings so long, that a take-off from a bush or tree is a precarious undertaking, especially if there is no wind. It may become hopelessly entangled in the branches and perish.

The condor, mightiest of flying land birds, also needs space for its take-off from level ground. Unless it can have room enough to run and gain impetus it is forever grounded. The Indians of Brazil still capture these majestic birds by the long-established custom of luring them with bait into enclosed areas from which, though the whole sky opens overhead, they are powerless to escape.

The widespread, powerful wings of the great gliders and soarers thus have their limitations; and every other wing, specialized for a particular task, carries with it the liabilities that are the natural



Woodpecker Landing.

accompaniment of its assets. At the start of flight, the condor and the albatross are faced with dilemmas which are unknown to the lark or the robin. Many of the smaller birds, however, intentionally or not, conserve their energy by habitually alighting on wires and branches from which the take-off is easy.

At the end of every flight comes a landing, when the bird drops down out of the air and re-establishes its contact with the earth and its fixtures. It drops down into dense foliage, or onto the ground, or onto water, or wherever else its errand has taken it, deftly and unerringly. The pewee regains its lookout on a slender twig in a flash; the gannet heads straight into the cliff and makes a split-second landing on its ledge; the crane and heron come in slowly and alight amid branches or onto the shore so gently that their long legs sustain no injury. These are processes that call for skills as fine in their way as those needed for the take-off.

The bird comes in for a landing with wings set at the proper angle for losing altitude at the desired rate, and it glides until, having reached the selected spot, it uptilts its body, thrusts out its feet, and settles down. In the final gesture as the body rears backward, the wings make so wide an angle of incidence that lift is destroyed; and at the same time they present more of their under surface to the resisting air to increase "drag." Drag is that part of the total resistance met by the wing as it pushes through the air which hinders its progress in the direction of flight. Like lift, it varies with the shape of the wing, with its area and with speed. As the bird lands with its wings slanted upward at a wide angle, it acts as a brake. The effect is the same as that produced when flaps on the rear edges of the airplane wings are lowered for the landing.

For the slow landing the bird settles with wings beating back and forth horizontally, with the helicopter action which maintains lift and eases the shock as the feet find their resting place. A different method still is that called by John H. Storer the "reversed propeller action," when the primaries are turned on the downstroke in such a way that the pressure from below, instead of twisting them into propeller blades, bends them so that they strike the air flatly, a position in which they meet increased resistance and so act as brakes.

The tail also acts as a brake when it is lowered and spread. Since, under the control of powerful muscles, it may be lifted or depressed, spread or furled, and rotated even to a position at right angles to the body, it is, in addition to being a brake, an important agent in producing lift and in steering. Wings also help to steer, either by a change in the angle of attack or by a change in the rate of their vibration. By these means the bird can equalize pressures for the sake of maintaining its balance. It can increase the lift of one wing and decrease that of the other by techniques that are comparable to those employed by the airplane pilot as he manipulates the ailerons at the rear edges of his wings. By the faster beat of one wing it drives that side forward; by flexing both wings, and thus altering the center of gravity, it modifies its direction up or down.

14

Flapping Flight

My highway is unfeatured air. . . .

—William Ellery Channing, *The Earth*

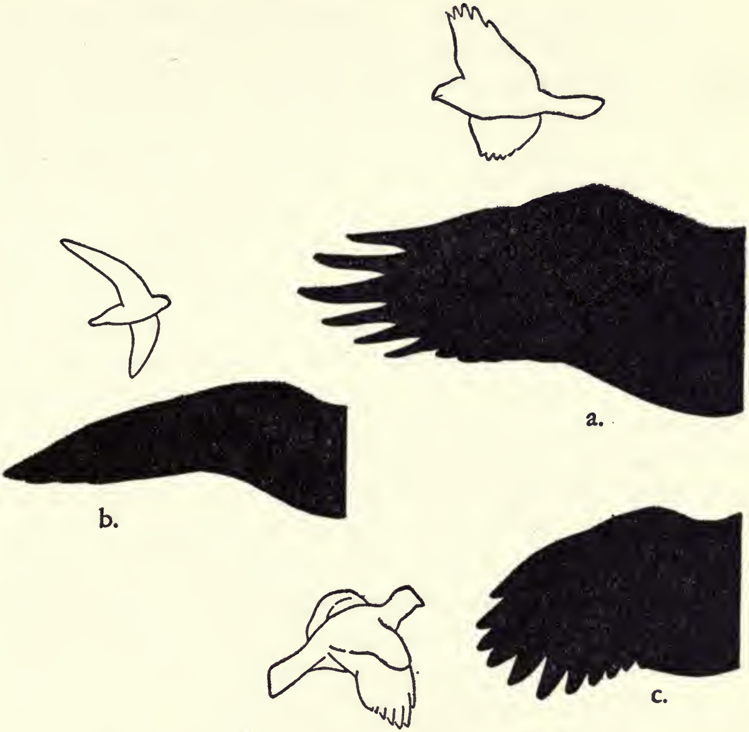
The wing's outward form, as well as its use, often varies even among closely allied birds. Conversely, wings of unrelated groups may resemble one another if they are used in the same way. In the span of a hundred and thirty million years the bird has had plenty of time and opportunity to undergo unlimited diversification; and its evolutionary paths, fanning out through time and space, have by no means continued uniformly and undeviatingly in any given direction. They have branched this way and that, crossed and recrossed in response to the fluctuating factors of environment. A dearth of customary food, increase of competition, multiplication of enemies might force the group subjected to their rigors to experiment with other than the usual ways of keeping alive. Abundance of food of a given sort or some other favorable influence, on the other hand, might draw unrelated species into similar habits.

The families that now make up the order Falconiformes, the vultures, eagles, hawks—birds which betray their kinship in hooked beak, raptorial foot, and many other characters—show a wide variety of habits. Vultures are scavengers that assiduously scan large areas in slow circlings of gliding and soaring flight. The condor and the bald eagle also pick up refuse, but the former searches for it while coasting over mountainsides; the latter watches the beach for what the sea rejects. The osprey in a splendid dive snatches live, surface-feeding fish from lake or ocean inlet. The gyrfalcon hunts from a great height and plunges in a terrific burst of speed to strike its living quarry in mid-air. The marsh hawk flaps low over moist meadows and looks for mice and frogs. Other hawks idle above open country, after the manner of vultures, but peer below for rodents. Still others frequent wooded tracts and give chase to smaller birds. The kestrel from a lookout on a telegraph wire drops on a grasshopper.

On the other hand, birds of different lineage share the same habitat and meet in the forest or in the field, or on marsh, or shore, or open sea, where, within each population, specialization averts the dangers inherent in too keen a rivalry. Even those that agree in a general way on the choice of food seek it in different zones and with definite predilections. Most woodpeckers probe for larvae in tree trunks; creepers find them in the bark; warblers, among the leaves. Swallows, flycatchers, whippoorwills, and nighthawks take insects from different regions of the air; thrushes rake the forest floor; larks hunt amid the stubble; plovers scour the beach. Walking or hopping, climbing, wading, swimming, or diving, each species fills a particular spot in Nature's great mosaic.

In each and every case the wings, correlated with all the other physical attributes, take the form best suited for the duties put on them. To function successfully through devious passageways in the woodland or in undergrowth, they must be adapted for adroit manipulation in close quarters no matter to whom they belong. Out in the open unobstructed highways they are cast for speed or endurance, with further consideration of the type of air current each will encounter. In other words, each wing assumes the form that provides the sort of flight that most appropriately fits the need of its owner. For some this means flapping and fluttering through lanes and bypaths; for others, soaring and gliding out into the great free expanses above land or sea.

While it is quite impossible to fit the wings of birds too precisely into neat categories based either on their shapes or the habits



Wing Types: a. soaring (hawk) ; b. speed (swift) ;
c. quick escape (grouse, etc.).

of their masters, it is usual and convenient to admit several main types: the rounded wing built for maneuverability; the long, pointed one adapted for speed; what Coues called the "ample" wing—long, broad, square- or round-tipped, suited for slow soaring flight; and, lastly, the long, narrow, flat, tapered wing of the glider. Clear-cut and obvious as these types are when fully expressed in the partridge, the swift, the eagle, and the gull, they merge into one another in every possible combination and degree.

Generally speaking, the short, blunt wing is the one best suited for short-distance flying in close quarters where maneuverability is the prime requisite. In a reedy marsh or in dense undergrowth, in the cramped byways of the forest, or under water, the long, pointed wing is obviously a disadvantage. So the rail and the limpkin find themselves appropriately provided with short, rounded organs of flight, and they flutter off for short distances when flushed from their lodgings among the cattails, settling down again into them as soon as possible. On wings that are broad, rounded, and rather longer in proportion, the bittern weaves through the rank growth of the marsh in the same way. On short, round wings the ground-feeding woodcock, quail, and grouse scurry into cover; the catbird and the thrasher dodge through tangles of vine and shrubbery; the jay and the cuckoo slip through the green labyrinths of the trees. The towhee, cardinal, whippoorwill, titmouse, chickadee, creeper, wren for one reason or another find the rounded tip to their advantage, and so do the woodland owls. It is the choice of the great-crested flycatcher and of both the sharp-shinned and the Cooper's hawk. The flycatcher waits at a strategic station in the tree until it can make a quick sally and pick its insect out of the air; the accipitrine hawks from the same sort of screened lookout await their victim and dart through the forest in pursuit. To say that these wings belong together in the same loosely knit category does not mean that they are alike in all respects. They differ in degree of bluntness, in the proportion of length to breadth, in amount of camber, and in other ways; but they are all relatively short in relation to the length of body and they are more or less blunted at the tips.

An interesting example of the type is found in the wings of the dipper or water ouzel. Small, thrushlike, resembling an overgrown wren, it lives on aquatic insects, and searches for them wading in the beds of rapid mountain streams. Its wings are short, rounded, and deeply concave; and they work equally well when, in its curious adaptation to aquatic life, it flies beneath the surface of the water or when, emerging, it immediately takes off for its nest in a cranny behind a waterfall.

The road runner or "chaparral cock," of our Western states seems to contradict the rule which links the short, rounded wing to the restricted passage. A relative of the cuckoo, its wing conforms to the design that is a family character; yet, far from edging through foliage, it sprints over the ground in open country. Essentially a runner, it makes only short flights when flushed from the occasional tangles which provide its shelter. Nevertheless, in spite of this apparent inconsistency, its wings are appropriately used. Held out at the sides as it runs, they act as sails and, like those of the other great avian runner, the ostrich, help it to cover the ground at great speed.

In such ways do adaptive measures take surprising and delightful turns; and their endlessly varied products are constant reminders of the intricacies of life processes and the futility of trying to reduce them to strict tabulation.

The short, rounded wing changes by degrees into one that is tapered, as the primary feathers lengthen and vary their lengths in relation to one another. The tip may be formed by the third primary, by the second, by the first, or by two feathers of the same length. There are all degrees of acuteness and many ways in which the hand section varies its relationship with the rest of the wing.

By and large, wings tend to sharpen as the need to cover longer distances rapidly replaces that of maneuverability. When a bird's chief activity is staged on the floor of open woodland or in clearings, when it nests in the forest's canopy or along its border or in hedgerows but makes frequent excursions into open territory, the pointed wing appears. Out in the great open spaces of field and shore it predominates. So the ground-feeding wood thrush and robin, the starling and the grackle have tapered wings. In the tanager, oriole, waxwing, they are narrowed at the tips; and the same is true of pigeon, dove, and crow, although when the crow and its larger kinsman, the raven, cruise deliberately toward their feeding grounds the notched primaries form slots and disguise the actual shape. Ducking into leafage for protection but ranging back and forth through exposed tracts, the goldfinch and bunting, bluebird and field sparrow dip and flutter on pointed pinions. In meadow and field, bobolink and redwing, horned lark and killdeer need the same design, yet the terrestrial meadow lark, which habitually makes only short flights and stays close to dense low coverage, slips in and out of its abode on wings that are short and blunt.

Above the fields and pasture lands the martin cruises, and other members of the swallow family skim the surface of ponds, lakes, and lowlands, all pursuing insects on the wing. Their organs of flight are not only pointed but also long and narrow. Moreover, the first primary equals or exceeds in length the second, and the remaining seven (there are in swallows only nine in all) succeed one another in a rapidly graduated series, the ninth being only half as long as the first. The secondary feathers also are short, so that the wing as a unit is exceedingly long for its width. It has what the airplane designer calls a high aspect ratio. It is thin, moreover, and acute, and somewhat falcate. It takes charge of all locomotion, for the feet, though formed for perching, are dwarfed and incapable of any kind of progression on the ground.

Terns are often called sea swallows. They are not members of the swallow family, but they act like swallows, pursuing insects over the sea or dipping a small fish from the surface, with the same mercurial, kaleidoscopic flight. Their wings are acutely pointed. The oceanic petrels, shearwaters, and fulmers have wings that are long and tapered; those of sandpipers and plovers and other shore birds are pointed at the tips though wider where they are joined to the body. The extent to which some of these wings are adapted for speed and long-distance flight can be judged by their performances. The arctic tern, breeding in the Arctic Circle, spending the winter months in the Antarctic, traverses eleven thousand miles twice a year in the longest migration route of any bird. Its record is almost equaled by the Wilson's petrel, which, reversing the schedule, nests in the Antarctic and returns north in the summer. The golden plover has been accredited with the ability to cover the twenty-five hundred or three thousand miles of its migratory flight over the ocean nonstop.

The swift, which bears such a close superficial resemblance to the swallow but to which it is not allied, keeps almost continuously on the wing during its waking hours, for it cannot perch. Its feet are useless except for clinging to the perpendicular surfaces where nests are attached; it cannot walk or hop or alight on any branch or wire. But as if in compensation for the cancellation of all its terrestrial contracts, it is able to flitter from dawn till twilight in unrestricted areas high overhead, twittering in what looks like joyous abandon, with wings now flickering in quick pulsations, now stretched in dark crescents against the sky. In the swift's wing the emphasis is on the hand section, from which the primaries grow long and stiff. The secondaries are few in number. It is a slender, flat, stiff, pointed wing; and a very deep-keeled breastbone provides for huge muscles that pull it down ten times to the second.

This rate is lower than that of the sparrow, which Marey determined to be thirteen strokes to the second, yet by its means the swift, living up to its name, has become the fastest of all birds. Its normal cruising speed of seventy miles an hour can be increased to two hundred if need be. Although there is not yet complete acceptance of the opinion, some observers are convinced that the swift often beats its wings alternately; and this could account for its ability to make the fitful, instantaneous changes in its course required to match the capricious flight of its prey. The accelerated beat of one wing and the use of the tail as a rudder is the usual method of all birds in making a change of course; but in the swift's case, the tail, modified into a stiff, short prop (a support for it as it clings to its wall or cliff), is useless as a rudder. All steering devolves on its wings, which might, as a consequence, so need to accentuate the changes in their respective rates of vibration that they would at times beat alternately.

The extreme development of the hand section of the wing has been made by the smallest of all birds, the swift's diminutive cousin, the hummingbird. Extremely shortened in the forearm, its wing is practically all propeller. It too has a very deep-keeled, entire breastbone, to which are attached powerful flight muscles; and the swivel action of the shoulder joint, often compared to that of the fly, enables it to adjust the angle of attack so adroitly that it can fly in all directions. It can hover before the nectar-bearing blossom. It can back off, rise perpendicularly, descend, move sideways, dart away to distant prospects, and come to an instantaneous halt before the new objective. The tail, of course, plays its part in these astounding performances; but the wing action is the real source of its power. The most wonderful feat of all, perhaps, is the "pendulum" courtship flight of the male rubythroat. In this ecstatic exhibition before the object of its choice, it swings from side to side as if suspended by an invisible cord, describing an arc of which the radius may be only a few feet or forty. Sometimes the path rises vertically at either side, U-shaped, and, again, it may rise higher at one side than on the other. The oscillations, two or three or twenty in number, are accomplished at great speed.

The rate of the hummingbird's wingbeat has been the object of much study and speculation. It has been estimated at about fifty-eight to the second, a rate slower than that of its namesake, the hummingbird moth, which Marey computed at eighty-five. Those who have matched the hum with the tone of a vibrating violin string believe that it approaches two hundred, a frequency comparable to that of the wings of the bee. In their study of western hummingbirds Harold F. Edgerton, R. J. Niedrach, and Walker Van Riper concluded that the wings of the male broad-tailed hummingbird had different rates of vibration at different moments in its flight. They vibrated about fifty-five times per second when it hovered, at which time there was little sound. In level flight the rate rose to seventy-five or more and the hum was then distinctly audible. In its "dive-bombing" courtship display, the sound became loudest and the rate of vibration reached two hundred beats per second. This sound, described as a "rattling whistle," is evidently produced by the rush of air through slots made by the narrowed tips of the two outermost primaries. The wings of the female of this species have no notched feathers at their tips, and they make only a moderate hum.

At even their lowest rate of vibration the wings of the hummers beat far more rapidly than those of any other bird—at a rate that would be impossible for a larger creature. And it is on the rate of vibration and the angle, of course, that their wonderful powers depend. As far as loading is concerned, the wings of the rubythroat are as heavily burdened as those of the rose-breasted grosbeak. If a rubythroat be placed in one scale pan, its weight will be balanced by a penny in the other; it weighs three grams, and, according to Poole's figures, this load is carried by a total wing area of about twelve and a half square centimeters. There are, therefore, about four and one-sixth square centimeters of wing for each gram, and this is the approximate wing loading of the larger bird.

One might suppose that, since the upper arm is so abbreviated, the usual supporting area being reduced to six short secondary feathers, this wing would be incapable of sustained flight. Yet hummingbirds undertake migratory journeys with what appears to be as much assurance as any other bird. Each autumn the wings of the rubythroat, only about four and a half inches from tip to tip, carry some individuals nonstop out over the Gulf of Mexico five hundred miles to Yucatan or over the Atlantic six hundred miles to Bermuda. On the return trip in the spring they deliver the intrepid mites to their northern destinations on a definite schedule, which, in the Ohio Valley, synchronizes their arrival with the first opening of the columbine. The cruising speed of the rubythroat is supposed to be from forty-five to fifty-five miles an hour. This rate is about that of a duck, a fact which seems to contradict the law that the bulkier a bird is the faster it must fly. But it does not. For the hummingbird does not have to fly forty-five miles an hour to maintain altitude. It does not have to make any headway at all to do so: like the moth and the bee, it can hang in the air poised and motionless indefinitely.

Many birds can hover momentarily and some do so for longer periods under the right conditions. The kingfisher, the gull, and the tern, among others, pause in mid-air fluttering in supporting air currents. The sparrow hawk often halts its flight for a considerable length of time to scrutinize the ground below, and in doing so it either faces into the wind or takes advantage of updrafts deflected from a building or other surface. The hummingbird, on the other hand, with body uptilted, hovers when and where, and for as long a time, as it pleases. The blades of its propellers vibrating horizontally duplicate the action of the helicopter and create the forces that sustain it, forces whose strength can be judged by the trembling foliage near by; for a foot or more below the visited blossom the leaves of a columbine will be set aquiver in response.

All of these birds—round-winged woodland dwellers, birds of the fields and borderlands, pointed-winged swallows, swifts, terns, heavy-bodied waterfowl, owls, accipitrine hawks, and many others depend on flapping flight or on a combination of flapping and short sails. The nature of the continuous beat, determined as it is by so many factors, may be short and rapid, long and slow, steady or labored; and when it is interrupted by periods of sailing, other flight patterns develop. A rhythmic, undulating line, characteristic of finches, is particularly obvious in the goldfinch. The nuthatch, titmouse, and chickadee rise and fall in a similar fashion but with different timings. Woodpeckers dip through the air, alternately flapping and closing their wings. The bluebird with a curious gesture, indescribable and lightning-fast, seems to feel out its way.

The dive-bombing flight of the broad-tailed hummingbird, made with wings vibrating at astonishing speed, has its counterpart in the antics of the nighthawk, which in summer twilight takes up the pursuit of high-flying insects and from time to time plunges in what is also thought to be courtship display. But in this case the pointed wings do not vibrate. They are held slightly flexed and motionless until, at the end of the dive, they open. Then the sudden rush of air through the primaries produces the booming sound so distinctive of the nighthawk's flight.

The greatest of all aerial dives are those made by the falcons, the speediest of all birds of prey. The wings of the falcon are long, acutely pointed, but wide at their attachment to the body. The flight feathers are stiff, straight, and gently tapered. The wing tip is very strong, the first three or four primaries being of almost equal length, although the second is normally the longest. These are wings combining speed with power, qualities evoked by their duties, for instead of overtaking its prey in direct chase, the falcon assaults it from above. It ranges over open country; with strong, quick wingbeats it mounts above its quarry and, plunging with wing flexed, dispatches it with a single blow. The remarkable eye-sight, the courage, strength, and speed, possessed by all members of the family in greater or less degree, are concentrated in the peregrine falcon and its American equivalent, the duck hawk. In its aerial dives, or in emergencies, this bird attains a speed that almost equals the maximum rate of the swift, and in its version of dive-bombing it gives the greatest of all exhibitions of raptorial flight.

15

The Art of Falconry

A course precipitous, of dizzy speed,
  Suspending thought and breath. . . .
—PERCY BYSSHE SHELLEY, *The Revolt of Islam*

THE superb wing power developed by many raptorial birds in their struggle for life, and by falcons especially, was no doubt from the very first eyed with envy by the human hunter. The dramatic spectacle of the sudden, deadly attack through the immeasurable expanse of open sky must have stirred him deeply. He did not rest until he had turned it to his own account. At first as a means of helping him secure food for his own survival, and later as a way of satisfying his craving to kill for the sake of killing, the practice of training captive birds for the hunt arose.

The encyclopedic pages of Pliny contain the statement: "In that part of Thrace which lies above Amphipolis, men and hawks go in pursuit of prey, in a sort of partnership as it were: for while the men drive the birds from out the woods and reed-beds, the hawks bring them down as they fly; and after they have taken the game, the fowlers share it with them." This is one of the earliest Western comments on the practice, but more than seven hundred years before it was written a pictorial record had been made on the walls of Sargon's palace at Khorsabad, which suggests that what had begun as a utilitarian measure had in the East become a royal pastime. There the Assyrian sculptor carved in relief a hunting scene in which a youthful prince brings down his game with bow and arrow while an attendant precedes him through the forest with what is evidently a hawk on his fist. Even before that, Egyptian works of art gave evidence of the same exploitation of the splendid powers of flight and legitimate habits of birds of prey.

Indeed the "art of falconry," a product of the East, originated, as far as one can tell, about two thousand years before our era—in China, perhaps, or in Persia. Inevitably it spread westward. Unknown to the ancient Greeks as a diversion, it had by the ninth century become a general practice in western Europe and had crossed the channel into Saxon England. Given impetus by returning crusaders, it reached the height of its vogue during the Middle Ages, when it was elaborated into a highly complex system, with code and vocabulary all its own.

The birds used were divided into two main catagories, "noble" and "ignoble," and were further graded into a hierarchy as rigid as that of the masters on whose fists they sat and to whom they were assigned according to their respective ranks. The European code, as recorded in the fifteenth-century *Boke of St. Albans,* assigned the eagle to an emperor. This was the golden eagle, King of Birds, from the earliest time the symbol of majesty. The king had his gyrfalcon; the prince, his falcon gentle; the earl, his peregrine. Other species were allotted to duke, baron, knight, and squire. The yeoman used the goshawk. The sparrow hawk was granted to the priest, although when a member of the clergy was of noble birth he was allowed the bird that befitted his rank. "You may know a gentleman," went an old Welsh saying, "by his hawk, horse, and greyhound." The little merlin was reserved for the use of ladies, and the kestrel was flown by the knaves. In all cases the female bird, larger than the male by about a third, was the more highly prized.

