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**Tool Forces and Chip Types  
In Orthogonal Cutting  
Of Southern Hardwoods**

*BY G. E. WOODSON*

**Southern  
Forest  
Experiment  
Station**

## SUMMARY

Specimens (1/8 to 1/4 inch thick) from 5 trees of each of 22 hardwood species were cut orthogonally at 5 inches per minute. Average parallel and normal cutting forces for various rake angles (50, 60, and 70 degrees for veneer; 10, 20, and 30 degrees for planing; 20, 30, and 40 degrees for crosscutting) were measured at three moisture contents (10 percent, 20 percent, and saturated) and four depths of cut (.015, .030, .045, and .060 inch). Average parallel forces generally increased with deeper cuts and greater specific gravity but decreased with greater rake angle and moisture content. Average normal forces increased with deeper cuts but were unrelated to specific gravity, moisture content, or rake angle when cuts were in the veneer direction. In the crosscutting and planing directions, average normal forces decreased algebraically with increasing rake angle and changed from positive to negative between 20 and 30 degrees, decreased with increasing moisture content, and increased in magnitude with increasing specific gravity. The general conclusions about chip types that follow are the result of observations made throughout the study:

### ***Chip Type***

- Planing-Crushing occurred at low rake angles in low density diffuse porous hardwoods.
  - Cantilever-type failure occurred in all species at high rake angles and low moisture content.
  - Continuous chip formed when making thin cuts and also at intermediate rake angle (20°).
- Veneer-Continuous veneer formed at high rake angle in saturated wood.
- Crosscut-Smooth cut made at high rake angle and high moisture content.

# Tool Forces and Chip Types In Orthogonal Cutting Of Southern Hardwoods

BY G. E. WOODSON

The objectives of the study reported here were to determine average parallel and perpendicular tool forces and observe chip formation during orthogonal cutting of 22 species of hardwoods commonly found on southern pine sites. Basic aspects of machining such as chip formation, surface quality, and tool life can be better understood with knowledge of the forces needed during orthogonal cutting.

Orthogonal cutting is the machining process in which the cutting edge is perpendicular to the relative motion of tool and workpiece. (See figure 1 for nomenclature used in orthogonal cutting.) A two-number notation introduced by McKenzie (1961) is useful for describing the process. In this notation, the first number indicates the orientation of the cutting edge with respect to the grain, and the second number indicates the direction of movement of the cutter. Thus, planing has the simple notation of 90-O. The first number indicates the cutter edge is perpendicular to the grain direction and the second number indicates the movement of the cutter is parallel to the grain direction. Similarly, veneer cutting is O-90 and crosscutting is 90-90 (fig. 2).

Variables for which cutting forces were measured are as follows:

- I. Twenty-two species (table 1)
- II. Cutting direction
  - A. Veneer (O-90)
  - B. Planing (90-O)
  - C. Crosscut (90-90)
- III. Moisture content
  - A. Equilibrium at 50 percent R.H.
  - B. Equilibrium at 83 percent R.H.
  - C. Saturated

- IV. Rake angle
  - A. 50°, 60°, and 70° with 0° clearance angle (Veneer direction)
  - B. 10°, 20°, and 30° with 15° clearance angle (Planing direction)
  - C. 20°, 30°, and 40° with 15° clearance angle (Crosscut direction)
- V. Depth of cut (inch)
  - A. 0.015
  - B. .030
  - C. .045
  - D. .060
- VI. Replications-one from each of five trees per species

## Collection, Preparation, and Machining of Material

Material for the study was selected from logs collected by Manwiller<sup>1</sup> from throughout the South. The collection consisted of 10 trees from each of 22 species and was representative of 6-inch hardwoods growing on southern pine sites.

Three specimens for machining were prepared for each cutting direction from each of five logs (selected randomly) per species. One specimen per cutting direction was conditioned at 50 percent R.H., another at 83 percent R.H., and the remaining specimen was saturated.

Specimens for veneer cutting were 1/4-inch wide along the grain and cutting distance was at

<sup>1</sup>Manwiller, F. G. 1972. Collection plan for a series of studies characterizing wood and bark properties of 22 species of low-grade hardwoods growing on southern pine sites. U.S. Dep. Agric. For. Serv., South. For. Exp. Stn., Study Plan FS-SO-3201-1.38, 11 p.

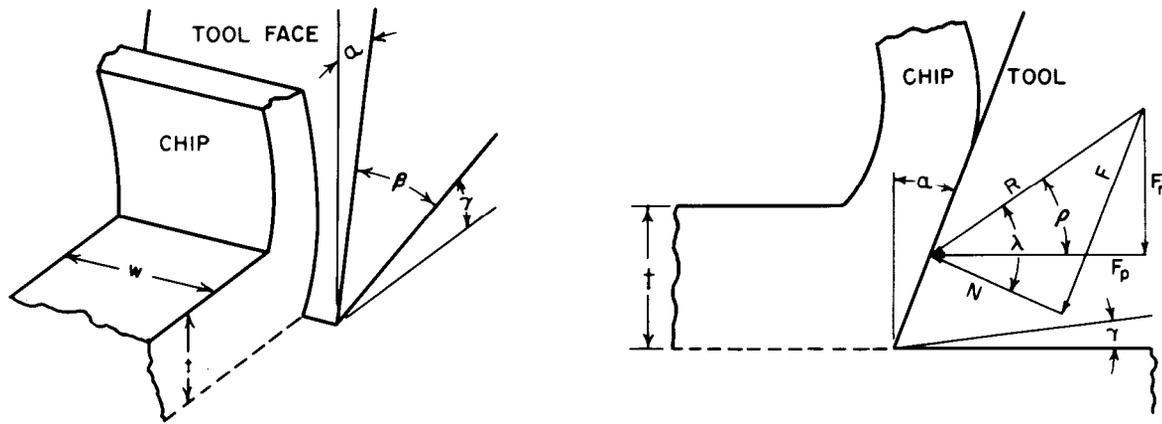


Figure 1. -Nomenclature in orthogonal cutting.

- $\alpha$  — Rake angle: angle between the tool face and a plane perpendicular to the direction of tool travel.
- $\beta$  — Sharpness angle: angle between the tool face and back.
- $\gamma$  — Clearance angle: angle between the back of the tool and the work surface behind the tool.
- $t$  — Nominal chip thickness; depth of cut.
- $w$  — Width of undeformed chip.
- $F_n$  — Normal tool force: force component acting perpendicular to parallel tool force and perpendicular to the surface generated.
- $F_p$  — Parallel tool force: force component acting parallel to tool motion in workpiece, i.e., parallel to cut surface.
- $R$  — Resultant tool force: the resultant of normal and parallel tool force components.
- $p$  — Angle of tool force resultant: the angle whose tangent is equal to the normal tool force divided by the parallel tool force.
- $F$  — Friction force: force component acting along the interface between tool and chip.
- $N$  — Normal to the friction force: force component acting normal to tool face.
- $\lambda$  — Angle between resultant tool force and the normal frictional force; the angle whose tangent is equal to the friction force divided by the normal friction force.

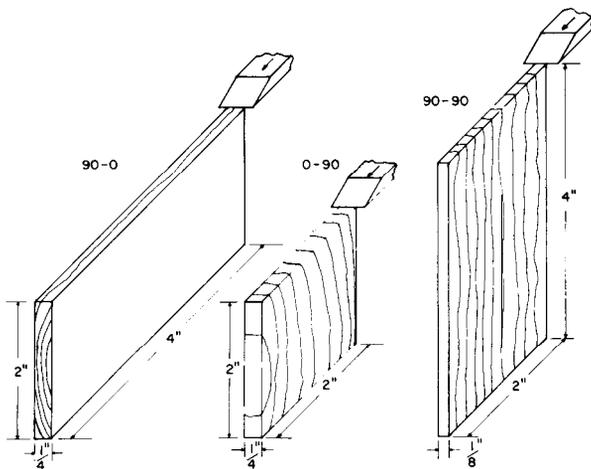


Figure 2.-Specimens for orthogonal cutting.

least 2 inches in a radial direction toward the log center. Crosscut specimens were cut radially, as in quarter sawn lumber, about 1/8-inch thick by 2 inches wide and 4 inches along the grain. Planing specimens were 1/4-inch thick by 2 inches wide by 4 inches along the grain and machining was done in the radial face (fig. 2).

Specimens were machined in random order within a moisture content. Effects of change in moisture content of surface fibers were minimized by keeping the specimens in the desired environment until test cuts were to be made. Cuts were made in sequence from 0.015 to 0.060 inch after one or, when roughness made it necessary, more smoothing cuts. Knives were sharpened with an Arkansas stone after each sequence of four cuts.

Instantaneous tool forces were measured with a two-component tool dynamometer" (fig. 3) connected to a multi-channel oscillographic recorder. The dynamometer was calibrated by suspending known weights on a dummy knife. Thus, normal and parallel tool forces were recorded in terms of pen deflection and converted to load in pounds by use of a calibration equation. A normal force was considered negative when the knife tended to lift the workpiece (i.e., deflected toward the workpiece) and positive when the knife deflection was away from the workpiece. The dynamometer was attached to a modified grinding machine and was positioned to allow movement of the workpiece past the dynamometer at 5 inches per minute. The workpiece, fixed in an air actuated vise attached to the grinding-machine table, was trimmed with a thin cut before adjustment for initial experimental cuts. For each cut, cutting forces were determined from the oscillographic recordings as illustrated in figure 4.

To generalize the data and make them more meaningful, cutting forces were correlated with specific gravity by linear regression analysis. Further generalizations were made to include only typical rake angles and wood moisture conditions for a particular cutting direction.

Moisture content and specific gravity were determined from the material left after all cuts were made; specific gravity (ovendry weight and green volume) was determined on saturated specimens only. Saturated specimens were cut from

<sup>2</sup>I thank N. C. Franz for providing the dynamometer used in this study. He is with the Faculty of Forestry, University of British Columbia, Vancouver, B. C.

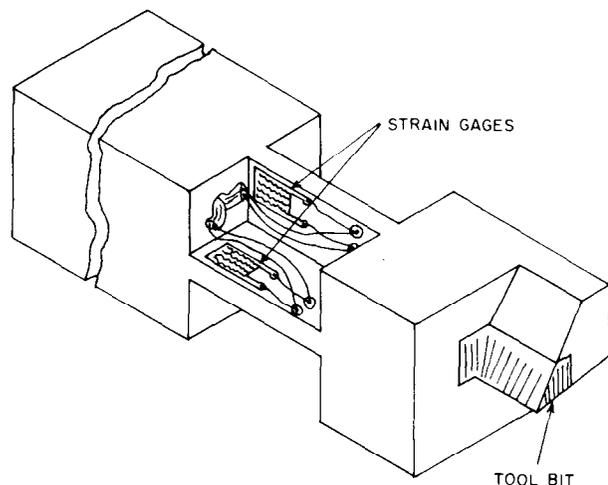


Figure 3.-Sketch of a two-component tool dynamometer.

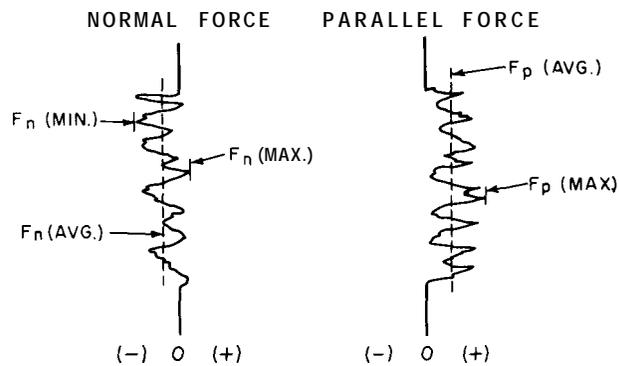


Figure 4. -Illustration of method for obtaining cutting forces from typical oscillographic force patterns.

wood adjacent to specimens conditioned at 50 and 83 percent relative humidity and were therefore considered identical.

## Results

Appendix tables contain values for average and maximum parallel tool forces and average, maximum, and minimum normal tool forces by species, rake angle, moisture content, and depth of cut.

Average moisture contents and specific gravities of saturated samples are shown by species in text table 1. Specimens conditioned at 50 percent relative humidity averaged 10.90 percent and those conditioned at 83 percent averaged 18.85 percent moisture content.

Yellow-poplar and red oak were chosen to illustrate the effects of rake angle and moisture content on average parallel and normal tool forces. These species were selected to show the differences between a low density diffuse-porous hardwood (yellow-poplar) and a high density ring-porous hardwood (southern red oak).

As expected, average cutting forces were generally greater in southern red oak than in yellow-poplar (tables 2 and 3). For both species, average parallel forces usually decreased with higher moisture content and greater rake angle. Variation in normal force patterns was usually caused by formation of different chip types.

Average normal forces for cutting veneer were quite variable. Normal forces for planing and crosscutting changed from positive to negative as rake angle increased from 20° to 30°; in Woodson and Koch (1970) we found similar results in orthogonal cutting of southern pine earlywood

Table 1.-Specific gravity (oven-dry weight and green volume) and average saturated moisture contents of 22 southern hardwoods.

	Moisture content percent	Specific gravity
White oak ( <i>Quercus alba</i> L.)	<b>81</b>	<b>0.644</b>
Winged elm ( <i>Ulmus alata</i> Michx.)	<b>89</b>	.642
Hickory, true ( <i>Carya</i> spp.)	<b>92</b>	.640
Post oak ( <i>Q. stellata</i> <b>Wangenh.</b> )	<b>80</b>	.636
Northern red oak ( <i>Q. rubra</i> L.)	<b>88</b>	.626
Blackjack oak ( <i>Q. marilandica</i> Muenchh. )	<b>118</b>	.626
Shumard oak ( <i>Q. shumardii</i> Buckl.)	<b>90</b>	.620
Scarlet oak ( <i>Q. coccinea</i> Muenchh.)	<b>92</b>	.618
Southern red oak ( <i>Q. falcata</i> Michx.)	<b>91</b>	.618
Cherrybark oak ( <i>Q. falcata</i> Michx. var. <i>pagodaefolia</i> Ell.)	<b>92</b>	.609
Black oak ( <i>Q. velutina</i> Lam.)	<b>94</b>	.598
Laurel oak ( <i>Q. laurifolia</i> Michx.)	<b>92</b>	.597
White ash ( <i>Fraxinus americana</i> L.)	<b>104</b>	.577
Water oak ( <i>Q. nigra</i> L. )	<b>101</b>	.573
Green ash ( <i>F. pennsylvanica</i> Marsh.)	<b>107</b>	.562
American elm ( <i>U. americana</i> L. )	<b>106</b>	.551
Hackberry ( <i>Celtis</i> spp.)	<b>115</b>	.541
Black tupelo ( <i>Nyssa sylvatica</i> Marsh.)	<b>121</b>	.501
Red maple ( <i>Acer rubrum</i> L. )	<b>132</b>	.489
Sweetbay ( <i>Magnolia virginiana</i> L.)	<b>140</b>	.442
Sweetgum ( <i>Liquidambar s tyraciflua</i> L. )	<b>145</b>	.439
Yellow-poplar ( <i>Liriodendron tulipifera</i> L.)	<b>157</b>	.376

Table 2.-Average parallel ( $F_p$ ) and normal ( $F_n$ ) tool force per 0.1 inch of knife for orthogonally cutting yellow-poplar at .030 inch depth of cut, with three knives in each of three directions, at three moisture contents and five replications.

