AERODYNAMIC FEATURES OF THE TREE

by John M. Haller

Of the many factors that influence the shape and size of the above-ground parts of a tree—light, gravity, and the tendency of every organism to invade space in all useful directions—one factor easily overlooked is the necessity of the tree to adapt itself to the push of the wind.

To consider a tree as aerodynamically conditioned seems at first sight absurd. A fish or a submarine must adapt its shape to the water through which it moves; a bird, an insect, and an airplane must do the same in relation to the air. All such objects eventually become more or less streamlined in response to the laws of fluid dynamics. But what stationary object is streamlined?

The answer is, very simply, the tree. The whole tree is streamlined, from its trunk to its leaves. And it has good reason to be. For although the tree does not fly, the air blows past it, which is very nearly the same thing. From this standpoint we may regard the shape, size and structure of a tree quite as much as aerodynamically determined as the shape, size, and structure of a bird. Moreover, the bird and the airplane may regulate their speeds as they wish and in times of gale may seek shelter on the ground. The tree, in contrast, has no way of regulating the speed of the air that flies past it, and no matter how strong the gale may become, it has no recourse but to stand and face it. Considered in this way, the tree's need for streamlining is even greater than the bird's. The bird is streamlined in order to pass more easily through the air; the tree is streamlined in order to preserve its very existence.

To better visualize the streamlining of the whole tree, let us imagine some giant hand plucking it out of the ground and throwing it through the air, as a boy may shoot an arrow from its bow. Just as the weighted point and the feathered hilt cause the arrow to maintain a straight course in its flight, so the heavy trunk at one end and the leafy branches at the other would cause the tree to behave in a similar fashion.

It may be objected that the wind strikes the tree perpendicular to its axis rather than parallel with it and therefore the analogy of the arrow is not apropos. This is true, but the very objection lends strength to the thesis. The tree is streamlined, and it is so under the most difficult of conditions. For of all the streamlined organisms that exist the tree is the only one not free to turn its entire body parallel with the lines of force that flow around it. The bird or boat may turn into the waves or scud along with them. The tree is firmly anchored in the ground, incapable of adjusting its main axis to the stream flow; its problem is much more difficult than the bird's or the fish's. It must be prepared to meet winds from every possible direction. It must, therefore, be streamlined in all directions—a seeming impossibility.

Flexibility in one particular direction is a phenomenon of frequent occurrence among organic forms. Flexibility in opposite directions is much rarer. Our arms and legs, for example, bend forward but not backward. Universal flexibility is still rarer. But this is precisely the faculty the tree's superstructure must possess. From whatever quarter the wind strikes it, it must roll with the punch(Fig. 1).

If the wind blew always from the same direction, trees would be more easily and more patently streamlined. Their limbs would develop on one side only, all would follow a uniform contour, even the trunk would grow diagonally or in a smooth curve in an attempt to shape itself to the direction of the air flow. In those parts of the world where winds *do* blow prevailingly from one direction only, such odd-shaped trees are actually found.

But since in general winds are likely to blow from any quarter of the compass, trees must be streamlined in *every* direction. As a consequence thay have made their trunk and limbs round, so as to present at least a partially streamlined surface to the wind from any quarter; they have constructed their branches and twigs with as much flexibility as is consistent with strength to permit them to sway and bend without breaking; and they have endowed their flat surfaces—the leaves—

with complete flexibility and instant mobility and made them small in size and streamlined in shape.

At first blush the trunk's adoption of a perpendicular attitude might seem ill-advised, for in no other position could it more rashly defy the winds that strive intermittently to level it. But leaving to one side for a moment all other factors, such as the influence of light, the distribution of weight, etc., it becomes obvious that since the tree must be prepared to resist winds from every direction, the most nearly neutral position in this play of antagonistic forces is precisely the strictly perpendicular one.