Since it was only by close association with its master that a bird could learn to know his call and to obey him, it often became a companion and a toy as well as a symbol of rank or gentility. Perched on his left wrist (in the East hawks were carried on the right hand), it shared in his activities. The knight seldom rode

Hooded Falcon.

abroad without his falcon. It went on longer journeys, as can be seen in the Bayeux tapestry, where Harold is shown setting out for Normandy with hawk on hand. It was often part of the crusader's train as he started off on his interminable trek; and we are told that Philip Augustus, having lost a precious white gyrfalcon at the siege of Acre, offered high ransom for its recovery. On the tombs of those who encountered death not on the field of battle but unconventionally in peaceful pursuits, a hawk might find a place, along with a greyhound, as fitting accessory to the recumbent effigy. It would be no stranger to the diffused light and stale air (how different from that of its own immaculate sphere!) of the Romanesque or Gothic edifice, where during life it had like as not accompanied its master even to the observance of religious rites. In the account book of Nicholas de Litlington, Abbot of Westminster, for the year 1368, there is listed the expenditure of six pence for a waxen image of a falcon offered for the recovery of a sick bird. A few years later the Bishop of Durham ordered all the clergy of his diocese to proclaim the sentence of excommunication against those who had stolen a cherished falcon from his friend Sir Philip Neville unless they returned it within ten days.

The gyrfalcon, largest of the true falcons, captured in its northern haunts—Iceland, Greenland, Scandinavia—and trained in royal mews, was frequently bestowed in kingly munificence as a mark of royal favor. The chronicler of the *Chanson de Roland* lists among the presents sent by the Saracens to Charlemagne bears, lions, greyhounds, camels, and *"mille autours qui ont passé la mue."* The *autour* was the goshawk, a species of great repute in the East, where it was trained and used far more extensively than in Europe. After the first molt, young birds were much more valuable than before.

From Chaucer to Shakespeare English literature is replete with references to "hawking"; and the custom was mirrored in other works of art wherever it flourished. Among the sculptured reliefs on the Portal of the Virgin at Notre Dame, in the series representing the signs of the zodiac and the human activities that mark their round, a youth with hawk on wrist is associated with the twins of Gemini. It is in the month of August in the *Très Riches Heures du Duc de Berry* that a hawking party sets out. With the Château d'Etampes and the placid banks of a gently flowing stream for the background, the gentlemen and ladies mounted on their palfreys are shown. Each holds his hawk and a falconer precedes them on foot with two more birds and the decoy hanging from his belt. In millefleurs tapestries the huntsman feeding his hawk or the nobleman about to start the day's sport are as much at home among the foxgloves and the daisies as the youthful swain or the lady at her dulcimer; and in that famous fabric of the *Lady and the Unicorn* series in the Cluny museum, where the cryptic legend *"A mon seul désir"* encircles the top of the tent in the center of the composition, a noble white gyrfalcon stoops to a crane.

In Italy there is pictorial evidence of the same sort, as in Orcagna's war-devastated fresco in the Campo Santo, where two members of the carefree, youthful party who come suddenly upon the mementos of death and recoil in horror hold hooded falcons, and a third, a lady, turns to her unhooded bird, an eagle, as if to restrain it. Benozzo Gozzoli, representing the journey of the Magi in terms of a procession of the Medici princes and their retinue, placed them against a background where a hunt is in progress and not only dogs and huntsmen pursue the stag, but winged predators overtake their prey. In Gentile da Fabriano's *Adoration of the Magi,* riders with birds on their wrists appear in the distant section of the winding procession. Holbein introduced a hooded falcon into the eighth woodcut of his *Dance of Death,* and a portrait of Robert Cheseman by him represents this gentleman with his stately bird. Persian miniatures, Japanese color prints, and Mogul paintings reflect the widespread appeal of the custom in the Orient. There is a portrait miniature of the great Shah Jehan seated with his hawk on wrist.

In different parts of the world the species of hawks commonly used naturally varied with the locality, but everywhere they were sharply divided into two main groups. The basis of the separation was the length and sharpness of the wing. There were the long-winged noble hawks and the short-winged ignoble species. In the East the former were called the "dark-eyed" hawks because the irises of their keen eyes are a deep rich brown. These were the birds that modern classification recognizes as the "true" falcons. Their wings are long and acutely pointed, with the second primary the longest of all or else equaling in length the third. In England they included the gyrfalcon, the peregrine, the lanner (the equivalent of our prairie falcon), the sacre or saker (a desert falcon), the hobby, the kestrel (similar to our sparrow hawk), and the merlin (our pigeon hawk). The wing of the little merlin, flown by ladies for the taking of larks, deviated slightly from those of the other falcons: it was pointed by the third, not the second, primary.

Of the short-winged species, the chief were the goshawk, the sparrow hawk (equivalent to our sharp-shinned hawk), the kite, and the buzzard. This English "buzzard" was not the bird to which we have wrongfully given that name: it was not a vulture. It was a "true" hawk related to our red-shouldered, red-tailed, and rough-legged hawks of the genus *Buteo*. In the short-winged birds, the organ of flight was wide in proportion to its length and the tips were rounded, the fourth primary being the longest. Short-winged hawks were seldom hooded. They were flown from the hand, whereas long-winged hawks were "flown from the hood." The hood was a close-fitting cap and its purpose was to control the excitable falcon and keep it quiet until the prey was sighted. Since it is the nature of the short-winged hawks to sit quietly in wait for their prey, it was easy to teach them to consider their masters' fists as their stations, and they were hooded only during periods of training or, perhaps, while traveling.

As the wings of the two groups differed, so did the nature of the "stoop" made by them. Never attacking a victim resting on the ground, never "binding to" it, the true falcons hunted through the immensities of the deep and boundless sky, and dispatched their prey in full flight by one decisive blow from the half-closed talons. Mounting above it to whatever height was necessary, they circled into the position from which they could make the terrific, headlong plunge. If they missed, they repeated the climb and the attack. Of all the falcons, the peregrine was and still is the most widely distributed, and in it are epitomized the qualities associated with the noble tribe—courage, teachability, speed, power. Its American counterpart, the duck hawk, is said to be able to overtake any other bird in direct flight, with the possible exception of the chimney swift, and, in the words of E. H. Forbush, gives "one of the most wonderful exhibitions of speed and command of the air" of any bird.

The long-winged hawks hunted only in open country, each sort being more or less specialized to take a particular quarry, but the short-winged hawks could be flown over more restricted terrain, even in woodland, for low-flying or ground species. Overtaking the quarry in direct pursuit, they held to it either in the air or on the ground. They were, on the whole, slower, less persevering and less courageous than the falcons, yet the largest of them, the goshawk, was both brave and powerful. It had all the qualities that made a great predator—the furious and deadly assault, the tenacious hold; and the lifting power of its wings was such that it could bear away the hare or pheasant its great talons had transfixed.

Marco Polo was evidently much impressed by falconry as practiced in Cathay, and from him we learn something about the Eastern birds. In the mountainous district of the kingdom of Kierman [Kirmân], he says, "are bred the best falcons that anywhere take wing. They are smaller than the peregrine falcon; reddish about the breast, belly and under the tail; and their flight is so swift that no bird can escape them." He tells of the peregrine falcons of the northern part of the country through which he was traveling, and of the gyrfalcons that the grand khan obtained from an island where they bred in great numbers. "It must not be supposed," he wrote, "that the gyrfalcons sent from Europe for the use of the Tartars are conveyed to the court of the grand khan. They go only to some of the Tartar or other chiefs of the Levant, bordering on the countries of the Comanians and Armenians."

Kublai Khan himself was greatly addicted to the sport; but, being a victim of the gout, he was unable to participate actively. He therefore went hawking borne in a pavilion lined with cloth of gold, covered with skins of animals, and mounted on the backs of four elephants. In Marco Polo's *Travels* the custom is described:

> In the pavilion he always carries with him twelve of his best gyrfalcons, with twelve officers from amongst his favorites, to bear him company and amuse him. Those who are on horseback by his side give him notice of the approach of cranes or other birds, upon which he raises the curtain of the pavilion, and when he espies the game, gives direction for letting fly the gyrfalcons, which seize the cranes and overpower them after a long struggle. The view of this sport, as he lies upon his couch, affords extreme satisfaction to his majesty, as well as to the officers who attend

> him, and to the horsemen by whom he is surrounded. After having thus enjoyed the amusement for some hours, he repairs to a place named Kakzarmodin, where are pitched the pavilions and tents of his sons, and also of his nobles, the lifeguards, and the falconers; exceeding a thousand in number, and making a handsome appearance.

The birds, each identified by a silver label attached to the leg, were retrieved by parties of men stationed about the hunting area and equipped with calls and hoods. Marco Polo mentions also eagles "which are trained to stoop at wolves, and such is their size and strength that none, however large, can escape from their talons."

The appreciation of the brilliant exploits of the birds trained for falconry was focused, no doubt, on their proficiency in vanquishing the hapless victim rather than on the powers that made the conquest possible; yet it may be that part of the "sport's" appeal lay in the spectacle of their flight in and for itself. At least that is the impression given by the enthusiastic falconer of *The Compleat Angler.* As he competed with the fisherman and the hunter in defining the merits of his calling, he says, perhaps, the best that can be said for this diversion:

> And first, for the element that I use to trade in, which is the air, an element of more worth than weight, an element that doubtless exceeds both the earth and water; for though I sometimes deal in both, yet the air is most properly mine, I and my hawks use that most, and it yields us most recreation. It stops not the high soaring of my noble, generous falcon; in it she ascends to such a height as the dull eyes of beasts and fish are not able to reach to; their bodies are too gross for such high elevations: in the air my troops of hawks soar up on high, and when they are lost in the sight of man, then they attend upon and converse with the gods; therefore I think my eagle is so justly styled "Jove's servant in ordinary"; and that very falcon that I am now going to see, deserves no meaner a title, for she usually in her flight endangers herself, like the son of Daedalus, to have her wings scorched by the sun's heat, she flies so near it; but her mettle makes her careless of danger; for then she heeds nothing,

> but makes her nimble pinions cut the fluid air, and so makes her highway over the steepest mountains and deepest rivers, and in her glorious career looks with contempt upon those high steeples and magnificent palaces which we adore and wonder at; from which height I can make her descend by a word from my mouth (which she both knows and obeys), to accept of meat from my hand, to own me for her master, to go home with me, and be willing the next day to afford me the like recreation.

In this panegyric, Walton's falconer puts the emphasis on the inspiring exhibitions of flight rather than on raptorial prowess. He stresses particularly the splendid climb into the great dome of the sky and the ability to soar to the sun. Though he does not say so, his "noble generous falcon" was no doubt the peregrine, for it, more often than any other member of its family, makes use of rising air to soar. Soaring, however, is not the typical flight pattern of any falcon. As a rule their long pointed wings, and the rounded pinions of the goshawk as well, "cut the fluid air" by strong, quick beats, or by a combination of flapping and short glides. In his troupe of "hawks" the true adept at soaring flight (and by soaring is meant gliding on outstretched, motionless wings with increase in altitude) was his eagle. Circling leisurely at a great height, even above the clouds, the majestic golden eagle plays and hunts through the loftiest precincts, scanning the distant earth as well. Its far-spreading, quiet wings keep it on its course or allow it to hang poised, waiting. When the prey is sighted—a smaller bird, a hare or other mammal far below—it furls its sails and drops to seize it in an attack that is sudden, direct, and final.

Though falconry still persists in the East, and sporadically in the West too, it waned in Europe as lands were brought more and more under cultivation and as the gun came into general use as the instrument of slaughter. Gradually the raptorial birds were released from the necessity of displaying their skills for man's amusement. Of course they continue to exercise those skills. They continue to keep themselves and their gaping nestlings alive in the way Nature has provided, in the only way they know.

16

Soaring and Gliding Flight

Eagles may seem to sleep wing-wide upon the air.

—JOHN KEATS

THE eagle was grouped by Walton's falconer among the short-winged hawks not because its wings are of relatively shorter span than those of gyrfalcon or peregrine, but because they are not pointed and because its stoop is different. Its wings are not designed for speed. Long, broad, and deeply slotted at the tips, they are adapted for the use of the heavy bird that soars over land.

Slots are gaps caused by the emargination of one or more of the primary feathers, which, instead of tapering gradually to the end, become abruptly narrowed on one or both sides of the shaft. They open up in the fully extended wing as the outer primaries are spread apart at the tips like sensitive fingers, groping, feeling out the textures of the air. They are to a great extent adjustable and under the control of the bird. They vary in depth and are prolonged in some cases to half the length of the feather; but they are prevented from opening beyond a certain point by the specialized roughened textures of the overlapping surfaces.

In many rounded wings one or more nicked or notched primaries create a serrated outer edge, and in some of the more tapered ones a slot or two can be opened up to meet the requirements of air pressures; but the deeply slotted tip is the particular property of large birds that predominantly soar over land—of eagle, condor, vulture, buzzard, of birds that circumnavigate great spaces over large areas in their search for food. The vulture is a scavenger exclusively; the condor and bald eagle prefer carrion but for want of it take small mammals and other birds. The golden eagle and the buzzards search for rodents, but they also shift to other fare rather than go hungry. Having found the object of their search, all of these predators elevate the wings, so that lift is destroyed, and drop in a flash to snatch it up with their talons. They never dive.

The most mystifying and inspiring of all forms of flight, soaring is, like gliding (from which it differs only in that it implies increase in altitude), accomplished on outstretched and apparently immobile wings. The ability of a bird to rise without any visible effort remained an inexplicable mystery long after the principles of flapping flight were more or less correctly glimpsed. As Coues put it, "the sailing of some birds for an indefinite length of time, up as well as down, without visible motion of the wings, and without reference to the wind, remains an enigma. The flight of the albatross and the turkey vulture, I venture to affirm, is not yet explained. The riddle of the wing will be read when we know how the archsaurian escaped from ilus [ἰλύς=mud, slime] to aether."

At the time the eminent ornithologist expressed this opinion, he evidently saw no prospect that the riddle would ever be solved; but six months before his death in December 1899 a step toward it had been made by two brothers in Dayton. In pondering the difficulties of making a stable man-made glider, they had found that by the twisting or warping of the wing tips lateral instability, the source of so much peril, could be overcome. It was the application of this truly momentous discovery that permitted man, at last, to venture farther, higher, into the untamed and despotic element, to feel out its form and test its properties experimentally, and, finally, to navigate it safely. By reshaping his wings to meet the stresses and strains encountered, even as the descendants of the mud-born reptile had done, he too escaped into that unseen "aether" and came to understand its ways. In it he found the long-sought key to the enigma of soaring and gliding flight. For as his knowledge increased, he began to see how and why the calm, avian wings high above him functioned as they did; how the vulture over the land and the albatross over the sea was each in its own way a masterpiece of engineering skill, equipped with the perfect organ of flight for a particular end.

The wings of the soaring bird do not generate the forces that sustain and propel it. They are, rather, transformers which extract from their surroundings the energies needed and convert the ready-made forces of air currents into the desired effects. We know now that when the eagle spirals upward toward the sun, when the red-shouldered hawk reconnoiters over the fields, when the gull mounts above the headland, they are all, strange as it may seem, coasting downhill on rising air. They rise to the extent that the velocity of the upward-moving air exceeds the rate at which they gravitate earthward. The process has been compared to that of a person descending the steps of an upward-moving escalator. The fact that air currents over land are far different from those over water explains why the wings of eagle and vulture bear little resemblance to the wing of the albatross, why those of rough-legged or red-tailed hawk are on a plan that differs materially from that of a gull.

Over land the rising air currents essential for soaring flight are formed in several ways. Upslanting wind is only one of them. They may be born of horizontal currents that meet obstructing surfaces—a mountain, a hill, an embankment, a wall, a building—to be deflected upward. They may be created by an advancing cold front as heavy masses of cool air push up the warm air they displace. Above fields and barrens and rooftops heated by the sun's radiance, columns of warmed, light air called "thermals" rise. They rise to varying heights, depending both on their potency (for every sort of surface absorbs the sun's energy to a different degree and so gives off its corresponding amount of heat) and on the temperature of the surrounding air. They rise a few hundred or several thousand feet, as the case may be, before their warmth is dissipated or before they are transformed into white cumulus. Cooler air from adjacent areas flows in laterally to replace the rising masses, so that a circulatory system is established which continues until overcast sky or the sinking sun equalizes temperatures. There is nothing stable about such land currents, dependent as they are on ever-fluctuating temperature, ever-changing wind. Not only do they vary in strength and extent; they tilt at angles determined by the velocity and direction of the wind. Often they are more like bubbles than continuous updrafts. Often the air is not soarable. When soarability ceases, the bird must revert to flapping flight or remain grounded.

Birds that soar start their flight as any other, with wings flapping, often laboriously, and they continue to flap upward until they find air masses they can trust. Then, fully extending their sails so that the hand section loses its identity as propeller and merges with the arm section to form a united sustaining surface, they commit themselves to these forces in what appears to be perfect relaxation. In his study of the soaring birds of India, *Animal Flight* (it is in the tropics that soaring flight can be studied best), E. H. Hankin observed that the different kinds of birds under observation began to soar in a definite order. Invariably the lightest of them, the cheel (a kind of kite), was the first to begin, and the others followed in the order of their wing loading. Obviously each species had to wait until the sun's energies had created forces strong enough to bear it.

Effortless and casual though it seems to be, soaring flight entails innumerable fine adjustments of surface and scarcely perceptible movements—a slight rotation at the shoulder, an inconspicuous advance of the entire wing, a deft flexing at wrist or elbow. The effect of the forward extension is to shift the center of support forward in relation to the center of gravity, and this gesture contributes to the gain in altitude. When the wings are retracted, the weight is shifted forward and the bird noses downward. An analysis of the process of the upward-spiraling flight shows that altitude is gained at that place in the circuit where the bird heads into the wind with wings fully spread and wing tips pushed forward almost on a line with the beak. As it turns away and travels with the wind, with slightly retracted tips it loses altitude but gains momentum. When the circuit is completed and it swings again into the wind, the increased speed (speed being one of the sources of lift) enables it not only to regain altitude lost but to mount higher still. From a suitable height it can glide from one column of air into another, stronger one and ride to ever-loftier regions.

Hankin noticed that, as the air's soarability increased, there came a time when circling with gain in altitude gave way to "flex-gliding," when the sky was traversed in a horizontal path at great speed and apparently without either gain or loss of altitude. During this process the forearm kept its position, but a bend at the wrist turned the hand section backward. The more the wrist was flexed the greater was the speed.

When through the waning of the strength of air currents or the diminution of speed the soaring bird tilts its wings to a wider angle to keep from losing altitude, or to increase it, the value of the slotted wing tip is revealed. There is still much to be learned about the interacting forces set up between the twisting, recurved, separated feathers and the streaming air, but it is generally agreed that slots allow the angle of incidence to be increased beyond what would normally be the stalling point. They permit the air that banks up in front of the wing's leading edge to escape; they re-establish the smooth flow and thereby the lessened pressure on the upper surfaces, the main source of lift.

When Handley-Page designed a wing with seven slots for one of his model aircraft, he found that by their means lift was more than doubled at a forty-two-degree angle. What he did not know at the time was that his invention was quite similar to that long ago evolved by the eagle. The individual feathers between which slots are formed are so banked one behind the other that the air streams rushing through do not interfere with one another. The small thumb with its tuft of four feathers, the alula, so inconspicuous ordinarily, can be managed to form another slot. Controlled by a set of muscles all its own, it can be moved by the bird at will in several directions; and it plays so large a part in the efficient functioning of the wings of the large, slow fliers that some of them are unable to take off without its help. Still other slots which are unquestionably functional are formed between the wings' rear margins and the spread tail.

By helping the wings to create the necessary lift, the slotted tip helps the stork, crane, and ibis to take off quickly in limited areas. It is used by the heavy white pelican and the smaller brown pelican in their soaring and gliding flights in coastal areas. It is essential to the slow-flying hawks as they patrol their territories at moderate heights, in moderate currents.

Many of the birds that soar at high altitudes indulge in antics which can scarcely be interpreted in any other way than as manifestations of exuberance and joy and which are made possible by the sensitive responses of the wing tip. Cradled in the strong arms of wind and mounting air, they seem to exploit all possibilities and flaunt their own powers in all sorts of aerial acrobatics. Bald eagles, wood ibises, and ravens have been seen looping the loop, flying upside down, doing barrel rolls and other types of stunt flying, evidently for the pure fun of it. On occasion their actions are purposeful. Maurice Broun, director of the Hawk Mountain Sanctuary, tells, in *Hawks Aloft,* what happened when a red-shouldered hawk made several petulant attacks on a golden eagle. Watching them through powerful glasses as they passed high above, he saw the mighty eagle bring the incident to a close by executing an Immelmann turn and plucking its tormentor out of the air with one decisive gesture. In this maneuver a flier wheels upward in a half loop, then rolls half of a complete turn, and attacks from above. It was "invented" by a German aviator in the first world conflict for aerial combat among men.

In the wings of birds that soar and glide over water far from land the deeply slotted tip does not exist. Above the sea where air currents are stronger, steadier, more dependable than those over land the oceanic gliders travel on wings adapted for long-distance flying and speed—long, narrow, flat, tapered wings.

The only obstacles to the free sweep of the wind over water are the waves themselves and the occasional boat; and by such barriers obstruction currents are formed just as they are by a cliff along the shore or by a mountainside. In the old days when the sea was flecked with white sails, the scavenging gulls would ride the currents upturned by the great spreads of canvas for hours or days at a time; and now that the era of the windjammer is passed, they follow the ocean liner, supported by the air that bounces off its surfaces, or by the rising columns of heated air issuing from the funnels. Near the surface of the sea they coast in the currents detoured by the waves. When the wind is strong enough the greater shearwater, for instance, is able to weave through the lanes of upward-moving air formed in troughs between the great billows for miles without flapping its wings. Banking into the wind occasionally to gain altitude, it returns to the air lanes to resume its long glides.

These shallow channels of rising air are thought to account for the behavior of the flying fish as it leaps from the water to flash through the air in a so-called "flight." But the flying fish does not really fly. Its greatly enlarged pectoral fins, its "wings," are tapered membranes, smooth on their upper surfaces, ridged beneath by fin rays of varying length. Carried close against the body until the leap from the water is made, they then unfold and spread, but they do not strike the air even at the beginning of the glide through it. All impetus is due to the vigorous strokes of the tail as the creature rises in a slant out of the water. The slight movement of which they are capable is a sort of flutter and is probably used for modifying the angle at which they are held and the speed. Usually they are held horizontally, yet, in some rare cases of fish observed by Hankin in the Arabian Sea, they had a downward tilt. At heights that vary from several inches to twenty feet above the water and for distances that vary from a few feet to six hundred or more, according to the species, the flying fish on pseudo wings volplanes through the updrafts formed over the waves.

Masses of warm air rise from the heated surface of the water in much the same way that they do over land areas which have absorbed the radiant energy of the sun, provided that the temperature of the atmosphere is lower than that of the water. However, since the broad plain of the sea is heated everywhere to the same degree, and since the blanket of warmed air cannot rise uniformly without creating Nature's abhorred vacuum, it breaks up to form closely packed hexagonal columns, with the warmer air rising in the center of each and the replacements of cooler air flowing downward at its edges; or, by a reversal of direction, the cold mass may rise in the center of each shaft as the warm air sinks at the border. Bent by the force of the wind, these columns tilt more or less; and if the gale is strong enough, they become horizontal, rotating structures so geared together that where they meet each other strong horizontal rivers of air flow. On these the gliding bird coasts confidently. A gull can thus turn to account the conditions imposed by wind and temperature, either to soar or to glide grandly, according to the type of current it encounters.

For every sort of bird there is a "gliding angle," the rate at which it normally loses altitude, a rate that depends on the angle of the wings and their shape—on the relation of lift to drag. The gull, one of the best gliders, can travel for twenty feet or more horizontally for each foot of altitude lost. The albatross goes almost as far, the eagle about sixteen feet. The pigeon, a poor glider (but a good flier), drops one foot for each nine feet of distance. A relatively small upflow of air will offset the gull's descent; and when the upcurrent is not altogether strong enough, a few waves of the hand section of the wing are all that is necessary for it to regain its height. When the force of the upward-moving air exactly equals the combined forces of weight and drag, the soaring or gliding bird remains stationary and fixed in space. By intuitively, automatically shifting the wing to meet the air currents at the proper angle, by flexing the wrist to modify its area, by adjusting the position of the two wings in respect to each other, by countless other co-ordinations and delicate movements, it utilizes the energies it finds and translates them into the action that answers its needs.

Whenever a warm front moves in and the temperature of the air rises above that of the water, convection currents cannot form and no gulls will soar or glide unless they can find obstruction currents reflected from a boat or other surface. Conditions for convection soaring are best when the air is more than five degrees centigrade colder than the water and when the wind blows between twenty and thirty miles an hour. At least, that is the conclusion of Alfred H. Woodcock after having studied the flight of herring gulls off the Massachusetts coast. He too found that circling preceded horizontal soaring and that it had a definite relation to the wind's velocity. Circling gave way to linear soaring when the wind blew about twenty-four miles an hour—which seemed to indicate that at this stage the columns of rising air had been converted into horizontal "strip" cells. When the force of the wind increased still more there was, supposedly, a disintegration of the supporting currents, for soaring ceased altogether.