Cutting direction and rake angle		Moisture Content					
		10%		20%		Saturated	
		$F_p$	$F_n$	$F_p$	$F_n$	$F_p$	$F_n$
		-----pounds-----					
Veneer	50°	<b>2.20</b>	.05	2.12	-.08	<b>1.84</b>	.10
	60°	<b>1.93</b>	-.28	2.02	-.38	<b>1.70</b>	-.12
	70°	<b>1.89</b>	.18	1.98	.12	<b>1.49</b>	.28
Planing	10°	<b>20.12</b>	<b>4.66</b>	15.36	<b>4.81</b>	<b>12.81</b>	<b>5.67</b>
	20°	<b>18.59</b>	<b>2.34</b>	13.90	<b>1.81</b>	<b>10.24</b>	<b>1.61</b>
	30°	<b>10.74</b>	-.66	11.69	-.08	<b>7.53</b>	.81
Crosscut	20°	<b>18.73</b>	<b>4.07</b>	22.12	<b>2.24</b>	<b>15.47</b>	<b>1.34</b>
	30°	<b>16.74</b>	<b>1.34</b>	15.04	-.30	<b>12.78</b>	-.10
	40°	<b>12.27</b>	<b>-1.03</b>	12.27	<b>-1.80</b>	<b>8 . 0</b>	<b>8-1.10</b>

Table 3.-Average parallel ( $F_p$ ) and normal ( $F_n$ ) tool forces per 0.1 inch of knife for orthogonally cutting southern red oak at .030 inch depth of cut, with three knives in each of three directions, at three moisture contents and five replications.

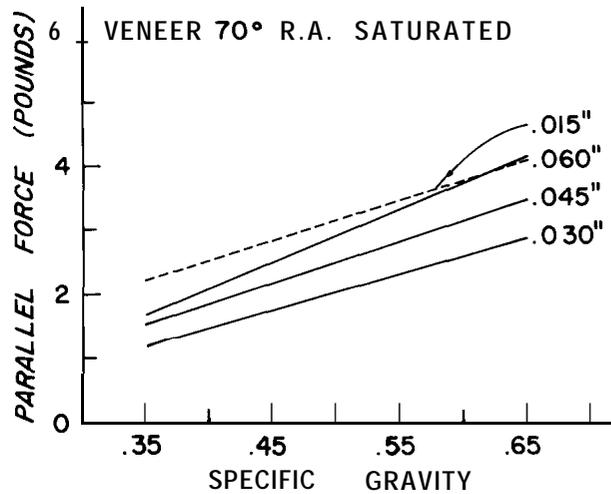
Cutting direction and rake angle		Moisture content					
		10%		20%		Saturated	
		$F_p$	$F_n$	$F_p$	$F_n$	$F_p$	$F_n$
-----pounds-----							
Veneer	50°	6.12	.19	4.57	-.48	3.76	-.26
	60°	6.40	.35	3.83	-1.16	3.19	-.82
	70°	4.72	.29	3.39	-.08	2.49	.09
Planing	10°	37.97	10.15	22.46	5.54	18.90	4.55
	20°	32.78	3.05	19.11	1.74	14.23	1.18
	30°	21.47	-1.29	11.38	-.71	8.91	-.37
Crosscut	20°	43.01	2.89	31.01	1.04	25.30	.52
	30°	37.03	-3.03	25.74	-2.57	17.13	-2.02
	40°	26.86	-6.74	18.86	-4.78	14.05	-3.93

and latewood. Generally, average normal forces for planing and crosscutting were much lower than average parallel forces and decreased algebraically with increased rake angle and moisture content. Although normal forces decreased algebraically with increasing rake angle, their magnitude at the higher rake angles were sometimes larger but changed from positive to negative.

Veneer Cutting: 0-90 Direction

Average parallel force was consistently highest for the thinnest cuts (.015-inch) (fig. 5). Thinner cuts and cuts in saturated wood generally produced continuous chips with the knife continuously in the wood (fig. 6A). Conversely, the thickest cuts and cuts in dry wood generally produced discontinuous chips (fig. 6B) with the knife disengaged from the wood much of the time. Thus, discontinuous chips could produce higher maximum parallel forces and yet have lower average parallel forces. Averaged over all depths of cut, diffuse-porous hardwoods generally yielded chips that were slightly more continuous than ring-porous hardwoods.

When cut radially, ring-porous hardwoods exhibit zones of weakness in thin-walled earlywood cells. As the knife edge approaches the earlywood zone, stresses build until the chip fails as a cantilever beam (fig 6B). These zones of weakness are not present if the cuts are made tangentially (fig. 6C). To eliminate the problems associated with cutting all latewood or all earlywood, cutting in the tangential direction was not included in this study.



Depth of cut	y-intercept	Slope	r
---inch---			
.015	.04	6.21	.49
.030	-.71	5.47	.87
.045	-.78	6.55	.91
.060	-1.23	8.22	.93

Figure 5. Relationship of average parallel cutting force per 0.1-inch knife length with specific gravity (oven-dry weight and green volume) for veneer cutting saturated wood of 22 species with a 70° rake angle (0° clearance angle) at four depths of cut. The dotted line indicates regression significant at .05 level; others are significant at .01 level.

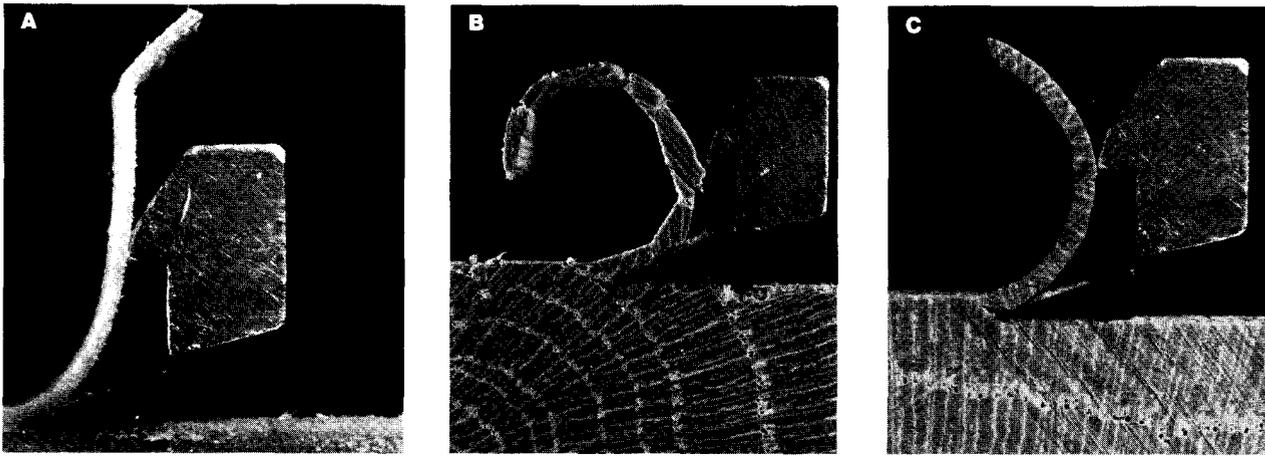


Figure 6.-Typical chip types resulting from orthogonal cutting in the veneer direction ( $o-90$ ). A. Continuous veneer in saturated red maple cut .030-inch deep with  $70^\circ$  rake angle and  $0^\circ$  clearance angle. B. Cantilever beam type failure in dry (11.4 percent) cherrybark oak cut .045-inch deep with  $60^\circ$  rake angle and  $0^\circ$  clearance angle. C. Continuous veneer in dry (11.4 percent) cherrybark oak cut tangentially .060-inch deep with  $70^\circ$  rake angle and  $0^\circ$  clearance angle.

Among the species, average normal forces were not correlated with specific gravity, moisture content, or rake angle but increased with deeper cuts. Average parallel forces increased with deeper cuts and with higher specific gravity but decreased with increased rake angle and moisture content.

To summarize the effects of the principal factors (depth of cut, moisture content, and rake angle), the tool forces were averaged over all other variables (table 4). In general, maximum parallel forces for veneer cutting were about twice as large as the average forces. Maximum and minimum forces generally were similar in magnitude but opposite in sign.

#### Planing: 90-O Direction

As expected, average parallel and normal forces increased with increasing depth of cut and with increasing specific gravity when dry wood was planed with a  $10^\circ$  rake angle (fig. 7). At low rake angle, chips were continuous (fig. 8A) and normal forces were positive (i.e., the knife was pushing the workpiece). As rake angle increased, the normal forces became more and more negative and produced broken chips (i.e., broken as a cantilever beam as in figure 8B). A combination of low rake angle and low wood specific gravity produced extensive crushing ahead of the knife and a chip similar to that shown in figure 8C. In those species exhibiting interlocked grain (such as black tupelo and the elms), high rake angles produced tearing ahead of the knife and left a rough surface (fig. 8D).

As rake angle increased, the normal forces

changed from positive to negative. This transition occurred at about  $20^\circ$ ; consequently, the relationship between average normal force and specific gravity was not significant with a  $20^\circ$  rake angle. The  $30^\circ$  rake angle produced increasingly negative cutting forces as the specific gravity increased.

Maximum parallel forces appeared to be about 30 percent greater than the average parallel forces (table 5). Similarly, the maximum normal forces were 30 to 40 percent greater than the average normal forces.

#### Crosscut: 90-90 Direction

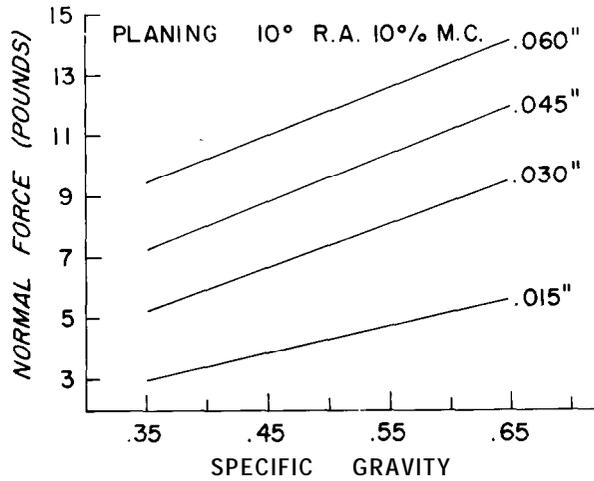
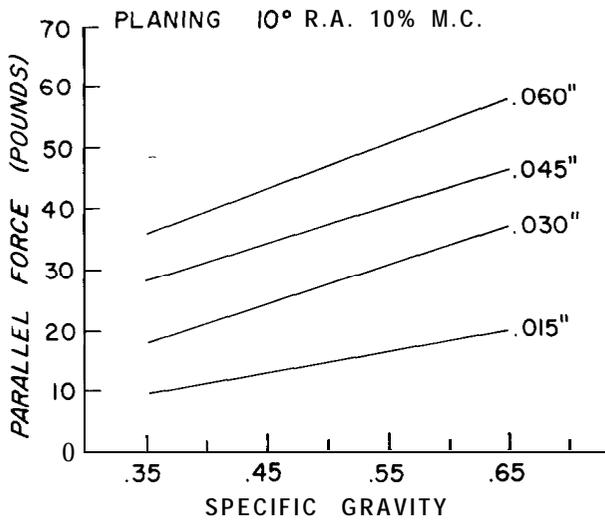
Average parallel force increased with increasing depth of cut and specific gravity (fig. 9). Generally, average normal forces were positive for specific gravity below 0.50 and negative for specific gravity above 0.50. For specific gravity greater or less than 0.50, normal force increased with depth of cut.

Average normal forces changed from positive to negative as rake angle increased from 20 to 30 degrees (table 6). The maximum parallel forces were about 23 percent greater than average parallel forces.

Uniform chips and smooth surfaces were produced with high rake angles in all types of wood (fig. 10A). Low rake angles in dry wood produced very rough surfaces with considerable failure beneath the plane of the knife cut (fig. 10B). Low density species (of all moisture contents) cut with low rake angles produced chips less than the desired thickness because the knife skimmed over the surface and did little cutting (fig. 10C).

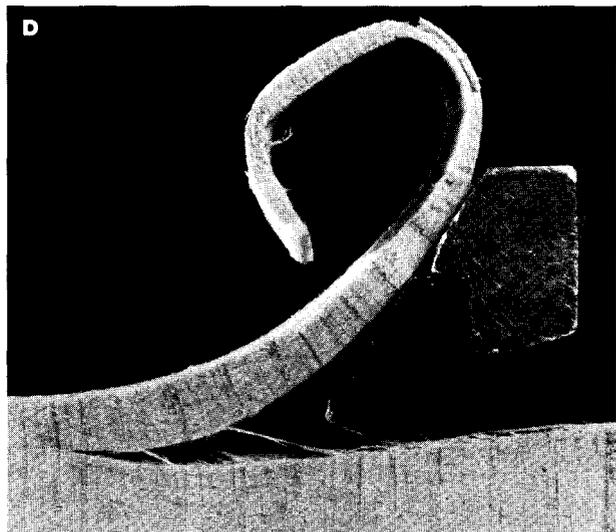
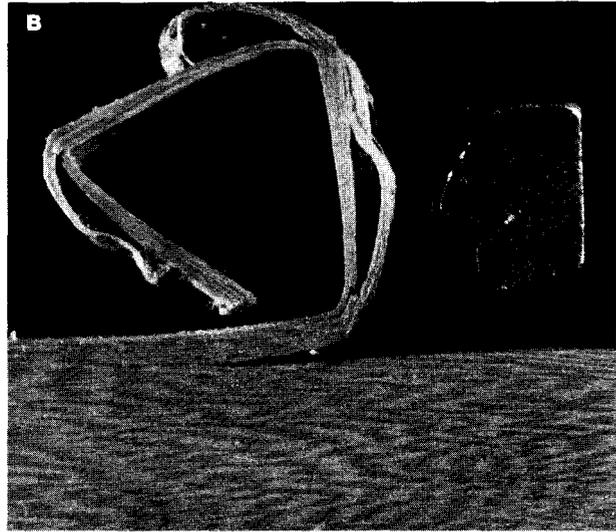
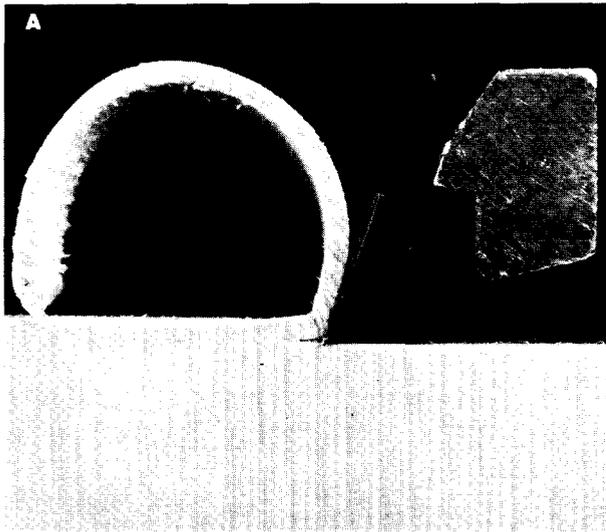
Table 4.—Tool forces when orthogonally cutting in the veneer direction with various depths of cut, moisture contents, and rake angles. Values are averaged over all other variables.