Branch Streamlining

The shape and pattern of the branches carry out the streamlining. They taper from thick to thin. They divide and subdivide, and the angle they make in their branching is always an acute one so that in a strong wind they tend to fold together, reducing wind resistance and lessening danger of breakage. They are strong at their bases and flexible at their tips, bending and swaying in order not to break. They are capable of bending to the right, to the left, up, down, horizontally, vertically, diagonally; of aligning themselves smoothly with the wind when it blows in their favor and of doubling ingeniously upon themselves when it blows against them.

That branches are occasionally broken off in high winds does not invalidate the thesis. If the tree were horizontally oriented and if the wind blew always from the base toward the tip, no branches would ever break. The upright, growing tree represents the nearest possible approach to perfect streamlining consistent with the tree's fixed position and the variability of wind direction.

Leaf Streamlining

But it is with the leaves that streamlining becomes most conspicuous, most ingenious, and most necessary.

Before examining the subject in detail let us consider what might be the consequences if the leaves were *not* streamlined. Let us imagine a tree with all its foliage sewn together into a single tissue. What would the wind, which even when moderate furnishes enough power pushing against a ship's canvas to drive the most heavily laden vessel through the seven seas, do to the tree when pushing against *its* extended canvas? The tree's predicament with its sail always spread would be far more serious than the predicament of a ship unable to trim sail. For the ship is free to move in the direction of the wind's push, lessening its force, while the tree is fixed in the soil. Imagine the ease with which the mast would snap if a gale caught a fully rigged ship *at anchor!* This is the tree's case: it is always at anchor, hence its necessity to take in sail is much more urgent.

The tree "takes in sail" by reducing the size of its leaves from one single large piece to many

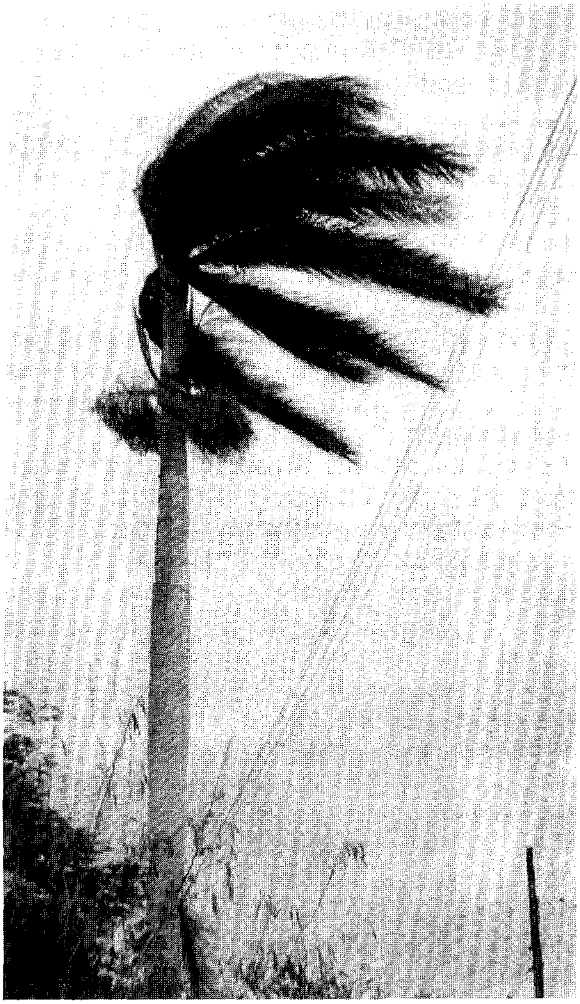

Fig. 1. Wind adaptation of the royal palm. Strong and stiff though they are, the fronds are still flexible enough to conform to the wind flow. A moderate wind produces partial alignment, a high wind total alignment.

small pieces, by making them streamlined in shape, and by mounting each on a slender, flexible petiole so that they are free to move instantly in any direction.

