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NORTH CENTRAL FOREST EXPERIMENT STATION, FOREST SERVICE—U.S. DEPARTMENT OF AGRICULTURE

Folwell Avenue, St. Paul, Minnesota 55101

Weights and Centers of Gravity For Quaking Aspen Trees and Boles

ABSTRACT. — This paper discusses the results of field tests to determine experimentally the weights and locate the centers of gravity for aspen trees and boles.

OXFORD: 526.1:539:U531.2:176.1 *Populus tremuloides*

Most of the attempts to mechanize logging up to the early 1960's concentrated on improving single work functions, such as skidding and loading. These efforts have significantly improved logging productivity and are expected to continue into the future. Since the early 1960's much of the research effort has been directed toward development of multifunctional logging equipment, with special emphasis on the log-making phases of the harvesting operation. At minimum, multifunctional harvesting machines both cut and handle material. Before machines of this type can be designed for maximum economy and efficiency, accurate information is needed concerning the variables that affect the machine's operation.

Such information is available for cutting methods, but few data are available on the forces and moments required to handle entire trees or their boles. To obtain the required values for the forces and moments that must be considered, it is first necessary to know the weight and center of gravity for the tree and its bole. This paper presents estimates of both for quaking aspen (*Populus tremuloides* Michx.).

In the summer of 1966, a cooperative study was initiated by the Forest Engineering Laboratory of the North Central Forest Experiment Station, U.S.D.A. Forest Service, and Michigan Technological University to determine weights and locate centers of gravity of quaking aspen

trees of various diameters and heights. The sample trees were selected from two stands in Houghton County, Michigan. Each stand supported 3 to 5 cords of aspen pulpwood per acre. One stand was pure aspen on a dry, upland site; the other consisted of aspen mixed with spruce and pine on a swampy site. Data were obtained from 97 aspen trees ranging from 5 to 17 inches in d.b.h. and from 28 to 77 feet in height.

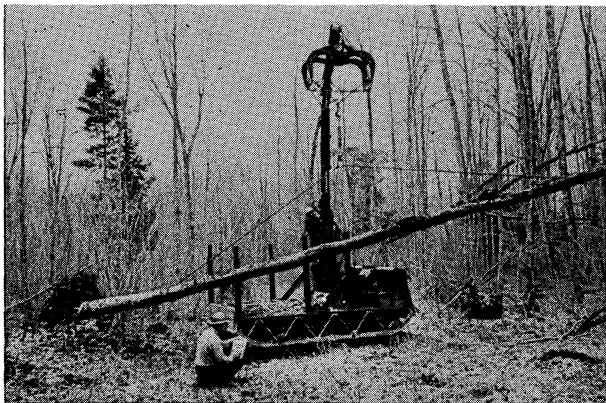
In this paper, the tree is defined as the entire tree above the stump. The bole is defined as the portion of the stem above the stump, delimbed and topped at a 3-inch diameter outside bark. The center of gravity is the distance in feet from the butt to the point of balance of the bole or tree.

FIELD PROCEDURES

The d.b.h. of each sample tree was measured to the nearest 0.1 inch and an 8 mm. increment core was taken at the d.b.h. for determining percent moisture content. The tree was then felled in the direction causing the least damage and loss of limbs. To determine taper, diameter outside bark of the felled tree was measured at the stump, at 2 and 4 feet from the butt, and at 8-foot intervals thereafter to the top diameter of 3 inches. The length and top diameter of any residual portion of the bole above the last 8-foot section were also measured. The total overall length of the tree above the stump was also recorded. All lengths were measured to the nearest 0.1 foot.

As soon as possible after felling (usually within 4 hours) the tree was picked up by a tractor-mounted, knuckle-boom loader. A specially de-

signed weight transducer ¹ was placed between the boom and a chain sling suspending the tree (fig. 1): The sling connections included a swivel and a uniball joint to allow the tree to hang freely. A point on the tree vertically below the apex of the sling was marked as its center of gravity. The tree was then limbed and topped to a 3-inch diameter outside bark, the resulting bole was suspended and weighed, and its center of gravity was also marked in the same way.