When the strength of air current ebbs, gulls revert to labored, flapping flight. They flap laboriously because of the very fact that they are so highly specialized for gliding. Their wings, like those of all oceanic gliders, are long, narrow, of almost uniform width, with little camber. Aerodynamically they are very efficient, for it is an advantage to have the eddies and vortices that form at wing tips as far apart as possible so that their disturbing influences are confined to a small part of the total surface. Moreover, since they are flat, drag is reduced to a minimum. However, the relatively small pectoral muscles are unequal to the task of pulling down such long organs easily.

It has often been observed that gulls, and eagles, and hawks as well, do not take the shortest route to their nesting sites if they have to flap to get there, provided they can reach their goal by gliding. They prefer to find an updraft, ride high on it and then glide down to their objective rather than flap for a much shorter distance. The elongation of the wings of gulls and of oceanic gliders takes place in the arm sections. From shoulder to elbow and from elbow to wrist the bones are relatively longer in relation to the hand section than they are in land species. As they become longer, they are furnished with a greater number of secondary and tertiary feathers; but the number of primaries on the hand section is never increased.

It may be that the greatest of all oceanic gliders is the pelagic albatross. Ranging over unmeasured stretches of sea far beyond the scope of gull or gannet, coming to land only for the purpose of nesting, this great white wayfarer will sail for days on end on level, still wings balancing the forces of air current and gravitation. Sliding low over the water, soaring into the wind-swept sky, outriding the hurricane, it finds its wings, pointed at the tip and extremely long for their width (with an aspect ratio of about eleven to one), equal to all its tasks as long as the air is moving. With a span of eleven feet and four inches, the wandering albatross is the largest bird having the power of flight. It outreaches even the condor, whose slotted wings, more than ten feet from tip to tip but of greater relative width, sustain him in rarefied zones above the Andes or Rockies. On sea and land these two giants, soaring, gliding, utilize the forces engendered by sun and wind above two vastly different sections of the earth's surface. Each in its own tempo and rhythm sweeps over its world on wings shaped by eons of effort in contending with those forces.

Epitomizing power, endurance, liberation, soaring and gliding flight has appealed to the earth-bound human being in a way not even the dramatic plunges of peregrine or duck hawk can equal. Exercising the faculty of empathy (according to some the basis of appreciation of any work of art), he transfers to the bird his own feelings as he follows its course. He calls its flight sublime. Is the bird aware of the sublimity of its performance? No. Said W. H. Hudson:

> The air is their element: they float on it and are borne by it, abandoned to it, effortless, even as a ball of thistledown is borne; and then merely by willing it, without any putting forth of strength, without a pulsation, to rise vertically a thousand feet, to dwell again and float upon an upper current, to survey the world from a greater altitude and rejoice in vaster horizon. To fly like that! To do it all unconsciously, merely by bringing this or that set of ten thousand flight muscles into play, as we will to rise, to float, to fall, to go this way and that—to let the wind do it all for us, as it were, while the sight is occupied in seeing and the mind is wholly free! The balloons and other wretched machines to which men tie themselves to mount above the earth serve only to make the birds' lot more enviable. I

would fly and live like them in the air, not merely for the pleasure of the aerial exercise, but also to experience in larger measure the sense of sublimity.

But this is a delusion, seeing that we possess such a sense only because we are bound to earth, because vast cliffs overhanging the sea and other altitudes are in some degree dangerous. At all events Nature says they are, and we are compelled to bow to her whether we know better or not. We cannot get over the instinct of the heavy mammalian that goes on the ground, whose inherited knowledge is that it is death or terrible injury to fall from a considerable height. Only so long as we are quite safe is this instinct a pleasurable one; but when we look over the edge of a sheer precipice, how often, in spite of reason, does the pleasure, the perfect joy, lose itself in apprehension! Could we know that it would not hurt us to drop off, purposely or by accident, that the air itself and a mysterious faculty in us would sustain us, that it would no more hurt us to be flung from the summit of a cliff than it would hurt a jackdaw, we should be as the bird is, without a sense of sublimity.

PART III

MEN

17

Visions, Dreams, and Tentative Efforts

> Before the starry threshold of Jove's court
> My mansion is, where those immortal shapes
> Of bright aerial spirits live insphered
> In regions mild of calm and serene air,
> Above the smoke and stir of this dim spot
> Which men call Earth. . . .
>
> —JOHN MILTON, *Comus*

THE mysterious and inspiring phenomenon of flight could not fail to impress the human consciousness at an early stage. Its innumerable manifestations, from the gentle undulations of the butterfly to the majestic sweep of the eagle, were constantly about for earthbound man to observe, yet quite beyond the range of his comprehension. It is no wonder that the organs in which the wondrous faculty resided became for him objects of symbolic import. By their agency it was possible to escape from all the constraints of earthly existence, with a rise into what appeared to be an unrestricted territory, boundless, unobstructed, free. Wings became, therefore, emblems of that which was unearthly, of the superhuman, the spiritual, the aerial—of divinity, power, inspiration, mobility, speed. Detached from the creature to which they naturally belonged and recombined with animal, human, geometric, or a combination of forms, they endowed the composite being with one or more of their attributes.

The idea of protection was often joined to that of divinity and of power, as in the winged solar disk of Egypt. Emblem of Ra and Horus, it spread the beneficence of the supreme god of the sky wherever his protective power was needed or invoked. With the sun's disk transmuted into a ring framing an anthropomorphic god, the motif was appropriated by the Assyrians for Assur and by the Persians for Ahura Mazda. It was borrowed by the prophet Malachi, who, when he ascribed to the Lord of hosts the words "But unto you that fear my name shall the Sun of righteousness arise with healing in his wings," was but expressing verbally a concept inherited from Mesopotamian pictorial tradition and one which had been used in more remote times by sculptor and artisan throughout the valley of the Nile.

When the psalmist sang, "Keep me as the apple of thy eye, hide me under the shadow of thy wings," he too was giving voice to the idea implicit in the figure of Isis as often represented on the wall of burial chamber or on sarcophagus, an Isis kneeling with outspread arms which support wings and confer protection and benediction. It was in all probability from Egyptian sources that the conception of the protecting cherubim on the ark of the tabernacle was derived: "The cherubim shall spread out their wings above, overshadowing the mercy seat with their wings." Solomon in his temple "put the cherubim in the innermost part of the house; and the wings of the cherubim were spread out so that a wing of one touched the one wall, and a wing of the other cherub touched the other wall; their other wings touched each other in the middle of the house."

Colossal winged bulls, human-headed, and winged genii were the mystic guardians of the palace gates of Sargon at Khorsabad, of his son Sennacherib at Nineveh, of Xerxes at Persepolis. In Assyrian reliefs both king and priest, when taking part in religious rites, were winged. On the sculptured walls of the palace at Nimrud, Ashur-Nasir-Pal was shown taking part in various sacrificial rites and officiating at the symbolic ritual centering about the tree of life. Priests, some of whom wear eagle masks, take part in similar ceremonies. The wings worn by the officiants, of which there are sometimes two pairs, and which are so prominently featured, were ceremonial wings donned for the religious occasion by those who were the representatives or even the incarnation of the deity.

In all mythologies winged supernatural personages abound. Among the Greeks, Eos, goddess of the dawn, frequently assumed a winged state and so did Artemis, the huntress. Death, Sleep, Fame, Victory, the Winds, when personified, bore the organs of flight. Cupid, prototype of many a later winged form, flew on his errands, and Hermes, messenger of the gods, used winged cap and sandals. Wings carried the avenging Furies as they brought swift retribution to those whom they pursued.

Pegasus, the winged horse of the muses, tamed by Athene, became the symbol of inspiration by virtue of his wings; on him Bellerophon attempted to ride even into the abode of the gods. It was on winged Buraq, a strange composite beast the swiftness of which was such that at a single stride it could reach as far as eye could see, that Mahomet, accompanied by the angel Gabriel, did on a single night rise through the seven zones and reach the highest heaven. The emblems of the four Evangelists—the lion of Mark, the ox of Luke, the eagle of John, the angel of Matthew—were all winged figures, as befitted their state of inspiration.

There were winged demons as well as deities in the mythologies of India, China, and Japan, of Scandinavia, Central America, and elsewhere. On the painted walls of Etruscan tombs the wings worn by the demons and deities of the underworld differentiate them from those who have just entered the region of the dead.

In Christian iconology, wings were the especial attributes of the angels, the divine messengers, and signified above all else the mobility inherent in their nature. The prophet Ezekiel, attempting to put the splendor of a vision into words, suggested the nature of these incorporeal beings with splendid, if confused, imagery: they were living creatures in the likeness of a man, yet their appearance was like burning coals of fire, like lamps, like lightning. "Each had four faces, and each of them had four wings"; "and their wings were spread out above; each creature had two wings, each of which touched the wings of another, while two covered their bodies." Associated with them were wheels "full of eyes round about"; moreover, "the spirit of the living creatures was in the wheels." The forms of these angelic creatures as described by Christian artist and poet were thus the outgrowth of a long-established tradition.

While all these celestial intelligences were winged, their attributes and functions differed. As classified by Dionysius the Areopagite, they were divided into nine ranks or orders, which were grouped into three main divisions or hierarchies. Angels, Archangels, and Principalities constituted the "ministers" whose special function it was to minister to man. The Powers, Virtues, and Dominions were "governors," regents entrusted with relaying the divine commands. In the highest category were the Thrones, Cherubim, and Seraphim, "counsellors." Only in this last hierarchy was there a departure from the usual method of representing the angelic host as two-winged beings with human form. The Thrones, no doubt conceived in terms of Ezekiel's vision, were often portrayed as two fiery wheels each with four wings and eyes. The Cherubim, the embodiment of knowledge and of contemplation, were variously portrayed, frequently with six wings. Six wings were always allotted to the Seraphim, who, nearest to the Divine Presence, were the most perfect embodiment of spirit, mobility, and love. "Each had six wings: with two he covered his face, and with two he covered his feet, and with two he flew."

In his descriptions of the winged creatures conjured up in man's imagination, the poet with words could indulge in subtleties and abstractions. The sculptor, painter, craftsman, when called on to objectify the symbols of superhuman potency, did so in terms of the tangible forms they knew. In most cases the symbolic wing was patterned after the wing of the bird. In the guise of the winged disk, the solar divinity of Egypt was thought of as a falcon coursing across the sky; but as pictorially represented these wings

Conventionalized Wing from Totem Pole.

resembled rather the broad, square-tipped sails of the eagle or of its relative the vulture, so frequently seen hanging there between earth and sky.

The wings of the Assyrian reliefs and related works of art also resembled those of the King of Birds. Those of the composite animals, the sphinx, the griffin, the dragon, those of divinities and personifications were also avian. Some of the later variations of the angelic forms, the winged heads of baby cherubs and the *putti,* bore the wings of the smaller birds whose flight was limited; but the usual alar shapes possessed by celestial messengers were, as befitted their function, the long-pinioned wings of the far, fast fliers. In Egypt the disembodied soul was pictured as a human-headed bird; in Greece the psyche was the butterfly. When they became instruments of the forces of evil, of the fallen angel Lucifer and his band, for instance, the alar forms were modeled after the dark, leathern wing of the innocent bat.

Man's desire for wings of his own must have taken form in his dreams when he was very young. It was a deeply ingrained aspiration reflected not only in myth and folklore but also in legend and fable. He endowed many of his divinities with mastery of the air and at times achieved it for himself as well.

Just when, where, how, and by whom the first attempts were made to convert the dream into the reality are matters quite beyond our ken. The wings of the first human fliers have left no trace except in the insubstantial medium of human lore. Here the true and the false merge confusedly as myth gives way to legend, tradition to recorded fact. It is not always possible to extricate fact from fancy, to differentiate between the actual experimentations of the first gifted artificers and the imaginary enterprises of the dreamers who inspired them. It does not matter much. It is enough to recognize the underlying theme on which all the tales, real and imaginary, are woven—the irresistible lure of the sky and man's resolute longing for wings.

Even in his imagination he did not win them immediately. In many myths his aerial exploits are accomplished not on his own but with the help of avian wings. The earliest of all the legends dealing with human flight is of great antiquity and is illustrated on Babylonian seal cylinders dating from about twenty-five hundred to two thousand years before Christ. It related that Etana, a shepherd king, is carried by an eagle whom he has befriended, up through the heavens to the dwelling of the goddess Ishtar (the planet Venus). The purpose of the journey, which was to intercede for his city, fails and he falls to earth.

In Chinese lore there are several instances of this sort of transportation. Li Shao-kun, a magician at the court of the emperor Wu of the Han dynasty, declared that he could (among other feats) "bestride the hoary crane and soar above the nine degrees of heaven." Wang Tse-k'iao, a prince of the Chou dynasty and a student of the black arts, was seen, on an appointed day, ascending to heaven on a white crane; and a courtier of Han times by the name of Wang K'iao traveled to court on a pair of wild ducks. In Greek mythology Jove's eagle bore Ganymede to the abode of the gods.

The mighty wings of the eagle were exploited in another fashion by a king of Iran who lived about fifteen hundred years before the Christian Era. His name was Kai Kawus, and among other extravagant enterprises he attempted to extend his rule into the celestial sphere. He prepared to make the journey thereto seated on a light throne of aloe wood to the four corners of which young, strong, hungry eagles were harnessed. At each corner of the seat was fastened also a long spear, and from the top of each spear a leg of lamb was suspended. The famished eagles, striving to reach the food, raised the throne and its occupant; but, tiring eventually in their hopeless quest, they gave up the struggle and brought Kai Kawus back to earth ignominiously.

Sixteenth-century Persian miniatures picture the flight as it was described by Firdausi in his *Book of Kings,* and it was transplanted into medieval manuscripts (derived from the Greek source) as part of the *Romance* of Alexander the Great. However, Alexander was represented seated in a palanquin drawn by sixteen griffins. One version of the Alexander story, which was widely translated during the Middle Ages, had it that a bird with a human face halted the conqueror's course and advised his return to his earthly abode. Still another version of the original excursion, from an Arabian source, recounts that after his failure with the Tower of Babel, Nimrod took to the air in a cage drawn by four great birds.

Gods and goddesses were borne in all sorts of wonderful aerial vehicles, some of which were drawn by winged creatures. Doves were harnessed to Venus' car; peacocks to Juno's; and in Hindu mythology a man-bird with golden body and red wings was the vehicle of Vishnu.

Aerial chariots that proceeded under their own power were not uncommon conveyances of legendary kings and heroes, although the means by which they were propelled is not always apparent. The first one on record is a Chinese invention mentioned in the *History of the Ancient Emperors,* which was written in the third century of our era. It was made by one Ki-kung, who lived long before the rule of the founder of the Shang dynasty, Ch'eng T'ang, 1766-1754 B.C. The Chinese chronicler says of Ki-kung's chariot that it was blown by the west wind as far as Ho-nan, that the emperor ordered its destruction so that it should not become common property, and that ten years later when the east wind blew he had another one built in which Ki-kung returned. A woodcut of comparatively recent date represents it as a square, open, box-like car moving through clouds and fitted with two wheels that vaguely resemble propellers. Berthold Laufer, who discusses this and all the other Eastern manifestations of attempts at flight in *The Prehistory of Aviation,* believes that it was powered by a combination of sails and kites and reminds his readers of the experiments made in 1826 by George Pocock, an English schoolmaster, and by several others. Pocock called his invention a "charvolant, or Kite Carriage," and it was, in fact, a huge kite, with a chair swung below, so controlled by various cords that it would meet the wind at any angle desired. A valorous woman, whose name has not come down to us, was the first to be raised aloft—to a height of a hundred yards—and she expressed herself as greatly pleased with the experience. She liked the easy motion of the swaying kite and the lovely view.

In the great Indian epic, the *Mahabharata,* there is mention of an aerial war chariot provided with wings; and Sanskrit literature abounds in references to flying machines. Laufer concludes that the Indians professed to have had two distinct types of aerial car: one built on the principle of bird flight and another constructed on a system derived from the Greeks. The carefully guarded details of the latter were never divulged. One more instance of a legendary flying chariot may be mentioned: a "vessel wherein one could traverse the air" was included among the parting gifts showered on the Queen of Sheba by Solomon when her visit to him came to an end. The Coptic text which contains this information does not take up the mechanical details of construction or tell how it was propelled.

It is again to China that one turns to learn of the first man in recorded history who not only made wings for himself but used them successfully. This was the Emperor Shun, who lived, according to tradition, from 2258-2208 B.C. and who was instructed in the "art of flying like a bird" by the two gifted daughters of the Emperor Yao. In the commentary to the *Annals of the Bamboo Books* it is related that Shun was commanded by his father and stepmother to plaster a granary and, having done so, found himself trapped on top of it when his hateful parents set fire to it from the bottom. Equal to the emergency, "Shun donned the work clothes of a bird, and flying made his escape." Another tradition has it that he got himself out of the same predicament by spreading out two large reed hats and using them as a sort of parachute.

It was for the purpose of escape that the next renowned bird-man, Daedalus, a thousand years later, fashioned wings for himself and his son Icarus in order to flee from the persecution of King Minos, for whom he had built the famous labyrinth of Crete. These wings were made of feathers and wax; and when they were finished Daedalus

> poised himself
> And lightly floating in the winnowed air
> Waved his great feathered wings with bird-like ease.

After a second pair were ready for the use of Icarus, the two took off. At first all went well; but, as everyone knows, Icarus, disregarding his father's injunction not to fly too near the sun, met with disaster when the wax melted, the wings parted, and he fell into the sea which now bears his name. Daedalus continued on an indirect route and arrived at last in Sicily.

The story of Daedalus and Icarus was repeated or referred to in the writings of many Greek and Roman historians and poets and was used as a motif for dramatic spectacles and stage productions. Suetonius in his description of the games and public diversions provided by Nero for the Roman populace, and the emperor's attendance at them, mentions that "Icarus, upon his first attempt to fly, fell on the stage close to the emperor's pavilion, and bespattered him with blood." A spurious legend which took form much later placed an actual attempt at flight in the latter part of Nero's reign. There are various versions of it, the one most commonly circulated being to the effect that a magician by the name of Simon, aided by demons, rose into the air before a large crowd, but that by a prayer of Saint Peter, who was among those present, the evil powers were canceled and Simon fell. The most interesting feature of this legend is the introduction of the idea, typical of the thought of the Dark Ages, that human flight was evil.

In Scandinavian legend there is another story of escape by flight. The smith Wayland, maker of wonderful weapons, was lamed by order of King Nidung, who wished to retain him in his service. The smith made for himself a robe of feathers and flew off to Seeland, launching himself from the highest tower of the castle.

In 852 B.C., Bladud, the mythical tenth king of Britain, the founder of Bath, the father of King Lear and a student of the art of necromancy, attempted a flight which was recorded long afterward by Geoffrey of Monmouth. Bladud, like Daedalus, made a pair of feathered wings; but his were not so effective as those of the Greek. Taking off from the top of the temple of Apollo in his capital, he fell to his death.

From Arabic sources comes the story of the Sage of Spain, a Spanish mechanician with the impressive name of Abu'l Qasim Abbas Ibn Firnas, who about A.D. 875 clothed himself with feathers and with the aid of wings flew for some distance. The chronicler of the flight attributed the painful landing that came at the end of it to the failure of the flier to provide himself with a tail. Since this craftsman gave many proofs of his inventive turn of mind, such as making a model of the heavens with stars and clouds, lightning and thunder, constructing water clocks, and manufacturing glass, it is quite credible, in Laufer's opinion, that he might also have made a serious effort to fly.

There was a tenth-century architect of Persia who was confined on the top of a great tower he had built for King Shapur I, the victim of the king's nefarious design to keep others from obtaining his services. He begged for some wood with which to build for his body a protection from the vultures, and, with the materials granted, made for himself wings. Helped by the wind, he successfully carried out his plan and reached a hiding place in safety.

In his book *Spain,* Sacheverell Sitwell repeats the legend of the sculptor of the choir stalls of the Cathedral of Plasencia, Rodrigo Aleman. Having boasted that God himself could do no better work, he was punished for his impiety by being imprisoned in one of the towers. He kept himself alive by eating the birds he was able to snare and at length made a fatal effort to escape by launching himself from a window on wings he had fashioned from their feathers. Since the Cathedral of Plasencia has no tower, the story must be regretfully discounted. At least it reflects the continuing widespread preoccupation with the possibility of human flight.

There are at least two well-authenticated trials in the twelfth century. One was made by the "Saracen of Constantinople," a brash adventurer who undertook to give an exhibition before the Emperor Comnenus during festivities held in honor of the visiting Sultan. He mounted to the top of a tower in the hippodrome with the intention of flying across the racecourse. In the words of an eyewitness, quoted by Cousin in his *Histoire de Constantinople,* he stood there "clad in a very long and wide garment of white color braced with rods of willow-wood laid over a framework. The cloth was loosely draped over this frame, and he intended to fly like a ship with its sail, hoping that the wind would catch in the folds of the garment." There was great to-do as he stood waiting for the propitious moment. The crowd was impatient and kept urging him to fly; the Emperor sent word to detain him; the Sultan was torn between fear and hope; but he "remained undisturbed, frequently examined the wind and put the audience off. He often raised his arms, used them like wings, and lowered them to catch the wind. When the wind appeared to him favorable, he soared like a bird and seemed to fly in the air." Unfortunately his artificial organs of flight could not long sustain him. Perhaps the wind changed. In any case he fell and received injuries that caused his death.

In England, in the early part of the same century, an astrologer and artisan by the name of Oliver of Malmesbury tried to fly. The event as summarized by John Milton in his *History of Britain* is as follows:

> He in his youth strangely aspiring, had made and fitted wings to his hands and feet; with these on the top of a tower, spread out to gather air, he flew more than a furlong; but the wind being too high, came fluttering down, to the maiming of all his limbs; yet so conceited of his art, that he attributed the cause of his fall to the want of a tail, as birds have, which he forgot to make to his hinder parts.

As far as can be judged, the thirteenth and fourteenth centuries were not air-minded. It is true that Roger Bacon, one of those seers who, though circumscribed by his own time, is able to open up vistas of things to come, toyed with the idea of a flying machine for man, affirming about 1250 that "flying machines can be made in such a way that a man is seated in the midst of the machine, revolving some sort of device by means of which wings artificially composed may beat the air after the fashion of a flying bird." But his suggestions had no effect in his own day. They were not only unknown then but subjected to centuries of neglect. Not until the end of the fifteenth century is the saga of human flight resumed by the endeavors of the Italian mathematician, Giovanni Battista Danti of Perugia, who is said to have attempted winged flights over Lake Trasimeno. There is no description of the appliances Danti used, but they were presumably good enough to warrant the continuation of his experiments. However, when he tried to demonstrate his skill in Perugia, taking off from its highest tower, he is said to have sailed across the public square and balanced himself for some time, until the mechanism which controlled the left wing broke and he crash-landed on the roof of a building.

It was with feathered wings that John Damian, in 1507, engaged in a similar venture unsuccessfully. An Italian by birth, Damian had come to Edinburgh by way of France in 1501 and had won the favor of King James IV, by whom he was created Abbot of Tungland. He was court physician, a dabbler in alchemy, and evidently a very versatile fellow. Declaring that by flying he could overtake an embassy which was then on its way to France, he prepared his wings and made a take-off from the top of Stirling Castle. He ascribed his failure, in which he sustained a broken thigh, to the presence of some hen feathers in his wings, which by their nature were attracted more to the barnyard than to the lofty reaches of the sky. A strange and amusing explanation this was, but it reflected one of the superstitions of the Middle Ages which attributed all sorts of evil consequences to the presence of bird feathers, especially chicken feathers, in pillows and bedding.

What a tremendous gulf there was between the methods and mental processes of this adventurer and those of Leonardo da Vinci, his contemporary! There could be no greater contrast than that existing between his confused, offhand improvisation and the enlightened study of bird flight and mechanical devices to duplicate it that were being made by the great Florentine at the same time.