So effective are these adaptations that even the ship tends to copy them in so far as it can, given its very different purpose: while a small boat may make do with one sail, the large ship finds it can better exploit the wind and increase its mobility by use of many sails, differently positioned and of different sizes; thus the multi-sailed ship tends insensibly in the direction of the multi-leaved tree. The important distinction, of course, is that in order to fulfill its function the sail must be secured at both ends while the leaf is secured at one end only and thus free to "roll with the punch," however swiftly or strongly this may come. The ship attempts to roll with the punch by moving its whole ponderous bulk, but sometimes it is unable to do so with sufficient promptitude and is capsized. The leaf, forced to stay in one place, reduces the push of the wind to an absolute minimum by presenting—instantly—its paper-thin edge to the onrushing current.

Endowed, then, with such mobility why should not a single large leaf serve as well as many small ones? There are many reasons why a single large leaf will not do.

One is the difficulty of producing such a structure, given the bifurcating pattern of the exogenous tree. How could it be formed, how suspended? Would it, perhaps, enclose the whole canopy like an umbrella? Or would it grow on one side only like a flag on its staff? Or project outwardly in all directions like the solar panels on a satellite?—But then it would not be a single leaf.

A second reason is the much inferior photosynthetic surface possessed by a single large leaf in comparison with a multitude of small ones occupying the same area. This apparent impossibility is true because the small ones, occupying many different planes, overlap and are distributed throughout the total space filled by the tree's superstructure, while a single sheet would be limited to one plane; it is the relation that obtains between a circle's area and its volume.

Third, destruction by the wind, insects, disease, or any other cause would entail the slow, costly reconstruction of the whole large piece, whereas damage to a single small leaf or even many of them is easily repaired.

Fourth, any large flat sheet of flexible material fastened at one end and free to flap in the wind at the other, is inevitably shredded at the free end, such as sails which become loose and are not promptly furled or the flapping ends of tarpaulins on trucks that are soon torn to bits; such shredding is the clearest possible indication that many small leaf strips are better suited to resist wind action than a single large sheet.

Thus we see that the effect of the wind determines the shape of the tree leaf and sets a definite limit to its size. In order to exceed that limit, it would need to be made stronger. This would involve increasing its weight and decreasing its flexibility. This in turn would bring us back to the danger of offering too much resistance to the wind, to say nothing of increased functional inefficiency due to the increased weight and rigidity. Hence we conclude that the present pattern of tree leaves as they actually exist, free to vary widely in shape and size but only within definite limits and according to a strict pattern, is the best possible construction for the purpose as hand; and we come to say of leaves, paraphrasing Leibnitz, that "they are the best of all possible forms". (Palms are an exception to all this; their case will be taken up farther along.)

In striking confirmation of this thesis, we observe that leaves of shrubs, bushes, and small plants of all kinds that grow habitually close to the ground or in protected lower stories of a forest are seldom streamlined, as having no reason for being so. Such plants have leaves that are large—sometimes very large—sessile (without petiole), or nearly so, often thin and fragile, and formed into a variety of different shapes which seem to be more the result of capricious and random variation than the response to a dominant physical force[1]. These are the plants that strain the vocabulary of the botanist; it is their endless variability that drives him to mine ever more deeply the long-

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[1] This does not mean that such leaves *must* be large or sessile or fragile or oddly shaped; it merely means that they often are, and that *only* in sheltered, close-to-the-ground situations are they to be found.

buried Greek and Latin linguistic ore-beds. Here are found the spatuliform leaves, the reniform, the ensiform, the ovate and the obdeltoid, the clavate, the obclavate, the rotundate, the subulate and so on almost without end.

Tree leaves are far easier to classify and describe for the simple reason that, subject to a single, dominant force, they vary less. A few strongly marked main types are found with great regularity; and although their size and form are obviously affected by altitude, latitude, heat and cold, rainfall and dryness, these main types recur again and again so commonly that the traveler comes to expect them in Alaska as much as in Brazil, in the New World as in the Old, impartially on all continents and in all latitudes.