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Figure 1.—Method of suspending full tree and tree-length bole to obtain weight and locate center of gravity.

ANALYTICAL PROCEDURES

The cubic-foot volume for each bole was calculated from the taper measurements, using the formula for the volume of a truncated cone for

each section of the bole. Because the taper measurements were taken outside the bark, calculated volumes of the boles include both wood and bark. The green weight in pounds per cubic foot for each bole was determined by dividing its weight in pounds by its calculated volume in cubic feet. In addition, the moisture content on a wet-weight basis, basic density, and weight (green basis) per cubic foot were calculated for each sample tree from an 8-mm. increment core taken at d.b.h. ² The ranges and means of measured variables for the 97 quaking aspen trees sampled are presented in table 1.

RESULTS AND DISCUSSION

Because the objective of the study was to predict the weight and locate the center of gravity for trees and boles, d.b.h., tree height, and bole length were the significant independent variables. Notation for these variables follows:

Y_1 = Weight of the tree in pounds.

Y_2 = Weight of the bole in pounds.

Y_3 = Center of gravity of the tree in feet from butt.

Y_4 = Center of gravity of the bole in feet from butt.

X_1 = D.b.h. of tree in inches.

X_2 = Tree height in feet.

X_3 = Bole length in feet.

Several mathematical models were developed to analyze the data. Some of the models that were tried included additional terms, which did not significantly improve the predictions. The

Table 1.—Range, mean, and standard deviation of variables for 79 aspen trees, Houghton County, Michigan

No.	Variable	Range	Mean	Standard deviation
1.	D.b.h.	5.30 to 17.40 in.		
2.	Tree height	28.30 to 77.00 ft.		
3.	Tree-length bole	17.50 to 59.00 ft.		
4.	Green weight, tree	80.00 to 3,080.00 lbs.		
5.	Green weight, tree-length bole	50.00 to 2,600.00 lbs.		
6.	Tree center of gravity	10.25 to 28.42 ft. from butt		
7.	Tree-length bole center of gravity	7.58 to 24.25 ft. from butt		
8.	Tree length bole volume	1.87 to 51.61 cu. ft.		
9.	Moisture content of wood (based on wet weight)	35.60 to 61.10 %	48.60 %	± 4.97%
10.	Weight per cu. ft. of wood and bark	26.73 to 60.95 lbs.	49.32 lbs.	± 5.45 lbs.
11.	Basic density	19.13 to 31.82 lbs.	25.43 lbs.	± 1.91 lbs.
12.	Calculated weight (green basis) per cu. ft.	41.25 to 66.64 lbs.	49.87 lbs.	± 5.70 lbs.

¹ Arola, Rodger A. A dual-range strain gage weighing transducer employing automatic switching. U.S.D.A. Forest Serv. Res. Note NC-44, 4 p. N. Cent. Forest Exp. Sta., St. Paul, Minn. 1968.

² Keen, R. E. Weights and centres of gravity involved in handling pulpwood trees. Pulp and Pap. Res. Inst. Can. Tech. Rep. 340, 93 p. 1963.

remaining discussion deals only with those models that proved satisfactory in predicting weights and centers of gravity for quaking aspen trees and boles. The models and prediction equations for each dependent variable follow:

Tree Weight:

$$\frac{Y_1}{X_1^2 X_2} = k_1 + \frac{k_2}{X_1 X_2} + \frac{k_3}{X_1^2 X_2} \quad (\text{Regression model})$$

Values of coefficients were:

$$k_1 = .117, k_2 = 58.63, k_3 = -287.4$$

The regression model can be rewritten as the prediction equation:

$$Y_1 = -287.4 + 58.63 (\text{DBH}) + .117 (\text{DBH})^2 \quad (\text{Tree height})$$

$$\text{S.E.}_{\text{est.}} = .0226 (\text{DBH})^2 (\text{Tree height}).$$

Bole weight:

$$\frac{Y_2}{X_1^2 X_3} = k_1 + \frac{k_2}{X_1 X_2} + \frac{k_3}{X_1^2 X_3} \quad (\text{Regression model})$$