In the ignorance and superstition which so befogged the intellectual outlook of the Middle Ages the idea, implicit in the story of Simon the Magician, that human flight was the product of evil forces took root and thrived. Its growth was fostered by such arguments as those advanced by Eusebius in the fourth century, that it was unwise to break the laws of nature and the decrees of Providence. Human flight was, of course, deemed to be against those laws; and it followed naturally enough that anyone who busied himself with the study of mysterious natural phenomena or the fabrication of strange mechanisms should be put down as a collaborator with satanic forces. He was called wizard, magician, sorcerer. It was in the face of this generally held opinion that the first would-be aeronauts had to fly.

In this state of affairs it was only to witches, abetted by the powers of evil, that travel by air was conceded. On the back of an animal—a black sheep, a horse, a dog—or preferably on a broomstick, or, at times, transported by the devil himself, they rode about by night on their dark errands. The anointing of the body, in whole or in part, with a magic ointment usually preceded the aerial excursion. The ingredients of the ointment, for which three recipes have been given, included aconite or belladonna or both; and at least one writer who has discussed the matter has speculated on the possibility that its use might have produced the illusion of flying. At all events, the air travel of these strange personages had nothing to do with wings.

If the average man of the medieval world ever dreamed of flight for himself, he did so furtively; for the only winged beings countenanced by that world were those supernatural (though to him no less real) entities, the long-pinioned angels and the bat-winged satanic legions. From their stations in heaven and hell these two volant hosts issued to engage in perpetual conflict for possession of the wayward human soul. This was warfare waged on intangible wings in the invisible realm of the spirit. In the material arena of human effort wings were not vouchsafed to man.

The great domain of the air was declared outside his province. It was reserved for the wings of insects, birds, bats. Any attempt on his part to invade it was taboo.

As far as his early trials to do so were concerned, it seemed indeed as if his ingrained aspiration might be a snare and delusion. All the efforts of mountebanks, artisans, budding scientists, and "magicians" alike came to nothing. For another four hundred years the endeavors of more enlightened students, more proficient mechanics, were to fail. It really seemed as if there were truth in the conviction generally held and expressed as late as 1783 by William Cowper that if man had been intended to fly, God would have provided him with wings.

18

The Labors of Leonardo da Vinci

> Limited in his nature, infinite in his desires, man is a fallen god who remembers the heavens.
>
> —LAMERTINE, *Second Meditation*

THE first person to approach the problem of flight from anything like a modern point of view was Leonardo da Vinci. Driven as he was by insatiable curiosity to inquire into the nature of all natural phenomena, he inevitably found that it claimed his interest. It was no passing interest. For over thirty years it fascinated him. In the midst of all his other pursuits his thoughts returned again and again to the contemplation of this miracle. One may think of him laying aside the work at hand—the study of optics or acoustics or hydraulics, the drafting of a design for an engine of war or a pageant, the dissection of a body, the execution of a fresco, the sketch for a portrait, the model for a bronze, the scrutiny of the stars and the planets—to watch for a while the wings of flying things. Widespread, indolent wings of soaring birds upheld by the wind, small fluttering wings of finches and larks and insects, and, as dusk approached, the black webs of the bat—these were always near for him to turn to.

Of all the flying things, birds were the constant and the most rewarding objects of his observation. He studied the structure of their wings. He watched their movements and caught with remarkable accuracy their articulations in both flapping and soaring flight. He speculated about the medium in which they functioned. And all the while he tried to apply what he learned to the invention of mechanical appliances which should reproduce their actions and make man air-borne. If he failed in this ambition to adapt his knowledge to human needs, it was not altogether his fault. Like many who came after him, he had to rely for motive power on the only source then available, the inadequate muscular energy of man.

The record of the operation of Leonardo's avid mind has come down to us in the form of memoranda set down, often ambiguously, in the notebooks which he kept assiduously for over forty years. From his youthful days in Florence until his death at the age of sixty-seven at Amboise, he made notations of whatever happened to be uppermost in his thoughts at the moment—observations, discoveries, comments, sketches, household accounts. Made without order, the entries accumulated in bewildering confusion. To this fact as well as to the lamentable fate by which the notebooks were, after the death of the friend to whom he had bequeathed them, dispersed and plundered is due the difficulty, not to say the impossibility, of reconstructing a coherent and chronological account of his endless enterprises.

It was his expressed intention ultimately to sort his entries and "put them in their right order, according to the subjects which they treat." But like so many other projects of his, this one was never carried out. He did, however, actually begin a compilation of his material on the flight of birds, the *Codice sul volo degli Uccelli*. This too was left unfinished. As it has come down to us it is a small notebook of thirty pages, a mere fragment of what he had intended it to be. After having passed through various hands this important document now reposes in the Royal Library of Turin. The rest of the material on flight must be gleaned from other manuscripts of which more than five thousand pages are extant. With their members dislocated and mutilated and to some degree reassembled, the other notebooks designated by various names, numbers, and letters are now safely deposited in the Ambrosian Library at Milan, the Library of the Institute of France, the British Museum, and elsewhere. It is from entries in these several manuscripts and from the incomplete *Treatise on the Flight of Birds* that Leonardo's research on flight must be pieced together. The vast amount of material has been translated, arranged, and edited by Edward MacCurdy and thus made available to English readers.

The first of the notations on flight were made about 1490 when he was thirty-eight years old and a resident of Milan in the service of Ludovico Sforza. Sixteen busy years were spent at the court of this prince in the capacity of painter, sculptor, and engineer; but of all the projects undertaken, the crumbling fresco of the "Last Supper" on the walls of Santa Maria delle Grazie is the only memento. In 1503 he was back in Florence, working on his composition for the proposed murals for the council chamber of the Palazzo della Signoria. The project, for which the young Michelangelo was also making a cartoon, was never consummated. It was during this sojourn of three years in Florence that Mona Lisa sat for her portrait and that Leonardo began the treatise on bird flight. The thirty pages of which it consists were written between March 15 and April 15, 1505. For a part of the time, at least, he stayed at Fiesole and worked on a model of a flying machine, for the last entry in the notebook refers cryptically to a proposed trial flight of his latest invention then under construction which was to take place there.

The scope of his investigations on the subject of flight and the extent of his knowledge can be judged by the notation (in one of the other notebooks) that he planned to divide "the treatise on Birds into four books; of which the first treats of their flight by beating their wings; the second of flight without beating the wings and with the help of the wind; the third on flight in general, such as that of birds, bats, fishes, animals and insects; the last of the mechanism of this movement." In another place he reminds himself that "you must needs in the first book explain the nature of the resistance of the air, in the second the anatomy of the bird and of its wings, in the third the method of working of the wings in their various movements, in the fourth the power of the wings and of the tail, at such times as the wings are not being moved and the wind is favorable, to serve as a guide in different movements." Never before, as far as we know, had the study of flight been so logically undertaken.

In the study of air and its properties, Leonardo da Vinci displayed the same remarkable acumen that he evinced in so many other fields of inquiry. Realizing that it is a fluid, he compared it to water and the action of the bird to that of a swimmer. He knew that it is compressible and that its density decreases with altitude. In regard to its resistance he observed that "there is as much power of movement in the water or the air against an object as there is in this object against the air or the water," and that the "movement of the wing against the air is as great as that of the air against the wing"—statements which foreshadowed Newton's third law of motion (one of the cornerstones of the science of aeronautics), that to every action there is an equal and opposite reaction. That he recognized also the force of inertia, first expressed by Galileo more than a hundred years later, is evident, for he noted that "all moved bodies continue to move as long as the impression of the force of their motors remain in them." He knew something about drag: "Every slanting movement made by a heavy substance through the air divides the gravity of the movable thing in two different aspects, one of which is directed to the place towards which it moves and the other to the cause that restrains it."

He could not adequately explain the nature of the wind or account for its movement, but he refuted the theory that its direction was caused by the signs of the zodiac, that the fiery signs, the Ram, the Lion, and the Archer moved the eastern winds, the cold, dry signs of the Bull, the Virgin, and the Goat moved the southern winds, and so on. He was well aware of its effects and saw that air currents striking the water or the earth at various angles "set up lateral movements along various lines, as does the water which penetrates other water." He also remarked that there are "reflex winds" many of which as they come against a mountainside "proceed up in a straight line and especially those that strike nearest the bases of the mountains."

He tried hard to understand the relation of air currents to wing action and made such observations as that when "there is no wind stirring in the air then the kite beats its wings more rapidly in its flight, in such a way that it rises to a height and acquires an impetus; with which impetus, dropping very gradually, it can travel for a great distance without moving its wings." He knew nothing about pressure differences on the wing's two surfaces, and attributed all support to the pressure from beneath: "Since the wings are swifter to press the air than the air is to escape from beneath the wings the air becomes condensed and resists the movements of the wings; and the motive power of these wings by subduing the resistance of the air raises itself in a contrary movement to the movement of the wings." Yet he knew that the pressure was not uniformly distributed over the underside and asked, "In what part of the under surfaces of the breadth of the wing does this wing press the air more than in any part of the length of the wings?"

In flapping flight, he observed that unless "the movement of the wing which presses the air is swifter than the flight of the air when pressed, the air will not become condensed beneath the wing, and in consequence the bird will not support itself in the air." He asserted, "The hand of the wing is that part that causes the impetus," and then described the articulation of the "elbow" and the rest of the organ.

In the set of pages known as Manuscript E, he is more explicit in describing the functions of the two sections of the wing in flapping flight: "The wing of the bird is always concave in its lower part as far as the part that extends from the elbow to the shoulder, and in the rest it is convex. In the concave part of the wing the air is whirled round, and in the convex it is pressed and condensed." He saw, moreover, that "the shoulder where the helm of the wing is placed is hollow below after the manner of a spoon, and being thus concave it is convex above. It is fashioned thus in order that the process of rising may be easy and that of lowering itself difficult and may meet with resistance. . . ."

He even noticed that the primary feathers separated on the upstroke: "I have seen the sparrow and the lark fly upward in a straight line when they were in a level position. And this happens because the wing raised with swift movement remains filled with holes, and only rises with the impetus it has acquired, and this is renewed in the lowering of the wings, for the wing then reunites and presses one feather in beneath another. . . ."

He marked the acceleration of beat which produces changes in direction and also the flexing of one wing to produce the same result. He explained the flight of the small bird that flies in spurts by saying that it "acquires impetus in its descent, because in the course of this by closing its wings it acquires weight, and consequently velocity," and that the subsequent beating of the wings utilizes the increased resistance to regain altitude.

Leonardo called attention to the two main techniques used by birds in the take-off, the "one which commences by lowering themselves with their body to the ground and then making a leap into the air by extending very rapidly their folded legs" and the second, when from a height "they merely throw themselves forward and at the same time spread their wings high and forwards and then in the course of the leap lower their wings downwards and backwards and so using them as oars continue their slanting descent."

In one important matter he was mistaken, as the last part of this comment and other memoranda prove, for his comparison of the flying bird to the swimmer or the oarsman misled him as to the direction of the stroke. This was not surprising, for, since "the movement of the wings is twofold inasmuch as part of the movement descends towards the earth and part towards the place from whence the bird is flying," it was easy to conclude that "that part of the movement which is made towards the earth checks the bird's descent and the backward movement drives it forward." No, it is not surprising that the true direction of the stroke (forward-downward, upward-backward) of the rapidly vibrating wings of small birds was not detected. The slower motions of the kites and eagles were still too fast as well as too far away. It was an error that persisted and was not fully removed until modern photography presented irrefutable evidence. Leonardo did not even have field glasses.

When it came to the study of soaring and gliding flight, Leonardo's insight was no less keen. His understanding of the difference between the center of gravity and the center of support was the basis for many astute comments. He saw how, as the soaring bird rises, the wings are advanced so that "its center of gravity remains behind the center of its resistance," and that in descending they are retracted or flexed so that it is "outside" the center of support. He analyzed the play of forces that allows the bird to rise circling without a wingbeat, and he knew that it is able to hang motionless in the sky because it "arranges its wings so as to slant so much that the wind which strikes it below does not form itself into a wedge of such a kind as tends to raise it, raising it however just so much as its weight wishes to lower it. . . ."

Many other just and penetrating observations relating to flying with and against the wind, with maintaining equilibrium, gaining altitude, descending, banking, are expressed and repeated in different wording. He was aware of the function of the tail as rudder, stabilizer, brake, and producer of lift; and he was mindful of the problems involved in landing. "The opening and lowering of the tail," he wrote, "and the spreading out of the wings at the same time to their full extent, arrests the swift movements of birds."

When this great thinker turned from the study of the flight of birds to the practical problem of providing man with wings, his whole research centered on one idea, that of emulating the bird; and this for him meant the reliance on wings that flapped. All of his designs incorporated movable wings for which muscular effort supplied the motive power. Although he knew that the power of the flight muscles of the bird was far greater in comparison than that available to man, he thought that the bird had an excess of power over and above what it really needed and that man would be able to summon an amount sufficient for his needs. He declared, "A bird is an instrument working according to mathematical law, which instrument it is within the capacity of man to reproduce with all its movements, but not with a corresponding degree of strength, though it is deficient only in the power of maintaining equilibrium. We may therefore say that such an instrument constructed by man is lacking in nothing except the life of the bird, and this life must needs be supplied from that of man."

Leonardo can hardly be blamed for his reliance on muscular effort, for it was the only source of power there was, except water power and wind. It evidently never occurred to him to experiment with the stationary wings of the glider, although he understood the sustaining power of the bird wing and even applied it to his problem. "The bird acquires more lightness the more it spreads itself out and expands its wings to the wind. That body shows itself lightest which extends in greatest breadth. From this conclusion one infers that by means of a wide expanse of wings a man's weight can support itself in the air." The outstanding product of this line of thought was his invention of the parachute.

Neither did the idea of a lighter-than-air appliance have any place in his speculations, although Vasari said that he used to make hollow figures of animals out of a kind of waxy paste "entirely hollow and exceedingly slight in texture, which he then filled with air. When he blew into these figures he could make them fly through the air, but when the air within had escaped from them they fell to the earth." He invented also a contrivance which worked on the principle of the helicopter. It was a spiral surface which revolved about an upright post when a twisted spring was released. A drawing of it was accompanied by the explanation: "I find that if this instrument made with a screw be well made—that is to say, made of linen of which the pores are stopped up with starch—and be turned swiftly, the said screw will make its spiral in the air and it will rise high. . . . The framework of the above-mentioned linen should be of long stout cane. You may make a small model of pasteboard, of which the axis is formed of fine steel wire, bent by force, and as it is released it will turn the screw." But these devices were mere toys.

It was to be by means of an artificial bird that he believed man could be transported through the air; and when he set about determining what the actual size of its wing should be he used the pelican as a basis for his computation. Comparing, first, the length of its outstretched wings to its weight and, second, their width to their length, he decided that the span of man's wings should be twenty braccia and their width three. Since the braccio was about eighteen inches (the length of the arm from the elbow to finger tips), these dimensions can be translated into thirty feet and four and a half feet, respectively.

For a time he turned to the bat for guidance as to their construction. Its wing was the best model to follow, he thought, inasmuch as its membrane bound together the elements of the framework so perfectly. Wings of birds, he pondered, were more powerful as far as their structure of bone and sinew was concerned, since the feathers were so arranged that air passed through them. "But the bat is aided by its membrane, which binds the whole together and is not penetrated by air." Nevertheless, he soon designed a framework with a permeable surface, fitted out with appliances like little shutters which, as he put it, "cause the wing as it rises to be all pierced through and as it falls to be reunited."

His materials consisted of cane and fustian and starched taffeta. There were cords made of oxhide, well greased, and springs made with bands of iron or strips of cow's horn. When equipped with his wings, the man "should be free from the waist upwards in order to balance himself as he does in a boat in order that his center of gravity and that of the instrument might be able to balance and change when necessity required it according to the change in the center of its resistance."

It is not easy to trace in consecutive steps Leonardo's efforts to make man air-borne. It is thought that his first idea was to attach wings directly to the human body. If such is the case, he evidently found out very soon that chest muscles alone were not equal to the task of moving them fast enough. In any event he abandoned that plan in favor of one which consisted of a mechanism to which the operator harnessed himself lying face downward, extended at full length, somewhat like a boy on a coasting sled. The wings were jointed and were to be controlled by the feet by means of cords attached to stirrups. Working alternately, the right foot lowered them, the left caused them to rise. On second thought he decided that "the action of lowering the wings should be done by the force of the two feet at the same time, so that you can regulate the movement and preserve your equilibrium by lowering one wing more rapidly than the other according to need, as you may seen done by the kite and other birds. Also the downward movement of both feet produces twice as much power as that of one: it is true that the movement is proportionally slower. The raising is by force of a spring or if you wish by the hand, or by drawing the feet towards you, and this is the best for then you will have the hands more free."

This particular entry includes a suggestion that it would be well for the flier to try out this machine over a lake, equipped with a long wineskin worn as a girdle so that in case of a fall there would be no danger of drowning. In the *Treatise* another safety device for use over land is mentioned, a double chain of leather bags to be managed so that they strike the ground first.

The possibility of using a double set of wings instead of one pair was for a time considered feasible, and their control by both hands and feet was described. Then, as the result of further study, perhaps in the effort to obtain greater stability, Leonardo was off on another tack. "I conclude," he wrote, "that the upright position is more useful than face downwards, because the instrument cannot be overturned. . . . And the raising and lowering movement will proceed from the lowering and raising of the two legs, and this is of great strength and the hands remain free; whereas if it were face downwards it would be very difficult for the legs to maintain themselves in the fastenings of the thighs. And in resting [landing] the first impact comes upon the feet. . . ."

A drawing gives an idea of the apparatus that evolved from this trend of thought. It shows a man standing in the center of a low, circular, basin-shaped basket or car from the bottom of which two posts rise. The tops of the posts support a wheel around which cords are wound which raise and lower two pairs of wings working in opposite directions. The man, crouched between the posts, with hands, feet, and head operates the treadles and pulleys that move the wheel that moves the wings. Two ladders project from the floor of the car. Leonardo in his characteristic right-to-left script made two notations on the drawing, the one at the top asserting that "the man exerts with his head a force that is equal to two hundred pounds, and with his hands a force of two hundred pounds, and this is what the man weighs. The movement of the wings will be crosswise after the manner of the gait of the horse. So for this reason I maintain that this method is better than any other."

It may be said in passing that this Italian "libbra" was not the equivalent of our pound. At the bottom of the page is written: "Ladder for ascending and descending; let it be twelve braccia high, and let the span of the wings be forty braccia, and the body from stern to prow twenty braccia and its height five braccia and let the outside cover be all of cane and cloth." A note of precaution is added: "Make trial of the actual machine over water so that if you fall you do not do yourself any harm."

Although he was the first to present the principle of the parachute, Leonardo seems to have been unaware of its value as a safety device for the aviator. Perhaps this was because the operators of his machines had no chance of extricating themselves in case of mishap. He did see the advantage of flying high so that the apparatus could be righted should it be overturned by the wind, and he confidently expressed the opinion that it would be able to regain equilibrium "provided that its various parts have a great power of resistance, so that they can safely withstand the fury and violence of the descent, . . . and its joints should be made of strong tanned hide, and sewn with cords of very strong raw silk."

What are thought to be his most advanced ideas are incorporated in another sketch of an upright model and a plan of its base. The system of pulleys, cogwheels, and springs by which the jointed framework of the wings was to be manipulated is supposed to represent a great improvement over his other methods of utilizing human muscular energy.

Although Leonardo's interest in flight was keen and long sustained, and although he left a great mass of written record, the story of his accomplishment in the field of aeronautics is incomplete. One of the unfortunate omissions in the manuscripts as they have reached us is the lack of any mention of the actual trial flights which are supposed to have taken place. It is certain that numerous experiments were made with small models, as the following entry testifies: "Make a small one to go over the water, and try it in the wind without much depth of water over some part of the Arno, with the wind natural, and then as you please, and turn the sail and the helm."

Judging from other cryptic and fragmentary notations an attempted flight was supposedly made at Milan. One of these reads, "Tomorrow morning on the second day of January 1496 I will make the thong and the attempt"; and what appears to be a bit of corroborating evidence that such a thing was planned is contained in another entry which refers to the work of constructing a "model large and high" on a roof where "if you stand upon the roof at the side of the tower the men at work upon the cupola will not see you." Since the dome of the Cathedral of Milan was under construction at this time, this memorandum is thought to mean that work on Leonardo's machine was being done on the roof of a building in the line of vision of the men busy on the dome, from whose eyes he wished to shield his own project. A map of Europe sketched on the page that bears these words is thought to be an indication of what was in his mind—a vision of the possibilities to be opened up by his invention.

On the last page of the *Treatise on the Flight of Birds,* written in April 1505, he wrote, "From the mountain which takes it name from the great bird, the famous bird will take its flight, which will fill the world with its great renown." And on the inside of the back cover of that notebook, following a bit of bookkeeping, is a final entry, a restatement of the coming event: "The great bird will take its first flight upon the back of the great swan, filling the whole world with amazement and filling all records with its fame; and it will bring eternal glory to the nest where it was born."

The "mountain which takes it name from the great bird" of the first passage and the "great swan" of the second are both references to Monte Ceceri (*cecero* meaning swan), a mountain near Fiesole from which the trial was to be made.

It is from such meager hints as these that the record of Leonardo da Vinci's experimentation with flying machines must be extracted. Proof that a trial really did take place at some time or other rests on the laconic testimony of Jerome Cardan, a physician and philosopher, whose father was Leonardo's contemporary and an acquaintance of his during the stay in Milan: "Leonardo da Vinci also attempted to fly, but misfortune befell him from it. He was a great painter."

19

The Quest Resumed

> If the heavens then be penetrable, and no lets, it were not amiss to make wings and fly up; and some new-fangled wits, methinks, should some time or other find out.
>
> —Burton, *The Anatomy of Melancholy*

Leonardo da Vinci's experimentation and research came to nothing. His inventions failed and his valuable observations on the flight of birds were lost sight of for more than three hundred years. Their very existence was known to few and their eventual publication did not take place until late in the nineteenth century. The *Treatise on the Flight of Birds* did not appear in print until 1893. By that time flight by man was all but achieved.

The study of the air and of the bird's sway over it had to proceed as if he had never lived. Only the idea of a parachute was revived in 1595, and this may or may not have been inspired by his sketch and notation. In that year Fausto Veranzio in a book on new inventions described such a device, and the accompanying illustration with the title "Homo Volans" depicted a man jumping from a tower at the end of ropes fastened to the four corners of an oblong sail. The first actual recorded jump, made with a cone-shaped appliance of cloth or oiled silk fourteen feet in diameter, did not take place until almost two hundred years later, in 1783, when Sebastian Lenormand leaped into the air from a tower at Montpellier.

This was an epoch-making year. On June 5, 1783, the brothers

Montgolfier made the first balloon ascension and thus fulfilled the prophetic speculations of Francesco Lana de Terzi made about a hundred and fifty years after Leonardo's death. Lana, in 1670, expressed his belief that two methods of aerial navigation were possible: one by means of heavier-than-air appliances, the other constructed on the aerostatic principle. He even made a design that embodied his idea of how the lighter-than-air conveyance might be made. His airship consisted of a boat-shaped body sustained by four large copper globes each twenty-five feet in diameter, from which the air had been withdrawn so that they would be lighter than the surrounding atmosphere. A triangular sail was to take care of the steering and propulsion.

It was a purely theoretical conception, made without any attempt at experimentation. Since neither the air's pressure nor its specific gravity had yet been accurately measured, Lana had no way of knowing that such globes as he described could never withstand atmospheric pressure. As a matter of fact, in presenting his idea he did not look forward to any fulfillment of it. This was not because he was aware of the impossibility of success but because, envisioning all the devastation and horror the misappliance of its possibilities might entail, he was convinced that "God will not suffer such an invention to take effect, by reason of the disturbance it would cause to the Civil Government of men."

As far as any progress toward the solution of the heavier-than-air principle was concerned, the seventeenth, and the eighteenth century as well, contributed nothing. Nevertheless, the idea of the winged man was not to be dispelled. It was kept alive in both philosophical treatise and romance. In the *New Atlantis* of 1624 Francis Bacon put into the mouth of the philosopher of the fictitious Utopian society the statement that its members are able to imitate the flight of birds. Three years later in his serious speculations, *De Arte Volandi,* Friedrich Hermann Flayer opined, but without giving specific instructions, that men ought to be able to fly with wings as easily as birds.