PRINCIPAL LEAF TYPES

The five main types are (1) the needle type, such as those found on pines, firs, and spruces; (2) the scale type, as on junipers, incense cedar, and Big Tree (Sequoia gigantea); (3) the simple, ovoid type, as on the elm and the hackberry; (4) the broad type characterized by deep lobing, as on the sycamore, the sweet gum, the tulip tree, the maples; (5) the compound type, as on the locust and the mesquite. Each of these types is streamlined in its own way; each represents a different solution to the problem of providing maximum photosynthetic surface and minimum air resistance.

Needle Type

The needle type is self-explanatory. What could offer less resistance to the wind than the toothpick shape of the pine needles, free to move on their flexible twigs and to align themselves with every passing wind? Such trees, however, have deceptively heavy foliage; while the leaves individually are small, their number is great. The narrow pine needle, so insignificant in itself, is yet adequate, when replicated in sufficient numbers, to manufacture the food required to produce a 30 foot tree in ten years.

Scale Type

Scale type foliage consists of many tiny, overlapping leaves closely appressed to the twig; without careful examination one may fail to see any leaves at all, believing the twig itself to be green, as indeed is the case with Casuarina. This imbricated pattern with no projecting surfaces offers minimal resistance to the wind; the twigs look as if they were braided, hence the name "whipcord foliage" often applied. The biggest tree in the world, the interior redwood (Sequoia gigantea) has such foliage; so have the immense baldcypresses of southern Mexico. The tamarisks have leaves built on this plan with the result that they are many times confused with the pines. Here, too, the foliage is deceptively heavy, and a paradoxical situation arises. The cylindrical filaments of the tamarisk while offering negligible resistance to air flow, occur in such profusion that the tree is actually planted as a windbreak!

Elm Leaf Type

The simple, ovoid, undivided leaf of the elm, hackberry, Osage orange, etc., is for the Temperate Zone broadleaved trees the commonest type of all. Such leaves are usually not more then 3" to 4" long by 1½" to 2½" broad. They are characterized by a short petiole, ½" to 1½" long, a gradual widening of the blade as it recedes from the petiole, reaching its widest part about one-third of its way along its length and then a tapering down of the blade to an acute or acuminate tip. Such a leaf strikingly resembles the profile of a fish, the acute tip being the tail and the proximal (petiole) end being the head. One has only to sketch in an eye, a mouth and a fin, and the similarity becomes too strong for coincidence and can only be interpreted as parallel adaptions in response to similar environments: the fish adapting to flow of water, the leaf to the flow of air.

By a simple and homogeneous transformation (based on the principal of topological similitude) the ovoid leaf becomes the lanceolate one. Such a leaf, although narrower and longer, maintains the same profile features: sloping shoulders, maximum width a third of the way along and a gradual tapering down to an acute tip. On a given tree all possible intergrading forms are found between the ovoid and the lanceolate. More significant, however, than a merely random occurrence of different forms is the fact that toward the bottom of the tree the leaves are larger and the ovoid or elliptical forms are more pronounced, while towards the top the leaves become smaller, the ovoid form occurs with less frequency and the lanceolate form with more frequency. (Apart from their need to offer less resistance to the wind, the leaves at the top of a tree are smaller because they are better exposed to the sun and hence need less surface in order to function efficiently, while those near the bottom, being more shaded, need to be larger in order to catch the few rays that are reflected down to them. The same reason helps explain the enormity of the elephant's ear and other plants growing near the forest floor.)

Few trees exhibit this preferential differentiation so well as the eucalyptus. The lower leaves, particularly those on new shoots, are short and ovoid; transitional forms occur a little higher up; while the narrow lanceolate form constitute the whole top of the tree, comprising perhaps 4/5 or 9/10 of the foliage. Being one of the tallest trees in the world, the eucalyptus has extraodinary need of foliage that can offer as little resistance as possible to the wind; its tough, tapering, lanceolate leaf is admirably adapted for the purpose.

