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Preliminary Work in Developing SAWBOLT GRADING Systems for White Oak

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TOWARD TOTAL TREE UTILIZATION

ONE WAY to cope with the increased demand for wood is to strive toward total tree utilization during timber harvesting. Greater use of bolts (sections of the tree stem shorter than 8 feet) will play an important role in attaining this goal. By using bolts, loggers can utilize tree sections considered unmerchantable under present utilization practices.

According to Gill and Phelps *(4)*, use of boltwood by manufacturing industries increased 61 percent from 1960 to 1965. Manufacturers of wood products have realized that the cutting patterns their production lines demand can often be satisfied better economically by the short lumber from bolts than by cross-cutting and ripping longer lumber. As the use of bolts increases, the need for and the benefits from a bolt-grading system will become apparent to the logging and milling industry.

This paper is principally a description of one technique used in the development of white oak *(Quercus alba L.)* sawbolt grades—not a final sawbolt grading system for the species over its range. This technique can be used by anyone in developing other bolt-grade specifications or in refining the system presented in this paper.

SAMPLE DATA

The sample of 164 bolts used in this study came from 61 white oak trees cut in southern Illinois. Only trees that would produce straight and sound bolts were bucked, using all the stem to a 6-inch top diameter. No bolts were cut from limbs. Bolts damaged in logging were excluded. The diameter of the sample bolts ranged from 6 to 14 inches; and lengths were 4, 5, and 6 feet (table 1). All bolts were diagramed, the number of clear faces was tallied, and the bolts were sawed through and through on a portable bolter saw. See Appendix for sawing techniques. Each board was diagramed, using a system of rectangular coordinates to delineate the board outline and all defects within the board.

ANALYSIS OF DATA

Method of Analysis

Multiple regression techniques were used to evaluate the relationship of volume in Clear One Face and Better lumber (C1F & B) in a bolt to ten independent variables. C1F & B = the surface area of all C1F or C2F cuttings from all of the boards in each bolt, expressed as board feet measure.

To test the proposed grading systems, analysis of variance by use of the pooled residual mean square was used. From information derived from work with developing log and tree grades, and the knowledge that, in bolts, length and diameter are the key to the prediction of volume, the following hypothesis model was formed:

$$Y_{(C1F\ \&\ B)} = a + b_1 X_1 + b_2 X_2 + e$$

in which:

$Y_{(C1F\ \&\ B)}$ = Board-foot volume of Clear One Face & Better Lumber.

X_1 = Length.

X_2 = Diameter squared.

e = Error.

The hypothesis model was tested against each maximum model (the proposed trial models thought to be an improvement over the hypothesis model) *(3)*.

Table 1.—*Distribution of 164 white oak bolts by diameter class, bolt length, and number of clear faces*

Diameter class (inches)	Bolt length and number of clear faces															Total
	4 feet					5 feet					6 feet					
	0	1	2	3	4	0	1	2	3	4	0	1	2	3	4	
6	1	—	—	—	—	2	—	—	—	—	2	—	—	—	—	5
7	2	—	—	1	—	6	2	—	—	—	—	1	—	—	—	12
8	6	1	1	—	3	8	1	2	1	1	3	1	—	—	—	28
9	4	1	1	1	—	3	2	1	2	2	3	—	2	—	2	24
10	5	4	1	4	2	5	1	2	3	—	5	2	—	3	—	37
11	2	1	1	3	—	4	4	1	1	1	2	2	1	1	1	25
12	—	2	—	3	3	—	—	2	2	1	—	2	—	1	2	18
13	—	—	1	2	3	—	—	1	—	—	—	—	2	—	3	12
14	—	—	—	1	—	—	—	—	1	—	—	—	—	1	—	3
Total	20	9	5	15	11	28	10	9	10	5	15	8	5	6	8	164

Variables

The dependent variable, volume of Clear One Face and Better lumber (C1F & B) in a bolt, was expressed in terms of board-foot volume of 4/4 air-dried lumber. The total board-foot volume and the volume of C1F & B for each bolt was determined by use of a computer program developed at the Forest Products Laboratory *(5)*. Dunmire and Englerth have explained the method of obtaining the data for this yield program *(2)*. To conform to the program's limitation of 100 cutting sizes, 10 widths and 10 lengths were used. These cutting sizes range in width from 1½ to 6 inches in ½-inch increments, and in length from 12 to 48 inches in 4-inch increments. The selection of widths and lengths used was made after considering the quality and dimensions of the boards in the study.