About the same time Francis Godwin, Bishop of Hereford, wrote a romance, published posthumously in 1638, which dealt with a voyage to the moon by one Domingo Gonsales. This remarkable journey was made not on the traveler's own power, but with the help of a number of wild swans harnessed to what appears to be (in the engraving that illustrated the exploit) a most inadequate and uncomfortable seat, on which the hero sits precariously with his feet dangling in space. This means of air travel harkened back to the venture of Kai Kawus; but Gonsales' swans were not induced to undertake the journey (which took eleven days) by any ruse. As he found out afterward, they were making their normal migratory flight and in due season they brought him back to Spain again. The notion that birds migrated to the moon was widely held at the time, when the students of natural history were hard put to it to explain their annual disappearance. It was one of several curious conjectures advanced, and it was offered as plausible in a treatise on the subject published in 1703.

It is incredible, but nonetheless true, that the possibility of using large birds as a source of motive power was revived again and again. It was considered practical by M. Uncles in 1786 when he announced his plans for a balloon to be drawn by "four harnessed eagles, perfectly tame, and capable of flying in every direction at their master's will"; and he proclaimed his aspiration to be the "First Aerial Charioteer." As late as 1835 Thomas Makintosh proposed that "there is a mode by which balloons may be conducted (in moderate weather) with safety; and certainly this is to be accomplished by having a sufficient number of large birds, such as hawks—eagles would do better, if they could be tamed—but perhaps strong pigeons would do very well, and let them be harnessed to the balloon, to draw it along."

Godwin's tale was not the only romance in which the moon was made the objective of a fantastic flight. There was one by Cyrano de Bergerac and, much later, another by the Italian Filippo Morghen. In 1686 Fontenelle published his *Entretiens sur la pluralité des mondes,* a sort of popular-science treatise in which he wrote that the newly invented art of flying would improve by degrees and "in time grow perfect; then we may fly as far as the moon." Nothing had transpired to warrant this optimism.

Two actual attempts at flight had taken place in France in the latter half of the seventeenth century, the first in 1660 when Fontenelle was only three years old. It was made by a tightrope dancer by the name of Allard at St. Germain before Louis XIV. Allard affirmed that he would fly from the terrace toward the woods of Vesinet. He took off as planned but fell miserably. It is thought that his trial was made with the help of inclined planes of some sort and was to be in the nature of a glide rather than an attempt at flapping flight.

Eighteen years later, in 1678, Bésnier, a French locksmith from Sablé, concocted an extraordinary appliance by which he hoped to sustain and propel himself in the air, although he did not pretend that it would allow him to rise from the ground or proceed horizontally. It consisted of two long rods or bars of wood hinged and fastened or held across the shoulders, grasped by the hands in front and attached to the feet at the rear ends by means of cords. At the ends of the rods were affixed flaps—oblong frames covered with "taffety"—so contrived that they opened on the downstroke and folded edgewise as they were raised. They were seesawed up and down by the alternating action of hands and feet as in walking—that is, when the right hand pulled down the right "wing" the left leg lowered the left one, and so on. Bésnier is supposed to have learned to manipulate his invention by gradually increasing the height of his take-off, leaping first from a stool, then from a table, next from a window, until at length he bravely ventured to leap from a garret and sail over the roof of a neighboring building. He seems to have faded into obscurity after his one public exhibition.

In the eighteenth century allusion to human flight continued to occur in satirical, fanciful, and philosophic verse and prose, and it reflected the persistent interest in the elusive problem. Addison contributed an amusing satire on flight to *The Guardian*; and Richard Owen Cambridge, in a satirical poem, included an episode inspired by Bésnier's performance. One of the most celebrated pieces of prose was a bit of science fiction by Robert Paltock published in 1751. It was called *The Life and Adventures of Peter*

Wilkins and it narrated the exploits of the hero among an aerial race, whose wings were not mechanical devices but organic structures of their bodies. Composed of elastic membrane reinforced by riblike veins, they could be extended into rigid sails or brought "so close and compact to the body, as no tailor can come up to it." One of the copperplate engravings that illustrated the tale represents a woman of this strange race with her wings outspread. Extending the entire length of her body, the membrane is shown supported by parallel lateral ribs which diminish in length from shoulder to ankle and by a diagonal rib extending outward and upward from each shoulder. They were used for both swimming and flying.

Only a few years after Peter Wilkins' adventure appeared in print, Rasselas, Prince of Abyssinia, discussed the problem of human flight with the artist of the happy valley, by whom he was told: "I have been long of opinion that, instead of the tardy conveyance of ships and chariots, man might use the swifter migration of wings; that the fields of air are open to knowledge, and that only ignorance and idleness need crawl upon the ground. . . . He that can swim needs not despair to fly; to swim is to fly in a grosser fluid, and to fly is to swim in a subtler."

Some years later, in 1784, the year following the first balloon ascension, in a letter to Mrs. Thrale, Dr. Johnson referred to the construction of a flying machine then actually under way. He writes about "a daring projector, who, disdaining the help of fumes and vapours, is making better than Daedalean wings, with which he will master the balloon and its companions as an eagle masters a goose," and he goes on to say that "a subscription of eight hundred pounds has been raised for the wire and workmanship of iron wings—one pair of which, and I think a tail, are now shown at the Haymarket, and they are making another pair at Birmingham." The weight of the whole was to be about two hundred pounds, and Johnson adds that "there are those who expect to see him in the sky."

It is the opinion of J. E. Hodgson that the machine Johnson had reference to was the very one described in a postscript to a small treatise on *The Air Balloon* published in England the year before. He thinks the account of it is possibly the earliest extant description of a flying machine. It reads as follows:

> The second artist demands our wonder more, as he scorns the auxilary of an Air Balloon, and means to traverse the air in what direction he thinks proper, by the assistance of a machine in the form of a canoe, to which are to be attached a pair of artificial wings and a tail. This apparatus is now nearly compleated, the wings are nine feet by nine inches, the tail about a yard and a half long, both made of the purest elastic steel, and to be worked at discretion by the artist as he sits in his canoe. This wonderful attempt the Editor has seen and examined, through the courtesy of the Inventor who adds urbanity to a love of science. The wings are said to be constructed on the model of those of the West India crow; and the tail, though not so long, has somewhat of the plumage of a peacock. These the artist works with great facility, spreading and contracting both at pleasure, and he now only waits to commit them to the air till a second pair of wings are ready for him to use in case of any accident happening to the first.

Nothing more is known of this ambitious undertaking.

The serious efforts of those who were groping their way to an understanding of the phenomena of the physical world, the forerunners of modern science, were also mirrored in the literary products of the day. That both Paltock and Dr. Johnson were acquainted with the writings of Bishop Wilkins, widely read at the time, is obvious, for Paltock named his hero after the Bishop, and Johnson put into the mouth of Rasselas some of his observations in regard to the difficulties in the way of the attainment of flight by man. John Wilkins, first a teacher at Wadham College, next a Master at Trinity College, Cambridge, then Bishop of Chester, one of the founders of the Royal Society and its first secretary, published his speculations on flight in 1640 in a *Discourse concerning the possibility of a passage to the World of the Moon.* Eight years later they were amplified in a second book called *Math-*

ematical Magic, under the heading "Daedalus, or Mechanical Motions."

Presenting the three main obstacles to flight then recognized—the weight of man's body, the extreme coldness of the higher regions of the air, and its thinness—Wilkins concentrated on the solution of the first difficulty. It was a problem which would cease to exist, he thought, if once that higher region could be reached—about twenty miles up—where, as it was believed, the earth's "magnetical vigor" no longer operated. He referred to the idea advanced by Albertus of Saxony that on the "outward borders of this elementary air" a hollow vessel filled with "fire, or rather aetherial air" would float just as a boat floats on water, by the displacement of a heavier element. The problem of getting to this desirable region where the force of gravity no longer presented embarrassing opposition might be solved, he theorized, in one of three ways: by attaching wings to the body; by the help of a large bird; or by the creation of a "flying chariot, in which a man may sit, and give such a motion unto it, as should convey him through the air." A fourth method was added when he developed his ideas more fully in the *Mathematical Magic*. It was to be "by spirits or angels."

In discussing the use of artificial wings, he advocated constant practice and suggested "trying first to use wings, in running on the ground, as an ostrich or tame geese will do, touching the earth with his toes"; and he repeated a report of one who, on good authority, had been enabled in such an experiment "by the help of wings, in such a running pace, to step constantly ten yards at a time." Recognizing that arms would soon tire, he recommended that the work might be done by the feet, by nature more strong and indefatigable, in such a way that the motion of the wings "should be from the legs being thrust out, and drawn in again one after the other, so as each leg should move both wings, by which a man should (as it were) walk or climb onto the air." He offered no plans or specifications for the construction of the appliance; he did not deny there were difficulties, but he trusted they might somehow be overcome:

> For if the possibility of such a Motion be yielded, we need not make any scruple of granting the Difficulty of it; It is this must add a Glory to the Invention; and yet this will not perhaps seem so very difficult to any one who hath but diligently observed the Flight of some other Birds, particularly of a Kite, how he will swim up and down in the Air, sometimes at a great height, and presently again lower, guiding himself by his Train, with his wings extended without any sensible Motion of them; and all this, when there is only some gentle breath of Air stirring, without the help of any strong forcible Wind. Now I say, if that Fowl (which is none of the lightest) can so very easily move it self up and down in the Air, without so much as stirring the Wings of it, certainly then it is not improbable, but that when all the due Proportions in such an engine are found out, and when Men by long Practice have arrived to any Skill and Experience, they will be able in this (as well as in many other Things) to come very near unto the imitation of Nature.

As for the "flying chariot," he felt that it "might be made large enough to carry divers men at the same time, together with food for their *viaticum,* and commodities for traffic." He did his best to dispel the two main difficulties: the capacity of the air to support such a vehicle and the ability of the men inside it to supply sufficient motive power. In regard to the first, he astutely remarked, after having called attention to the fact that any body will float on water if it displaces more than its own weight, that air too will support bodies "if we suppose them to be extended into a proportionable Space of Air." It has been pointed out that this was an adequate statement of the lighter-than-air principle, based on Archimedes' law governing the flotation of bodies in fluids.

The work of Bishop Wilkins was entirely in the realm of theory and speculation. That of his friend and younger contemporary, Robert Hooke, was enlarged to include actual experimentation with model flying toys. There are no detailed records of his frustrated efforts—only his statement that in 1655 he made a model of a flying machine, which by means of springs and wings sustained itself in the air. It is just possible that this was the first model flying machine which really flew. It did not take Hooke long to discover both by trial and calculation the inadequacy of man's muscles, and he set about trying to find a way to make artificial ones, asserting in 1674 that he knew how to make "succedaneous muscles" which would supply this defect and give one man the strength of ten or twenty.

Following another train of thought, he wondered whether it might not be possible "to fit a pair of Wings for a Man to fly with, which may be contriv'd somewhat after the Manner of the long Fins of these flying Fish." Among his papers were found sketches and plans "for fastening succedaneous Wings not unlike those of Bats, to the Arms and Legs of a Man, as likewise of a Contrivance to raise him up by means of Horizontal Vanes plac'd a little aslope to the Wind, which being flown round, turn'd an endless screw, in the Center, which help'd to move the Wings. . . ."

It is quite possible that Hooke discussed the perplexing problem of muscular power with Francis Willughby, one of the first British ornithologists, a Fellow of the Royal Society and his exact contemporary. Willughby died in 1672 when he was only thirty-seven, but the record of his work is fortunately preserved in a posthumously published ornithological treatise brought out by his collaborator, John Ray. Willughby stated that the strength of a bird's wings is comparable not to that of a man's arms, but to that of the legs. By actually measuring the pectoral muscles of the bird he computed their strength and arrived at the conclusion that anyone who hoped to fly would have to adapt his wings so that they would be managed by the legs and not the arms.

Hooke probably heeded this advice which agreed perfectly with his own convictions, but there is no way of knowing if or how he applied it. Hooke has been called the greatest mechanic of his age and he was held in high esteem as an experimental scientist. He tried to study the resistance of the air by "shooting horizontally from ye top of some tower . . . several kinds of bodies" for the purpose of timing their descent; and he read a paper before the Royal Society on the subject. As secretary of this organization he began in 1679 the publication of the "Philosophical Collections" and in the first number contributed the first English translation of

Lana's description of his "aerial ship" as well as a reprint of a letter about Bésnier's attempt at flight made the previous year.

It is to be regretted that the two great seventeenth-century diarists, John Evelyn and Samuel Pepys, have made no mention of the speculations on flying or the experiments with wings that occupied the thoughts of Wilkins and Hooke, with whom they were both acquainted. Evelyn enthusiastically sets down as of July 13, 1654, the pleasant experience of having dined at "that most obliging and universally curious Dr. Wilkins's at Wadham College," and of being shown his transparent apiaries built like palaces from which honey could be taken without destroying the bees, and also many "artificial, mathematical, and magical curiosities, a waywiser, a thermometer, a monstrous magnet, conic and other sections, a balance on a demi-circle, most of them his owne and that prodigious young scholar Mr. Chr. Wren, who presented me with a piece of white marble. . . ."

In August 1666 Pepys said that he "discoursed with Mr. Hooke about the nature of sounds, and he did make me understand the nature of musicall sounds made by strings, mighty prettily; and told me that having come to a certain number of vibrations proper to make any tone, he is able to tell how many strokes a fly makes with her wings, (those flies that hum in their flying) by the note that it answers to in musique, during that flying. That, I suppose, is a little too much refined; but his discourse in general of sound was mighty fine."

Perhaps a discussion of that most visionary aspiration, human flight, would also have been "a little too much refined," yet it is scarcely to be imagined that it would not have delighted the ears of Evelyn and Pepys, both of whom were members of the Royal Society. Nevertheless, they seem to have been unaware of the extravagant expectations looming on the mental horizons of their illustrious associates.

In their studies and laboratories these English students and philosophers approached the problem of flight speculatively, while in France a tightrope dancer and locksmith blithely risked life and limb with preposterous appliances, apparently with utter disregard of theoretical considerations, in total ignorance of the physical laws involved. From such opposite poles of endeavor did these enthusiasts make their contribution toward the fulfillment of the fantastic prophecy of Mother Shipton, then recently published though uttered a hundred years before: "In the air men shall be seen," and of the cryptic oracles of her renowned contemporary Nostradamus.

20

Failures with Flapping Wings

> The vehicles [balloons] can serve no use until we can guide them; and they can gratify no curiosity till we can mount with them to greater heights than we can reach without; . . . The first experiment . . . deserved applause and reward. But since it has been performed . . . I had rather now find a medicine that can ease an asthma.
>
> —SAMUEL JOHNSON

THE truth which had been forced on Leonardo da Vinci at an early stage in his experimentation, which was perceived by both Wilkins and Hooke in their theoretical reflections as well as by Willughby in his ornithological study, and which may or may not have been understood by Allard and Bésnier as they crashed—the truth that man's muscles could not supply sufficient motive power for flapping wings—was proclaimed in unmistakable terms in 1680 by Giovanni Alfonso Borelli. In a treatise called *De Motu Animalium,* this Italian mathematician calculated the extent to which the motive power of pectoral muscles must exceed the resistance of the body in order to accomplish flight. By next comparing the bulk and weight of the muscles used by the bird in flapping its wings (which he computed to be one sixth of its weight) to those of man (which he estimated as less than a hundredth part), he concluded that, unless man could either increase the size of his muscles or decrease his weight, flapping flight would be for him impossible.

Borelli thus arrived at his famous deduction that "the Icarian invention is entirely mythical because impossible, for it is not possible either to increase a man's pectoral muscles or to diminish the weight of the human body; and whatever apparatus is used, although it is possible to increase the momentum, the velocity or the power employed can never equal the resistance; and therefore wing flapping by the contraction of muscles cannot give out enough power to carry up the heavy body of a man."

The disheartening confirmation of the inadequacy of man's physical powers checked, though it did not altogether put an end to, the attempt to fabricate wings. Yet the eighteenth century could do nothing to vindicate the stubborn refusal to accept Borelli's dictum as final. Its scientists, meanwhile, taking up the study of the air and natural phenomena where Hooke left off, contributed materially to the understanding of the physical world. Newton formulated the laws of motion. Other men studied the air's resistance to spherical bodies, calculated the sustaining power of the kite, and discovered the important fact that the pressure of the air on an inclined plane moving through it varies as the square of its velocity. As the century closed, Thomas Young studied the effects of air currents on suspended curved surfaces. But there was no application of the scattered bits of knowledge and no accumulation of data on which any real science of aerodynamics or aeronautics could be founded. Moreover, there was no way to make any practical application of the principles that did result. Human power, however inadequate, still seemed to be the only power available.

So when, in spite of deterrents, in spite of the satire and ridicule heaped on it, the chronic ambition to fly manifested itself sporadically the old methods held. All attempts to imitate the bird continued to be based on designs for flapping wings attached directly to the human frame or to flying chariots.

One of the most famous of the eighteenth-century performances was that perpetrated in Paris in 1742 by the Marquis de Bacqueville. Little is known about the means he employed except that he fastened wings of some sort to his arms and feet and trusted to their support as he leaped from a building at the corner of the quay and the Rue des Saints Pères and tried to fly across the Seine. He hoped to traverse a distance of five or six hundred feet and land in the Tuileries, but came down instead on a barge moored in the river.

Various designs for aerial conveyances were made, although few were actually constructed and none was put to the test. The Abbé Desforges of Etampes constructed a flying carriage in 1722 which consisted of a car of wickerwork fitted with wings. With commendable foresight he mounted a parasol above the apparatus to serve as parachute in case of need; but this, it goes without saying, was an unnecessary precaution. When the time came for the actual trial, four men held aloft the carriage, with the abbé in it, while he flapped its wings vigorously. His best efforts came to nothing; it could not move.

A *"vaisseau volant"* was built in 1781 by Jean-Pierre Blanchard. It was a sort of car fitted with four wings which were to be moved by levers controlled by the hands and feet of the operator seated inside and steered by a rudder activated by the movement of his body. It too was equipped with a parachute. Blanchard believed that "it is not the material or form of wings which causes flight, but the volume and celerity of movement which should be as rapid as possible"; but it is likely that he very soon realized the impossibility of his undertaking. He afterward confessed that these wings only agitated "an indocile element, with no more effect than those of a heavy ostrich." Blanchard, disappointed and disillusioned for a time, revived his interest in aerial navigation a few years later and directed his energies into new channels. His thoughts, like those of many others, were withdrawn from the quest for winged flight and centered on the then newly invented balloon. In this field he was eminently successful.

It has been pointed out that the experiments of the Abbé Desforges and Blanchard with flying carriages and the trials of De Bacqueville and others who sought to outfit themselves with alar appliances revealed the "two horns of the dilemma that confront inventors who endeavor to provide man with wings to be worked by his own muscular power." If the wings were small enough to be waved rapidly, they did not provide sufficient supporting area; and if they were made of a size approximating the proportion of a bird's wing, they were so large that they could not be made to move fast enough.

An architect of Karlsruhe, C. F. Meerwin, meanwhile, also was discovering this truth. His apparatus consisted of two light wooden frames covered with calico, hinged at the center, and shaped like the longitudinal section of a spindle. Of a truly scientific turn of mind, Meerwin had at least approached the problem very logically by trying to determine the actual amount of wing surface needed to support a man. Using the weight and wing area of a wild duck as the basis for his calculation, he decided that an area of about a hundred and twenty-six square feet would be sufficient to sustain a machine and a passenger weighing two hundred pounds—an estimate that was later verified by Otto Lilienthal, the great pioneer of gliding flight.

In a purely theoretical study of flight, A. J. P. Paucton, a French mathematician, conceived the idea of what he called a "pterophore," announcing it to the world in a treatise published in 1768. He proposed a flying machine equipped with two mechanical propellers, one to lift it vertically and the other to send it on a horizontal path. It was never constructed; but a few years later, in 1784, two of his countrymen, a naturalist by the name of Launoy and a mechanician named Bienvenu, collaborated in the creation of a device which embodied his idea. It was a small model made of feathers, string, and whalebone. At each end of a rod four feathers were arranged to form a screw about a foot in diameter; the rod was made to revolve as a cord twisted around it was rapidly unwound by the tension of a bow of whalebone made taut in the winding. Exhibited before the French Academy of Science, it rose in the air and afforded what was probably the first practical demonstration of the underlying principle of the helicopter and the airscrew.

The idea of flapping wings motivated by muscular energy cropped up again and again even far into the nineteenth century—even after it was evident that greater hope for success lay in a different kind of wing. Perhaps it was to some extent fostered by Thomas Walker in his *Treatise on the Art of Mechanical Flying* published in 1810. This obscure English artist expressed confidence in the possibility of propulsion by means of wings driven by muscular power aided by mechanical means, but the methods he used for applying manual power were entirely inadequate. Twenty years later Walker revised his design, using "flat passive surfaces large enough to reduce the force of gravity" at the front and rear of the machine, with flapping wings between them. He then theorized that if this did not work, hydrogen might be introduced into the wings to "increase the sustaining power."

Several imprudent inventors, aware of the fact that their movable wings could not raise them, nevertheless still trusted to them to carry on once they were under way, and saw in the balloon the means of getting up into the air to begin with. Thus Jakob Degen, a clockmaker of Vienna, made a machine with two umbrellalike wings shaped like poplar or aspen leaves. Their silken surfaces were made in bands fastened to the frame so as to open and close as the feathers of birds were thought to do. With this device he was able to rise with the help of a small balloon, which lifted over half the total weight. His experiments were carried on for several years and in 1812 three inept exhibitions made in Paris resulted only in his being blown away and, on the third trial, of being attacked by disappointed and irate spectators.

Later in the century two other men made lamentable attempts to fly or glide to earth after being raised suspended beneath a balloon. The appliance of the Frenchman Latur was rather like a great umbrella-shaped parachute beneath which he sat and, with hands and feet, worked movable wings and tail. That of the Belgian shoemaker, De Groof, vaguely resembled one of Leonardo's designs. The operator stood on a little platform within an upright framework to which wings and tail were attached. When De Groof cut loose from the balloon the wings, unable to withstand the pressure from beneath, collapsed overhead.

An engraving entitled "Aerostat worked by Manual Power" illustrated an aerial device of the ornithopter type designed by W. Miller in 1843. It represents a gentleman standing upright on a small platform and with his hands working levers which activate wings hinged to a frame that fits about him somewhat like a life preserver. The plan and descriptive text in the margin of the print explain the details of construction. The wings, with a spread of about seventeen feet, were to be of oiled silk stretched over a framework of hollow cane, of which the thick front edge was curved both horizontally and vertically, and the transverse ribs were tapered off toward the rear edge to make it flexible. Into the description is inserted the remark that the wings of birds have a yielding rear edge and that it is due to this peculiarity that they are able to fly. In addition to the wings there were two "passive surfaces," also made of silk and cane, one, curved and inflexible, attached to the frame in front of the aeronaut and the other, thin and yielding, projecting at the rear. The initial headway was to be effected "by running rapidly along an inclined plane or horizontally towards a brink" five or six feet high. With sufficient momentum gained, the operator was supposed to hop onto the footboard suspended from the encircling frame, and then to oar his way along.

Several Frenchmen added to the number of strange and futile designs. One submitted by Bréant in 1854 featured two wings, each about fifty-four square feet in area, fitted with three valves to relieve the pressure on the upstroke. This was to be accomplished by means of elastic cords. For the downstroke both feet and hands were to be used. In 1866 Bourcart undertook experiments, which he was forced to abandon, with an appliance made with four wings so arranged that they cut through the air edgewise on the upstroke and presented their broad surfaces in their descent. The operator, standing, worked the wings with his feet. The standing position of the aviator was adopted also by Dandrieux when, in 1873, he invented a pair of wings supposedly inspired by the ideas of Pettigrew in his then recently published *Animal Locomotion*. Pettigrew proclaimed the fact (as did Marey also in his *Animal Mechanism* and other publications) that the wing tips of birds and insects describe a figure-of-eight motion; and Dandrieux, taking his cue from this, attached the wings of his apparatus to an oblique axle so that they would duplicate such an action. Again results were negative.

In his cogitations on mechanical flight Pettigrew clung to the idea of flapping wings and so did numerous inventors who were trying to find a way to use the steam engine as a source of power. Invented by James Watt in 1768, the steam engine had by 1829 been applied to the cause of locomotion, and though its adaptation for use in the air presented insurmountable difficulties, still this demonstration of the use of a new source of power opened up fresh possibilities for the imagination of the designer of wings to play with.