Sycamore Type

When a leaf exceeds the average size of about 4½" by 3" it resorts to an ingenious expedient to prevent its becoming a danger to the tree that bears it and at the same time to prevent its substance from being shredded by the wind: *it breaks up into lobes.* (Some trees, such as the magnolias, the avocados, and the tropical almond, *Terminalia catappa,* bear simple undivided leaves in larger dimensions. These are not, however, forest trees and do not ordinarily grow in any except sheltered conditions. On all such trees, moreover, the leaves become progressively smaller toward the top, where most exposed to wind.) Thus lobing, which we think of as being merely ornamental, exists for a definite reason: it permits the leaf to retain a large photosynthetic surface while at the same time reducing its air resistance. Lobing is a streamlining device of the first order and as such we should expect it to occur primarily at the distal portion of the leaf, where the most air-drag is experienced.

Examination shows that this is indeed the case. The majority of lobed leaves, such as those of the sycamore, tulip tree, Japanese varnish, mulberry, are lobed only at their distal end. Other leaves, such as of the Spanish oak, the burr oak and some of the maples, are lobed more or less uniformly entirely around the periphery. These cases, fewer in number than the others, may be interpreted as a step in the direction of streamlining, which has begun by the invagination of surface but has not yet localized that invagination at the free end where it is aerodynamically most effective. If we make the assumption that many leaves represent only transitional forms that have not yet perfected the problem of streamlining, we may explain even multiple types of *margins*—serrate, crenate, crenulated, rounded, etc.,—as incipient forms of lobing. Significantly, all tree leaf margins—*all*—point toward the tail end of the leaf. Only on ornamental potted plants, grown in sheltered locations where the wind never strikes them, do we find scalloped margins that point neither forward nor backward.

To study the action of the leaves as the wind blows them to and fro is to learn many a curious fact. Those trees that have foliage that is colored underneath, like the silverleaf poplar, respond to a brisk breeze by suddenly turning gray or silver in a striking demonstration of the leaves' perfect alignment to a dominant force.

When no wind is blowing, one may break off a branch and dangle it in front of an electric fan, just as avaiation engineers test their models in wind tunnels. Many leaves, so tested, appear to possess an actual lifting effect. Even the simple ovoid or elliptical forms are slightly folded upward along the midrib, with the curious result that whether the wind presses against the leaf's lower (convex) surface or its upper (concave) surface (doubling it back on itself), a lifting effect is created in both cases that is noticeably greater than would be the case if the leaf were perfectly flat. While no leaf is cambered, like the wing of an airplane or of a bird (which is almost too much to ask, since the leaf's photosynthetic function demands that it be of approximately uniform thickness throughout), the slight upward and inward folding along the midrib corresponds strikingly with the upward tilting of plane and bird wings.

Under the electric fan the cordate types of leaves, such as these of the catalpa and the *Paulownia* and certain varieties of maple and sycamore, which approximate the cordate type, show a very interesting response. The large frontal "shoulders" (closely corresponding to the curve formed by the folded wings of a bird) roll upward and backward, the whole blade folds together ever so slightly and the lobed trailing edge flattens out parallel with the air stream. Since the "shoulders" often grow backwards toward the twig while at the same time approaching each other, they frequently come to envelop and conceal the petiole's point of attachment, in such a manner that this structure seems to originate at a point near the leaf's center—or more specifically, at a point corresponding to the intersection of two sticks nailed together to make a cross. Due to this peculiar arrangement, such a leaf looks much like a simple, cross-stick kite, with the long petiole (which almost invariably goes with such leaves) functioning as the string. In a brisk wind such a leaf literally flies—at least as much as a kite may be said to do. If such a lifting or flying effect really exists, as I believe it does, may it not serve as a compensating mechanism during high winds? At the time the whole tree is being subjected to severe wind stress, some of its branches may actually be obtaining a brief reprieve from the omnipresent pull of gravity, enjoying the weightlessness of an astronaut between two gravitational fields.