The following 10 variables were considered independent in developing trial bolt-grading systems:

X_1 = Length (L), rounded to the last whole foot.
X_2 = Diameter (Dia.) rounded to the nearest inch (e.g., 7″ = 6.6″ to 7.5″) and measured inside the bark at the small end of the bolt.
X_3 = X_2 squared (Dia.^{2}).
X_4 = X_1 times X_3 (L x Dia.^{2}).
X_5 = Dummy variable *(1)* one (D-1) 4 clear faces.
X_6 = Dummy variable two (D-2) 3 clear faces.
X_7 = Dummy variable three (D-3) 2 clear faces.
X_8 = Dummy variable four (D-4) 1 clear face.
X_9 = Dummy variable A (NED) — no end defect.
X_{10}— Dummy variable B (ED) — has end defect.

Clear face is defined as one-fourth the circumference of a bolt for its entire length, and containing no defects. Light bark distortions and low bumps were not considered defects.

Clear faces (No.)	Dummy variables D_1	D_2	D_3	D_4
4	+1	0	0	0
3	0	+1	0	0
2	0	0	+1	0
1	0	0	0	+1
0	—1	—1	—1	—1

End defects: +1 has end defect.
—1 no end defect.

Formulation of Preliminary Models

Regression analyses were run on number of clear faces and sound end defects, and the F-statistics were developed to test their significance. The number of clear faces proved to be highly significant, but the presence or absence of end defects did not, principally because only sound end defects were allowed, and the number of these were minimal. All the variables were run on a step-wise regression program, and only length times diameter squared·and number of clear faces proved to be significant at the 5-percent level.

Preliminary plots of percent of C1F & B over diameter, volume of C1F & B over number of clear faces, and percent of C1F & B over number of clear faces, indicated that a three-grade system would fit this data better than a two-grade system.

Model Selection

Two trial grading systems were developed; one was based on number of clear faces, and the other was based on percent of clear cuttings on the three best faces. Only two- and three-grade models were tested. Eight modifications of the two systems were made. The test statistics used in comparing the models are given in table 2.

In setting up the modifications, first, only the number of clear faces was considered; then diameter and length restrictions were added. Next a system based on the percent of clear cuttings on three best faces was set up (this system was patterned after a bolt-grading system devised by Carpenter and Lockard). Finally, a combined system was set up, using both types of models. The 50 percent clear on the three best faces ties in with the percent-

Table 2.—*Specifications, pooled mean squares, and the overall F for the test of significance for each trial grading-system model*

Grading system model	Grade	Grade specifications	Pooled residual mean square for model	Overall F statistic for model
A	1	1-4 CF[1]		
	2	0 CF	4.2106	60.95**
B	1	1-4 CF: 9 - 14″		
	2	1-4 CF: 6 - 8″	4.2840	58.55**
		0 CF: 6 - 14″		
C	1	3-4 CF		
	2	1-2 CF	3.6825	41.05**
	3	0 CF		
D	1	4 CF		
	2	1-3 CF	3.2928	50.55**
	3	0 CF		
E	1	4 CF: 9 - 14″; 5 - 6′		
		4 CF: 12 - 14″; 4′		
	2	4 CF: 6 - 8″; 5 - 6′		
		4 CF: 6 - 11″; 4′	3.2850	50.75**
		1-3 CF		
	3	0 CF		
F	1	Butts: 6 - 14″; 100% clear on 3 best faces		
		Uppers: 10 - 14″; 100% clear on 3 best faces		
	2	Butts & Uppers: 8 - 14″, 2/3 clear on 3 best faces	3.5973	42.95**
	3	Butts & Uppers: 6 - 14″, No restrictions on faces		
G	1	4 CF: 9 - 14″; 5 - 6′		
		4 CF: 12 - 14″; 4′		
	2	50% clear on 3 best faces, 4 - 6′	3.1425	54.85**
	3	6 - 14″; 4 - 6′		
H	1	4 CF: 10 - 14″; 5 - 6′		
		4 CF: 12 - 14″; 4′		
	2	50% clear on 3 best faces, 8 - 14″; 4 - 6′	3.2558	51.58**
	3	6 - 14″; 4 - 6′		