Principal factor	Parallel force		Normal force		
	Average	Maximum	Average	Maximum	Minimum
Depth of cut, inches	----- Pounds/0.1 inch -----				
.015	3.1	6.2	0.0	1.3	-1.0
.030	3.5	7.2	-.2	1.2	-1.3
.045	4.2	9.0	-.5	1.2	-1.9
.060	4.9	10.6	-.7	1.3	-2.4
Moisture content, percent					
10.9	4.7	10.8	0.0	2.0	-1.6
18.9	4.0	8.0	-.6	1.0	-1.9
104.3	3.1	6.0	-.4	.7	-1.4
Rake angle, degrees					
50	4.1	9.3	-0.2	1.5	-1.5
60	3.9	8.0	-.5	1.0	-1.9
70	3.9	7.4	-.3	1.2	-1.6



Depth of cut ---inch---	Average parallel force			Average normal force		
	y-intercept	Slope	r	y-intercept	Slope	r
.015	-2.24	33.79	.87	.03	8.61	.80
.030	-3.20	61.68	.89	.22	14.34	.84
.045	7.55	59.38	.74	1.83	15.44	.75
.060	10.40	73.26	.79	3.94	15.63	.67

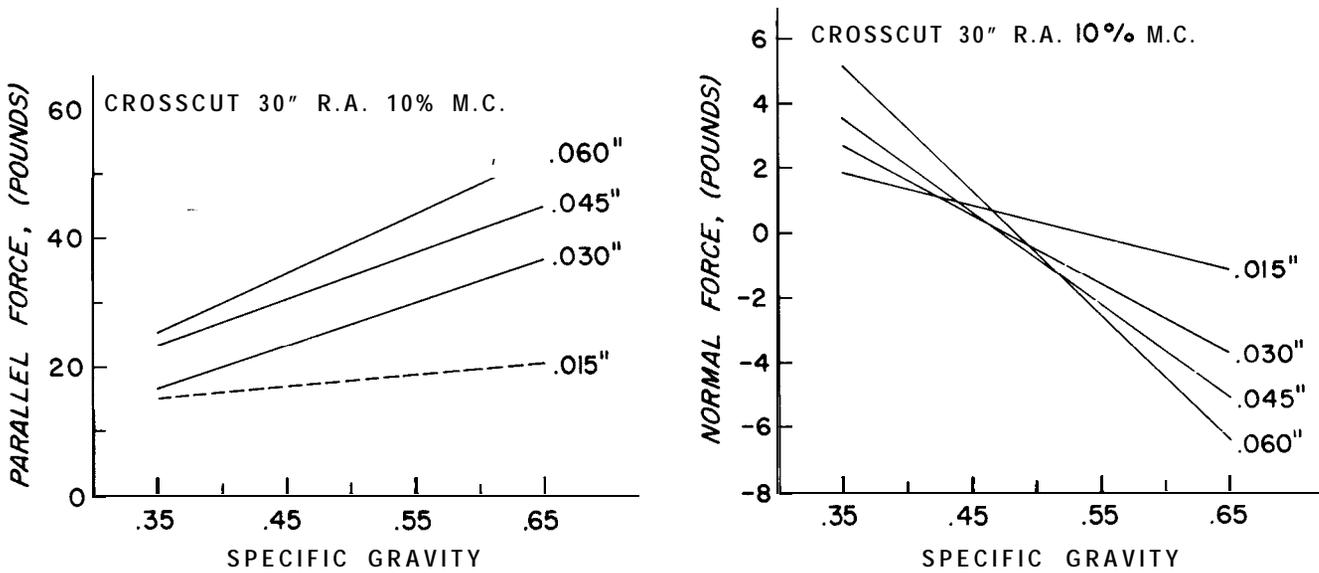
Figure 7.—Relationship of average parallel and normal cutting force per 0.1-inch knife length with specific gravity (oven-dry weight and green volume) for planing dry wood (10 percent moisture content) of 22 species with a 10° rake angle (15° clearance angle) at four depths of cut. All regressions are significant at .01 level.



**Figure 8.**—*Typical chip types resulting from orthogonal cutting in the planing direction. A. Continuous chip formed when making a .045-inch cut in black tupelo at 10.9-percent moisture content with a 20° rake angle and 15° clearance angle. B. Broken chips formed when making a .060-inch cut in winged elm at 10.9-percent moisture content with a 30° rake angle and 15° clearance angle. C. Crushing ahead of the knife produced when making a .060-inch cut in black tupelo at 10.9-percent moisture content with a 10° rake angle and 15° clearance angle. D. Tearing ahead of the knife produced when making a .030-inch cut in black tupelo with interlocked grain at 10.9-percent moisture content with a 30° rake angle and 15° clearance angle.*

**Table 5.-Tool forces when orthogonally cutting in the planing direction with various depths of cut, moisture contents, and rake angles. Values are averaged over all other variables.**

Principal factor	Parallel force		Normal force		
	Average	Maximum	Average	Maximum	Minimum
Depth of cut, inches	----- Pounds/0.1 inch -----				
.015	9.9	12.0	1.7	2.3	1.0
.030	18.5	23.1	2.5	3.5	1.5
.045	24.2	31.4	3.1	4.4	1.7
.060	30.0	40.1	3.8	5.4	2.0
<b>Moisture content, percent</b>					
<b>10.9</b>	28.2	38.4	4.0	5.5	2.2
<b>18.9</b>	20.0	24.5	2.6	3.5	1.5
<b>104.3</b>	13.8	17.1	1.8	2.6	1.0
<b>Rake angle, degrees</b>					
<b>10</b>	26.3	33.2	6.7	8.6	4.6
<b>20</b>	23.1	27.0	2.3	2.9	1.6
<b>30</b>	12.5	19.8	-.6	.2	-1.5



Depth of cut	Average parallel force			Average normal force		
	y-intercept	Slope	r	y-intercept	Slope	r
---inch---						
.015	<b>9.46</b>	<b>16.32</b>	.50	5.57	- 10.45	.88
.030	<b>-6.04</b>	<b>65.40</b>	.90	10.35	- 21.72	.91
.045	<b>-1.34</b>	<b>70.93</b>	.79	13.80	- 29.13	.90
.060	<b>-7.13</b>	<b>92.16</b>	.82	18.81	- 38.77	.88

Figure 9.-Relationship of average parallel and normal cutting force per 0.1-inch knife length with specific gravity (ovendry weight and green volume) for crosscutting dry wood (10 percent moisture content) of 22 species with a 30° rake angle (15° clearance angle) at four depths of cut. Dotted line indicates regression significant at .05 level; others significant at .01 level.

**Table 6.-Tool forces when orthogonally cutting in the crosscutting direction with various depths of cut, moisture contents, and rake angles. Values are averaged over all other variables.**

Principal factor	Parallel force		Average	Normal force	
	Average	Maximum		Maximum	Minimum
Depth of cut, inches	----- Pounds/0.1 inch -----				
.015	14.1	17.5	-0.4	0.8	-1.3
.030	23.5	28.6	-1.5	.4	-3.0
.045	29.9	36.5	-2.3	.3	-4.5
.060	35.7	44.2	-3.1	.5	-6.0
Moisture content, percent					
10.9	32.5	41.1	-1.6	1.9	-4.4
18.9	25.5	30.8	-1.9	.1	-3.6
104.3	19.4	23.2	-1.9	-.5	-3.1
Rake angle, degrees					
20	31.5	38.3	1.9	4.1	0.1
30	25.6	31.4	-2.2	.1	-4.1
40	20.2	25.3	-5.1	-2.6	-7.1

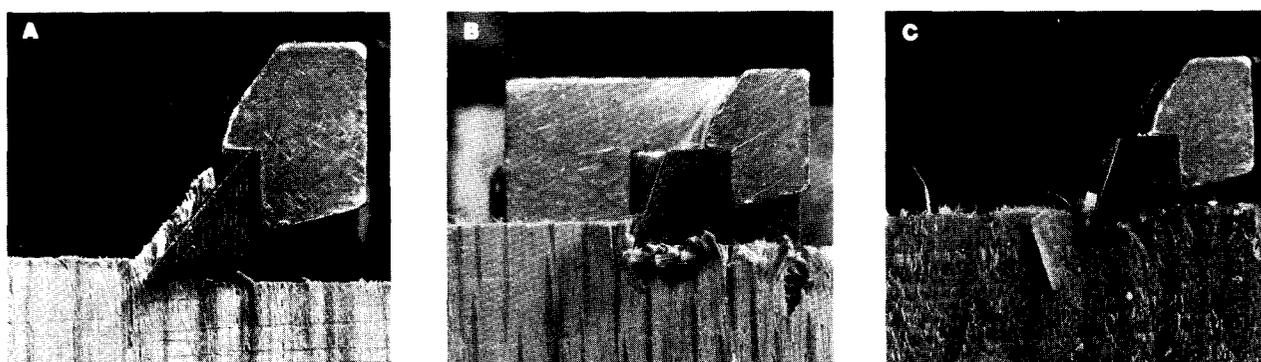


Figure 10.—Typical chip types resulting from orthogonal cutting in the crosscutting direction (90-90). A. Uniform chips and smooth surfaces formed when making a .030-inch cut in black oak at 10.7 percent moisture content with a 40° rake angle and 15° clearance angle. B. Broken chips and rough surfaces formed when making a .060-inch cut in cherrybark oak at 9.9 percent moisture content with a 20° rake angle and 15° clearance angle. C. Undersized chips formed when making a .045-inch cut in saturated sweetbay with a 20° rake angle and 15° clearance angle.

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# **APPENDIX**

## **TABLE OF CONTENTS**

<u>Common name</u>	<u>Table number<sup>1</sup></u>
Ash, green	1 ABC
Ash, white	2 ABC
Elm, American	3 ABC
Elm, winged	4 ABC
Hackberry	5 ABC
Hickory	6 ABC
Maple, red	7 ABC
Oak, black	8 ABC
Oak, blackjack	9 ABC
Oak, cherrybark	10 ABC
Oak, laurel	11 ABC
Oak, northern red	12 ABC
Oak, post	13 ABC
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Oak, Shumard	15 ABC
Oak, southern red	16 ABC
Oak, water	17 ABC
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Tupelo, black	21 ABC
Yellow-poplar	22 ABC

<sup>1</sup> A indicates veneer direction (0-90); B indicates planing direction (90-0); C indicates crosscut direction (90-90).

**TABLE 1A.--TOOL FORCES WHEN ORTHOGONALLY CUTTING GREEN ASH VENEER IN THE 0-90 DIRECTION<sup>1</sup>**

Depth of cut and moisture content (percent)	Rake angle, degrees		
	50	60	70

-----Pounds per 0.1 inch of knife-----

**PARALLEL FORCE<sup>2</sup>**

<b>0.015 inch</b>			
<b>11.3</b>	2.9 ( 6.8)	3.4 ( 7.1)	3.3 ( 5.8)
<b>19.1</b>	2.7 ( 4.6)	2.5 ( 5.0)	4.6 ( 9.6)
<b>109.4</b>	1.6 ( 3.2)	1.7 ( 2.7)	3.9 ( 6.9)
<b>0.030 inch</b>			
<b>11.0</b>	4.1 (10.7)	4.3 ( 9.2)	3.7 ( 7.0)
<b>19.1</b>	3.6 ( 7.5)	3.4 ( 7.7)	3.1 ( 5.3)
<b>109.4</b>	2.4 ( 5.2)	2.3 ( 4.1)	2.1 ( 3.0)
<b>0.045 inch</b>			
<b>11.0</b>	4.6 (13.5)	4.6 (11.2)	4.1 ( 9.0)
<b>19.1</b>	4.5 ( 8.7)	4.6 ( 9.8)	3.8 ( 7.2)
<b>109.4</b>	2.9 ( 6.8)	2.9 ( 5.7)	2.4 ( 4.1)
<b>0.060 inch</b>			
<b>11.0</b>	5.9 (15.7)	5.2 (12.5)	5.8 (11.4)
<b>19.1</b>	5.5 (11.0)	4.6 (10.5)	4.7 ( 8.7)
<b>109.4</b>	3.4 ( 7.4)	3.5 ( 7.0)	3.0 ( 5.2)

**NORMAL FORCE<sup>3,4</sup>**

<b>0.015 inch</b>			
<b>11.0</b>	0.3 (-0.8 to 1.9)	0.4 (-0.7 to 1.6)	-0.1 (-1.2 to 1.0)
<b>19.1</b>	-.2 ( -.8 to .6)	-.1 ( -.9 to .9)	.0 (-1.5 to 1.3)
<b>109.4</b>	-.2 ( -.6 to .2)	-.2 ( -.6 to .2)	-.2 (-1.4 to .8)
<b>0.030 inch</b>			
<b>11.0</b>	.0 (-1.3 to 1.5)	-.2 (-1.6 to .8)	.3 (-1.0 to 1.5)
<b>19.1</b>	-.6 (-1.5 to .1)	-.1 (-2.0 to -.3)	1.1
<b>109.4</b>	-.4 (-1.2 to .1)	-.6 (-1.3 to -.2)	-.0 ( -.9 to .3)
<b>0.045 inch</b>			
<b>11.0</b>	-.1 (-1.5 to 1.4)	-.2 (-1.9 to .9)	.2 (-1.6 to 1.6)
<b>19.1</b>	-.7 (-1.8 to .4)	-1.1 (-2.9 to .3)	-.3 (-1.4 to .8)
<b>109.4</b>	-.5 (-1.5 to .1)	-.9 (-1.8 to .3)	-.7 (-1.5 to .0)
<b>0.060 inch</b>			
<b>11.0</b>	-.1 (-1.8 to 1.6)	-.4 (-2.2 to .9)	-.2 (-1.9 to 1.4)
<b>19.1</b>	-.9 (-2.4 to .3)	-1.0 (-2.7 to .2)	-.5 (-2.0 to .9)
<b>109.4</b>	-.6 (-1.9 to .3)	-.9 (-2.2 to .3)	-.8 (-1.9 to .1)

<sup>1</sup> Clearance angle 0°; cutting velocity 5 inches per minute.

<sup>2</sup> The first number in each entry is the average cutting force; the numbers following in parentheses are maximum forces (average of five).

<sup>3</sup> The first number in each entry is the average cutting force; the numbers following in parentheses are minimum and maximum forces (average of five).

<sup>4</sup> A negative normal force indicates that the knife tended to lift the workpiece; force was positive when the knife pushed the workpiece.

**TABLE 1B.--TOOL FORCES WHEN ORTHOGONALLY CUTTING GREEN ASH PARALLEL TO THE GRAIN IN THE 90-O DIRECTION<sup>1</sup>**

Depth of cut and moisture content (percent)	Rake angle, degrees		
	10	20	30
-----Pounds per 0.1 inch of knife-----			
<b>PARALLEL FORCE*</b>			
<b>0.315 inch</b>			
10.7	17.7 (21.7)	16.8 (18.6)	10.7 (14.2)
18.8	11.6 (14.6)	9.5 (10.6)	5.9 ( 8.2)
100.7	8.4 ( 9.2)	7.1 ( 7.9)	4.5 ( 5.4)
<b>0.030 inch</b>			
10.7	32.4 (41.1)	34.7 (39.0)	12.1 (29.5)
18.8	21.9 (25.7)	20.3 (22.8)	12.7 (17.2)
100.7	15.6 (17.4)	13.2 (15.1)	8.0 ( 9.8)
<b>0.045 inch</b>			
10.7	43.2 (54.5)	43.4 (48.1)	15.4 (38.3)
18.8	30.2 (36.5)	26.8 (29.3)	17.4 (23.2)
100.7	21.3 (25.0)	18.5 (21.6)	11.1 (13.7)
<b>0.060 inch</b>			
10.7	57.0 (72.7)	57.4 (63.2)	16.2 (48.8)
18.8	38.1 (46.4)	34.7 (38.8)	18.1 (28.1)
100.7	28.0 (33.8)	23.1 (26.9)	12.5 (16.6)
<b>NORMAL FORCE<sup>3,4</sup></b>			
<b>0.015 inch</b>			
10.7	5.3 ( 3.9 to 6.5)	2.2 1.8 to 2.7)	-0.3 (-0.7 to 0.1)
18.8	3.4 ( 2.4 to 4.3)	1.4 1.1 to 1.8)	.0 ( -.4 to .7)
100.7	2.5 ( 2.1 to 2.9)	.9 .7 to 1.3)	.2 ( -.2 to .6)
<b>0.030 inch</b>			
10.7	8.8 ( 6.3 to 11.2)	4.3 3.8 to 4.8)	-.5 (-1.6 to .6)
18.8	5.9 ( 4.3 to 7.1)	2.3 1.6 to 2.7)	-.6 (-1.2 to .2)
100.7	3.7 ( 3.2 to 4.2)	1.2 .7 to 1.7)	-.3 ( -.8 to .1)
<b>0.045 inch</b>			
10.7	11.3 ( 7.1 to 14.3)	5.5 4.7 to 6.1)	-1.1 (-3.1 to .9)
18.8	8.0 ( 6.3 to 9.5)	2.7 2.3 to 3.2)	-.9 (-1.8 to -.3)
100.7	4.8 ( 3.8 to 5.6)	1.2 .6 to 1.7)	-.9 (-1.4 to -.1)
<b>0.060 inch</b>			
10.7	15.2 (10.3 to 18.5)	6.8 6.0 to 7.7)	-.8 (-3.2 to 1.0)
18.8	9.7 ( 7.7 to 12.1)	3.6 2.3 to 4.1)	-1.1 (-2.2 to -.3)
100.7	5.9 ( 4.6 to 6.8)	1.1 .5 to 1.7)	-.8 (-1.8 to -.2)

<sup>1</sup> Clearance angle 15°; cutting velocity 5 inches per minute.