Values of coefficients were:

$$k_1 = .152, k_2 = 20.04, k_3 = -103.6$$

The regression model can be rewritten as the prediction equation:

$$Y_2 = -103.6 + 20.04 (\text{DBH}) + .152 (\text{DBH})^2 \quad (\text{Bole length})$$

$$\text{S.E.}_{\text{est.}} = .02126 (\text{DBH})^2 (\text{Bole length}).$$

Tree center of gravity:

$$\frac{Y_3}{X_2} = k_1 + k_2 X_2 \quad (\text{Regression model})$$

Values of coefficients were:

$$k_1 = .430, k_2 = -.001$$

The regression model can be rewritten as the prediction equation:

$$Y_3 = .430 (\text{Tree height}) - .001 (\text{Tree height})^2$$

$$\text{S.E.}_{\text{est.}} = .0284 (\text{Tree height}).$$

Bole center of gravity:

$$\frac{Y_4}{X_3} = k_1 + k_2 X_3 \quad (\text{Regression model})$$

Values of coefficients were:

$$k_1 = .438, k_2 = -.001$$

The regression model can be rewritten as the prediction equation:

$$Y_4 = .438 (\text{Bole length}) - .001 (\text{Bole length})^2$$

$$\text{S.E.}_{\text{est.}} = .02602 (\text{Bole length}).$$

The regression model was set up in terms of ratios to facilitate the statistical analysis of the data and to simplify calculation from the final form of the equation.

Tree and bole weights are presented in table 2. In each case a 95 percent upper tolerance weight is given for each d.b.h. and height class.³ The centers of gravity for trees and boles are presented in figures 2 and 3. A 95 percent upper tolerance limit is also presented for the centers of gravity. This upper tolerance limit allows reasonable assurance (probability $\gamma = .90$) that not more than 5 percent of the trees from the population represented will exceed this limit; or alternatively, that at least 95 percent will be below it.

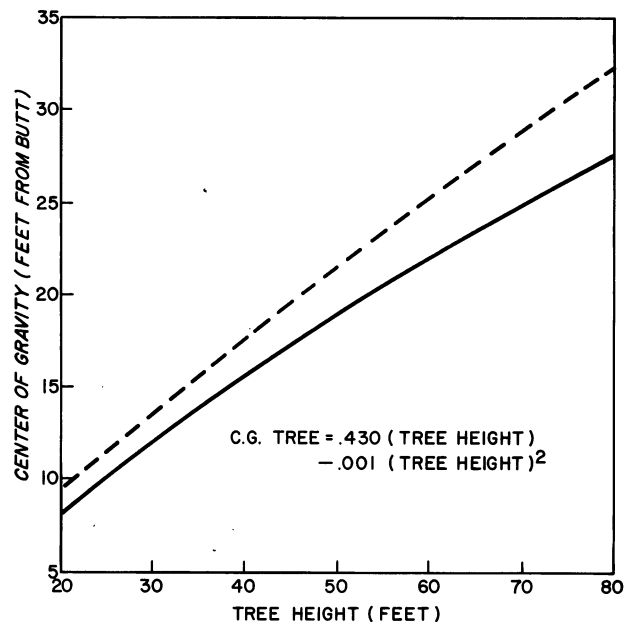


Figure 2.—Center of gravity for quaking aspen tree heights. The solid line is the mean value for center of gravity; the dashed line is the upper tolerance limit (95% level).

Upper tolerance limits for weights and centers of gravity are important for tree-harvesting machine design. The design cannot be based on the mean weight, because theoretically half of the trees will exceed the mean. Likewise, because most harvesting equipment will handle the tree or bole from a position below the center of gravity, an upper tolerance limit for center of gravity would insure against underdesign of the machine.

³ Owen, D. B. *Factors for one sided tolerance limits and for variables sampling plans*. Sandia Corp. Monogr. p. 9, 10, 164-189, 399-402. 1963.

