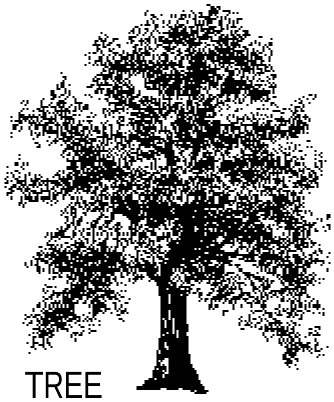

TREE
BIOMECHANICS
SERIES

Estimating Wind Forces On Tree Crowns

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Wind and gravity are the two primary forces acting upon tree crowns. The structural resistance to these forces by the tree require complex allocation processes and dedication of limited resources. Assessing the shear scale of both wind and gravity forces, and considering most trees do not usually fall under their own weight, wind forces on the crown are dominant and immense. Resistance to wind forces can be summarrized by measures of crown density, living crown height, and total height of the tree.

This publication will concentrate on theoretical approaches to estimating wind force resistance by open grown tree crowns. The dynamic and complex circumstances of soil, tree, and environment can not be adequately modeled here. Only a few isolated static components will be examined. The purpose of this publication is to allow tree specialists to appreciate tree biomechanics. Figure 1 graphically defines the calculations involved.

This publication contains three tables all derived from the amount of force exerted by the wind, and how an open grown tree resists this force. Force resistance by the tree is based upon bending moments (resistance to bending) in the following tables. Torsional strength was calculated but not presented. Torsional strength (resisting twist) is two times (2X) bending strength in both solid and hollow (closed, centered cavity) stems.

Table 1 presents the pounds of wind force per square feet of crown varying by wind speed (mph -- miles per hour) and crown density. Crown density is provided in 10% density classes, where 100% crown density stops and absorbs all wind energy. In a tree with 100% crown density, a 50 mph wind measured on the windward (upwind) side of a tree would be measured as 0 mph on the leeward (downwind) side of the tree. Crown density as used here is actually a wind drag factor across the crown and assumes tree crowns do not reorient with increasing wind velocity. Crown density is a measure of the difference in wind velocity across the crown.

For example in Table 1, a 50 mph wind would be reduced to 35 mph by passing through a tree crown with a 30% crown density -- calculated by: ((up-wind side in mph) x (1 - (crown density)) = (down-wind side in mph). Using Table 1, a 50 mph wind and 30% crown density generates four (4) pounds of force on each square foot of tree crown. (Dotted lines on Table 1 represent standard conditions).

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Table 2 is the percentage of force resistance remaining in the crown as living crown ratio declines. Living crown ratio is the height of the living crown compared with the total height of the tree. A 50% live crown ratio would be represented by a 100 feet tall tree with a living crown occupying the top 50 feet of the height. Wind forces are concentrated across the living crown and can be considered centered at a point 60% of the distance upward from the bottom of the living crown. Table 2 gives the percent of force remaining in the crown at different crown heights regardless of total tree height. Table 3 presents estimated total pounds of force per square feet varying by living crown ratio and tree height. Note the assumptions made in Figure 1 to calculate these values.

Conclusions

Table 1 suggests that low wind velocities are easily resisted by tree crowns. As wind velocity increases, more pounds of force are deposited upon the crown. If general, tree crown safety factors are in the range of three to five times more resistive strength than average wind conditions require. Increas-

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Table 1: The amount of wind force in pounds per square feet resisted by tree crowns over various wind speeds in miles per hour (mph) and various crown densities. Dashed lines show standard conditions used in other tables and text. Figure 1 graphically defines wind-crown calculations.