<sup>2</sup> The first number in each entry is the average cutting force; the numbers following in parentheses are maximum forces (average of five).

<sup>3</sup> The first number in each entry is the average cutting force; the numbers following in parentheses are minimum and maximum forces (average of five).

<sup>4</sup> A negative normal force indicates that the knife tended to lift the workpiece; force was positive when the knife pushed the workpiece.

**TABLE 1C.--TOOL FORCES WHEN ORTHOGONALLY CUTTING GREEN ASH ACROSS THE GRAIN IN THE 90-90 DIRECTION<sup>1</sup>**

Depth of cut and moisture content (percent)	Rake angle, degrees		
	20	30	40
-----Pounds per 0.1 inch of knife-----			
<b>PARALLEL FORCE<sup>2</sup></b>			
<b>0.315 inch</b>			
10.5	23.4 (28.5)	18.7 (22.4)	15.2 (17.5)
18.4	16.6 (19.5)	13.7 (16.8)	11.5 (13.9)
111.7	12.7 (15.1)	10.8 (12.2)	8.6 (10.3)
<b>0.030 inch</b>			
10.5	35.9 (45.0)	32.4 (39.5)	25.3 (29.7)
18.4	30.3 (35.4)	22.3 (26.4)	18.3 (22.0)
111.7	21.2 (23.7)	16.2 (18.4)	12.2 (14.7)
<b>0.045 inch</b>			
10.5	45.7 (56.6)	46.5 (57.9)	34.0 (39.3)
18.4	37.2 (42.3)	30.2 (35.8)	24.2 (28.7)
111.7	28.3 (33.1)	21.2 (24.5)	16.5 (20.6)
<b>0.060 inch</b>			
10.5	44.5 (59.1)	54.6 (66.8)	38.4 (46.4)
18.4	45.5 (53.5)	36.4 (43.6)	28.7 (34.7)
111.7	30.2 (35.7)	25.4 (29.2)	20.5 (25.2)
<b>NORMAL FORCE<sup>3,4</sup></b>			
<b>0.015 inch</b>			
10.5	2.5 (1.8 to 4.5)	0.2 (-0.9 to 2.2)	-2.5 (-3.4 to -1.1)
18.4	1.9 (1.1 to 3.3)	-.2 (-1.1 to .7)	-1.6 (-2.6 to -.6)
111.7	.6 (-.1 to 1.2)	-.5 (-1.2 to .1)	-1.8 (-2.4 to -1.1)
<b>0.030 inch</b>			
10.5	4.1 (2.5 to 7.1)	-1.3 (-3.2 to 1.3)	-5.5 (-7.2 to -2.3)
18.4	2.4 (1.2 to 4.3)	-1.7 (-2.8 to -.2)	-4.0 (-5.1 to -2.0)
111.7	.5 (-.1 to 1.2)	-1.8 (-2.6 to -.9)	-3.6 (-4.8 to -2.2)
<b>0.045 inch</b>			
10.5	5.4 (2.5 to 8.4)	-1.9 (-4.7 to 3.1)	-7.9 (-10.0 to -3.5)
18.4	2.5 (1.0 to 4.3)	-3.0 (-4.7 to -.4)	-5.9 (-8.0 to -3.0)
111.7	.5 (-.6 to 1.5)	-2.8 (-3.9 to -1.7)	-5.1 (-6.8 to -3.1)
<b>0.060 inch</b>			
10.5	6.3 (2.1 to 10.3)	.9 (-6.5 to 11.9)	-9.1 (-11.8 to -5.1)
18.4	2.6 (.8 to 5.6)	-3.8 (-6.3 to -.4)	-7.3 (-9.7 to -4.3)
111.7	.6 (-.8 to 2.3)	-3.7 (-4.9 to -2.5)	-6.4 (-8.3 to -4.1)

<sup>1</sup> Clearance angle 15°; cutting velocity 5 inches per minute.

<sup>2</sup> The first number in each entry is the average cutting force; the numbers following in parentheses are maximum forces (average of five).

<sup>3</sup> The first number in each entry is the average cutting force; the numbers following in parentheses are minimum and maximum forces (average of five).

<sup>4</sup> A negative force indicates that the knife tended to lift the workpiece; force was positive when the knife pushed the workpiece.

**TABLE 2A. --TOOL FORCES WHEN ORTHOGONALLY CUTTING WHITE ASH VENEER IN THE 0-90 DIRECTION<sup>1</sup>**

Depth of cut and moisture content (percent)	Rake angle, degrees		
	50	60	70
-----Pounds per 0.1 inch of knife-----			
<b>PARALLEL FORCE<sup>2</sup></b>			
<b>0.015 inch</b>			
11.2	3.7 ( 7.4)	3.7 ( 6.7)	4.2 ( 7.5)
19.1	2.9 ( 5.5)	2.5 ( 4.7)	5.0 (11.5)
106.0	2.1 ( 3.6)	2.0 ( 3.1)	4.7 ( 8.0)
<b>0.030 inch</b>			
11.2	4.8 (12.9)	4.8 (10.4)	4.7 ( 7.9)
19.1	4.5 ( 8.9)		3.3 ( 5.7)
106.0	2.9 ( 6.0)	4.6 ( 8.2)	2.2 ( 3.8)
<b>0.045 inch</b>		2.8 ( 4.5)	
11.2	5.8 (15.0)	5.8 (13.9)	5.8 (10.9)
19.1	4.7 (10.9)	5.3 (10.2)	4.4 ( 7.8)
106.0	3.5 ( 7.3)	3.4 ( 5.9)	2.8 ( 4.7)
<b>0.060 inch</b>			
11.2	6.5 (15.8)	6.6 (15.6)	6.8 (13.9)
19.1	5.9 (13.0)	5.9 (13.4)	5.5 (11.0)
106.0	4.1 ( 8.2)	4.1 ( 7.3)	3.3 ( 5.5)
<b>NORMAL FORCE<sup>3,4</sup></b>			
<b>0.015 inch</b>			
11.2	-0.1 (-1.0 to 1.2)	0.2 (-1.1 to 1.2)	0.1 -2.2 to 1.4)
19.1	-.2 (-.9 to 1.0)	-.2 (-1.0 to .6)	.3 -1.2 to 2.5)
106.0	-.2 (-.6 to .4)	-.3 (-.8 to .2)	-.3 -1.4 to .7)
<b>0.030 inch</b>			
11.2	-.2 (-1.8 to 1.6)	-.1 (-1.4 to 1.3)	.7 -1.3 to 2.2)
19.1	-.7 (-1.8 to .1)	-1.1 (-2.5 to .2)	-.4 -1.2 to .9)
106.0	-.4 (-1.2 to .5)	-.8 (-1.8 to .1)	.3 -.2 to 1.1)
<b>0.045 inch</b>			
11.2	-.1 (-1.9 to 1.5)	-.1 (-1.9 to 1.8)	.4 -1.0 to 2.4)
19.1	-.7 (-2.0 to .8)	-1.1 (-3.2 to .2)	-.9 -2.2 to .6)
106.0	-.6 (-1.6 to .3)	-1.1 (-2.5 to .1)	-.2 -1.1 to .6)
<b>0.060 inch</b>			
11.2	.0 (-2.7 to 1.8)	.0 (-1.8 to 1.7)	.6 -1.1 to 2.8)
19.1	-1.0 (-2.4 to .3)	-1.4 (-3.3 to .1)	-1.0 -2.4 to 1.3)
106.0	-.7 (-1.6 to .2)	-1.1 (-2.7 to .2)	-.3 -1.5 to .6)

<sup>1</sup> Clearance angle 0°; cutting velocity 5 inches per minute.

<sup>2</sup> The first number in each entry is the average cutting force; the numbers following in parentheses are maximum forces (average of five).

<sup>3</sup> The first number in each entry is the average cutting force; the numbers following in parentheses are minimum and maximum forces (average of five).

<sup>4</sup> A negative normal force indicates that the knife tended to lift the workpiece; force was positive when the knife pushed the workpiece.

**TABLE 2B.--TOOL FORCES WHEN ORTHOGONALLY CUTTING WHITE ASH PARALLEL TO THE GRAIN IN THE 90-0 DIRECTION<sup>1</sup>**

Depth of cut and moisture content (percent)	Rake angle, aegrees		
	10	20	30
-----Pounds per 0.1 inch of knife-----			
<b>PARALLEL FORCE*</b>			
<b>0.015 inch</b>			
11.0	17.3 (21.9)	14.3 (15.8)	9.7 (12.8)
19.2		8.5 (9.9)	7.0 (8.0)
98.5	12.3 (14.2), 7.5 (8.7)	6.2 (7.4)	4.4 (5.1)
<b>0.030 inch</b>			
11.0	29.3 (39.6)	25.6 (28.3)	18.3 (23.6)
19.2	22.6 (26.7)	17.2 (19.6)	
98.5	14.1 (16.4)	11.0 (13.1)	13.1 (14.4), 8.0 (9.0)
<b>0.045 inch</b>			
11.0	40.0 (52.7)	37.5 (41.3)	21.9 (32.3)
19.2	28.4 (37.2)	23.1 (26.2)	17.0 (18.9)
98.5	20.8 (25.8)	16.5 (18.1)	10.5 (11.7)
<b>0.060 inch</b>			
11.0	49.0 (64.5)	53.3 (58.3)	22.1 (37.8)
19.2	34.3 (45.1)	32.7 (36.4)	21.0 (24.0)
98.5	26.3 (32.8)	21.8 (24.7)	11.3 (13.6)
<b>NORMAL FORCE<sup>3,4</sup></b>			
<b>0.015 inch</b>			
11.0	5.0 (3.7 to 6.6)	1.9 (1.5 to 2.3)	-0.1 (-0.4 to 0.4)
19.2	3.4 (2.8 to 4.1)	1.1 (.8 to 1.6)	-.1 (-.4 to .3)
98.5	2.3 (1.8 to 2.9)	.9 (.6 to 1.2)	.1 (-.1 to .4)
<b>0.030 inch</b>			
11.0	8.4 (3.9 to 10.8)	3.2 (2.8 to 3.8)	-.7 (-1.4 to .0)
19.2	5.8 (3.9 to 7.1)	2.0 (1.5 to 2.5)	-.6 (-1.0 to -.2)
98.5	3.5 (2.6 to 4.4)	.9 (.5 to 1.4)	-.3 (-.7 to .2)
<b>0.045 inch</b>			
11.0	11.4 (6.4 to 14.3)	4.4 (3.9 to 5.1)	-1.0 (-2.0 to .0)
19.2	7.3 (4.8 to 9.6)	2.5 (2.0 to 3.0)	-1.0 (-1.4 to -.3)
98.5	4.8 (3.8 to 6.1)	1.0 (.6 to 1.5)	-.6 (-1.1 to -.2)
<b>0.060 inch</b>			
11.0	12.8 (7.9 to 16.7)	5.8 (4.8 to 6.7)	-1.1 (-2.6 to .3)
19.2	8.7 (5.6 to 10.6)	3.4 (2.7 to 3.9)	-1.1 (-1.4 to -.5)
98.5	5.5 (3.6 to 7.2)	.8 (.3 to 1.4)	-1.2 (-1.7 to -.6)

<sup>1</sup> Clearance angle 15°; cutting velocity 5 inches per minute.

<sup>2</sup> The first number in each entry is the average cutting force; the numbers following in parentheses are maximum forces (average of five).

<sup>3</sup> The first number in each entry is the average cutting force; the numbers following in parentheses are minimum and maximum forces (average of five).

<sup>4</sup> A negative normal force indicates that the knife tended to lift the workpiece; force was positive when the knife pushed the workpiece.

**TABLE 2C.--TOOL FORCES WHEN ORTHOGONALLY CUTTING WHITE ASH ACROSS THE GRAIN IN THE 90-90 DIRECTION<sup>1</sup>**

Depth of cut and moisture content (percent)	Rake angle, degrees		
	20	30	40
-----Pounds per 0.1 inch of knife-----			
<b>PARALLEL FORCE<sup>2</sup></b>			
<b>0.015 inch</b>			
10.8	19.9 (24.3)	22.6 (26.2)	17.1 (20.6)
18.3	22.3 (25.0)	12.6 (14.4)	11.2 (13.2)
106.2	13.5 (15.3)	9.9 (11.7)	9.1 (10.5)
<b>0.030 inch</b>			
10.8	42.1 (49.2)	33.7 (39.2)	27.2 (31.5)
18.3	33.8 (37.8)	23.2 (26.6)	20.3 (23.2)
106.2	21.2 (23.8)	15.6 (17.8)	13.7 (15.3)
<b>0.045 inch</b>			
10.8	51.3 (60.7)	44.8 (50.7)	35.0 (43.4)
18.3	41.8 (46.9)	31.1 (35.2)	24.7 (28.0)
106.2	27.5 (31.5)	20.5 (23.3)	17.4 (20.3)
<b>0.060 inch</b>			
10.8	62.7 (76.2)	51.2 (60.2)	41.8 (49.7)
18.3	49.4 (57.8)	38.1 (43.6)	30.3 (35.8)
106.2	35.5 (41.3)	25.0 (28.2)	21.7 (24.6)
<b>NORMAL FORCE<sup>3,4</sup></b>			
<b>0.015 inch</b>			
10.8	2.3 ( 1.3 to 3.6)	-0.8 (-1.9 to 0.4)	-3.2 ( -4.4 to -1.9)
18.3	1.6 ( 1.0 to 2.5)	-.3 (-1.0 to .3)	-2.0 ( -2.6 to -1.2)
106.2	.4 ( .0 to 1.0)	-.7 (-1.3 to -.2)	-1.8 ( -2.3 to -1.2)
<b>0.030 inch</b>			
10.8	3.1 ( 1.7 to 4.9)	-2.3 (-3.8 to -.4)	-6.1 ( -8.2 to -4.2)
18.3	1.5 ( .7 to 3.0)	-2.3 (-3.4 to -1.3)	-4.6 ( -5.9 to -2.9)
106.2	.2 ( -.5 to .8)	-2.1 (-2.9 to -1.3)	-3.8 ( -4.8 to -2.7)
<b>0.045 inch</b>			
10.8	4.1 ( 1.5 to 6.1)	-3.8 (-6.1 to -1.1)	-9.1 (-11.8 to -6.3)
18.3	1.6 ( .1 to 3.5)	-3.7 (-5.1 to -2.0)	-6.8 ( -8.2 to -4.2)
106.2	-.1 ( -.9 to 1.0)	-3.3 (-4.4 to -2.2)	-5.3 ( -6.6 to -4.0)
<b>0.060 inch</b>			
10.8	4.8 ( 1.6 to 8.0)	-4.4 (-7.7 to -.7)	-11.3 (-14.0 to -7.9)
18.3	1.9 ( -.2 to 4.1)	-5.1 (-7.5 to -2.8)	-8.5 (-11.5 to -4.9)
106.2	-.2 (-1.4 to 1.1)	-4.3 (-5.5 to -2.9)	-6.9 ( -8.7 to -5.2)

- <sup>1</sup> Clearance angle 15°; cutting velocity 5 inches per minute.
- <sup>2</sup> The first number in each entry is the average cutting force; the numbers following in parentheses are maximum forces (average of five).
- <sup>3</sup> The first number in each entry is the average cutting force; the numbers following in parentheses are minimum and maximum forces (average of five).
- <sup>4</sup> A negative normal force indicates that the knife tended to lift the workpiece; force was positive when the knife pushed the workpiece.