Compound Type

The compound type of leaf represents still a different approach to the problem. Aerodynamically, the compound leaves, like the lobed leaves, represent an attempt to conserve as much photosynthetic surface as possible while at the same time reducing air resistance to a minimum. (They also reduce evaporative surface and are thus found in many desert plants). Lobing and compounding are two parallel means toward the same end; indeed, the *palmately* compound leaf, like that of the horse-chestnut, may with equal validity be considered an extreme case of lobing. The papaya leaf is an even more interesting type; it is both palmately compound *and* lobed. Each of its 7 to 11 incompletely palmate leaflets is itself deeply lobed, and sometimes each of these lobes is lobed in turn.

Compounding may occur palmately or pinnately. Palmately compound leaves are those made up of several leaflets that radiate outward from a common center, as the outspread fingers of the hand seem to do (hence the name); examples are the horsechesnut and the silk-cotton tree. Pinnately compound leaves, built on the pattern of a feather, consist of a central longitudinal axis from which arise lateral pairs of leaflets. Such leaves may be simply compound, as in the walnut, pecan, and tree-of-heaven; doubly compound, as in the locust, mimosa, and mesquite; or even triply compound, as in the horseradish tree (Moringa oleifera). In the doubly compound leaf each lateral leaflet of the simple type is replaced by a secondary longitudinal axis, which itself bears paired lateral leaflets. In the triply compound leaflet the process is carried a step farther, and we see a primary axis bearing lateral pairs of secondary axes which in turn bear lateral pairs of tertiary axes which bear the leaflets proper.

Characteristic of all compound leaves, large or small, palmate or pinnate, is the fact that the leaf is morphologically and physiologically a unit. It develops from a single bud, and when it dies, it falls from the tree as a single structure, leaving a leaf scar on the twig exactly as a simple leaf does.

The leaflets of some compound leaves, such as those of the walnut, pecan, and the tree-of-heaven, merely duplicate the streamlined, ovoid shape of many simple leaves and in many cases approach very closely to the average size of the simple leaf. Other leaflets, however, such as those of the mesquite, sweet acacia, locust, and Royal Poinciana, are so small that they escape the need for being streamlined individually, coming to be simple ovals or ellipses.

The more one contemplates the compound pinnate leaf the more admirable its structure becomes and the more apparent its morphological unity. As one twirls the leaf about between his fingers, the paired leaflets fall into line with a rapidity and uniformity of response that suggests the movement of Venetian blind slats in response to a pull on the cord. Few more striking examples of symmetry are to be found anywhere in nature. The little leaflets are all exactly alike (at least to the naked eye), each member of a pair is the same size and the same shape, each grows outward at exactly the same angle, each moves in unison with all the others at the slightest puff of wind. Compounding may be considered the last word in streamlining. The system of many tiny leaflets on reduplicated petioles mounted at the ends of slender, flexible twigs provides a perfect latticework through which the wind passes without let or hindrance.

Palms

Finally we come to the palms, apparent exceptions to everything that has just been said. For hundreds of thousands of years these plants have experimented with giant leaves, carrying the principle of bigness to its apparent uttermost limit. Although there are many reasons for considering palms to be not true trees but only overgrown herbaceous types, they must in the present context be taken as trees, for they grow tall, some of them exceeding 100 feet, and their leaves, mounted at the very top of the stem, are exposed to the wind's full force. (The famous Andean wax palm grows to 200 feet and before the discovery of the redwoods, the Douglas firs, and the eucalypti was catalogued as the world's tallest tree.)

Palm leaves are very large—huge is the better word—and they spring directly from the trunk without intermediation of branch or twig. There are two principal kinds: the fan type and the feather type; the former may reach the size of an old-fashioned table top, six feet by four, while the latter may attain a length of 15 to 20 feet in the common varieties and an unbelievable 50 to 60 feet in certain tropical species. Each great frond is a single leaf; when it dies, it dies as a unit, the trunk bearing along its length the scars of all former leaves.

With such enormous leaves, how does the palm manage to resist the push of the wind? What is there aerodynamic about these immense leathery structures? Does not their existence destroy the whole chain of argument in favor of the small, streamlined leaf? Imagine the reaction of a botanist who after painstakingly elaborating some such aerodynamic analysis as the present one and having never seen or heard of a palm were suddenly to be confronted with one of these incredible plants! His would be the tragedy of a theory slain by a fact; his the discomfiture of the astronomer who, precisely toward the end of a long lecture in which he had conclusively proved the impossibility of asteroids existing between Mars and Jupiter, was interrupted by an excited messenger bearing tidings of their discovery.