[1]CF = clear face.
** = Significant at the 1-percent probability level.

yield figures, and no restrictions were placed on the grade-3 bolts except for the minimum size bolt accepted, because all bolts had to be sound and free of crook and sweep.

The associated tests statistics confirmed the choice of the three-grade model over the two-grade model for these data (table 2).

The following *a priori* restrictions were applied to each three-grade system that was developed:

Grade	C1F & B
B-1 =	Over 65 percent
B-2 =	46 to 65 percent
B-3 =	25 to 45 percent

Although model H, the selected trial grading system, did not have the lowest pooled residual mean square, it was chosen because it was the only model that satisfied the *a priori* restrictions (table 3). Two cells (8 inch and 4 foot in grade 2 and 6 inch and

Table 3.—*Volume of C1F & B and percent of total volume for the selected grading system*

Diameter (inches)	4 feet		5 feet		6 feet	
	Volume in C1F	Percent of total volume	Volume in C1F	Percent of total volume	Volume in C1F	Percent of total volume
	Bd. ft.	*Pct.*	*Bd. ft.*	*Pct.*	*Bd. ft.*	*Pct.*
			GRADE 1			
10	—	—	14	78	16	73
11	—	—	17	77	20	74
12	16	76	20	74	24	73
13	19	76	23	72	28	74
			GRADE 2			
8	4	44	6	55	7	50
9	6	55	8	57	10	56
10	8	57	10	56	13	59
11	10	56	13	59	16	59
12	12	57	16	59	20	61
13	15	60	20	63	24	63
14	18	62	23	62	28	62
			GRADE 3			
6	2	50	2	33	3	43
7	2	33	3	37	4	40
8	3	33	4	36	5	36
9	4	36	6	43	7	39
10	6	43	7	39	9	41
11	7	39	9	41	11	41

Table 4.—*Specifications for the selected trial grading system*

Grading factors	Grade					
	B-1		B-2			B-3
Length (w/o trim)	5′ - 6′	4′	4′ - 6′			4′ - 6′
Diameter (min. top)	10″	12″	8″			6″
Faces	No defects* allowed on any face		Best 3 faces	% in clear cuttings:	50	No restrictions
				Max. No. of cuttings:	2	
				Min. length of cuttings:	2′	
Sweep**	—			—		—
Interior scalable defects**	—			—		—
End defects**	—			—		—

*Low bumps and light bark distortions were not considered grading defects in this study.
**All study bolts were straight and sound, and end defects were minimal.

4 foot in grade 3) failed to meet the restrictions, but it was felt that, with more data, these percentages would come within the standards set. The specifications for the selected grading system are given in table 4.

The following are the prediction equations for the three grades of the selected grading system:

$$\text{B-1}\ Y_{C1F\,\&\,B} = -\,0.4650 + 0.0281\,X_1$$
$$\text{B-2}\ Y_{C1F\,\&\,B} = -\,3.0545 + 0.0268\,X_1$$
$$\text{B-3}\ Y_{C1F\,\&\,B} = -\,0.6990 + 0.0156\,X_1$$

where:

$X_1 = \text{Length x Diameter}^2$

See table 5, Appendix, for relevant statistics associated with each equation and table 6 for individual bolt reliability.

No extrapolation was attempted, which is why grade B-1 stops at 13 inches and grade B-3 stops at 11 inches.

A volume table, to the nearest board foot, was developed from all 164 bolts and fitted by the least-squares technique (table 7, Appendix).

SUMMARY AND CONCLUSIONS

The principal objective of this study was to develop a technique that may be used in future studies of bolt grades. A grading system was developed for white oak saw bolts, with the restrictions imposed by the available data.