**TABLE 3A.--TOOL FORCES WHEN ORTHOGONALLY CUTTING AMERICAN ELM VENEER IN THE 0-90 DIRECTION<sup>1</sup>**

Depth of cut and moisture content (percent)	Rake angle, degrees		
	50	60	70
-----Pounds per 0.1 inch of knife-----			
<b>PARALLEL FORCE<sup>2</sup></b>			
<b>0.015 inch</b>			
11.7	2.7 ( 5.5)	2.9 ( 5.0)	2.8 (4.5)
18.9	2.2 ( 4.4)	2.0 ( 3.3)	3.6 (7.4)
108.0	1.8 ( 2.9)	1.5 ( 2.5)	3.3 (5.3)
<b>0.030 inch</b>			
11.7	4.0 ( 8.5)	3.8 ( 7.5)	<b>3.3 (5.6)</b>
18.9	3.3 ( 6.4)	3.0 ( 5.5)	<b>2.5 (4.2)</b>
108.0	2.7 ( 4.8)	2.2 ( 3.6)	<b>2.1 (3.1)</b>
<b>0.045 inch</b>			
11.7	4.9 (10.7)	4.8 ( 9.1)	<b>3.7 (7.1)</b>
18.9	4.3 ( 8.8)	3.8 ( 7.0)	<b>3.3 (5.3)</b>
108.0	3.1 ( 5.8)	3.0 ( 4.8)	<b>2.7 (4.1)</b>
<b>0.060 inch</b>			
11.7	<b>5.8 (12.1)</b>	<b>5.1 (11.1)</b>	4.4 (8.1)
18.9	5.2 (10.0)	4.3 ( 8.4)	3.8 (6.5)
108.0	3.6 ( 7.0)	3.5 ( 5.8)	<b>3.0 (4.8)</b>
<b>NORMAL FORCE<sup>3,4</sup></b>			
<b>0.015 inch</b>			
11.7	<b>0.1 (-0.6 to .6)</b>	<b>0.4 (-0.4 to 1.1)</b>	<b>-0.2 (-1.0 to 0.6)</b>
18.9	-.2 ( -.8 to .7)	-.3 ( -.8 to .2)	-.4 (-1.8 to .9)
108.0	-.2 ( -.5 to .2)	-.3 ( -.6 to .2)	-.4 (-1.6 to .7)
<b>0.030 inch</b>			
11.7	-.2 (-1.3 to .6)	-.1 (-1.3 to .8)	.3 ( -.6 to 1.2)
18.9	-.5 (-1.5 to .8)	-.9 (-1.8 to .1)	-.2 ( -.8 to .6)
108.0	-.5 (-1.1 to .2)	-.7 (-1.3 to .0)	.1 ( -.4 to .6)
<b>0.045 inch</b>			
11.7	-.5 (-1.9 to .8)	-.3 (-1.8 to 1.2)	-.2 (-1.6 to .9)
18.9	-.7 (-2.1 to .9)	-1.2 (-2.7 to .2)	-.7 (-1.7 to .3)
108.0	-.7 (-1.6 to .3)	-.9 (-1.8 to -.1)	-.5 (-1.1 to .3)
<b>0.060 inch</b>			
11.7	-.7 (-2.5 to 1.1)	-.6 (-2.6 to 1.2)	-.4 (-1.9 to .9)
18.9	-.9 (-2.4 to .5)	-1.4 (-3.1 to .1)	-1.0 (-2.2 to .4)
108.0	-.9 (-2.2 to .2)	-1.2 (-2.5 to -.2)	-.8 (-1.9 to .3)

<sup>1</sup>Clearance angle 0°; cutting velocity 5 inches per minute.

<sup>2</sup>The first number in each entry is the average cutting force; the numbers following in parentheses are maximum forces (average of five).

<sup>3</sup>The first number in each entry is the average cutting force; the numbers following in parentheses are minimum and maximum forces (average of five).

<sup>4</sup>A negative normal force indicates that the knife tended to lift the workpiece; force was positive when the knife pushed the workpiece.

**TABLE 3B. -- TOOL FORCES WHEN ORTHOGONALLY CUTTING AMERICAN ELM PARALLEL TO THE GRAIN IN THE 90-0 DIRECTION'**

Depth of cut and moisture content (percent)	Rake angle, degrees		
	10	20	30
-----Pounds per 0.1 inch of knife-----			
<b>PARALLEL FORCE<sup>2</sup></b>			
<b>0.015 inch</b>			
10.8	15.8 (18.7)	14.9 (17.1)	9.3 (12.0)
18.8		9.2 (10.2)	6.7 (8.7)
102.8	12.0 (13.6)	7.5 (8.0)	5.0 (6.1)
8.7 (10.4)			
<b>0.030 inch</b>			
10.8	30.3 (38.2)	31.0 (35.0)	11.9 (21.1)
18.8	22.5 (27.9)	19.1 (21.4)	
102.8	14.1 (17.2)	14.1 (15.9)	13.5 (17.5)
			8.0 (9.6)
<b>0.045 inch</b>			
10.8	40.5 (50.8)	38.7 (46.6)	13.0 (35.1)
18.8	30.7 (37.7)	26.4 (30.5)	14.7 (23.7)
102.8	25.4 (31.9)	19.6 (22.9)	10.7 (15.8)
<b>0.060 inch</b>			
10.8	50.1 (64.6)	50.6 (60.4)	13.9 (43.3)
18.8	37.7 (46.3)	33.4 (37.6)	16.4 (32.3)
102.8	30.0 (38.5)	23.0 (27.4)	12.7 (18.6)
<b>NORMAL FORCE<sup>3,4</sup></b>			
<b>b.015 inch</b>			
10.8	4.6 (3.8 to 5.2)	1.8 (1.5 to 2.1)	-0.2 (-0.5 to 0.2)
18.8	3.5 (2.7 to 4.0)	1.3 (.9 to 1.6)	-.2 (-.5 to .4)
102.8	2.6 (2.0 to 3.2)	.8 (.6 to 1.1)	-.1 (-.4 to .2)
<b>0.030 inch</b>			
10.8	8.2 (6.0 to 9.7)	3.6 (3.0 to 4.0)	-.6 (-1.5 to .1)
18.8	5.9 (3.8 to 7.3)	2.0 (1.6 to 2.4)	-1.0 (-1.3 to -.5)
102.8	4.1 (3.3 to 5.0)	1.1 (.8 to 1.5)	-.5 (-.8 to -.1)
<b>0.045 inch</b>			
10.8	10.5 (7.5 to 12.8)	3.8 (2.7 to 4.6)	-.6 (-2.4 to .2)
18.8	7.6 (5.0 to 9.4)	2.5 (2.0 to 2.9)	-1.2 (-2.0 to -.1)
102.8	5.7 (4.6 to 6.9)	1.2 (.8 to 1.7)	-.8 (-1.6 to -.2)
<b>0.060 inch</b>			
10.8	12.7 (8.9 to 16.5)	4.9 (3.6 to 6.0)	-.8 (-3.1 to .0)
18.8	9.2 (6.1 to 11.4)	2.9 (2.3 to 3.5)	-1.3 (-2.7 to -.3)
102.8	6.8 (5.0 to 8.4)	1.2 (.6 to 1.7)	-1.1 (-2.1 to -.3)

<sup>1</sup>Clearance angle 15°; cutting velocity 5 inches per minute.

<sup>2</sup>The first number in each entry is the average cutting force; the numbers following in parentheses are maximum forces (average of five).

<sup>3</sup>The first number in each entry is the average cutting force; the numbers following in parentheses are minimum and maximum forces (average of five).

<sup>4</sup>A negative normal force indicates that the knife tended to lift the workpiece; force was positive when the knife pushed the workpiece,

**TABLE 3C.--TOOL FORCES WHEN ORTHOGONALLY CUTTING AMERICAN ELM ACROSS THE GRAIN IN THE 90-90 DIRECTION'**

Depth of cut and moisture content (percent)	Rake angle, degrees		
	20	30	40
-----Pounds per 0.1 inch of knife-----			
<b>PARALLEL FORCE<sup>2</sup></b>			
<b>0.015 inch</b>			
10.4	20.1 (25.0)	18.9 (23.0)	13.8 (18.3)
18.4	17.2 (19.3)	13.2 (15.4)	11.0 (13.3)
107.9	12.0 (14.0)	10.4 (11.8)	7.8 (9.0)
<b>0.030 inch</b>			
10.4	38.3 (44.0)	30.5 (35.3)	23.1 (28.7)
18.4	30.1 (33.0)	22.9 (26.4)	17.3 (21.1)
107.9	22.3 (25.1)	17.1 (19.5)	12.6 (14.6)
<b>0.045 inch</b>			
10.4	42.9 (50.0)	38.0 (44.6)	30.6 (36.6)
18.4	38.5 (43.4)	29.1 (33.2)	22.7 (26.6)
107.9	30.4 (33.3)	21.8 (24.0)	15.3 (18.7)
<b>0.060 inch</b>			
10.4	51.3 (60.5)	42.0 (51.5)	35.5 (43.7)
18.4	48.4 (54.8)	35.5 (39.7)	28.0 (36.0)
107.9	38.2 (42.9)	26.7 (30.7)	19.4 (22.5)
<b>NORMAL FORCE<sup>3,4</sup></b>			
<b>-0.015 inch</b>			
10.4	1.7 (0.8 to 2.3)	-0.6 (-1.8 to 0.8)	-2.6 (-3.8 to -1.6)
18.4	1.5 (1.0 to 1.8)	-.7 (-1.2 to -.1)	-1.6 (-2.5 to -1.1)
107.9	.6 (.3 to .9)	-.5 (-.9 to -.1)	-1.7 (-2.4 to -.9)
<b>0.030 inch</b>			
10.4	2.3 (1.0 to 4.3)	-2.3 -3.9 to -.2)	-5.3 (-7.3 to -3.7)
18.4	1.6 (1.0 to 2.8)	-2.0 -3.2 to -1.1)	-4.1 (-5.9 to -3.2)
107.9	.5 (-.1 to 1.0)	-1.7 -2.6 to -.9)	-3.6 (-4.4 to -2.7)
<b>0.045 inch</b>			
10.4	3.0 .1 to 4.7)	-3.1 (-5.3 to -.3)	-7.6 (-10.2 to -5.1)
18.4	1.8 .8 to 3.6)	-3.0 (-4.3 to -1.9)	-6.2 (-7.9 to -4.3)
107.9	.6 -.3 to 1.4)	-2.6 (-3.7 to -1.6)	-4.9 (-6.8 to -3.7)
<b>0.060 inch</b>			
10.4	3.9 (1.1 to 6.7)	-3.6 (-6.9 to -1.3)	-9.8 (-13.1 to -6.5)
18.4	2.3 (.8 to 4.4)	-4.4 (-5.9 to -2.6)	-7.8 (-10.6 to -3.9)
107.9	.9 (-.5 to 2.0)	-3.4 (-4.9 to -2.2)	-6.6 (-8.0 to -4.7)

<sup>1</sup>Clearance angle 15°; cutting velocity 5 inches per minute.

<sup>2</sup>The first number in each entry is the average cutting force; the numbers following in parentheses are maximum forces (average of five).

<sup>3</sup>The first number in each entry is the average cutting force; the numbers following in parentheses are minimum and maximum forces (average of five)

<sup>4</sup>A negative normal force indicates that the knife tended to lift the workpiece; force was positive when the knife pushed the workpiece

**TABLE 4A.--TOOL FORCES WHEN ORTHOGONALLY CUTTING WINGED ELM VENEER IN THE 0-90 DIRECTION<sup>1</sup>**

Depth of cut and moisture content (percent)	Rake angle, degrees		
	50	60	70
-----Pounds per 0.1 inch of knife-----			
<b>PARALLEL FORCE<sup>2</sup></b>			
<b>0.015 inch</b>			
11.6	3.2 ( 6.3)	3.9 ( 6.2)	3.3 ( 5.4)
19.1		2.7 ( 4.4)	5.3 (10.0)
88.8	2.6 ( 4.5),	2.3 ( 3.3)	4.4 ( 8.6)
<b>0.030 inch</b>	2.2 (3.6)		
11.6	5.3 (10.3)	5.4 ( 9.8)	4.3 ( 6.6)
19.1	4.1 ( 8.0)	3.9 ( 6.2)	3.3 ( 5.6)
88.8	3.3 ( 6.7)	3.3 ( 5.3)	2.6 ( 3.9)
<b>0.045 inch</b>			
11.6	6.8 (13.8)	6.5 (11.9)	5.0 ( 9.1)
19.1	5.2 (10.4)	4.7 ( 9.0)	4.4 ( 7.2)
88.8	4.3 ( 9.0)	3.8 ( 6.8)	3.1 ( 5.3)
<b>0.060 inch</b>			
11.6	7.5 (16.2)	7.0 (15.2)	5.9 (11.3)
19.1	6.1 (13.8)	5.8 (10.5)	5.2 ( 9.3)
88.8	5.0 (10.8)	4.4 ( 9.1)	3.8 ( 6.5)

**NORMAL FORCE<sup>3,4</sup>**

<b>-0.015 inch</b>			
11.6	-0.3 (-0.9 to .5)	0.7 ( 0.2 to 1.4)	0.0 (-1.0 to 1.1)
19.1	-.5 (-1.0 to .1)	-.7 (-1.1 to .1)	-.5 (-2.0 to 1.2)
88.8	-.3 (-.7 to .2)	-.2 (-.6 to .3)	-.9 (-2.2 to .7)
<b>0.030 inch</b>			
11.6	-.7 (-1.9 to .6)	-.3 (-1.6 to 1.2)	.1 (-.8 to 1.2)
19.1	-.9 (-1.9 to .1)	-1.3 (-2.3 to -.2)	-.4 (-1.2 to .8)
88.8	-.7 (-1.7 to .5)	-1.0 (-1.9 to .0)	-.1 (-.8 to .4)
<b>0.045 inch</b>			
11.6	-.8 (-2.8 to .8)	-.7 (-2.4 to .9)	-.7 (-2.0 to .7)
19.1	-1.0 (-2.5 to .5)	-1.5 (-2.9 to .2)	-1.3 (-2.2 to .3)
88.8	-.8 (-2.4 to .7)	-1.1 (-2.7 to .1)	-.9 (-1.7 to .0)
<b>0.060 inch</b>			
11.6	-.9 (-3.2 to 1.2)	-.6 (-2.6 to 1.2)	-.6 (-2.4 to .6)
19.1	-1.3 (-3.2 to .5)	-1.7 (-3.5 to .1)	-1.4 (-2.8 to .5)
88.8	-.9 (-2.8 to .6)	-1.2 (-3.0 to .6)	-1.2 (-2.5 to .3)

<sup>1</sup>Clearance angle 0°; cutting velocity 5 inches per minute.

<sup>2</sup>The first number in each entry is the average cutting force; the numbers following in parentheses are maximum forces (average of five).

<sup>3</sup>The first number in each entry is the average cutting force; the numbers following in parentheses are minimum and maximum forces (average of five).