Although at first sight there certainly seem to be no aerodynamic features about palm leaves, closer examination reveals that these do indeed exist. In the first place the huge leaves, like their smaller analogues, are secured at one end only and thus free to align themselves with the wind, which in spite of their bulk they do with surprising agility. In the second place, the largest of them, the leaf of the feather palm, is not a single tissue but a compound structure made up of many individual segments with ample separation between them. Third, each segment (leaflet or pinna) is itself made up of two long strips joined as by a piano hinge along the center line and easily folded together. When the air is still and the sun not too hot, the two halves of the pinna tend to open, but when the weather becomes hot and dry, they tend to close; when the wind blows strongly, they close instantly. With the pinnae folded together and well separated one from the other, the leaf presents minimal resistance to the wind. Fourth, the palmate type of palm leaf (named after itself), although apparently a single large sheet, is shredded at its distal or trailing edge from the moment it first issues from the bud—wind-adapted before the wind ever gets a crack at it—and this shredding increases with aging so that an old leaf, like those of the Washingtonia, is little more than a fan-shaped arrangement of narrow strips loosely connected toward their basal ends. These palmate leaves, although large, are very much smaller than the 50 or 60 foot feather palm fronds; moreover, they possess an altogether unexpected flexibility. In a strong wind all leaves will align themselves instantly parallel with the air-flow, all grouping together on the lee side of the trunk with not a single one on the windward side.

POSSIBLE ORIGINS

The question of how the compound leaf originated is an exceedingly interesting one. We have already seen (palms excepted) that the single, simple leaf has definite upper limits set to its size; that when it grows beyond those limits it is no longer efficient as a streamlining mechanism and runs the danger of being torn and shredded by the wind. The fact that the compound leaflet comes from a single bud indicates that quite possibly—even probably—it was many generations ago a simple leaf of unbroken surface. Moreover, a careful study of its structure shows how the midribs of the paired lateral leaflets correspond closely to the lateral venation of simple leaves. Finally, the overall comparison of size and shape with the size and shape of a large simple leaf indicates how easily the one could be cut from the other with a pair of scissors, particularly when folded together (as leaves *are* folded in the bud), just as children fold a sheet of paper and by the simple expedient of making random cuts into it produce figures which, when the paper is unfolded, turn out to be designs of great symmetry and beauty.

It seems probable that the simple leaf is the original form and the compound leaf the derived form. Many botanists interpret the compound leaf as an evolutionary response to desert conditions, the large, simple leaf reducing its evaporative surface by withdrawing, as it were, all excess soft tissue and conserving only thin, tough flanges immediately contiguous to the veins. Such reduction of surface and consequent fragmentation into many small leaflets may also be explained as a response to the shredding action of the wind. Perhaps both factors were operative, either separately or together.

In any case, whether we favor wind or dryness as the critical environmental factor we are faced with the problem of explaining how such a morphological modification managed to become incorporated into the germ plasm. Difficult as it is to explain how such a form first appeared it is still more difficult to explain how it became perpetuated.

For the shape of the leaf, like the shape of a fish or that of a bird, is determined *before* entering the environmental field of force. Its shape is already determined when it is still in the bud, as the most casual examination at once shows. The margins, the venation, the lobing, are all clearly present; and the growth of the leaf, unlike that of other plant tissues, is largely a matter of osmotic distension of the cells already formed. If a tree is grown under a glass dome where no faintest breeze ever troubles the leaves, these will develop exactly, or almost exactly, as if they grew unprotected in the open. Leaves unlobed in normal conditions will be unlobed under the dome, and leaves normally lobed or subdivided will exhibit the same pattern when protected.