wind speed (mph)	crown density									
	100%	90%	80%	70%	60%	50%	40%	30%	20%	10%
200 mph	209	188	167	146	125	104	84	63	42	21
175	160	144	128	112	96	80	64	48	32	16
150	118	106	94	82	71	59	47	35	24	12
140	102	92	82	72	61	51	41	31	21	10
130	88	79	71	62	53	44	35	27	18	9
120	75	68	60	53	45	38	30	23	15	8
110	63	57	51	44	38	32	25	19	13	6
100	52	47	42	37	31	26	21	16	10	5
90	42	38	34	30	25	21	17	13	9	4
80	33	30	27	23	20	17	13	10	7	3
70	26	23	21	18	15	13	10	8	5	2.6
60	19	17	15	13	11	9	8	6	4	1.9
50	13	12	10	9	8	7	5	**4**	2.6	1.3
45	11	10	9	7	6	5	4	3	2.1	1.1
40	8	8	7	6	5	4	3	2.5	1.7	0.8
35	6	6	5	5	4	3	2.6	1.9	1.3	0.6
30	5	4	4	3	3	2.4	1.9	1.4	0.9	0.5
25	3	3	2.6	2.3	2.0	1.6	1.3	1.0	0.7	0.3
20	2.1	1.9	1.7	1.5	1.3	1.0	0.8	0.6	0.4	0.2
15	1.2	1.1	0.9	0.8	0.7	0.6	0.5	0.4	0.2	0.1
10	0.5	0.5	0.4	0.4	0.3	0.3	0.2	0.2	0.1	0.05
5	0.1	0.1	0.1	0.09	0.08	0.07	0.05	0.04	0.03	0.01

(pounds of force / square feet)

ing wind velocity can quickly overload tree crown structure. Table 1 also suggests that reducing crown density through crown thinning can remove some level of load.

Table 2 suggests that regardless of tree height, different living crown ratios will have a specific percent of force resistance remaining in the crown. Pruning trees up (crown raising) can significantly reduce force on the crown. Table 3 estimates the total force on tree crowns. The less the living crown ratio (the higher above the ground the crown begins) and shorter the tree, the less accumulated force on the crown. The magnitude of forces which wind applies to tree crown is large.

Table 2: The percentage of force resistance remaining in a tree crown as the living crown ratio declines (base of living crown moves higher along stem) for standard conditions over all tree heights. Standard conditions are 30% crown density (drag on wind) and a 50 mph wind velocity.

Living Crown Ratio (100% = living crown along entire tree height)									
100%	90%	80%	70%	60%	50%	40%	30%	20%	10%
100%	96%	91%	84%	76%	67%	56%	44%	31%	16%
Percent of Force Resistance Remaining in Tree Crown									

Table 3: The estimated force (total pounds of force) on tree crowns across various heights in feet and various living crown ratios (total height of living crown / total height of tree) under standard conditions. Standard conditions are 30% crown density (30% drag on wind) and 50 mph wind velocity.

Tree Height (feet)	Living Crown Ratio (100% = living crown along entire tree height)				
	100%	80%	60%	40%	20%
20 ft.	2,816	2,553	2,140	1,577	863
30	9,504	8,617	7,223	5,322	2,914
40	22,529	20,426	17,122	12,616	6,908
50	44,002	39,895	33,441	24,641	13,494
60	76,035	68,939	57,787	42,580	23,317
70	120,742	109,472	91,763	67,615	37,027
80	180,233	163,411	136,977	100,930	55,271
90	256,620	232,669	195,031	143,707	78,697
100	352,017	319,162	267,533	197,129	107,952
110	468,535	424,805	356,086	262,379	143,684
120	608,286	551,513	462,297	340,640	186,541
130	773,382	701,200	587,770	433,094	237,170
140	965,936	875,782	734,111	540,924	296,220
150	1,188,059	1,077,173	902,925	665,313	364,338
160	1,441,864	1,307,290	1,095,816	807,443	442,171

(total pounds of force on tree)