<sup>4</sup>A negative normal force indicates that the knife tended to lift the workpiece; force was positive when the knife pushed the workpiece.

**TABLE 4B.--TOOL FORCES WHEN ORTHOGONALLY CUTTING WINGED ELM PARALLEL TO THE GRAIN IN THE 90-0 DIRECTION<sup>1</sup>**

Depth of cut and moisture content (percent)	Rake angle, degrees		
	10	20	30
-----Pounds per 0.1 inch of knife-----			
<b>PARALLEL FORCE<sup>2</sup></b>			
<b>0.015 inch</b>			
10.9	15.5 (18.9)	13.7 (15.7)	8.4 (10.9)
19.2		9.4 (10.4)	
87.7	13.0 (15.3),	7.2 (8.8)	6.2 (7.8),
<b>0.030 inch</b>	9.7 (11.1)		4.8 (6.7)
10.9	33.0 (41.3)	30.4 (34.7)	14.1 (20.3)
19.2	24.4 (29.0)	20.2 (22.8)	12.6 (15.7)
87.7	15.8 (20.5)	13.2 (18.3)	7.8 (10.5)
<b>0.045 inch</b>			
10.9	39.6 (55.4)	41.0 (46.0)	16.0 (28.5)
19.2	29.8 (38.2)	25.1 (29.3)	
87.7	21.3 (31.5)	15.8 (22.9)	16.4 (21.3),
<b>0.060 inch</b>			9.5 (13.6)
10.9	51.8 (71.3)	50.3 (56.2)	19.7 (34.6)
19.2	36.4 (47.7)	29.2 (35.0)	18.7 (25.4)
87.7	28.6 (40.9)	18.6 (30.6)	12.0 (15.9)
<b>NORMAL FORCE<sup>3,4</sup></b>			
<b>0.015 inch</b>			
10.9	4.7 (3.9 to 5.7)	2.0 (1.6 to 2.4)	-0.1 (-0.5 to 0.5)
19.2	3.8 (2.6 to 4.7)	1.2 (1.0 to 1.5)	.1 (-.2 to .4)
87.7	2.6 (2.1 to 3.0)	.8 (.6 to 1.1)	.0 (-.3 to .3)
<b>0.030 inch</b>			
10.9	9.0 (5.9 to 10.8)	3.7 (3.0 to 4.4)	-.5 (-1.3 to .3)
19.2	6.1 (4.8 to 7.1)	1.9 (1.5 to 2.2)	-.5 (-.9 to .1)
87.7	3.9 (2.6 to 5.0)	1.0 (.5 to 1.4)	-.4 (-.8 to .0)
<b>0.045 inch</b>			
10.9	11.1 (6.5 to 14.4)	4.7 (4.1 to 5.3)	-.7 (-2.2 to .1)
19.2	7.6 (5.3 to 9.1)	2.2 (1.9 to 2.6)	-.9 (-1.4 to -.1)
87.7	5.1 (2.8 to 7.3)	1.1 (.5 to 1.9)	-.6 (-1.2 to -.1)
<b>0.060 inch</b>			
10.9	13.9 (7.6 to 18.0)	5.6 (4.6 to 6.4)	-1.1 (-2.7 to .2)
19.2	9.0 (5.7 to 11.0)	2.5 (1.7 to 3.0)	-1.0 (-1.8 to -.1)
87.7	6.2 (3.9 to 8.9)	1.3 (.6 to 1.9)	-.7 (-1.4 to .1)

<sup>1</sup>Clearance angle 15°; cutting velocity 5 inches per minute.

<sup>2</sup>The first number in each entry is the average cutting force; the numbers following in parentheses are maximum forces (average of five).

<sup>3</sup>The first number in each entry is the average cutting force; the numbers following in parentheses are minimum and maximum forces (average of five).

<sup>4</sup>A negative normal force indicates that the knife tended to lift the workpiece; force was positive when the knife pushed the workpiece.

**TABLE 4C.--TOOL FORCES WHEN ORTHOGONALLY CUTTING WINGED ELM ACROSS THE GRAIN IN THE 90-90 DIRECTION<sup>1</sup>**

Depth of cut and moisture content (percent)	Rake angle, degrees		
	20	30	40
-----Pounds per 0.1 inch of knife-----			
<b>PARALLEL FORCE<sup>2</sup></b>			
<b>0.015 inch</b>			
11.6	22.0 (28.2)	19.7 (23.2)	15.8 (18.6)
18.6	17.4 (20.7)	14.2 (16.9)	11.9 (14.0)
91.2	14.5 (16.7)	10.2 (12.3)	8.3 (9.4)
<b>0.030 inch</b>			
11.6	42.5 (48.8)	35.5 (42.1)	25.6 (30.1)
18.6	34.5 (38.8)	24.9 (28.7)	19.3 (21.2)
91.2	26.2 (28.8)	17.7 (19.8)	14.0 (16.6)
<b>0.045 inch</b>			
11.6	54.3 (60.3)	40.7 (46.9)	34.2 (41.0)
18.6	41.9 (46.9)	32.8 (38.9)	24.8 (28.4)
91.2	35.4 (39.1)	24.6 (28.4)	19.0 (21.7)
<b>0.060 inch</b>			
11.6	60.2 (68.1)	53.7 (62.3)	39.9 (48.4)
18.6	52.6 (61.6)	39.0 (45.4)	29.7 (35.6)
91.2	44.0 (48.8)	30.7 (34.2)	23.3 (27.7)
<b>NORMAL FORCE<sup>3,4</sup></b>			
<b>0.015 inch</b>			
11.6	1.6 (0.9 to 2.5)	-1.0 (-2.0 to -0.2)	-3.3 (-4.3 to -2.4)
18.6	1.3 (1.0 to 2.0)	-1.0 (-1.6 to -.4)	-2.4 (-2.9 to -1.7)
91.2	.5 (.1 to 1.0)	-.7 (-1.1 to -.3)	-1.9 (-2.4 to -1.3)
<b>0.030 inch</b>			
11.6	2.0 (.8 to 4.9)	-3.3 (-5.1 to -.7)	-6.7 (-8.3 to -4.2)
18.6	1.3 (.4 to 2.4)	-2.9 (-4.1 to -1.8)	-5.2 (-6.4 to -4.1)
91.2	.3 (-.5 to .9)	-2.4 (-3.3 to -1.7)	-4.3 (-5.1 to -3.5)
<b>0.045 inch</b>			
11.6	2.9 (-.1 to 5.8)	-4.2 (-6.3 to -1.6)	-9.2 (-11.5 to -6.7)
18.6	1.5 (.4 to 2.9)	-4.3 (-6.1 to -2.7)	-7.3 (-9.1 to -5.3)
91.2	.3 (-.9 to 1.2)	-3.6 (-4.5 to -2.4)	-5.6 (-6.9 to -4.3)
<b>0.060 inch</b>			
11.6	3.4 (-.6 to 6.8)	-6.3 (-9.1 to -1.0)	-11.7 (-14.2 to -8.1)
18.6	1.8 (.3 to 3.6)	-5.6 (-7.5 to -3.4)	-9.7 (-12.1 to -5.8)
91.2	.5 (-.8 to 1.8)	-4.7 (-6.0 to -3.5)	-7.5 (-9.4 to -4.6)

<sup>1</sup>Clearance angle 15°; cutting velocity 5 inches per minute.

<sup>2</sup>The first number in each entry is the average cutting force; the numbers following in parentheses are maximum forces (average of five).

<sup>3</sup>The first number in each entry is the average cutting force; the numbers following in parentheses are minimum and maximum forces (average of five).

<sup>4</sup>A negative normal force indicates that the knife tended to lift the workpiece; force was positive when the knife pushed the workpiece.

**TABLE 5A.--TOOL FORCES WHEN ORTHOGONALLY CUTTING HACKBERRY VENEER IN THE 0-90 DIRECTION<sup>1</sup>**

Depth of cut and moisture content (percent)	Rake angle, degrees		
	50	60	70
-----Pounds per 0.1 inch of knife-----			
<b>PARALLEL FORCE<sup>2</sup></b>			
<b>0.015 inch</b>			
11.1	<b>2.8</b> ( 5.7)	2.8 ( 4.8)	<b>3.9</b> ( 7.3)
19.5	2.3 ( 3.8)	1.9 ( 3.3)	3.8 ( 7.8 )
115.0	1.8 ( 3.0)	1.7 ( 2.9)	3.7 ( 5.4 )
<b>0.030 inch</b>			
11.1	4.1 ( 9.5)	<b>3.6</b> ( 7.4)	<b>3.6</b> ( 6.1)
19.5	3.6 ( 6.0)	<b>3.5</b> ( 5.7)	<b>2.9</b> ( 4.2)
115.0	2.7 ( 5.1)	<b>2.6</b> ( 4.4)	<b>2.4</b> ( 3.4)
<b>0.045 inch</b>			
11.1	<b>5.8</b> (12.7)	4.4 ( 9.4)	<b>4.3</b> ( 7.8)
19.5	4.2 ( 7.9)	4.0 ( 7.7)	<b>3.6</b> ( 5.3)
115.0	3.2 ( 6.5)	3.3 ( 5.7)	<b>3.0</b> ( 4.3)
<b>0.060 inch</b>			
11.1	<b>5.1</b> (14.9)	<b>5.3</b> (11.3)	5.3 (10.4)
19.5	4.8 ( 9.6)	<b>4.8</b> ( 8.6)	4.2 ( 6.9)
115.0	3.6 ( 7.6)	<b>3.5</b> ( 6.8)	3.4 ( 5.2)
<b>NORMAL FORCE<sup>3,4</sup></b>			
<b>0.015 inch</b>			
11.1	<b>0.1</b> (-0.6 to 1.3)	<b>0.2</b> (-0.6 to 1.1)	<b>-0.1</b> (-1.7 to 1.2)
19.5	-.1 ( -.8 to .7)	-.4 ( -.9 to .1)	.0 ( -1.2 to 1.3)
115.0	-.3 ( -.6 to .2)	-.3 ( -.6 to .2)	-.7 ( -1.5 to .4)
<b>0.030 inch</b>			
11.1	-.1 (-1.4 to 1.3)	-.6 (-1.5 to .9)	.3 (-.7 to 1.2)
19.5	-.7 (-1.3 to .2)	<b>-1.0</b> (-1.9 to .2)	-.6 ( 1.2 to .2)
115.0	-.5 (-1.1 to .1)	-.7 (-1.3 to -.1)	-.1 (-.5 to .6)
<b>0.045 inch</b>			
11.1	-.1 (-1.5 to 2.0)	-.4 (-2.0 to 1.1)	.1 (-1.2 to 1.5)
19.5	-.8 (-1.8 to .4)	<b>-1.1</b> (-2.5 to .0)	<b>-1.1</b> (-1.9 to .0)
115.0	-.6 (-1.6 to .2)	-.9 (-2.1 to .1)	-.6 (-1.3 to .2)
<b>0.060 inch</b>			
11.1	-.2 (-2.0 to 1.8)	-.3 (-1.8 to 1.8)	.2 (-1.5 to 1.9)
19.5	-.9 (-2.3 to .3)	<b>-1.3</b> (-2.9 to .0)	<b>-1.3</b> (-2.4 to -.1)
115.0	-.6 (-2.1 to .6)	-.8 (-2.2 to .3)	<b>-1.0</b> (-1.7 to .2)

<sup>1</sup>Clearance angle 0°; cutting velocity 5 inches per minute.

<sup>2</sup>The first number in each entry is the average cutting force; the numbers following in parentheses are maximum forces (average of five).

<sup>3</sup>The first number in each entry is the average cutting force; the numbers following in parentheses are minimum and maximum forces (average of five).

<sup>4</sup>A negative normal force indicates that the knife tended to lift the workpiece; force was positive when the knife pushed the workpiece.

**TABLE 5B.--TOOL FORCES WHEN ORTHOGONALLY CUTTING HACKBERRY PARALLEL TO THE GRAIN IN THE 90-0 DIRECTION<sup>1</sup>**

Depth of cut and moisture content (percent)	Rake angle, degrees		
	10	20	30
-----Pounds per 0.1 inch of knife-----			
<b>PARALLEL FORCE<sup>2</sup></b>			
<b>0.015 inch</b>			
10.7	14.6 (18.7)	13.8 (16.2)	8.3 (12.9)
19.6	9.3 (11.9)	7.8 (8.9)	6.2 (7.3)
117.6	8.5 (11.1)	6.2 (7.7)	3.9 (4.8)
<b>0.030 inch</b>			
10.7	30.0 (37.8)	29.5 (34.4)	15.1 (24.7)
19.6	18.7 (25.0)	15.4 (18.6)	11.5 (13.4)
117.6	15.1 (18.4)	11.1 (12.6)	7.0 (8.7)
<b>0.045 inch</b>			
10.7	40.7 (52.3)	37.7 (40.9)	14.2 (33.9)
19.6	24.2 (33.9)	21.8 (24.8)	15.7 (19.1)
117.6	21.2 (26.6)	15.7 (18.6)	9.1 (11.5)
<b>0.060 inch</b>			
10.7	52.3 (66.0)	50.4 (56.4)	17.6 (43.0)
19.6	31.8 (43.7)	28.2 (32.4)	17.6 (25.3)
117.6	25.9 (31.9)	18.0 (22.0)	11.6 (14.1)
<b>NORMAL FORCE<sup>3,4</sup></b>			
<b>0.015 inch</b>			
10.7	4.2 (2.7 to 5.6)	1.7 (1.4 to 2.3)	-0.2 (-0.7 to 0.5)
19.6	2.9 (1.7 to 4.1)	1.1 (.7 to 1.6)	.0 (-.4 to .3)
117.6	2.7 (1.9 to 3.6)	1.2 (.6 to 1.8)	.5 (-.1 to 1.2)
<b>0.030 inch</b>			
10.7	8.1 (5.0 to 10.2)	3.4 (2.7 to 4.1)	-.9 (-1.6 to -.1)
19.6	4.9 (2.9 to 6.1)	1.7 (1.2 to 2.1)	-.5 (-.8 to .1)
117.6	3.9 (2.5 to 5.0)	1.2 (.7 to 1.8)	-.1 (-.7 to .9)
<b>0.045 inch</b>			
10.7	11.0 (7.2 to 13.9)	4.1 (3.4 to 4.7)	-.8 (-2.6 to .4)
19.6	6.3 (3.2 to 8.3)	2.1 (1.5 to 2.7)	-.8 (-1.3 to .0)
117.6	5.1 (3.4 to 6.4)	1.3 (.6 to 2.1)	-.2 (-.8 to .5)
<b>0.060 inch</b>			
10.7	13.5 (8.7 to 16.9)	5.6 (5.1 to 6.2)	-1.2 (-3.4 to .1)
19.6	7.9 (3.7 to 9.9)	2.6 (1.8 to 3.3)	-1.0 (-2.0 to .2)
117.6	5.6 (3.3 to 7.4)	1.4 (.5 to 2.4)	-.5 (-1.1 to .4)

<sup>1</sup>Clearance angle 15°; cutting velocity 5 inches per minute.

<sup>2</sup>The first number in each entry is the average cutting force; the numbers following in parentheses are maximum forces (average of five)

<sup>3</sup>The first number in each entry is the average cutting force; the numbers following in parentheses are minimum and maximum forces (average of five)

<sup>4</sup>A negative normal force indicates that the knife tended to lift the workpiece; force was positive when the knife pushed the workpiece.