Pettigrew reviewed the advantage of using four wings "so arranged that the two which are up shall always by their fall mechanically elevate the two which are down. Such an arrangement," he said, "is calculated to conserve the driving power, and, as a consequence, to reduce the weight."

A design for a four-winged machine with one pair of wings arranged behind the other—it looked in plan somewhat like a dragonfly—was made by Prigent in 1871. The wings were to be driven by steam, although whether the two pairs were to flap alternately or in unison is not clear.

A few years later a scheme for an "Anthropornis" was submitted by De Louvrié which consisted of one pair of wings shaped like those of a swallow and hinged to a body mounted on wheels. A steam engine or petroleum motor was suggested as a source of power. Another design, made in 1890 by E. P. Frost, used wings constructed to imitate those of the crow and to assume different positions during the stroke. A model was made, but attempts to obtain a suitable engine failed. Two Russians, Struvé and Telescheff, designed a machine with five pairs of wings, arranged one pair behind the other, and fastened to a central supporting surface which was to accommodate the human activator or the mechanical mover.

None of these proposed mechanisms was ever actually tested, for the steam engine was far too heavy and cumbersome to be of any use; and when an English experimenter, F. D. Artingstall, tried to study the effects of the mechanically powered wing by suspending a lightweight steam engine from the ceiling, it activated the slatted wings which he had contrived so forcibly and discordantly that the machine was whipped about in all directions. An explosion put an end to the experiment as well as to a second trial when four wings were used.

Perhaps the most promising experiments with flapping wings were those made by the Australian, Lawrence Hargrave, who succeeded in making several successful monoplane models driven by compressed air. One of these in 1891 flew for a distance of a hundred and twenty-eight feet. Hargrave was forced to give up the idea of building a large machine for want of a suitable engine, and he transferred his interest to the box kite, also his invention, with which he experimented with gliding flight.

Although the search for a motive power to sustain and propel the full-scale model seemed a hopeless quest, many small models, toys, were successfully made and flown. Clock springs and twisted rubber bands were the usual motivating agents, and some of the mechanical "birds" flying for a few seconds, over a few yards, were useful in helping to focus the attention of students of flight on the question of equilibrium. However, the various glimpses of the technique of winged flight so obtained could not be pursued on full-scale wings because there was "no motor sufficiently light, in proportion to its energy, to take the place of the rubber bands."

Every attempt to accomplish human flight with beating wings failed. Muscular energy was inadequate and engines with sufficient power were too heavy. The question of the amount of power needed was an important one, and those who tried to answer it turned again to the bird and tried to compute the amount of work, in foot-pounds, it expended in flapping its wings. Foot-pounds were then translated into horsepower to determine the size of the engine. In a general way, the amount of energy needed depended, it was clear, on the relation of the area of the wings to the weight to be borne; but this was not the whole story. It was easy enough to make these measurements, and it was possible by dissection to measure and weigh even the flight muscles which produced the movements of the wings of any given bird. It was not so easy, however, to determine other factors such as their rate or degree of contraction. While it was a simple matter to count the beats they measured off, the amplitude of the stroke was a less obvious and also a variable matter. In the laboratory a bird might be harnessed to an apparatus which timed both the upbeat and the downbeat separately, and recorded speeds; but such information had little or no bearing on what took place in the moving currents of the open air with their sustaining and retarding powers.

The extent to which the ingenuity of the investigators was taxed can be judged by the one who measured with a dynamometer the strain exerted by a twelve-ounce pigeon flexing its wing when excited by an electric current, and by another who, ascertaining the volume of carbon dioxide exhaled by a bird at rest, and then, assuming from experiments with other animals that it would give out three times as much in full flight, reckoned that the effort expended was one hundred and five foot-pounds per minute per pound of bird.

Since it was obvious that birds worked harder at some stages of their flight than at others, attempts were made to gather data relating to this fact. It was estimated, for instance, that a pigeon weighing somewhat less than a pound exerted one thousand and eighty-five foot-pounds per minute when hovering and only one hundred and nineteen in flight. It is perhaps needless to say that there were almost as many estimates of the work done by the bird in flight as there were theorists who made them, so that Octave Chanute as late as 1893 declared that "until a bird is taught to tow behind him some dynamometric arrangement at a regular rate of speed, and on a level course, it will be difficult to settle exactly what are the foot-pounds expended in ordinary flight."

The study of flapping wings had thus led nowhere. Fortunately some birds are borne in splendid flight on wings that do not flap.

21

Hope in the Inclined Plane

> Soon shall thy arm, unconquered steam! afar
> Drag the slow barge or drive the rapid car;
> Or on wide-waving wings expanded bear
> The flying chariot through the fields of air.
>
> —Erasmus Darwin, *The Botanic Garden*

It was natural and logical that those who were determined to fly should look to the birds for guidance—birds flew about everywhere so cleverly, often so effortlessly. It was indicative of the power of that persisting allure of the skies that, as the action of the beating wings eluded analysis (and imitation), aspiration did not die. Even as the hope of acquiring the wings of the dove faded, it was becoming gradually apparent to many that a different kind of flight might be possible.

The foundations for it had already been firmly laid at the very beginning of the nineteenth century by Sir George Cayley when, in 1809, he published his essay "On Aerial Navigation." Viewed in the light of subsequent events, this essay is seen to mark the turning point in man's struggle to achieve functional wings of his own, although the ideas it presented were not developed immediately.

Both by observation of flying birds and by laboratory investigation of air resistance Cayley not only added to the existing fund of knowledge but interpreted it as no one had yet done. Moreover, he organized it into principles which formed the very basis of the science of aeronautics. He saw what had been noted by previous observers and what was to be increasingly evident to later ones that, once up, birds expend less energy to keep going than they do to begin their flight; and he was led to believe, like Wilkins, that in full flight they expended far less than was commonly supposed. He realized that in full flight the wingbeats were used mostly to propel and that support was derived from the air itself. When he studied the air's resistance to surfaces moving through it horizontally he discovered that an inclined plane one square foot in area met a resistance equal to four ounces when it traveled at the rate of something over eleven and a half feet per second and that the resistance doubled when its velocity was increased to only a little over seventeen. Reappraising bird flight in the light of such knowledge, he estimated that a gliding rook (with a wing loading of about a pound to the square foot) would be able to keep to a horizontal path when its speed reached a little less than twenty-five and a half miles an hour. In an epoch-making statement he declared that the problem of mechanical flight was "to make a surface support a given weight by the application of power to the resistance of the air."

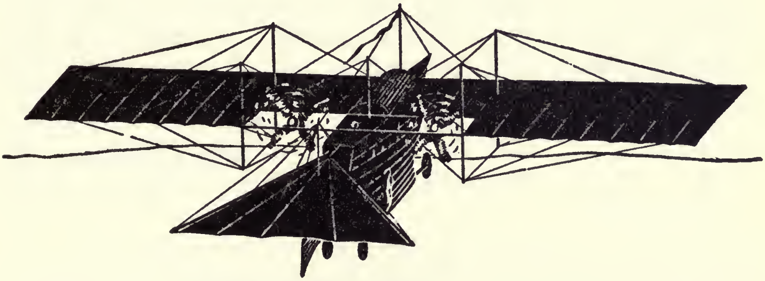
Cayley discarded utterly the idea of trying to imitate the beating of avian wings, and he heartily endorsed Borelli's contention that human energy could never supply sufficient motive power. However, he left the way open for the eventual solution of the problem of human wings by admitting the possibility of the application of mechanical power to fixed surfaces such as the apparently static wings on which birds glide and soar.

His own practical experimentations with mechanical flight took various forms. They began in 1796, when he was only twenty-two years old, with the creation of a toy (a "Chinese top" he called it) made on the same helicopter plan that had been demonstrated by Launoy and Bienvenu twelve years before; and he later combined helicopter and airscrew with lighter-than-air principles in several designs for "aerial carriages." These fell short of practical application. But when he made trials with a gliding apparatus with a supporting area of three hundred square feet (details of its construction are lacking) he was able to say, "It was very beautiful to see this noble white *bird* sail majestically from the top of a hill to any given point of the plain below it, according to the set of its rudder, merely by its own weight, descending in an angle of about 18° with the horizon." He recorded that at times the lifting power was so great that the person running with it into a light breeze would be lifted from the ground for several yards.

He continued to experiment with the wings of gliders until within a few years of his death in 1851; while his thoughts ranged over the possibility of using superposed wings, with the advantages of diagonal bracings for them, with streamlining (". . . every pound of direct resistance, that is done away with, will support thirty pounds of additional weight without any additional power"), and with the great unsolved enigma of producing a "prime mover," on which all depended. As he pondered the difficulties in the way of adapting the steam engine to use in the air, this great innovator toyed with the idea of a gas engine.

Several factors combined to postpone experimentation along the lines indicated by Cayley's genius: the unfitness of the steam engine, the continuing preoccupation with flapping wings and human motive power (prolonged perhaps by Walker's treatise of 1810), and the absorbing problem of making the balloon dirigible. The century was in its middle years before the first attempt was made to contrive stationary wings to be driven through the air by mechanical power.

It was in 1842 that a design based on such an idea was patented by William Samuel Henson. The first monoplane with rigid wings, mechanically driven by propellers turned by a steam engine, and controlled by tail and rudder, it incorporated all the facts of aerodynamics then known and most of the features to be tested and developed by later designers. Henson's collaborator in the project, John Stringfellow, occupied himself mostly with creating the engine which they hoped to use in a full-sized machine. The plans for this included square-tipped wings of canvas or oiled silk stretched on a light but rigid, trussed frame one hundred and fifty feet long and thirty feet wide. A sort of sail or "keel cloth" mounted transversely at the center was added for the purpose of helping to keep the machine on its course, and this was attached to upright posts or masts projecting upward from a car slung below in which the engine, supplies, and, possibly, passengers were to be placed. The two rotating propellers were mounted behind the wings. The large triangular tail and a rudder were to contribute to the control. The machine was not asked to raise itself. It was to be launched by being sent down an inclined runway to acquire the necessary initial velocity. After this had been gained the rotating propellers were supposed to take over and keep it going. Just how the landing was to be made is not clear.



THE ARIEL.

Henson called his invention the *Ariel.* So great was the confidence of the inventors in the proposed mechanism that they sought to raise funds by public subscription and to organize a company to develop the idea in the full-sized machine; and when these efforts failed they continued to work by themselves to perfect it. Cayley criticized the design on the ground that too much stress was put on too light a structure and suggested superposed planes. Henson himself admitted that "mechanical science is notoriously defective in all that relates to the impact of solids and fluids"; but as far as the proportion of wing surface to weight to be borne was concerned, he believed that the weight of his machine was "considerably less per square foot than that of many birds."

Three years later an improved model was tested. Its wings were twenty feet from tip to tip and three and a half feet wide. The engine motivated two four-bladed propellers each three feet in diameter. The whole weighed something over twenty-five pounds. The test, made on the downs near Chard in Gloucestershire at night in order to avoid the attention of obtrusive bystanders, was later described by Stringfellow:

> There stood our aerial *protégé* in all her purity—too delicate, too fragile, too beautiful for this rough world; at least those were my ideas at the time, but little did I think how soon it was to be realized. I soon found, before I had time to introduce the spark, a drooping in the wings, a flagging in all the parts. In less than ten minutes the machine was saturated with wet from a deposit of dew, so that anything like a trial was impossible by night. I did not consider that we could get the silk tight and rigid enough. Indeed the framework was altogether too weak. The steam engine was the best part. Our want of success was not for want of power or sustaining surface, but for want of proper adaptation of the means to the end of the various parts.

After this experience, in which Cayley's judgment was upheld, Henson, discouraged, unaware of the value of his efforts, migrated to America and disappeared "in the wilds of Texas," while Stringfellow doggedly continued to work on by himself.

In the effort to gain financial backing for the company which was to "work and prove the Patent," the *Ariel* had been widely publicized, largely through a pamphlet giving "Full Particulars of the Aerial Steam Carriage Which is intended To Convey Passengers, Troops, and Government Despatches To China and India, in a few days." The failure of the commercial enterprise by no means put an end to the notoriety. Many were the jibes leveled at the ambitious undertaking, some of which now are seen to have been unintentioned auguries of the future. Such were the verses of a broadside entitled "The Aërial Ship! or A Flight of Fancy" printed in 1843, which contained the couplets:

It matters not, I understand, whichever way the wind is
They'll waft you in a day or so, right bang into the Indies!

and

Or you may dine in London now, and then, if you're romantic,
Just call a ship and take a trip right over the Atlantic.

A souvenir linen handkerchief of the same year bore a caption—"The Flying Steam Company, To China in Twenty-four Hours Certain"—above a design depicting the *Ariel* and a panoramic view of its supposed route. In the far distance London can be distinguished, and Gibralter, and, progressively nearer, Malta, the Suez, Egypt (with pyramid and palm trees) and, in the foreground, a glimpse of China with the emperor and his court. At intervals along the way passengers are shown swinging from parachutes as they descend at their destinations; and a ship's officer, standing in the rigging of the mast, delivers orders to a mate on the wing below him. He shouts:

> Hallo! Bill Jackson keep your eye on Malta and get the parcels ready Waken the old lady in No. 7 drop the Pacha of Egypt's dispatches Tie a 56 to the Suez post bag or it will be blown into the Mediterranean. Tell the Bombay Gent. in No. 5 to have his parachute in readiness, tie his Hat on, shut his mouth, and keep a fast hold as it's blowing a stiff breeze. Keep a sharp look out for Pekin and get the Emperor of China's letter ready as we shall drop on his Palace directly.

Undeterred by the nonsuccess of the *Ariel* and by Henson's departure, Stringfellow worked on persistently and in 1848 succeeded in creating the first power-driven model flying machine that actually flew. Its wings, not square-tipped but slightly curved at the forward edge and tapered to a point, were ten feet from tip to tip and two feet across at the widest part, rigid at the front edge, "feathered" at the rear, and slightly curved on their under surfaces. It was provided with a tail and two four-bladed propellers mounted behind the wings, and with the small improved engine. The whole thing, including water and fuel, weighed less than nine pounds. A long room in an abandoned lace factory at Chard was used for the trial, and the model was started off along an inclined wire stretched part way of its length. On the second attempt, the first having failed because the tail was set at too high an angle, the model began the descent and "upon reaching the point of self-detachment, it gradually rose until it reached the farther end of the room," where a canvas had been stretched to stop it. In a later demonstration at Cremorne Gardens in London it covered a distance of forty yards before being stopped by the barrier. Both of these experiments took place indoors and it is the general opinion that they would not have succeeded in the open air, for, while the yielding rear edge of the wings provided enough fore-and-aft stability, the lateral equilibrium could not have been maintained in the slightest gust.

To the first aeronautical exhibition, held at the Crystal Palace twenty years later, Stringfellow sent a triplane model, which again revealed his inventive skill, for it marked the first time that anyone tried to use superposed surfaces in a steam-driven machine. No attempt was made to fly it.

It is quite possible that this model was inspired by a paper on "Aerial Locomotion and the Laws by which Heavy Bodies impelled through the Air are sustained" read before the Aeronautical Society of Great Britain two years before (in 1866) by Francis Wenham. This essay was another milestone in the study of air and its effects. Not only did Wenham recapitulate Cayley's theories; he established the fact that the air's pressure on inclined surfaces moving rapidly through it is greatest near the front or "leading" edge and that, therefore, a long narrow surface is advantageous. He suggested the possibility of superposing such wings, which he designated as "aeroplanes." Furthermore, he declared that a plane slightly concave at the front edge would derive more support from the air than a perfectly flat one: that "the whole secret and success in flight depends upon a proper concave form of the supporting surfaces." Wenham published his article midway of his long life, and before he died in 1908 at the age of eighty-four he had witnessed man's arrival at his winged estate. His theory of the greater lifting power of the cambered wing was developed and formulated by Horatio F. Phillips in 1884.

Before this stage had been reached, however, many other plans had been drawn for appliances with stationary wings to be propelled by mechanical power. While the results were inevitably negative as far as performance was concerned, they bore witness to the unflagging interest and exertion of inventors.

One of the most promising designs was patented by the French engineer and naval officer Félix du Temple in 1857. It called for a pair of wide-spreading wings of silk, triangular at the tips, stretched on a curved framework of cane or metal and fastened to a boat-shaped car. To the car were attached folding legs with wheels at the ends—in effect, a retractable landing gear. Du Temple had not been insensible of the need for stability, and in an effort to attain it had, among other things, arranged that the wings could be adjusted: a slight dihedral angle could be obtained during flight and the rear edges were flexible. There was a horizontal hinged tail and a vertical rudder beneath it, and a large propeller mounted in front of the machine to pull it forward. It rested on the ground with an upward slant (for the front legs were longer than the rear ones), and it was supposed to rise of its own accord when its propeller drew it forward at the rate of twenty miles an hour. Du Temple underestimated the amount of power necessary to attain this result; and another flaw was that lateral stability could not have been maintained even if the machine could have begun a flight.

At about the same time a design patented by Viscount Carlingford displayed wings shaped rather like those of a falcon when partly flexed. They also were attached to a boat-shaped car pulled by an "aerial screw." The machine was to be launched by the hazardous method of suspending it between two poles and then allowing it to fall on the air.

A small model, which its author Alphonse Pénaud called a "planophore," motivated by twisted rubber, made a successful horizontal flight of twenty seconds' duration in 1871. The outstanding feature of its design (which was never tested in a full-scale model) was the way in which its equilibrium was attained. The demonstration was made in the Tuileries gardens and takes its place in the history of aviation as being the first model flying machine ever to be flown in public.

There were many proposals to use stationary surfaces, flapping wings, and screw propellers in various combinations. A scheme originated by Aubaud in 1851 called for stationary planes for support, rotating screws above them for ascending power, and vibrating wings for propulsion. Tubes containing compressed air were to serve both as legs and shock absorbers at landing. Presumably this inventor realized that, in order to land safely, provision would have to be made for sustaining the weight of the machine during descent, which he proposed to do by means of the screws. Another French design made use of a supporting plane and four rotating wings for propulsion; and still another, that of M. Danjard, provided a sort of parachute at each end of the body of the apparatus between which were two widespread sustaining aeroplanes, and, between these in turn, centrally located along the length, a pair of vibrating wings.

An engineer of Glasgow by the name of Kaufmann mounted a steam engine on wheels and attached horizontal superposed planes for support and above them placed two long flapping wings so set that they turned at a forward angle during the upstroke and backward on the descent. It failed, of course, on trial. In England a patent was obtained by Smyth on a machine which consisted of a cylindrical car, pointed at the ends, equipped with two silk-covered planes (one in front and the other behind) and two lifting screws (one above, the other beneath the car) and still another screw to propel. Then there was an "aerial steamer" created by Thomas Moy in 1875 which consisted of two flat supporting surfaces, situated fore and aft of the propelling agents. These took the form of two large wheels, six feet in diameter, each made up of six blades arranged like spokes, each blade, in turn, composed of a number of thin laths placed crosswise. The blades changed their angle to the air as the wheels rotated. There was also a horizontal rudder. The large model, which was actually fashioned on this plan, did not rise.

The United States was not without its eager inventors. In 1882 a flying machine was patented by a Mr. Krueger which Octave Chanute describes in his book *Progress in Flying Machines.* It consisted "of three flat horizontal planes set one behind the other, the front one being triangular in plan, while the rear one might be shaped like the tail of the swallow. These were to be adjustable, as to guide the machine up or down. Beneath them was to hang a ship or vessel, and above them were to be set still other planes, sloping like the two sides of a roof, in order to act as a parachute. Four propelling screws were to be arranged between the three sustaining planes, while four adjustable keel cloths, vertically affixed both above and below the sustaining planes, were to steady the course and to furnish the steering power. No particular motive power was proposed, and no method indicated for maintaining stability. . . ." Chanute comments on how "misguided ingenuity sometimes runs to complications, while leaving untouched the really essential requirements."

These essential requirements were, in addition to the still unattainable lightweight engine, wings that assured sustaining power and equilibrium.

The labors of Horatio Phillips contributed to the attainment of the first of these requisites. In laboratory experiments with a sort of wind tunnel he watched the effects of a jet of steam played over surfaces of different curvatures, and tried to assess accurately the ratio of lift to drag afforded by each shape. He was the first to detect the part played by the lowered pressure formed over the top of the cambered surface, but he did not explain this by Bernoulli's principle. He thought that air meeting the leading edge bounced off it and so created the partial vacuum which increased the supporting effect.

Phillips published the results of his study and patented a series of profiles of the surfaces he deemed suitable for wings of powered machines. He went further and applied his theories by trying out various arrangements of multiple surfaces and by constructing a full-sized steam-driven machine. This was a curious thing resembling a huge Venetian blind mounted on a wheeled body, for its supporting surfaces were fifty narrow wooden strips placed one above the other. They could hardly be called wings. They proved their lifting power, however, by raising the contrivance three feet from the ground when it was sent pilotless, and tethered to prevent its escape, round a circular track for two complete circuits.

This demonstration was made in 1893, and the next year witnessed the culmination of the most pretentious of all experiments with superposed wings, the prodigious creation of Hiram Maxim.

A great upsurge of interest, a renewal of confidence in the practicability of the flying machine, took place about 1889. The invention of the internal-combustion engine, patented by Gustav Daimler, its inventor, in 1887, no doubt was partly responsible. At all events, many inventive minds were attracted by the still evanescent vision of human flight; and the inventor of the machine gun was one of those who felt the lure to such an extent that he took time out from his other activities to see what he could do. In the course of his other pursuits, Maxim had come to some valuable conclusions about air currents. He had seen eagles in the Pyrenees and gulls at Cadiz taking advantage of ascending columns of air and he had watched these as they followed boats floating on updrafts formed by currents deflected from their sides.

In his book *Artificial and Natural Flight* he voiced his very just conclusions about the nature and directions of air currents, and accounted for soaring flight on the theory that the bird is in reality falling through a rising column of air. But he disagreed with the premise of Otto Lilienthal (whose experiments with soaring flight were then under way) and averred that man would never be able to imitate the flight of soaring birds because he could not hope to make a sensitive apparatus that would work fast enough to take advantage of the changeable currents. He therefore insisted on a power-driven machine which should be propelled through those currents "after the manner of ducks, partridges, pheasants, etc." He did not mean by this, however, to subscribe to the idea of wings that flapped.

Maxim set about collecting his own data on the air's resistance to different surfaces. "I think we must all admit," he said, "that a wide plane is not as economical in power as a narrow one." He stated specifically that a surface ten feet square will not lift half as much for the energy consumed as one two feet wide and fifty feet long. Developing further this idea that length of wing as well as area is important and that the length of the front edge should bear a definite relation to the weight to be carried, he decided that for speeds of forty miles an hour or less there should be at least one foot of entering edge for every four pounds of weight to be carried. It was on this basis that he computed the dimensions of the supporting surfaces of his colossal machine.

To support the two steam engines (which he had himself designed) and the necessary water and fuel, one pair of narrow wings would have had to be very long indeed; but he saw no objection to cutting the long surface up, as it were, and placing the sections one above another. He planned five pairs of long narrow planes, square-tipped, superposed, and attached to the framework at a slight dihedral angle, which could be adjusted in the interests of lateral stability. The surfaces were mildly concavo-convex, for he understood the value of the pressure differences they created (although he disagreed with Phillips as to the cause), and they were mounted at a small upward slant. They reached out in a span of a hundred and four feet. There was also a great central plane, almost a roof, below which the five pairs of narrow wings protruded; and horizontal rudders were added fore and aft. No trial was ever attempted with all five pairs of lateral planes in position, but even with only two pairs—the upper and lower ones—the total lifting surface was four thousand square feet. The total weight to be borne, including the weight of three men, was about eight thousand pounds.

A great deal of money and several years' work went into the construction of the machine, and before it was completed its author granted an interview to the New York *Sun* in which he explained: "The machine is made with its present great length so as to give a man time to think; its length makes it easier to steer and to change its angle in the air. Its quantity of power is so enormously great in proportion to its weight that it will quickly get its speed. It will rise in the air like a sea-gull if the engine be run at full speed while the machine is held fast to the track, and if it is then suddenly loosened and let go." In the actual trials, Maxim by no means wished it to rise like a gull; and he took precautions to keep it from doing so.