Table 2.—Aspen tree and bole weights
(In Pounds)

MEAN WEIGHT ^{1/}										
D.b.h. (inches)	Bole length or tree height (feet)									
	30		40		50		60		70	
	Bole	Tree	Bole	Tree	Bole	Tree	Bole	Tree	Bole	Tree
6	181	232	--	--	--	--	--	--	--	--
7	261	352	335	410	410	--	--	--	--	--
8	349	481	447	556	544	631	--	--	--	--
9	447	619	571	714	694	809	904	--	--	--
10	554	767	706	884	859	1,001	1,118	--	--	--
11	--	--	855	1,066	1,039	1,207	1,349	--	--	--
12	--	--	1,015	--	1,234	1,427	1,596	--	--	--
13	--	--	1,187	--	1,445	1,662	1,859	--	--	--
14	--	--	1,372	--	1,671	1,910	2,139	--	--	--
15	--	--	--	--	1,912	2,172	2,435	--	--	--
16	--	--	--	--	--	2,448	2,748	--	--	--
17	--	--	--	--	--	--	3,077	--	--	--
18	--	--	--	--	--	--	3,422	--	--	--
UPPER TOLERANCE LIMIT WEIGHT AT 95 PERCENT LEVEL ^{2/}										
6	227	299	--	--	--	--	--	--	--	--
7	321	439	414	514	510	--	--	--	--	--
8	429	595	549	692	673	793	--	--	--	--
9	549	765	700	887	856	1,015	1,146	--	--	--
10	680	947	867	1,098	1,060	1,256	1,418	--	--	--
11	--	--	1,049	1,325	1,282	1,517	1,713	--	--	--
12	--	--	1,246	--	1,525	1,796	2,031	--	--	--
13	--	--	1,459	--	1,787	2,096	2,372	--	--	--
14	--	--	1,687	--	2,069	2,415	2,736	--	--	--
15	--	--	--	--	2,370	2,754	3,123	--	--	--
16	--	--	--	--	--	3,113	3,535	--	--	--
17	--	--	--	--	--	--	3,969	--	--	--
18	--	--	--	--	--	--	4,427	--	--	--

^{1/} Mean bole weight was determined from equation
 $Y_2 = -103.6 + 20.04 (\text{d.b.h.}) + .152 (\text{d.b.h.})^2$ (bole length).

Mean tree weight was determined from equation
 $Y_1 = -287.4 + 58.63 (\text{d.b.h.}) + .117 (\text{d.b.h.})^2$ (tree height).

^{2/} 95 percent of trees or boles in a given class should be below this weight.

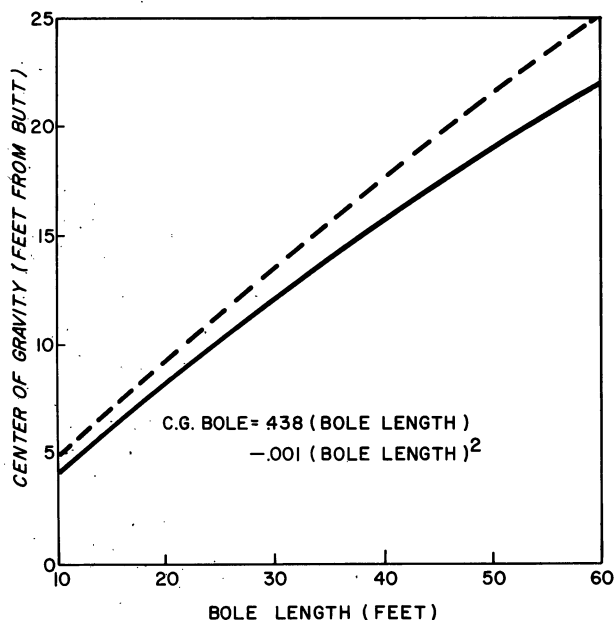


Figure 3.—Center of gravity for quaking aspen bole lengths. The solid line is the mean value for center of gravity; the dashed line is the upper tolerance limit (95% level).

A 14-tree sample was taken from a third site to test the prediction equations. Only one tree and one bole had weights exceeding the upper tolerance limits as presented in this report. The 14-tree test run employed equipment and instrumentation different from those used in the previous runs, thus indicating the results are valid.

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