**TABLE 5C.--TOOL FORCES WHEN ORTHOGONALLY CUTTING HACKBERRY ACROSS THE GRAIN IN THE 90-90 DIRECTION<sup>1</sup>**

Depth of cut and moisture content (percent)	Rake angle, degrees		
	20	30	40
-----Pounds per 0.1 inch of knife-----			
<b>PARALLEL FORCE<sup>2</sup></b>			
<b>0.015 inch</b>			
10.6	20.2 (25.7)	17.7 (20.9)	15.1 (18.3)
18.9	18.1 (21.8)	13.8 (16.4)	
111.7	10.9 (12.3)	9.2 (10.5)	11.1 (13.3)
<b>0.030 inch</b>			7.7 (8.8)
10.6	36.6 (43.7)	32.3 (37.7)	25.6 (29.6)
18.9	29.7 (35.9)	20.5 (24.4)	17.1 (20.0)
111.7	21.0 (22.6)	15.1 (17.2)	12.1 (14.9)
<b>0.045 inch</b>			
10.6	43.7 (53.1)	38.1 (45.1)	31.9 (38.3)
18.9	37.5 (42.9)	27.6 (32.4)	22.0 (26.4)
111.7	26.6 (29.7)	19.9 (22.3)	15.6 (18.4)
<b>0.060 inch</b>			
10.6	53.1 (67.0)	46.4 (55.0)	39.1 (48.6)
18.9	45.0 (51.1)	33.8 (38.5)	26.6 (32.2)
111.7	33.0 (37.2)	23.6 (27.6)	19.2 (22.0)
<b>NORMAL FORCE<sup>3,4</sup></b>			
<b>0.015 inch</b>			
10.6	2.3 (0.9 to 3.8)	0.0 (-1.0 to 1.3)	-2.5 (-3.5 to -1.3)
18.9	1.4 (.8 to 2.0)	-.7 (-1.4 to .2)	-1.8 (-2.4 to -1.2)
111.7	.9 (.5 to 1.1)	-.1 (-.8 to -.4)	-1.4 (-2.1 to -.9)
<b>0.030 inch</b>			
10.6	3.4 (.8 to 6.5)	-1.8 (-3.9 to .2)	-5.1 (-6.7 to -3.1)
18.9	1.4 (.5 to 2.8)	-1.9 (-3.2 to -.9)	-4.1 (-5.2 to -3.1)
111.7	.5 (-.1 to 1.2)	-1.3 (-2.3 to -.6)	-3.3 (-4.1 to -2.5)
<b>0.045 inch</b>			
10.6	4.1 (1.4 to 8.4)	-2.1 (-4.9 to 2.2)	-7.0 (-9.3 to -3.2)
18.9	1.5 (.3 to 3.2)	-3.1 (-4.7 to -1.7)	-6.0 (-7.8 to -4.1)
111.7	.6 (-.2 to 1.5)	-2.3 (-3.2 to -1.3)	-4.6 (-6.0 to -3.4)
<b>0.060 inch</b>			
10.6	5.1 (1.7 to 10.0)	-2.8 (-6.2 to 2.2)	-8.8 (-12.2 to -2.7)
18.9	2.1 (.1 to 3.8)	-4.1 (-6.1 to -2.3)	-7.6 (-9.9 to -4.6)
111.7	.5 (-.6 to 1.7)	-3.3 (-5.2 to -1.8)	-6.2 (-7.6 to -4.7)

<sup>1</sup>Clearance angle 15°; cutting velocity 5 inches per minute.

<sup>2</sup>The first number in each entry is the average cutting force; the numbers following in parentheses are maximum forces (average of five).

<sup>3</sup>The first number in each entry is the average cutting force; the numbers following in parentheses are minimum and maximum forces (average of five)

<sup>4</sup>A negative normal force indicates that the knife tended to lift the workpiece; force was positive when the knife pushed the workpiece

**TABLE 6A.--TOOL FORCES WHEN ORTHOGONALLY CUTTING HICKORY VENEER IN THE 0-90 DIRECTION<sup>1</sup>**

Depth of cut and moisture content (percent)	Rake angle, degrees		
	50	60	70
-----Pounds per 0.1 inch of knife-----			
<b>PARALLEL FORCE<sup>2</sup></b>			
<b>0.015 inch</b>			
12.1	3.6 ( 8.1)	4.1 ( 7.6)	3.5 ( 5.4)
20.5			
98.2	2.9 (5.6)	2.6 (4.5)	6.1 (11.3)
<b>0.030 inch</b>	1.9 (3.4)	1.7 (3.0)	4.3 (7.7)
12.1	5.9 (14.6)	5.9 (12.4)	4.4 (8.5)
20.5	4.5 (9.0)	4.1 (7.6)	3.9 (5.6)
98.2	3.2 (6.2)	2.7 (4.7)	2.7 (3.7)
<b>0.045 inch</b>			
12.1	7.3 (18.3)	6.6 (15.0)	5.9 (11.5)
20.5	5.6 (11.1)	5.0 (10.2)	4.7 (7.6)
98.2	3.9 (7.9)	3.3 (6.0)	3.2 (4.6)
<b>0.060 inch</b>			
12.1	8.5 (22.2)	7.5 (18.1)	7.2 (14.2)
20.5	6.3 (13.9)	5.6 (11.5)	5.5 (9.5)
98.2	4.6 (10.1)	3.9 (7.3)	3.9 (5.9)
<b>NORMAL FORCE<sup>3,4</sup></b>			
<b>0.015 inch</b>			
12.1	-0.3 (-1.4 to 0.8)	0.8 (-0.3 to 2.0)	0.1 (-0.7 to 1.1)
20.5	-.2 (-1.0 to 1.3)	-.3 (-1.0 to .4)	.3 (-1.8 to 2.2)
98.2	-.1 (-.6 to .6)	-.1 (-.7 to .4)	-.5 (-2.0 to 1.2)
<b>0.030 inch</b>			
12.1	-.4 (-2.4 to 1.7)	.5 (-1.6 to 2.4)	.6 (-.8 to 1.8)
20.5	-.4 (-1.8 to 1.1)	-1.1 (-2.5 to .3)	-.4 (-1.4 to .7)
98.2	-.4 (-1.3 to .5)	-.7 (-1.5 to .4)	-.1 (-.6 to .6)
<b>0.045 inch</b>			
12.1	-.3 (-3.3 to 2.2)	-.1 (-2.6 to 2.1)	.2 (-2.2 to 1.6)
20.5	-.8 (-2.6 to 1.3)	-1.4 (-3.4 to .5)	-.8 (-2.5 to .8)
98.2	-.5 (-1.6 to .5)	-.8 (-1.9 to .2)	-.6 (-1.2 to .2)
<b>0.060 inch</b>			
12.1	-.5 (-2.8 to 1.8)	-.4 (-2.7 to 2.5)	-.3 (-2.6 to 1.4)
20.5	-.6 (-3.0 to 2.0)	-1.8 (-4.1 to .4)	-1.6 (-3.5 to .6)
98.2	-.6 (-1.8 to .7)	-1.0 (-1.8 to .7)	-.8 (-1.8 to .3)

<sup>1</sup>Clearance angle 0°; cutting velocity 5 inches per minute.

<sup>2</sup>The first number in each entry is the average cutting force; the numbers following in parentheses are maximum forces (average of five).

<sup>3</sup>The first number in each entry is the average cutting force; the numbers following in parentheses are minimum and maximum forces (average of five).

<sup>4</sup>A negative normal force indicates that the knife tended to lift the workpiece; force was positive when the knife pushed the workpiece.

**TABLE 6B.--TOOL FORCES WHEN ORTHOGONALLY CUTTING HICKORY PARALLEL TO THE GRAIN IN THE 90-0 DIRECTION'**

Depth of cut and moisture content (percent)	Rake angle, degrees		
	10	20	30
-----Pounds per 0.1 inch of knife-----			
<b>PARALLEL FORCE<sup>2</sup></b>			
<b>0.015 inch</b>			
11.0	18.2 (21.9)	17.8 (19.7)	9.5 (14.5)
19.6	10.7 (12.4)	8.3 (10.0)	
91.2	7.2 (9.1)	6.0 (7.5)	6.3 (7.7)
<b>0.030 inch</b>			3.9 (4.7)
11.0	37.2 (45.2)	40.9 (45.2)	16.7 (26.7)
19.6	21.4 (24.5)	16.0 (18.3)	
91.2	14.4 (18.0)	10.9 (12.9)	13.1 (15.9)
<b>0.045 inch</b>			6.9 (8.4)
11.0	47.6 (62.2)	47.5 (52.7)	14.7 (35.1)
19.6	29.1 (33.0)	21.9 (26.5)	17.4 (19.8)
91.2	20.1 (24.0)	14.6 (17.1)	8.4 (11.9)
<b>0.060 inch</b>			
11.0	59.5 (78.0)	58.5 (71.7)	19.8 (49.5)
19.6	36.1 (42.9)	28.5 (34.3)	19.1 (25.5)
91.2	26.9 (31.7)	18.6 (22.5)	10.0 (14.4)
<b>NORMAL FORCE<sup>3,4</sup></b>			
<b>0.015 inch</b>			
11.0	5.2 (4.4 to 6.3)	2.0 (1.5 to 2.5)	-0.3 (-0.9 to 0.3)
19.6	3.0 (2.3 to 3.4)	1.1 (.8 to 1.4)	-.2 (-.4 to .2)
91.2	2.3 (1.7 to 2.9)	.9 (.5 to 1.4)	.3 (.0 to .6)
<b>0.030 inch</b>			
11.0	9.7 (7.2 to 11.5)	3.7 (2.9 to 4.5)	-.9 (-2.2 to .1)
19.6	5.5 (4.3 to 6.3)	1.8 (1.4 to 2.1)	-.8 (-1.2 to -.4)
91.2	3.6 (2.6 to 4.5)	1.2 (.9 to 1.9)	-.1 (-.4 to .3)
<b>0.045 inch</b>			
11.0	12.2 (7.2 to 16.5)	4.3 (2.9 to 5.5)	-1.1 (-3.1 to .5)
19.6	6.9 (5.1 to 7.9)	2.5 (2.0 to 3.0)	-1.1 (-1.6 to -.5)
91.2	4.7 (3.0 to 6.0)	1.3 (1.0 to 1.7)	-.2 (-.6 to .3)
<b>0.060 inch</b>			
11.0	14.4 (8.4 to 20.0)	5.8 (3.0 to 7.3)	-1.4 (-4.0 to .0)
19.6	8.5 (6.9 to 9.9)	2.9 (1.9 to 3.7)	-1.2 (-2.2 to -.5)
91.2	5.8 (4.1 to 7.2)	1.5 (1.0 to 2.0)	-.6 (-1.2 to -.1)

<sup>1</sup>Clearance angle 15°; cutting velocity 5 inches per minute

<sup>2</sup>The first number in each entry is the average cutting force; the numbers following in parentheses are maximum forces (average of five).

<sup>3</sup>The first number in each entry is the average cutting force; the numbers following in parentheses are minimum and maximum forces (average of five).

<sup>4</sup>A negative normal force. indicates that the knife tended to lift the workpiece; force was positive when the knife pushed the workpiece.

**TABLE 6C.--TOOL FORCES WHEN ORTHOGONALLY CUTTING HICKORY ACROSS THE GRAIN IN THE 90-90 DIRECTION<sup>1</sup>**

Depth of cut and moisture content (percent)	Rake angle, degrees		
	20	30	40
-----Pounds per 0.1 inch of knife-----			
<b>PARALLEL FORCE<sup>2</sup></b>			
<b>0.015 inch</b>			
10.7	25.8 (32.2)	21.8 (28.6)	16.3 (20.2)
20.0	19.7 (22.6)	15.1 (17.8)	
85.9	12.8 (15.1)	13.0 (14.5)	14.8 (17.9)
<b>0.030 inch</b>			9.0 (10.6)
10.7	42.6 (52.4)	36.8 (45.2)	29.0 (35.3)
20.0	34.1 (39.8)	25.9 (30.3)	22.4 (27.1)
85.9	23.9 (26.3)	19.3 (22.2)	14.7 (16.5)
<b>0.045 inch</b>			
10.7	49.1 (61.2)	49.2 (61.9)	35.3 (44.2)
20.0	43.2 (48.2)	33.6 (39.5)	29.1 (35.4)
85.9	31.9 (36.6)	23.5 (27.2)	18.6 (21.0)
<b>0.060 inch</b>			
10.7	56.0 (71.1)	52.1 (68.8)	46.1 (55.1)
20.0	52.6 (59.8)	40.5 (49.1)	34.6 (41.7)
85.9	38.8 (43.5)	29.3 (35.5)	22.0 (25.3)
<b>NORMAL FORCE<sup>3,4</sup></b>			
<b>0.015 inch</b>			
10.7	0.9 (-0.4 to 2.4)	-1.8 (-3.5 to -0.8)	-4.3 (-5.7 to -2.6)
20.0	1.2 (.6 to 1.8)	-1.4 (-2.1 to -.5)	-2.9 (-4.0 to -1.9)
85.9	.5 (.0 to 1.1)	-1.1 (-1.9 to -.3)	-2.2 (-2.8 to -1.4)
<b>0.030 inch</b>			
10.7	.2 (-2.1 to 2.4)	-4.8 (-7.1 to -2.9)	-8.7 (-11.4 to -5.4)
20.0	.8 (-.1 to 2.0)	-3.5 (-4.8 to -2.0)	-6.0 (-8.1 to -4.1)
85.9	.0 (-1.0 to .8)	-2.6 (-3.8 to -1.3)	-4.3 (-5.4 to -3.1)
<b>0.045 inch</b>			
10.7	.2 (-3.3 to 3.4)	-7.0 (-10.2 to -3.7)	-11.6 (-14.8 to -6.7)
20.0	1.0 (-.7 to 2.6)	-4.8 (-7.1 to -2.8)	-8.4 (-10.7 to -5.1)
85.9	-.3 (-1.5 to 1.2)	-3.7 (-5.5 to -2.0)	-6.0 (-7.7 to -3.7)
<b>0.060 inch</b>			
10.7	.2 (-4.0 to 5.6)	-8.3 (-11.9 to -3.2)	-15.1 (-19.1 to -9.7)
20.0	1.3 (-.3 to 2.9)	-6.4 (-9.2 to -3.5)	-10.9 (-14.5 to -6.1)
85.9	.1 (-1.3 to 1.8)	-4.8 (-7.5 to -2.7)	-7.8 (-10.0 to -4.8)

<sup>1</sup>Clearance angle 15°; cutting velocity 5 inches per minute

<sup>2</sup>The first number in each entry is the average cutting force; the numbers following in parentheses are maximum forces (average of five)

<sup>3</sup>The first number in each entry is the average cutting force; the numbers following in parentheses are minimum and maximum forces (average of five).