A railroad track a half mile long was used to launch the gigantic machine, and it was fitted with a set of heavy iron wheels for this purpose. To keep it in tow, a stout wooden "safety track" was built on either side of the steel rails and two feet higher. The undersides of these wooden rails were to be engaged by four additional wheels mounted on outriggers, if the machine rose more than an inch above the steel track. After several preliminary runs had been made the day came, July 31, 1894, for a more conclusive test. The powerful engines were started; the steam pressure mounted; the propellers whirred; the machine started off down the track. When about nine hundred feet had been covered it rose from the steel rails. In a short distance more such a powerful lift had been generated by its "wings" that it tore up the safety rail designed to restrain it and all but fulfilled the predictions of its inventor. He quickly brought it back to earth, or, according to some, it was the damage inflicted by the splintered timber of the safety track that brought it down. In any case, it toppled over and was badly damaged. Maxim's aeronautical venture was over. He evidently knew from the first that his winged monster could not be trusted in free flight; but he had the satisfaction of knowing that he had made a machine which had raised itself and three passengers from the ground.

While Maxim was working in England on mechanical appliances and aerodynamic theory, Clément Ader in France was trying hard to create a power-driven flying machine. Giving up his first idea of using flapping wings, which he soon saw to be impractical, he, like so many others, turned to the spectacle of soaring birds, especially the vulture, to find another method. For about ten years (from 1886 to 1897) he earnestly devoted himself to the task and built several full-scale mechanisms all of which consisted of a car borne by one pair of wide cambered wings. Tractor propellers motivated by a steam engine were to pull the crafts forward.

His general scheme had much in common with a design published by Alexandre Goupil in 1884. This engineer had tested air resistance with a device made with concavo-convex wings attached to a bird-shaped body, by tethering it in winds of known velocity and measuring the weight lifted. By this means he discovered what Phillips in England was finding out concurrently, that, when compared with a plane surface, the concave surface gave an enormous increase of lifting power. His design for a flying machine, which was never built, incorporated a rudder, an elevator, a tractor propeller, one pair of cambered wings, and, in addition, a rotatable surface projecting from the bird-shaped body beneath each wing, the purpose of which was to help maintain equilibrium.

Clément Ader's machines were actually constructed; and he is said to have been the first person to make a genuine attempt to fly in a heavier-than-air, power-driven machine. There were three versions of his idea, built one after the other with modifications of design; and all were wrecked during the trials, for they lacked both stability and control. The first one, the *Eole* of 1890, left the ground for a distance of about a hundred and fifty feet before it fell; the last one, the *Avion No. 3,* in 1897, made an occasional hop as it went round the circular track before being overturned and destroyed by a gust of wind.

In our own country Samuel Pierpont Langley entered the field of aeronautical research with the idea of organizing it into an exact science. Collecting data on air resistance by suspending brass plates from a long arm projecting from a revolving table and measuring the resistance at different speeds, he prepared statistical tables and mathematical formulas of great value, and he published his records in *Experiments in Aerodynamics* in 1891. His object was "not to build a flying machine at once, but to find the principles upon which one should be built." However, to prove his laboratory work he made many models, beginning with small ones propelled by twisted rubber bands, in the making of which he said he was helped by study of the toy invented by Pénaud; and he continued to experiment with larger models which he called "aerodromes."

After many failures, he at length triumphed with his steam-powered *Aerodrome No. 6.* This was a "tandem monoplane," the two pairs of wings being placed one behind the other. They were made of fabric and had a span of about twelve feet. They were slightly concave and uptilted, and they were fastened to the body at a small dihedral angle. The machine was powered by a small steam engine which weighed only seven pounds, and it actually flew over the Potomac River for more than half a mile, a record flight for a heavier-than-air appliance. At the conclusion of this demonstration in 1896 of the practicability of mechanical flight, which had taken place in quiet air, Langley felt that his work in the field was finished. However, two years later when the Spanish-American conflict was on, he was urged by the War Department to continue his endeavors and build a full-scale machine capable of carrying a man.

This project was not completed for another five years. In its general plan the large machine that eventually materialized resembled the model of 1896; but it was equipped with a gasoline engine for which Charles M. Manly was responsible. A quarter-sized model was successfully flown a few weeks before the trial of the large machine. When the time for this came, Manly, who had never before been in the air, took his place in the appliance which was to be tested for the first time, and made ready for the launching, which was to be effected by a mechanism that catapulted it from the deck of a houseboat in the Potomac.

On that first trial, on September 7, 1903, an accident to the launching apparatus plunged the machine into the river. On the second attempt three months later the same sort of mishap brought about the same disaster. This ended Langley's hopes. The heartbreaking failure of the second trial of the full-scale machine took place on December 8, 1903, just nine days before the Wright brothers rose from the ground at Kitty Hawk in the first successful flight in a power-driven airplane.

22

Possibilities of the Glider

> I will up and get me away where the hawk is wheeling. . . .
> —RICHARD HOVEY, *I Have Need of the Sky*

THE several trails, simultaneously explored during the second half of the nineteenth century to reach the goal of human flight, ended in blind alleys.

Those who persisted in trying to evolve flapping wings were frustrated anew when they sought to substitute mechanical power for the inadequate muscular energy of the human being. Misled for a long time by the belief that the reaction of the air downpressed by the wingbeat of the bird constituted the total force that counteracted its weight, they were reluctant to relinquish this notion even when confronted with the sight of the majestic wings of the larger birds, which did not flap at the requisite rate, or, for that matter, did not flap at all.

As the study of the mechanics of flight progressed, it was shown that a buzzard's wings beating two and a half times a second through a twelve-degree arc could generate a reaction which would sustain only about one tenth of its weight, but that if these same wings were thought of as inclined planes moving horizontally at a speed of forty-five miles an hour the supporting reaction could be accounted for. Writing about 1893, Chanute observed that, since the principal questions relating to flight are those of motive power and proportion of surface to weight, large birds are incapable of flapping flight and that "they are living aeroplanes, under whose inclined wings their velocity creates a pressure which is normal to the surface." He saw this theory confirmed in the difficulty large birds have in their take-off.

Nevertheless, those who proceeded from this point of view, who regarded the bird's wing as an inclined plane, and who, approaching the problem along the line marked out by Cayley, tried to "make a surface support a given weight by the application of power," achieved no practical results. In spite of the growing fund of knowledge about air pressures on both flat and curved surfaces and their relation to velocities and angles of attack, about the relations of weights to sustaining areas, about foot-pounds and horsepowers, results were in the main negative. Even when an engine of sufficient power had been harnessed to wings capable of producing the necessary lift at a given speed, nothing like true flight had resulted. Most of the appliances crashed. It was at length apparent to many that, as Chanute expressed it, "no amount of motive power will avail unless the apparatus to which it is applied is stable in the air—unless it can rise, sail, and come down again without danger of losing equipoise" and that most of the failures in experiments with airplanes were the result of the difficulty of maintaining equilibrium.

A third way of approaching the problem had begun at an early stage with an occasional experiment and had become of increasing interest as the nineteenth century drew to its close. Also starting with the contemplation of the bird—that unfailing source of inspiration and encouragement—certain men watched more knowingly the motionless wings of the great adepts of soaring flight, the wings which, outspread, could on occasion lift their owners and bear them away without any other motivating power than that obtained from the air itself. These men, discarding the search for a prime mover, inspired by the albatross, the vulture, and the gull, faced the wind in the glider.

Down the years references to attempts at gliding flight are met with here and there—the exploits of De Bacqueville, of Danti, and of Paul Guidotti, another Italian of Lucca, who in the latter part of the sixteenth century is said to have made wings of whalebone and feathers and used them several times successfully. On one occasion, the story goes, he sustained himself for about a quarter of a mile before becoming exhausted and falling on a roof. There was also a Spanish peasant, Francisco Orujo, who in 1863 was reported to have sailed on artificial wings a league in less than fifteen minutes. It has been pointed out that the majority of those who have been accredited with such performances lived in warm countries where soaring birds are common and where this mode of flight could be more easily seen and studied than in the north, and that these experiments, given a wind of sufficient strength, may possibly have had some slight and accidental success. Cayley also had some success with a glider.

The real pioneer in this field of experimentation, at least the person whose exploits can be followed in some detail, was a French sea captain named Jean-Marie Le Bris. Repeatedly voyaging into regions where the great oceanic birds displayed their marvelous and unexplained powers of flight, he was fascinated by the technique of the albatross. Consumed with curiosity to discover its secret, he killed one of the birds. Later on he recounted what happened: "I took the wing of the albatross and exposed it to the breeze; and lo! in spite of me it drew forward into the wind; notwithstanding my resistance it tended to rise. Thus I had discovered the secret of the bird! I comprehended the whole mystery of flight!"

That he had oversimplified the matter was clear from subsequent events. Back home in his native Breton village near Brest, he undertook to make an artificial albatross of his own. Wood and Canton flannel went into the construction of its wings, each of which was twenty-three feet long. The front edge of the framework was made of a flexible piece of wood shaped as nearly as he could make it like that of the living creature. There were cross ribs over which the flannel was stretched with its smooth surface on top. They were fastened to a body, shaped like a *sabot* about four feet wide and a little over three times as long, made of light strips of ash and covered with waterproofed cloth, and were manipulated by cords passing through pulleys attached to a sort of mast projecting from the front of the car. Their movement, effected by powerful levers in the hands of the operator standing upright in the body of the car, consisted of a rotary motion of the front edges and an adjustment of their angle with respect to the wind. There was a tail, controlled by a foot pedal, so hinged that it would steer up and down and also sideways. Proportioned as nearly as possible to the living bird, the creation had about two hundred and fifteen square feet of supporting surface and a weight, without the operator, of about ninety-two pounds.

It was of a Sunday morning in 1856 that Le Bris, taking advantage of a good breeze, made ready for the public trial of his invention. Knowing perfectly well that his bird would have to have a certain velocity with respect to the wind before it could be air-borne (the albatross itself does not rise from a level surface without considerable runway), Le Bris contrived to have his artificial albatross mounted on a cart and driven into the wind. Down the road to Douarnenez the strange pageant proceeded to the wonderment of the onlookers; *the Albatross* poised on the cart was held in place by a rope to be released at the proper moment by the helpers who ran alongside.

Surmounting the scene, the inventor stood erect at the controls. At first he held the front edges of the wings depressed so that they could not capture the wind, and he did not turn them to a small upward angle until the carter urged his horse into a trot. Fluttering, the slightly concave undersurfaces then filled like sails. With its load lightened, the horse galloped; the signal was given, and the rope was loosened. *The Albatross* rose with Le Bris aboard. Perfectly poised on the wind, it continued to rise. It had mounted nearly three hundred feet and had covered twice that distance before the triumphant flier was aware that the driver of the cart was dangling below, accidentally lifted from his seat by the entangling rope. Changing the angle of his wings, Le Bris was able to make a gradual descent and bring about a safe landing for the terrified man. His own landing was forced when he found that he was unable to regain altitude; but he was able to check his descent so that he came down with no evil consequences except some damage to the wing that hit the ground first.

In a second attempt the intrepid captain launched himself from the brink of a quarry and unfortunately met with misfortune when, as he sailed over it, he encountered an air current to which he could not adjust the angle of his wings quickly enough to keep his equilibrium. He dropped, for his sails were not large enough to act as parachutes. Luckily he escaped with only a leg broken. Although Le Bris tried to renew his experiments about ten years later with a second *Albatross,* he was never able to repeat his first achievement. It just so happened that on that occasion the weight of the dangling peasant supplied the perfect ballast: it provided the perfect automatic adjustment of the center of gravity to the center of support; it insured equilibrium for the wings held at the particular angle in the particular force of the wind. Le Bris, of course, had no idea of this. Orville Wright doubted the authenticity of Le Bris's performances, for he put no faith in the source which recorded them.

Le Bris stood alone in his early attempt to imitate the great birds that sailed the skies so confidently. He had approached the question empirically; but before disappointment, ridicule, and lack of resources brought his experimentation with actual contrivances to an end, a booklet had appeared which discussed the matter of sailing flight theoretically and, in addition, stressed the idea of trusting to the wind alone for motive power. This was the pamphlet *Du Vol des Oiseaux,* published in 1864 by the Count d'Esterno, wherein the author remarked: "Whoever has seen large birds of prey sailing upon the wind, knows that without one flap of their wings they direct themselves as they choose, save when they want to go dead with the wind or dead against it, on which occasions they must either tack or swing in circles."

The Count made no practical application of his theories beyond designing and patenting an appliance which embodied his ideas and, as he thought, met the requirements of the laws of flight as he defined them. It was never built. It was fitted with broad wings consisting of rigid triangular areas which projected forward and outward from the car to which they were attached (areas to be compared roughly to the inner section of the bird's wing), from which curved ribs extended into a flexible outer portion. They were so hinged that they could be set at any desired dihedral angle; and they could be moved forward or backward with reference to the car. Moreover, their rear edges could be raised to alter the angle of incidence. The tail, spreading fanwise behind, could be raised and lowered, moved sidewise, and twisted. A movable seat for the pilot allowed his weight to be shifted and thus permitted a shift of the center of gravity for the purpose of maintaining equilibrium. D'Esterno knew all about the need of acquiring initial headway for sailing flight and had probably thought of a way to obtain it, although there is no mention of the method to be employed.

When they were offered, the proposals of this able student were ridiculed; and by the time, twenty years later, some credence had been won for them and he had arranged for the construction of an apparatus that should test them, it was too late. He was by then seventy-seven years old and his death came before it could be finished.

The minds of those occupied with human flight were very slow to comprehend the potentialities of the motionless wings of soaring, gliding birds. The general incredulity which greeted the ideas of D'Esterno in 1864 was fostered to some extent by ignorance, for, as Chanute suggests, the magnificent exhibitions of the greatest masters of soaring and gliding flight were outside the common experience. To be sure, soaring hawks were to be seen throughout Europe, and in coastal regions, storks and gulls; but it was in the tropics and semitropics that vultures and kites were habitually hanging for hours at a time in the sky, and it was in oceanic wastes that the albatross sailed even for days effortlessly. Such flight had, nevertheless, been both observed and described from time to time, as when Darwin wrote of the condors of Peru:

> Except when rising from the ground, I do not recollect ever having seen one of these birds flap its wings. Near Lima, I

SOARING VULTURES.

watched several for nearly half an hour, without once taking off my eyes: they moved in large curves, sweeping in circles, descending and ascending without giving a single flap . . . and the extended wings seemed to form the fulcrum on which the movements of the neck, body, and tail acted. If the bird wished to descend, the wings were for a moment collapsed; and when again expanded with an altered inclination, the momentum gained by the rapid descent seemed to urge the bird upwards with the even and steady movement of a paper kite. In the case of any bird *soaring,* its motion must be sufficiently rapid, so that the action of the inclined surface of its body on the atmosphere may counterbalance its gravity. The force to keep up the momentum of a body moving in a horizontal plane in the air (in which there is so little friction) cannot be great, and this force is all that is wanted.

We know now, as indeed Maxim discovered, that the accomplishments of these birds depend on the particular types of air currents generated in their respective localities. It was but natural that in cooler climates and inland regions where sailing flight was less spectacular its possibilities were overlooked. And it was also natural that the next person to call attention to the feasibility of gliding flight should have been one whose life was spent in northern Africa where he watched the sailing vultures from his boyhood.

Louis-Pierre Mouillard studied his birds on the wing and measured them carefully in the hand; and he drew up a table of the ratios of wing area to weight of different types of "rowing" and sailing species. The book which he published in 1881, *L'Empire de l'Air,* was an inspiration to many who came after him and it contained his credo:

> I hold that in the flight of the soaring birds (the vultures, the eagles, and other birds which fly without flapping) ascension is produced by the skillful use of the force of the wind, and the steering, in any direction, is the result of skillful manoeuvres; so that by a moderate wind a man can, with an aeroplane, unprovided with any motor whatever, rise up into the air and direct himself at will, even against the wind itself.

In his examination of the wing and the way it functioned, Mouillard not only paid attention to area but also marked the influence of shape on the mode of flight and speed; and he postulated that, provided the wings are suitably fashioned, the heavier the bird is the more perfectly it soars and that it can sail on a wind of the requisite strength indefinitely once its initial speed is attained. Having noted that the broad-winged vultures and their kin utilize moderate winds and avoid a gale, while long narrow wings carry the frigate bird, the albatross, and other sea birds through winds of hurricane force, he concluded that man would do well to imitate the former. He believed that man-made wings patterned after those of one of the broad-winged African vultures could imitate its maneuvers. It will be remembered that Goupil and Phillips just about this time began experimenting with concavo-convex surfaces and found that they engendered far more lift than flat planes. But such surfaces were thought of by them as supporting agents only, to be propelled by mechanical power.

Mouillard was a practical designer as well as a theorist. His observations and research had begun while he was still a boy in Algeria; and by the time he was thirty-one (in 1865), he had constructed his third pair of wings with which, running into the wind, he made trials, on one occasion being lifted from the ground and carried off his feet for a distance of a hundred and thirty-eight feet. As described by him in his essay, the apparatus consisted of two flat, thin, stiffened boards hinged together, from which ribs of agave wood, covered with cloth, radiated. There was an open space in the center of the frame in which the operator stood, and he was fastened to it by means of straps passing over the shoulders and between the legs. The arms were slipped through more straps on the top of the two boards, and at their outer ends there were rods controlled by the feet, so that the angles of the wings with respect to each other could be adjusted. Equilibrium had to be maintained by moving the body this way and that to accord with changes in the angle of incidence.

It was a fragile affair, weighing only thirty-three pounds. Mouillard's experiments in flying were curtailed by his removal to Cairo and by physical handicaps which overtook him, but he continued his observations and studies and at length produced a gliding mechanism patterned after the vulture. It was fitted with a long tail and with a device for flexing the wings to insure control. Not the least of his contributions to the art of flying was the inspiration his written words afforded to those who came after him and shared his convictions.

The chief of these was Otto Lilienthal. This German engineer, Mouillard's junior by fourteen years, started his experiments at an early age in collaboration with his brother Gustav when the two concocted wings of various sorts and tried them out in their mother's attic. Their activities were resumed intermittently during their school days, and in 1871, when he was twenty-three, Otto set to work seriously. Although by this time much data had accumulated, it was but the beginning of what was needed to found a true science of flight. As he wrote later:

> . . . only that air resistance is generally known which is produced when we move a thin plane surface in a direction at right angles to its plane. But if the angle between direction of movement and plane differs from 90°, we find such a divergence between the formulae given in various technical handbooks as to shake our confidence in their value. Still less familiar are we with the air resistance of curved surfaces. The only sufficiently proved and often demonstrated law shows that the air resistance is proportional to the area and to the square of the velocity.

This was not enough. Lilienthal began earnestly to collect his own data. He too focused his attention on the sailing flight of large birds, which in his case were the storks of his native Pomerania. Gustav on his travels studied the albatross.

After eighteen years of study and experiment Otto Lilienthal presented his case for the attainment of the long-sought goal in what was the best treatise on aerodynamics that had yet been written, a book called *Der Vogelflug als Grundlage der Fliegekunst.* Here he reaffirmed the opinion that the secret of flight was probably to be found in the properties of slightly curved surfaces and, at the last, admitted:

> It will be no easy matter to construct a useful wing for man, built upon the lines of the natural wing and endowed with all the dynamically economical properties of the latter; and it will be even a more difficult task to master the wind, that erratic force which so often destroys our handiwork, with those material wings which nature has not made part of our own body. But we must admit the possibility that continued investigation and experience will bring us ever nearer to that solemn moment, when the first man will rise from earth by means of wings, if only for a few seconds, and mark that historical moment which heralds the inauguration of a new era in our civilization.

In 1891, two years after the publication of his book, Lilienthal, now convinced that any amount of paper work could not supply what one needed to know about the air and its effects and that it was the act of flying itself that had to be mastered, began his experiments in his first glider. Its two wide, billowing sails made of peeled willow rods covered with tough cotton cloth had radiating ribs which supported the surface in somewhat the same way that the fingers of the bat support its flexible membrane. Two surfaces at the rear were added for steering. The operator attached himself to the appliance without the help of straps or buckles, by merely resting his arms on cushions fastened to the framework and holding onto a crossbar. His body dangled in space below.

The first tentative efforts were made by Lilienthal in his garden from a springboard raised about a meter from the ground. Heights and distances were gradually increased as he launched himself into the wind from the springboard raised to a higher level, then from hills of different sorts, and from a fifty-foot artificial mound he had constructed for the purpose. He made various alterations in his apparatus as his experience widened. He found out how much supporting surface was best for certain wind velocities; and, by the movements of his body, he learned to maintain his equilibrium in the variable currents with remarkable success. These movements became in time, he said, instinctive and automatic. When he experimented with superposed wings he often reached positions which were higher than his starting point. Sometimes, coming to a standstill in the air, he had the feeling that he could remain floating if he leaned a little to one side, described a circle and proceeded with the wind.

When in the course of five years Lilienthal had made about two thousand glides, he believed the time had come to add a propelling mechanism to his glider. By August 1896 a power-driven machine was ready for its first trial. As a preliminary, Lilienthal took off in a glider to test the efficacy of a rudder. Through some failure of the mechanism the glider fell and he received injuries which proved fatal. He had once said that the first obstacle to be overcome by the practical constructor is that of stability. He had succeeded to a remarkable degree in imparting it to the wings of his gliders by shifting his own weight. Starting out from his premise that "indulging in subtle inquiries and theorizing does not promote our knowledge of flying, nor can the simple observations of natural flight, as useful as it may be, transform men into flying beings, although it may give us hints pointing towards the accomplishment of our purpose," he had done his best to solve this still elusive problem.

23

Consummation

They shall mount up with wings as eagles.

—Isaiah XL, 31

Otto Lilienthal was the youngest, and the first to die, of the six men who were making conspicuous efforts to fly in the 1890s. In the belief that "sailing flight was not the exclusive prerogative of birds, but that the possibility of man flying in this manner was established, since no powerful movement of wings but only a skillful direction of the wings, was required for the purpose," he cast himself into the wind on wide rounded sails to learn its ways. The physicist Langley, in his mature years recalling the sailing hawks he had watched as a child, asked himself "whether the problem of artificial flight was as hopeless and as absurd as it was then thought to be." Suspecting that it was not, he started afresh along Cayley's line of reasoning and applied himself to the task of driving rigid wings through the air by motive power; and he succeeded to the extent of creating a tandem-winged model which flew in still air. Maxim, an engineer, also inspired by the sight of birds, put his faith in multiple surfaces, superposed and very narrow in proportion to their length. Phillips also experimented with multiple surfaces. Ader adhered to the idea of a single pair of wings, patterned after the organs of the bird or bat.

The sixth experimenter, the oldest, agreed with Lilienthal that the way to the conquest of the air was through knowledge of its moods which could best be learned with a glider. This man was the American civil engineer Octave Chanute.

Chanute's interest in the cause of artificial flight had begun when he was a young man. It had been interrupted by business affairs, and then renewed about 1889, when he began to make weighted paper models of various shapes, projecting them into still air. Larger models with wooden framework and muslin wings followed, and these were dropped from the housetop with bricks as passengers. There were other experiments with tailless kites. After Lilienthal's gliding feats had proved the practicality of actual practice in the air, Chanute began to work with larger devices patterned on those of the German, but after Lilienthal's death he discarded this type of glider as hazardous and started to experiment with those of his own design.

From the very first, Chanute was keenly aware of the fact that the underlying cause of all the failures, whose numbers were steadily mounting, was lack of stability; and it was to overcome this great difficulty that he applied himself. Since, as he said, models seldom fly twice alike in the open air where the wind is usually blowing, and since, above all, they cannot "relate the vicissitudes which they have encountered," he determined to use full-sized machines. He saw the weakness of Lilienthal's system of maintaining balance by shifts of position of the operator's pendant body, and hoped to reverse it by keeping the man more or less stationary and shifting the wings instead.

On the sand dunes of northern Indiana, on the shore of Lake Michigan, many trials were made in the summer of 1896. His first apparatus was a multiple-wing affair of which each sustaining surface, bowed at the front edge and pointed at the tip, was six by three feet. Each was pivoted at the central framework so that it could move fore and aft. The first version of the machine had twelve wings—six pairs arranged one above the other. It was next tried in an eight-winged form, and then successively with four wings in front and eight behind, with eight in front and four behind, and finally with five pairs in front and one pair at the rear as a tail. He called this the *Katydid*. During all of these rebuildings, modifications were made in the distances at which the wings were spaced above one another, and, at last, still another surface was added which surmounted them and spread over the central area. On the whole, the experiments with the multiple-wing machine were disappointing.