Thus it is apparent that the shape of the leaf is *not* determined by the streamlining action of the wind acting on it during its formation or at any subsequent stage of its existence. The only alternative left us is to conclude that the shape is determined by the action of the wind acting on *the leaves of former generations* and that in some way this action, and the leaves' reaction to it, became incorporated into the germ plasm of the tree and hence transmitted to future generations. Here we are confronted with the twin problems of exquisite structural adaptation to environment and its hereditary transmissibility or, in other words, with the whole problem of evolution.

The two classic explanations are the Lamarckian and the Darwinian. The Lamarckian view, now out of favor, would postulate that sometime in the remote past as simple leaves strove repeatedly to exceed the size limit and were shredded repeatedly by the wind (or desiccated by heat and dryness), they came to "learn" that they could solve the problem by appearing in the shredded form in the first place. In other words, some modification in the somatic tissues of plants induced the germ cells to produce leaves better adapted to this particular stress. This view, although tempting, seems to be unsupported by the facts. That it continues to be believed by many is doubtless due to its implied suggestion of design and purpose. We like to think of organisms, even the lowest, as striving toward some goal; we endow them with our own sense of purpose.

The second explanation, and the one most widely accepted today, is the sequence: mutation/sexual recombination/natural selection. This explanation assumes that the compound leaf appeared as a germ plasm mutation at some time on some tree, that it was retained as a permanent genetic modification and transmitted to all that tree's progeny, that it conferred an advantage on its possessors, and that such advantaged forms gradually won out over rival forms not similarly endowed.

Banana vs. Palm

It is interesting in this connection to consider the case of the banana and the palm. Directly in front of me as I write stand growing side by side a feather palm and a banana plant. The banana has reached its full height, but the palm is still young, so at the moment both are about the same size, 12 or 15 feet tall. The leaves of the palm, pinnately compound, are perfectly formed to allow the free passage of the wind; although they bend and sway incessantly, they retain their shape and substance undamaged. In contrast, the leaves of the banana, unbroken as they emerge from the growing tip, are torn and shredded by the wind even before they have fully expanded, and the longer they live the more they are shredded. Each rent runs from the margin of the leaf back to the midrib, following the lines of the numerous parallel and equidistant veins, so that at last the leaves become divided into a series of parallel lateral segments of approximately equal width. The appearance of such leaves approximates so closely the appearance of the palm leaves that where the two overlap I have to look carefully to distinguish one from the other.

Why is the palm leaf so exquisitely wind-adapted and the banana leaf so patently ill-adapted? Why does the banana continue, generation after generation, to send forth its huge, single-surface leaves (8 or 10 feet long by 1 to 1½ feet wide), only to have them torn to shreds by the first strong wind? Why has it never "learned" to produce a feathered leaf in the first place, as the palm presumably did?

The Lamarckian interpretation would at once answer that the banana has never "learned" to pre-adapt its leaf to the wind because, reproducing vegetatively (by basal shoots), it has no germ plasm to be "taught". The natural selection view, although reaching the same conclusion, does so by a very different route: since no seeds are produced, no transmissible mutations can occur, hence all new plants are identical with their predecessors—are, in fact, not new individuals at all but nothing more than renovated parts of the same individual.

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ABSTRACT

SHURTLEFF, MALCOLM C. 1989. **Diagnosing shade tree diseases.** Grounds Maintenance 24(6):22, 24, 26, 68, 72.

Learning how to diagnose common diseases will help you maintain healthy trees. Rapid and accurate diagnosis is the first step in the treatment of any disease. Follow these basic steps: 1. Evaluate the overall appearance of an unhealthy tree. When you evaluate problem trees on-site, knowledge of the past history of a tree will help you to determine the *true* cause or causes of a problem. 2. Look for direct evidence (signs) of the cause. Examine the foliage, twig and branch system, trunk and roots. A weakened tree is much more susceptible to secondary attacks by insects (such as borers) or diseases (like canker, certain wilts, root rots and wood decay). 3. You may need a laboratory examination and/or culturing to confirm your tentative diagnosis.