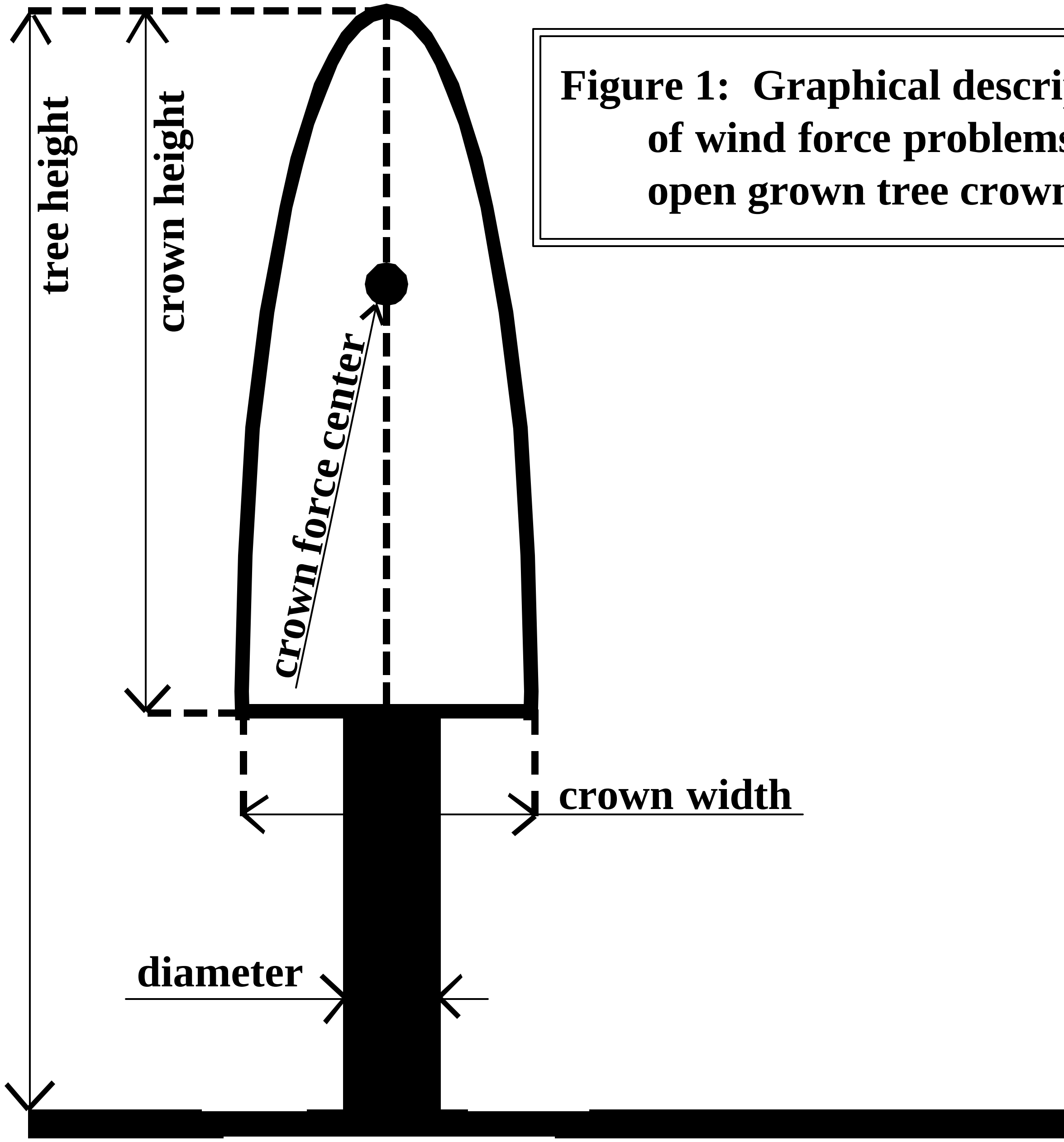

Figure 1: Graphical description of wind force problems on open grown tree crowns.

Crown Shape Factor (paraboloid) Area =
(2/3 x Crown Width x Crown Height)
60% of Crown Height is Crown Center (Center of Wind Force)
Crown Width = 0.22 x Tree Height
Wind Reduction Across Crown % (Crown Drag on Wind) =
Wind Velocity Leeward Side / Wind Velocity Windward Side
Air Density = 0.078 pds/ft^3
Wind Pressure = Crown Area x Force

(Note: No crown reorientation with increasing wind velocity was assumed for calculations.)