Better results were obtained with one built in a different fashion, with three oblong, square-tipped surfaces placed rigidly one above the other, with horizontal and vertical rudders at the rear. When the bottom layer of this three-decked machine was removed, as was done almost immediately, the double-decked "Chanute glider" came into being. The two surfaces were made of cloth stretched on frames sixteen feet long and four feet three inches wide and were joined together by means of uprights set at intervals along both front and back edges. Diagonal trussing ran between the upright struts laterally and also from front to back. The ribs which connected front and rear horizontal spars and supported the cloth were curved slightly so that they imparted to the supporting areas a concavo-convex form. The tail, with both vertical and horizontal vanes, was held in place by a spring which controlled its movement. It contributed to longitudinal stability. Lateral balance, however, still depended on the agility of the aeronaut who, with armpits resting on a pair of horizontal bars at the central area of the lower surface and hands grasping vertical ones, swayed his body this way and that to maintain equilibrium. The take-off was made by running a few steps downhill into the wind and at the last instant raising the front edge of the wings. Landings were made, Chanute said, in imitation of the sparrow by tilting them back to catch the wind. Then they acted as a brake.

Chanute and his assistants watched the eagles which came almost daily to show them how to overcome and utilize the effects of the wind. He said they "swept in circles on pulseless wings and rose high in the air. Occasionally there was a side-rocking motion, as of a ship rocking at sea, and then the birds rocked back to an even keel"; but they were "too far away to show us just how it was done, and we had to experiment for ourselves." During 1896 and 1897 about two thousand glides were made by Chanute's assistants (at sixty he felt himself too old to undertake the exercise himself); and although they were made without accident, he felt that the time had not yet come to add a motor. The longest distance covered was three hundred and sixty feet. The technique of the floating eagles was still to be fathomed.

Chanute's biplane glider was a return to the principle of the rigid wing, though not to the inclined plane. It had the slightly cambered surfaces, which had been proved to be of greater lifting power than flat ones, and they were narrow in proportion to their length, a feature shown by Maxim and others to be economical of power. The apparatus was far superior structurally to anything that had yet been made. It was capable of far greater control than the great billowing wings of Lilienthal's gliders. But the maintenance of stability still rested on the ability of an operator to counteract the fitful air currents with instantaneous shifts of his dangling body, "for neither wind nor gravity will wait on meditation."

In addition to supervising the building and testing of his appliances and collecting ever more data on the air's behavior, Chanute compiled and published a most valuable and complete account of the history of man's attempts to fly. This was his *Progress in Flying Machines* of 1894. He also contributed numerous articles to magazines and lost no opportunity of encouraging prospective fliers. In a résumé of the experiments, published in 1897, he invited others to improve on the methods discussed. He said later that his invitation went unaccepted until the spring of 1900. It was then that he received a letter from Wilbur Wright telling of his own plans for a proposed glider.

It was the tragic end of Otto Lilienthal on August 9, 1896, that had rekindled a latent interest in human flight in the minds of the two young men who were destined to remove the barrier which had for so long separated man from his goal. Wilbur Wright was twenty-nine years old and his brother Orville twenty-five when they read, first, of the gliding flights of the German engineer and then shortly afterward of his death. They reread Marey's *Animal*

Mechanism, and, about two years later, a book on ornithology which augmented their interest. Refusing to believe that the achievements of a bird in gliding and soaring flight could not be duplicated by man, they began to study the problem seriously. In reply to a request addressed to the Smithsonian Institution, they were supplied with papers by Lilienthal and Langley, with Mouillard's *Empire of the Air,* Chanute's *Progress in Flying Machines,* Langley's *Experiments in Aerodynamics,* and other material. They decided to take up gliding as a sport.

They too saw clearly that the attainment of stability was the chief requisite for flight. It had been for lack of stability that Lilienthal had perished and that Percy Pilcher three years later had met the same fate. This young Englishman had experimented with several gliders whose wings were variously shaped and adjusted. The first one, which he called the *Bat,* followed in a general way Lilienthal's design. It was succeeded by a second appliance called the *Beetle,* by a third called the *Gull,* and, lastly, by the *Hawk* to which he planned to add an engine. In all of them the operator tried to secure lateral stability by the shifting of his own weight. It was during a demonstration with the *Hawk* in unfavorable weather that Pilcher lost his life on October 2, 1899.

From the very first the Wright brothers determined to reject this hazardous method of countering the air currents that rocked the wings so dangerously. The observation of birds convinced Wilbur Wright (as he explained in his first letter to Chanute written May 13, 1900) that they maintain equilibrium in the air by other methods than the mere shifting of the center of gravity. Watching turkey vultures as they floated about, he saw that they righted themselves, when partly overturned by the wind, by the torsion of their wing tips: if the rear edge of one tip was twisted upward, that of the opposite wing had a downward turn. "The bird becomes an animated windmill," he wrote, "and instantly begins to turn, a line from its head to its tail being the axis. It thus regains its level. . . ." He was aware also of the part played by presenting the wings at different angles to the wind and by partly flexing them to reduce their area. It was by the first method, torsion of the wing tips, that he hoped to gain lateral stability for the appliance he had in mind.

At first the Wrights had considered the possibility of pivoting the wings at the center of the apparatus in such a way that, as the wing on one side was turned upward in front, the opposite one would be directed downward. They reasoned that the greater lift thus produced on one side would make it unnecessary for the operator to shift his weight. The only difficulty, and a very great one they knew it to be, was to make a mechanism strong enough to accomplish adjustment of the supporting surfaces and yet light enough to be practicable.

It was in the summer of 1899 that Wilbur showed his brother a better way of obtaining the same result. Using a small pasteboard box from which the opposite ends had been removed, he pressed together simultaneously the forward top corner and the rear lower corner of one end of the box and the rear upper and forward lower corners at the opposite end. In this way the upper and lower surfaces of the box were twisted so that on the right side they presented a different angle from that on the left. The actions of the vulture's wing tips corroborated their theory.

Seeing that the wings of a double-decked glider of the Chanute type would lend themselves to this warping process, they soon were busy constructing a model which should embody their idea. The method of trussing the uprights which connected the framework of the two wings, which were about five feet from tip to tip and about thirteen inches from front to back, differed from that used by Chanute in that they were not braced fore and aft. The absence of such trussing allowed the upper and lower surfaces to be shifted with relation to each other and the principle demonstrated by the twisted box to be incorporated. In the latter part of July, Wilbur made the tests, which were so favorable that experimentation with a machine large enough to carry a man was decided on.

In determining the size of the sustaining wings of their proposed glider, existing tables of air pressures on curved surfaces and accepted formulas were used. As Wilbur afterward explained, they thought that if they could build a machine which would be sustained at a speed of eighteen miles an hour and then find a locality where winds of this velocity were common, they might practice by the hour instead of by the second, as Lilienthal had done. They too were certain that the best way to learn about flight was to seek actual experience in the air. Wilbur, commenting on the unreliability of air currents and the necessity of learning how to manage them, referred to the bird whose skill in maintaining its equilibrium is so consummate that it is not apparent to the observer and is to be appreciated only when an attempt is made to imitate it. He compared the process of learning to fly with that of learning to ride a fractious horse. There are two ways of learning about the horse, he told the Western Society of Engineers in his first address to them in 1901: to mount the animal and learn by practice how to meet each motion and trick, or to sit on a fence and watch and then retire into the house and figure out how to do it. For understanding the problems of flight, he said, two ways were likewise open: one might either sit on a fence and watch the birds (the safe way) or take a machine up in actual trial.

Accordingly the brothers went to work on the man-carrying glider, constructing two supporting surfaces eighteen feet from tip to tip and five feet from front to back, joined by two series of struts, six along the front edge and six about a foot from the rear. The struts were not fastened rigidly to the spars (the lateral elements of the frame) but by means of flexible joints, and they were trussed laterally but not from front to rear. The ribs which connected the spars horizontally and supported the cloth covering (it was French sateen cut on the bias) were made of thin strips of ash bent slightly at their forward extremities, so that the surfaces when completed were slightly cambered. They were a little higher at the tips than at the center. Both spars and ribs were encased in cloth to eliminate sharp angles. Flexible cables attached to the outmost struts were arranged in such a way that the desired torsion of the surfaces could be effected. A tail was considered unnecessary, but a horizontal rudder or elevator was added in front, the purpose of which was to help obtain longitudinal stability. A horizontal position for the operator seemed definitely preferable to the upright position since it would greatly decrease the resistance, and so a "cradle" eighteen inches wide was set into the lower wing in which he might lie face downward and make the adjustments of the cable which moved the wing tips.

The wings of this first glider had a total area of one hundred and sixty-five square feet, which, according to Lilienthal's tables, was sufficient to carry the weight (a hundred and ninety pounds) at an angle of three degrees in a wind blowing about twenty-one miles an hour. They were tried out in the fall of 1900 at Kitty Hawk, the site in North Carolina chosen because steady winds prevailed there, when the glider was flown first as a kite, with and without a man aboard. When the wind did not blow strong enough to support the machine and the human load, the movements were controlled by means of cords reaching to the ground. Such times were all too frequent and the Wrights were not able to spend the hours aloft that they had hoped for. However, they contented themselves with flying the machine as a kite with various loadings and making accurate measurements of lift and drift under various conditions. The system of warping the wings to obtain lateral stability proved very satisfactory. When they felt that they were ready to make a free gliding flight, the machine was taken to Kill Devil Hills, a site about four miles south of the camp at Kitty Hawk. With an operator on board, the glider was launched with the help of two assistants who, holding the ends of the wings, ran forward with it downhill into the wind until it was air-borne. On the whole, while the machine was amenable to the system of control, its wings did not have the lifting power expected of them.

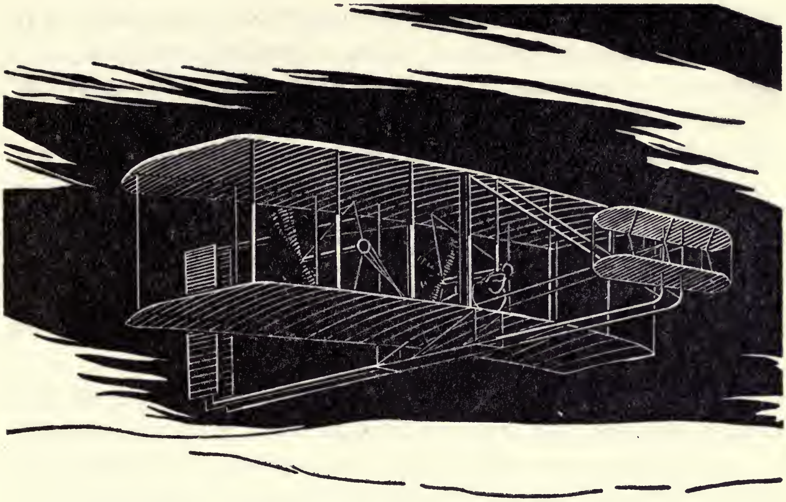
The Wrights sought to rectify this deficiency in the next glider, tested during the summer of 1901, by giving to its larger wings a deeper curvature. How they found that the new curvature was too great, how they modified it by adding a third spar, how they raised the central struts to give the wings a downward droop were matters which they worked out step by step with mechanical skill and clear thinking. Again they made a series of measurements of air pressures on their new wings and were dismayed to discover that their figures were so at variance with the tables of air resistances on which they were depending that they would have to start all over again and collect their own data. As Wilbur afterward declared, they had set out with absolute faith in the existing scientific data but had been "driven to doubt one thing after another, until finally, after two years of experiments, we cast it all aside and decided to rely entirely on our own investigations. Truth and error were everywhere so entirely mixed as to be indistinguishable." They realized that the sport they had hoped to enjoy would have to be approached from the point of view of the scientist.

The great series of wind-tunnel tests which followed were begun shortly after their return to Dayton in the fall of 1901, for the purpose of determining "the amount and direction of the pressure produced on curved surfaces when acted upon by winds at the various angles from zero to ninety degrees." With balancing mechanisms of several kinds, of their own manufacture, they measured the air's effect on square planes, on rectangular planes of different proportions, on surfaces with different degrees of curvature, on curved surfaces having the point of greatest curvature at different parts of the surface (forward or backward of the center), on such surfaces of different aspect ratio (different proportions of length to breadth), and on superposed surfaces. With the knowledge gained from these most comprehensive tests and the tables compiled from them, the Wrights felt themselves on surer ground when they fashioned the wings of their third glider, to be used in the fall of 1902.

These wings (of a thirty-two-foot span and five-foot width) were longer in proportion to their width than those of the previous year and they were of smaller camber. The addition of a vertical vane at the rear, and the adjustment of its control so that its movement was automatically combined with the warping of the wing tips, was worked out in the buffeting winds of the Kill Devil Hills. The purpose of the rear vane was to equalize the velocities of the right and left wing tips when they were twisted to opposite angles; for it had been discovered the year before that the relative velocities of the wing tips at the opposite sides of the machine were important items in the maintenance of lateral stability—a fact which seemed never before to have been considered by experimenters. A modification of the manner of trussing the struts of the central part of the machine kept the front edges of the wings parallel, and allowed only the rear edges of the outermost areas to be adjusted up or down. The wings retained the slight downward droop, the tips being about four inches lower than the central portion of their span.

After these and other details had been worked out, nearly seven hundred successful glides were made. In calm air and in winds which blew at the rate of thirty-five miles an hour it "performed all the evolutions necessary for flight." The record distance was something over six hundred and twenty-two feet; the record for time aloft, twenty-six seconds. On their return home at the end of October, Wilbur and Orville Wright were already making plans for their next machine, a larger one still, which they hoped to propel by mechanical power.

The building of a suitable motor (for they were unable to procure one in any other way) and the creation of screw propellers shaped to conform to their theoretical calculations were in themselves formidable tasks. As a result of more tests in the wind tunnel, the upright struts were reshaped so that they would produce the least possible head resistance. The revised design included wings of greater span than ever before. From tip to tip they measured forty feet; they were six and a half feet wide; and they were set six feet apart. They were not of equal extent from the center out: on the right side they were made about four inches longer in order to provide more lift for the motor, which was mounted a little to the right of the center and weighed thirty-four pounds more than the operator whose position was at the left of center. The downward droop was increased until they were ten inches lower at the ends than at the center. The ribs were of an improved construction and the cloth covering was double. It was stretched over both upper and lower sides of spars and ribs, an arrangement which created a smooth undersurface. The machine was assembled in a



THE WRIGHT BROTHERS' FIRST POWERED AIRPLANE.

new building made to house it at the camp at Kill Devil Hills, and after many delays was ready.

It was between half past ten and eleven o'clock on the morning of December 17, 1903, that the moment so long awaited, the solemn moment envisioned by Lilienthal, the moment when man would rise from the earth by means of wings, arrived. It was then that he lifted himself into the air, transported himself through it in the face of a winter gale, and brought himself back to earth again safely. It was the moment so long imagined by the romancer, forecast by the philosopher, courted by the adventurer, and earnestly awaited by all serious students of flight—by Leonardo, Cayley, Wenham, and all their successors. It was a moment of fulfillment and of promise—a portentous moment heavy with the sense of things to come.

It is an interesting fact that in his attainment of flight, man was inspired but not instructed by the birds he so ardently watched. The albatross, vulture, eagle, and gull, the great adepts of soaring flight, whose example he tried to follow, did not divulge the secret of their powers. The movements of their wings were too subtle, too rapid, too far away, for the straining eyes of man to follow. He had to learn to fly even as they had learned, by trial and error in turbulent air currents which had to be tamed and utilized. When Wilbur and Orville Wright had thought out certain principles, they returned to bird watching to check their theories and often found that the same technique was being used by the bird. "Learning the secret of flight from a bird," wrote Orville, "was a good deal like learning the secret of magic from a magician. After you once know the trick and know what to look for you see things that you did not notice when you did not know exactly what to look for."

From the observation of bird flight made in the light of their own experience, they made deductions which were at times very different from those usually accepted. Mouillard, for instance, was led to believe that of all wings those of the great tawny vulture—broad and uptilted in a dihedral angle—would be the best for man to imitate, because on them it sailed tranquilly in the moderate winds which seemed most suitable for the human flier. Wilbur Wright, observing the same phenomenon, reasoned that it was just because the vulture's wings were unstable in gusty currents that it avoided high winds. "In our first machine," he explained, "we set the wings at a dihedral angle, but when we found that every little side wind threatened to capsize it, we drew the tips down like the wings of the gull."

Chanute, reviewing the still unsolved problem of human flight, in 1894, when Lilienthal, Langley, and Maxim were all at work on it, theorized about the form of wings. That flight is possible with flat wings, he observed, can be seen in the butterfly, the dragonfly, and insects generally, but, he added, "they have greater power and the elasticity of their wings produces changes of shape under action." He went on to say that curved surfaces, such as those of birds, may prove to be more efficient than planes, that their wings as a whole are stiffer while the outer ends of the feathers are elastic—an observation which had been made many times before.

The outstanding contribution of Wilbur and Orville Wright to the accomplishment of human flight was the discovery of how to make a rigid, slightly cambered wing with an adjustable tip. Having done so, they saw that their system agreed with that of the bird. This was the key which unlocked the gateway to the sky.

In preparation for this triumph the human flier had progressed through stages analogous to those presumably followed by both bird and insect: at first short glides, then longer glides which were eventually converted into true flight when means of controlling the new mechanisms were perfected. During the process the wing of the bird had been man's constant inspiration and standard; he had been able, to some extent at least, to imitate it. However, by curious happenstance, the airplane he has created on the whole more nearly resembles the beetle than the bird. As Sir D'Arcy Thompson has observed, its wings correspond to the rigid elytra of the insect held out at the sides during flight. The beetle's vibrating membranous rear wings do the work of the whirling propellers.

With the accumulation of experience in his new role winged man has been able better to appraise the performances of the other fliers and more fully to understand the aerodynamic properties of their organs of flight. He can look on the wings of eagle, albatross, gull, falcon, sparrow, hummingbird, partridge, and duck; of bat; of moth, bee, dragonfly, and gnat more knowingly and appreciatively, in greater awareness of the logic of the inscrutable processes which have made of each the proper instrument for a given end and a superlative work of art as well.

24

Aftermath

> Were it not good your grace could fly to heaven?
>
> —William Shakespeare, *Henry VI*

THE man-made wings which sustained the first human fliers were as unspecialized in their way as those of the Palaeodictyoptera and of *Archaeopteryx.* Once they were achieved, however, they were subjected, as were those of the insect and the bird, to the still-unfinished process of modification and specialization. The fragile surfaces on which man made his first aerial expeditions—cotton or linen sails stretched on wooden framework—have evolved in fifty short years through various stages into metal airfoils trimmed and molded by mathematical formulas into strong, sleek forms of aerodynamic efficiency and abstract beauty. With modifications and refinements of contours, profiles, proportions, and other details of construction they have been adjusted for maneuverability, for speed, and for power. They have been adapted to meet man's requirements, whatever they may be.

Although essentially the pedestrian still, tethered to earth by his innate winglessness, man, their creator, need no longer stare with covetous and frustrated gaze into the arched sky above him nor envy the creatures whose admitted lot it is to fly. On artificial wings of his own devising he can mount with them into the alien element whose laws he is just beginning to understand. Far outdistancing the insect, he is already able to outfly the dove and out-soar the sun-loving eagle. Ever-widening horizons, ever-deepening immensities open before him.

On these diverse pinions, withheld by Nature and acquired through his own efforts, he has attained in his flight a state unknown to the bird. Still the heavy mammalian, he can appraise the scope of his conquest, the hazards overcome, the dangers implicit. He can, if he choose, experience a sense of exaltation, of sublimity. It remains to be seen to what extent he welcomes the promise inherent in his new estate and realizes the penalties of its profanation: whether he elects to rise to new heights of usefulness and ecstasy or to sink back to dust in disillusionment and despair. It remains to be seen whether or not his delta wings, crescent wings, and various other wings, so eloquent in their severe grace, will in time pass into the category of symbols and, if so, whether their significance for resurgent humanity will be predominantly sinister or sublime.

And my mind is filled and overflowing
With the things I did not say.

—LIU SHIH-AN

Geological Timetable[*]

Eras	*Periods*	
CENOZOIC	RECENT Began about 15,000 years ago.	
	PLEISTOCENE Began about 1,500,000 years ago.	Man
	PLIOCENE Began about 15,000,000 years ago.	
	MIOCENE Began about 30,000,000 years ago.	
	OLIGOCENE Began about 40,000,000 years ago.	
	EOCENE Began about 50,000,000 years ago.	Bat
	PALEOCENE Began about 60,000,000 years ago.	
MESOZOIC (about 120 million years' duration)	UPPER CRETACEOUS Began about 105,000,000 years ago.	
	LOWER CRETACEOUS Began about 120,000,000 years ago.	
	JURASSIC Began about 150,000,000 years ago.	Bird
	TRIASSIC Began about 180,000,000 years ago.	Flying Reptile
PALEOZOIC (about 160 million years' duration)	PERMIAN Began about 225,000,000 years ago.	
	PENNSYLVANIAN (UPPER CARBONIFEROUS) Began about 270,000,000 years ago.	
	MISSISSIPPIAN (LOWER CARBONIFEROUS) Began about 300,000,000 years ago.	Insect
	DEVONIAN Began about 345,000,000 years ago.	
	SILURIAN Began about 375,000,000 years ago.	
	ORDOVICIAN Began about 435,000,000 years ago.	
	CAMBRIAN Began about 540,000,000 years ago.	
PROTEROZOIC	Began about 1,000,000,000 years ago.	
ARCHAEOZOIC	Began about 1,500,000,000 years ago.	

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[*] Adapted from chart in *Prehistoric Life* by Percy E. Raymond. Cambridge: Harvard University Press, 1950.

Glossary

Alula: that part of the bird's wing which corresponds to the thumb. It bears several short feathers and is sometimes called "bastard wing."

Angle of attack or angle of incidence: the angle between the direction of the relative wind and the chord of an airfoil.

Aspect ratio: the ratio of the length of a wing to its breadth.

Camber: the arching of the airfoil from front to rear edge.

Chitin: a white amorphous horny substance forming the outer part of the outer integument of insects and other invertebrates.

*Chrysalis (*cf. *pupa, nymph):* a term applied to the pupae of certain butterflies.

Coverts: the feathers covering the bases of the quills of the wings and tail. They are designated upper, under, greater, lesser, etc., according to their position.

Dihedral angle: the angle made by wings so inclined upward that the angle between their upper surfaces is less than 180 degrees.

Dinosaur: "terrible lizard"; terrestrial reptile of the Mesozoic. There were many kinds of dinosaurs. They are grouped in two main divisions according to the structure of the hip bones.

Drag: that part of the resistance which is in opposition to the direction of flight.

Emarginate: having the margin notched.

Falcate: curved like a sickle.

Halteres: club-shaped organs possessed by the two-winged flies, which function as balancers.

Homologous: corresponding in type of structure.

Ichthyosaur: a marine reptile of the Mesozoic with fishlike body, long toothed jaws, and both dorsal and caudal fins.

Larva: the immature, wingless, wormlike form in which many insects hatch from the egg and in which they remain until they assume the pupa or chrysalis stage.

Lift: the force that is opposed to gravity.

Mosasaur: a large marine reptile with snakelike, scaly body of the Cretaceous of Europe and North America.

Negative pressure: a convenient term (though in bad standing among engineers) denoting the relatively lowered pressure on the top side of a cambered surface moving horizontally through the air.

Nymph (cf. *chrysalis, pupa):* immature state of an insect that undergoes gradual metamorphosis.

Ocellus (pl. *ocelli):* an eyelike spot of color. Also a minute simple eye found in many invertebrates.

Plesiosaur: a marine reptile of the Mesozoic with long neck, small head, and all four limbs developed as paddles.

Primaries (primary feathers): the feathers which are attached to the hand section of the wing.

Pteranodon: pteron ("wing") + *anodon* ("without teeth") designates a genus of pterosaur.

Pterodactyl: a certain kind of pterosaur.

Pterosaur: a flying reptile.

Pupa (cf. *chrysalis, nymph):* the intermediate, quiescent state of the insect that undergoes complete metamorphosis.

Secondaries (secondary feathers): the feathers which are attached to the forearm, from wrist to elbow.

Stegocephalian: a salamanderlike, tailed amphibian of the late Paleozoic and Mesozoic eras.

Stroboscopic photograph: a photograph taken by means of a special sort of flash bulb capable of emitting a flash of extremely short duration.

Teleosaur: a crocodilian reptile of the Mesozoic.

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