Tree of
Knowledge
Tree Care Information

BLOWING IN THE WIND:

Wind-resisting Features of Trees – *Part 2*

by Steven Vogel

Learning objectives—
The arborist will be able to

- explain the four schemes of root anchorage
- explain the effects that the four anchorage schemes have on a tree's trunk
- describe how leaf shape and other features help minimize drag

Leaves and the Minimization of Drag

Exposing a large area of leaf surface to sun and sky must be the most important facet of the design of a tree. Thus, a high level of drag a long way above the substratum appears unavoidable—but at least high winds are typically intermittent and most commonly associated with low light intensity. However, the situation may be worse than it appears at first glance. Stiff structures of great area require great material investment. Flexible structures of great area take less material but suffer much more drag. A flexible flag of ordinary shape experiences an order of magnitude more drag than does a rigid weather vane of the same shape and area.

What, then, might a tree do about the drag of its leaves? The first indication that trees don't simply endure a lateral force on their crowns that increases with the square of the wind speed came in 1962 from measurements on a pine *(Pinus sylvestris)* in a very large wind tunnel (Mayhead 1973). Drag increased with an exponent of less than 1 (0.72), rather than the expected 2.00 up to a speed of 38 meters per second (85 mph), at which the tree started to shed pieces (Vogel 1984). With increasing wind, the tree reconfigured its form, with needles and then branches coalescing into clumps. Instead of being a pure liability, as in a flag, flexibility is at least in part a virtue in the upper portions of a tree.

Such reconfiguration is not limited to pine needles that bend inward toward their twig. More spectacular and at least equally effective temporary and reversible changes of form occur in broad leaves as well. The leaves of holly *(Ilex opaca)* turn sideways by bending their petioles and end up as a tightly pressed sandwich of laminae on top of their twig (Vogel 1984). A wide variety of leaves are marked by relatively long petioles and stemward protruding lobes on each side of the attachment of petiole to blade. The arrangement occurs (probably convergently) in at least 15 families of plants. These, at least all that have been wind-tunnel tested, roll upward into cones whose open apices point upwind toward the stem and which become tighter (more acute) as the wind speed increases (Figure 5). These cones are stable in even highly turbulent flows. They open and close quickly enough to respond to even brief gusts, and they're associated with levels of drag much closer to that of a weather vane than of a flag (Vogel 1989). Drag even a little lower (relative to leaf area) is achieved by pinnately compound leaves, again to the extent (two species) that these have been tested. The leaflets bend and curl upward, interacting to form elongate, hollow cylinders just above their common rachis.

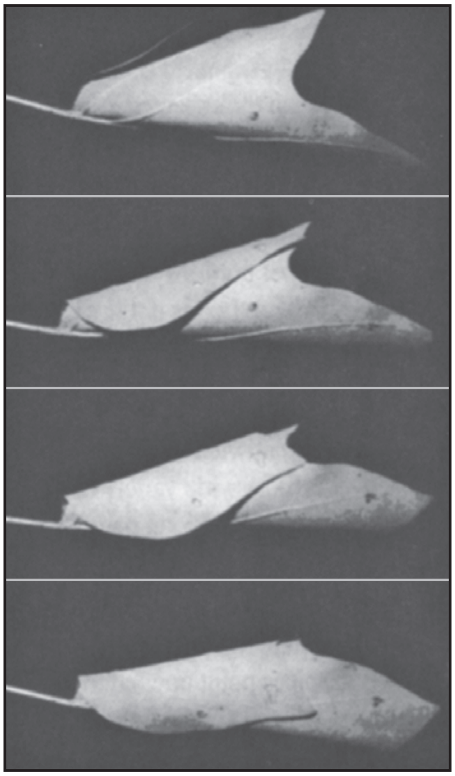

Figure 5 (from top to bottom). A leaf of tulip-tree in turbulent winds of 5, 10, 15, and 20 meters per second (11, 22, 33, and 44 mph).