A grading system for sawbolts must not be too time-consuming in application, for as the grading time increases, the benefit obtained approaches the cost of grading. If the developed grades are used, the following points should be kept in mind:

- Only straight and sound bolts were used.
- The sawing was done by slabbing a non-clear face and then sawing a clear face until conversion was complete.
- In selecting the bolts, no segregating was done as to product class, therefore yields may be overestimated or underestimated for a given product class.
- The yields are based on 1-inch material remanufactured into cuttings $1\frac{1}{2}$ inches by 12 inches and larger.

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APPENDIX

I

Standardized Sawing Method
For Each Combination of Clear Faces

1. *Class 1 bolts (four clear faces).* One face was slabbed. One or more boards were sawed from this face to provide a good bearing surface. (This was done for all classes of bolts.) The bolt was then turned down 90 degrees and sawed through and through until conversion was completed.

2. *Class 2 bolts (three clear faces).* The unclear face was slabbed and the bolt turned own 90 degrees and sawed through and through until conversion was completed.

3. *Class 3 bolts (two opposite clear faces).* The bolt was placed on the carriage with one of the clear faces up, and the adjacent face was slabbed. The bolt was then turned down 90 degrees and sawed through and through until conversion was completed

4. *Class 3 bolts (two adjacent clear faces).* The bolt was placed on the carriage with one clear face up, and the adjacent clear face was slabbed. The bolt was then turned 90 degrees and the remaining clear face sawed through and through until conversion was completed.

5. *Class 4 bolts (one clear face).* The bolt was placed on the carriage with the clear face up, and the adjacent face was slabbed. The bolt was then turned 90 degrees and sawed through and through until conversion was completed.

6. *Class 5 bolts (no clear faces).* The bolt was placed on the carriage with the major defects cornered, and the first face was slabbed. The bolt was then turned 90 degrees and sawed through and through until conversion was completed.

Table 5.—*Relevant statistics for the three sawbolt prediction equations*

Independent variable	Regression coefficient	Standard deviation
	GRADE B-1	
Intercept	—0.4650	2.7292
L x Dia.^{2}	0.0281**	0.0036
$R^2 = 0.81$		
Standard error of residual = 2.33		
No. of observations = 16		
	GRADE B-2	
Intercept	—3.0545**	0.6348
L x Dia.^{2}	0.0268**	0.0011
$R^2 = 0.87$		
Standard error of residual = 2.00		
No. of observations = 88		
	GRADE B-3	
Intercept	—0.6990	0.5009
L x Dia.^{2}	0.0156**	0.0013
$R^2 = 0.72$		
Standard error of residual = 1.39		
No. of observations = 60		

**Significant at 1-percent level.

Table 6.—*Distribution of bolts with regard to meeting of C1F & B specifications*[1]

Diameter class (inches)	Grade	Less than required % C1F & B	More than required % C1F & B	Within specifi-cations	Total
		No.	*No.*	*No.*	*No.*
6	B-3	1	—	4	5
7	B-3	4	2	6	12
8	B-2	6	1	6	13
	B-3	1	4	10	15
9	B-2	1	4	9	14
	B-3	—	5	5	10
10	B-1	—	—	1	1
	B-2	—	3	21	24
	B-3	—	2	10	12
11	B-1	1	—	1	2
	B-2	—	1	16	17
	B-3	—	4	2	6
12	B-1	4	—	3	7
	B-2	—	1	10	11
13	B-1	1	—	5	6
	B-2	—	3	3	6
14	B-2	—	2	1	3
	Total	19	32	113	164

[1]Specifications:
Grade B-1 = Over 65% C1F & B
Grade B-2 = 46 to 65% C1F & B
Grade B-3 = 25 to 45% C1F & B

IV

Table 7.—*Volume table (fitted by least-squares technique)*

Diameter (inches)	Length, feet		
	4	5	6
		Board feet	
6	4	6	7
7	6	8	10
8	9	11	14
9	11	14	18
10	14	18	22
11	18	22	27
12	21	27	33
13	25	32	38
14	29	37	45

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