Groups of leaves reconfigure as well, often forming tight, conical clusters with lower overall drag (again, relative to area) than achieved by individual leaves of the same species. For some trees, such as white oak, the individual leaves are not especially effective in reconfiguration, but they do relatively well as groups. Such oaks, in any case, may derive a compensatory advantage from their less extreme reconfiguration. In modest winds, they maintain their normal, skyward orientations where others, such as maples, have begun to turn and flutter. In general, some instability at low speeds seems to be associated with good facility for dealing with higher winds. The shimmering of quaking aspen *(Populus tremuloides)* leaves may just represent the low-speed instability associated with an especially good ability to reconfigure stably (in its case as multi-leaf clusters) in strong winds. At least that is the indication gained from work with the congeneric white poplar *(P. alba)* (Vogel 1989).

To reconfigure into clusters, petioles must be able to twist. But to support protruding leaves, they have to work as cantilever beams and resist bending. Thus, petioles, like trunks, ought to have a high ratio of twistiness to bendiness. And indeed they do. Whereas the trunks achieve a high ratio by manipulation of their material, the petioles do so by adjusting geometry as well. Short petioles in particular quite often have lengthwise grooves on top, side-to-side flattening, or other kinds of non-circular cross sections that effectively increase that ratio (Vogel 1992).

Perspectives and Prospectives

If a central theme pervades this analysis, it is how nature uses flexible structures—leaves, branches, trunks and roots. Human technology mainly uses more rigid materials—metals, ceramics, dry wood, and so forth. We thus have little experience in designing things that change shape in strong winds, and we reveal our underlying prejudice when we speak of "deforming" rather than the less pathological "reconfiguring." Quite beside learning about the trees themselves, a careful look at the mechanics of their wind resistance ought to reveal the subtle tricks possible when flexibility is embraced and treated as a complex, multidimensional and positive phenomenon. The flexible structures and materials that make up trees not only twist and bend but do other things as well. They can absorb and either store or dissipate energy. They can change properties reversibly or irreversibly over time scales from seconds to years. They can engage in complex tradeoffs among properties that the engineers call strength, stiffness, extensibility, toughness, and so forth. We might just learn things from this unfamiliar but certainly effective technology.

Even in a given habitat, trees are a diverse lot. Almost nowhere has one design emerged as clearly superior. Parts of the explanation must lie in the large number of factors involved in standing up to the wind and the number of functions to which each structural element must contribute. That explanation may make the world a great deal more attractive and provide a wide range of arboricultural options, but it certainly complicates any analysis. One should perhaps begin by looking for recurring arrangements such as those noted here—the long petioles with basal lobes of many leaves and high twistiness-to-bendiness ratio of trunks. Such convergent patterns (ones that don't simply reflect common ancestry) are a first indication of functional significance.

What is especially striking about the present topic is the limited amount of experimentally based information in the primary scientific literature of fields such as botany, agriculture and forestry that might naturally address its questions. We know a great deal about wood—cut and cured—but far less about trees. To the extent that work is being done, a relatively large contribution is coming from people outside of the traditional plant sciences. Of those cited here, Gordon and Mattheck come from engineering; Ennos and I are biologists who began by working on insect aerodynamics. General background for the subject is easily available from paperback books such as those of Gordon (1978) and Vogel (1988). The questions are neither scientifically arcane nor practically irrelevant. Neither do they present particular technical difficulties or expense. Indeed, addressing many of them is so inexpensive and easy that good basic work should be quite practical for nonacademic arborists working avocationally.

Corresponding test questions for this article are available in the ISA compendium entitled "Tree Biology." The compendium is a collection of *Arborist News* CEU articles with corresponding test questions worth a total of 8.5 CEU credits. ISA compendiums are available to purchase from the ISA online at www.isa-arbor.com or by phone at 888-472-8733.

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