<sup>4</sup>A negative normal force indicates that the knife tended to lift the workpiece; force was positive when the knife pushed the workpiece

**TABLE 7A.--TOOL FORCES WHEN ORTHOGONALLY CUTTING RED MAPLE VENEER IN THE 0-90 DIRECTION<sup>1</sup>**

Depth of cut and moisture content (percent)	Rake angle, degrees		
	-----Pounds per 0.1 inch of knife-----		
<b>PARALLEL FORCE<sup>2</sup></b>			
<b>0.015 inch</b>			
11.7	<b>2.6 ( 4.4)</b>	2.6 (4.1)	3.2 (5.2)
18.8	<b>2.3 ( 3.5)</b>	1.8 (2.7)	3.4 (7.3)
136.2	<b>1.9 ( 2.8)</b>	1.6 (2.1)	2.9 (5.2)
<b>0.030 inch</b>			
11.7	<b>3.4 ( 7.4)</b>	<b>3.5 (6.2)</b>	<b>3.0 (4.7)</b>
13.8	<b>3.2 ( 5.0)</b>	<b>2.8 (4.2)</b>	2.4 (3.7)
136.2	<b>2.6 ( 4.0)</b>	<b>2.3 (3.2)</b>	1.9 (2.5)
<b>0.045 inch</b>			
11.7	<b>4.2 (10.0)</b>	3.8 (7.8)	3.6 (6.3)
18.8	<b>3.8 ( 7.2)</b>	3.4 (5.5)	3.0 (4.5)
136.2	<b>2.8 ( 5.1)</b>	2.7 (4.1)	2.3 (3.4)
<b>0.060 inch</b>			
11.7	<b>4.5 (11.4)</b>	<b>4.1 (9.4)</b>	4.1 (7.7)
18.8	4.1 ( 7.7)	<b>3.7 (7.0)</b>	3.4 (5.3)
136.2	3.5 ( 6.2)	<b>2.9 (4.6)</b>	2.7 (4.1)
<b>NORMAL FORCE<sup>3,4</sup></b>			
<b>0.315 inch</b>			
11.7	<b>0.1 (-0.3 to 1.0)</b>	<b>0.0 (-0.4 to 0.5)</b>	<b>-0.5 -1.4 to 0.3)</b>
18.8	.0 ( -.5 to .7)	-.3 ( -.7 to .0)	-.4 (-1.4 to 1.0)
136.2	.1 ( -.3 to .5)	-.1 ( -.4 to .3)	-.5 (-1.4 to 1.0)
<b>0.030 inch</b>			
11.7	-.3 (-1.2 to .6)	-.4 (-1.3 to .4)	-.2 (-.8 to .4)
18.8	-.7 (-1.2 to .0)	-.9 (-1.5 to -.1)	-.5 (-.9 to -.1)
136.2	-.3 (-.8 to .3)	-.5 (-1.0 to .0)	.0 (-.3 to .5)
<b>0.045 inch</b>			
11.7	-.5 (-1.7 to .7)	-.6 (-1.9 to .7)	-.6 (-1.4 to .2)
18.8	-.7 (-1.7 to .1)	-1.0 (-2.1 to -.2)	-1.1 (-1.7 to -.2)
136.2	-.4 (-1.1 to .4)	-.7 (-1.5 to -.1)	-.5 (-.9 to .2)
<b>0.060 inch</b>			
11.7	-.6 (-2.1 to .7)	-.7 (-2.2 to .7)	-.6 (-1.9 to .5)
18.8	-1.0 (-2.2 to .1)	-1.4 (-2.6 to .0)	-1.3 (-2.4 to .1)
136.2	-.6 (-1.5 to .3)	-.8 (-1.9 to .0)	-.8 (-1.4 to .0)

<sup>1</sup> Clearance angle 0°; cutting velocity 5 inches per minute.

<sup>2</sup> The first number in each entry is the average cutting force; the numbers following in parentheses are maximum forces (average of five).

<sup>3</sup> The first number in each entry is the average cutting force; the numbers following in parentheses are minimum and maximum forces (average of five).

<sup>4</sup> A negative normal force indicates that the knife tended to lift the workpiece; force was positive when the knife pushed the workpiece.

**TABLE 7B.--TOOL FORCES WHEN ORTHOGONALLY CUTTING RED MAPLE PARALLEL TO THE GRAIN IN THE 90-0 DIRECTION<sup>1</sup>**

Depth of cut and moisture content (percent)	Rake angle, degrees		
	13	20	30
-----Pounds per 0.1 inch of knife-----			
<b>PARALLEL FORCE<sup>2</sup></b>			
<b>0.015 inch</b>			
10.8	13.6 (19.1)	13.2 (14.4)	10.5 (13.2)
18.7	10.2 (13.2)	7.5 ( 8.7)	7.4 ( 8.4)
124.8	7.7 (10.0)	5.4 ( 7.2)	4.7 ( 5.7)
<b>0.030 inch</b>			
10.8	25.2 (36.1)	27.1 (29.2)	13.5 (25.4)
18.7	17.3 (23.8)	16.9 (18.7)	14.2 (17.0)
124.8	14.8 (17.8)	11.2 (13.4)	8.5 (10.2)
<b>0.045 inch</b>			
10.8	34.3 (48.5)	37.4 (40.8)	11.6 (35.6)
18.7	24.3 (33.6)	25.5 (28.0)	16.7 (22.7)
124.8	21.2 (25.1)	16.7 (18.9)	10.6 (13.1)
<b>0.060 inch</b>			
10.8	43.7 (62.4)	47.3 (51.6)	12.8 (45.0)
18.7	31.5 (44.3)	31.9 (34.4)	18.3 (29.6)
124.8	27.0 (32.3)	22.0 (25.0)	13.2 (18.7)
<b>NORMAL FORCE<sup>3,4</sup></b>			
<b>0.015 inch</b>			
10.8	4.1 (2.5 to 6.0)	2.0 (1.6 to 2.5)	-0.1 (-0.5 to 0.5)
18.7	3.3 (2.1 to 4.8)	1.4 (1.0 to 1.7)	.2 ( -.2 to .6)
124.8	2.8 (1.6 to 4.2)	.9 ( .4 to 2.1)	.6 ( .0 to 1.1)
<b>0.030 inch</b>			
10.8	7.0 (4.2 to 9.3)	3.6 (3.3 to 4.1)	-.6 (-1.5 to .5)
18.7	4.7 (2.9 to 6.4)	2.1 (1.7 to 2.5)	-.4 (-1.0 to .2)
124.8	3.5 (2.7 to 4.7)	.9 ( .5 to 1.4)	.0 ( -.6 to .4)
<b>0.045 inch</b>			
10.8	8.8 (4.9 to 11.8)	4.8 (4.2 to 5.2)	-.6 (-2.2 to .4)
18.7	6.4 (3.4 to 8.4)	2.9 (2.3 to 3.3)	-.7 (-1.5 to .2)
124.8	4.8 (3.4 to 6.1)	1.1 ( .5 to 1.9)	-.3 (-1.1 to .5)
<b>0.060 inch</b>			
10.8	11.3 (6.4 to 15.4)	5.7 (4.6 to 6.5)	-.6 (-2.8 to .3)
18.7	7.6 (4.5 to 12.3)	3.1 (2.8 to 3.5)	-.8 (-2.0 to .4)
124.8	5.1 (3.1 to 6.6)	1.2 ( .5 to 2.1)	-.9 (-2.1 to .3)

<sup>1</sup> Clearance angle 15°; cutting velocity 5 inches per minute.

<sup>2</sup> The first number in each entry is the average cutting force; the numbers following in parentheses are maximum forces (average of five).

<sup>3</sup> The first number in each entry is the average cutting force; the numbers following in parentheses are minimum and maximum forces (average of five).

<sup>4</sup> A negative normal force indicates that the knife tended to lift the workpiece; force was positive when the knife pushed the workpiece.

**TABLE 7C.--TOOL FORCES WHEN ORTHOGONALLY CUTTING RED MAPLE ACROSS THE GRAIN IN THE 90-90 DIRECTION<sup>1</sup>**

Depth of cut and moisture content (percent)	Rake- angle, degrees		
	20	30	40
-----Pounds per 0.1 inch of knife-----			
<b>PARALLEL FORCE<sup>2</sup></b>			
<b>0.015 inch</b>			
11.3	18.3 (22.7)	16.1 (20.6)	12.6 (14.4)
18.3	14.9 (18.1)	12.6 (14.5)	9.5 (11.4)
135.1	12.0 (13.7)	9.5 (10.5)	8.1 (9.0)
<b>0.030 inch</b>			
11.3	29.1 (36.3)	25.6 (30.9)	19.1 (22.7)
18.3	26.1 (30.9)	20.1 (23.2)	15.1 (17.9)
135.1	19.3 (21.5)	15.1 (17.2)	11.2 (13.3)
<b>0.045 inch</b>			
11.3	34.6 (46.9)	36.5 (43.5)	26.7 (32.4)
18.3	33.1 (38.1)	26.7 (30.2)	19.6 (24.1)
135.1	26.3 (30.5)	19.4 (22.7)	14.1 (17.1)
<b>0.060 inch</b>			
11.3	32.0 (48.1)	40.4 (53.1)	28.3 (36.2)
18.3	41.3 (46.1)	32.1 (35.9)	24.1 (29.6)
135.1	31.9 (36.9)	24.5 (27.6)	17.5 (20.7)
<b>NORMAL FORCE<sup>3,4</sup></b>			
<b>0.015 inch</b>			
11.3	2.8 (1.7 to 4.8)	1.1 (-0.7 to 2.7)	-0.9 (-2.0 to 0.4)
18.3	1.7 (1.1 to 2.6)	.3 (-.4 to 1.1)	-1.1 (-1.7 to -.5)
135.1	.8 (.5 to 1.3)	.0 (-.3 to .5)	-1.2 (-1.6 to -.9)
<b>0.030 inch</b>			
11.3	4.6 (2.5 to 7.8)	1.0 (-1.4 to 4.5)	-2.8 (-4.5 to -.6)
18.3		.4)	-2.9 (-3.7 to -1.8)
135.1	2.0 (1.4 to 3.4)	-.9 (-2.0 to .0)	-2.4 (-3.3 to -1.7)
<b>0.045 inch</b>			
11.3	6.7 (2.3 to 12.6)	1.8 (-1.9 to 6.8)	-4.2 (-6.3 to .0)
18.3	2.4 (1.3 to 4.2)	-1.7 (-3.0 to .1)	-4.4 (-6.4 to -2.9)
135.1	.8 (.1 to 1.9)	-1.6 (-2.6 to -.5)	-3.5 (-5.1 to -2.6)
<b>0.060 inch</b>			
11.3	5.4 (1.1 to 16.5)	1.5 (-3.6 to 7.6)	-4.1 (-7.9 to 1.4)
18.3	2.4 (.9 to 4.9)	-2.4 (-4.2 to -.1)	-6.2 (-8.6 to -3.4)
135.1	1.0 (-.3 to 2.2)	-2.5 (-3.8 to -1.1)	-4.7 (-6.4 to -3.1)

<sup>1</sup> Clearance angle 15°; cutting velocity 5 inches per minute.

<sup>2</sup> The first number in each entry is the average cutting force; the numbers following in parentheses are maximum forces (average of five).

<sup>3</sup> The first number in each entry is the average cutting force; the numbers following in parentheses are minimum and maximum forces (average of five).

<sup>4</sup> A negative normal force indicates that the knife tended to lift the workpiece; force was positive when the knife pushed the workpiece.

TABLE 8A.--**TOOL FORCES WHEN ORTHOGONALLY CUTTING BLACK OAK VENEER IN THE 0-90 DIRECTION'**

Depth of cut and moisture content (percent)	Rake angle, degrees		
	50	60	70
-----Pounds per 0.1 inch of knife-----			
<b>PARALLEL FORCE<sup>2</sup></b>			
<b>0.015 inch</b>			
10.6	3.5 ( 9.3)	3.3 ( 8.0)	3.4 ( 6.3)
18.5	2.8 ( 6.8)	2.5 ( 5.6)	5.5 (12.0)
92.3	2.0 ( 5.1)	1.9 ( 4.8)	4.3 ( 8.5)
<b>0.030 inch</b>			
10.6	4.9 (13.4)	4.7 (11.3)	5.0 (10.4)
18.5	3.8 (10.6)	4.4 ( 8.8)	3.6 ( 6.8)
92.3	3.4 ( 7.7)	2.9 ( 6.1)	2.6 ( 5.7)
<b>0.045 inch</b>			
10.6	5.6 (17.7)	5.5 (14.6)	5.3 (12.1)
18.5	4.5 (10.8)	5.2 (11.6)	4.4 ( 8.3)
92.3	3.9 ( 9.0)	3.6 ( 7.8)	3.5 ( 6.9)
<b>0.060 inch</b>			
10.6	6.6 (19.4)	5.9 (16.0)	6.6 (14.2)
18.5	5.8 (14.4)	5.5 (12.2)	5.2 (11.0)
92.3	4.5 (10.4)	4.0 ( 8.6)	3.8 ( 8.0)
<b>NORMAL FORCE<sup>3,4</sup></b>			
<b>0.015 inch</b>			
10.6	0.6 (-0.8 to 3.8)	0.9 (-0.2 to 3.1)	0.3 (-0.7 to 2.0)
18.5	.7 (-.8 to 2.7)	.3 (-.9 to 2.0)	.5 (-1.9 to 2.7)
92.3	.4 (-.5 to 1.6)	.2 (-.7 to 1.3)	.2 (-1.4 to 1.9)
<b>0.030 inch</b>			
10.6	.4 (-1.7 to 3.9)	.6 (-1.4 to 3.1)	1.5 (-.4 to 3.5)
18.5	.0 (-1.5 to 2.1)	.0 (-1.7 to 1.7)	.3 (-.7 to 1.8)
92.3	.0 (-1.0 to 1.4)	-.3 (-1.6 to .9)	.4 (-.7 to 1.5)
<b>0.045 inch</b>			
10.6	.8 (-1.6 to 6.3)	.6 (-1.5 to 3.7)	.8 (-1.8 to 3.8)
18.5	.0 (-1.7 to 1.7)	-.1 (-1.9 to 1.9)	-.3 (-1.6 to 1.8)
92.3	-.1 (-1.2 to 1.3)	-.4 (-2.4 to 1.3)	.0 (-1.0 to 1.2)
<b>0.060 inch</b>			
10.6	.3 (-2.1 to 4.8)	.3 (-2.1 to 3.9)	.8 (-2.2 to 4.1)
18.5	-.4 (-2.1 to 2.1)	-.1 (-2.4 to 2.6)	-.6 (-2.3 to 1.6)
92.3	-.3 (-1.8 to 1.1)	-.7 (-2.5 to 1.3)	-.2 (-1.5 to 1.1)

1 Clearance angle 0°; cutting velocity 5 inches per minute.

2 The first number in each entry is the average cutting force; the numbers following in parentheses are maximum forces (average of five).

3 The first number in each entry is the average cutting force; the numbers following in parentheses are minimum and maximum forces (average of five).

4 A negative normal force indicates that the knife tended to lift the workpiece; force was positive when the knife pushed the workpiece.

**TABLE 8B.--TOOL FORCES WHEN ORTHOGONALLY CUTTING BLACK OAK PARALLEL TO THE GRAIN IN THE 90-0 DIRECTION<sup>1</sup>**

Depth of cut and moisture content (percent)	Rake angle, degrees		
	10	20	30
-----Pounds per 0.1 inch of knife-----			
<b>PARALLEL FORCE<sup>2</sup></b>			
<b>0.015 inch</b>			
10.6	19.2 (23.4)	15.2 (18.3)	9.8 (14.7)
18.3			8.3 (9.7)
90.5	13.2, (15.3),	10.5 (12.3),	4.9 (6.2)
<b>0.030 inch</b>	8.4 (10.1)	7.2 (8.8)	
10.6	36.3 (42.0)	32.8 (39.0)	13.4 (26.1)
18.3	27.1 (31.9)	23.7 (26.6)	15.0 (18.8)
90.5	17.7 (20.7)	12.6 (15.8)	9.0 (12.3)
<b>0.045 inch</b>			
10.6	47.9 (58.0)	41.7 (52.7)	16.8 (40.2)
18.3	36.9 (43.4)	31.7 (35.0)	19.4 (25.5)
90.5	25.6 (31.3)	20.0 (23.4)	9.3 (15.2)
<b>0.360 inch</b>			
10.6	57.6 (73.2)	52.0 (63.8)	17.7 (44.3)
18.3	45.1 (54.6)	39.3 (44.8)	21.7 (33.6)
90.5	33.1 (41.3)	23.6 (30.4)	10.9 (18.2)
<b>NORMAL FORCE<sup>3,4</sup></b>			
<b>0.015 inch</b>			
10.6	5.2 (3.7 to 6.2)	1.8 (1.3 to 2.3)	-0.5 -1.0 to 0.1)
18.3	3.4 (2.6 to 4.2)	1.5 (1.1 to 1.9)	-.2 -.7 to .3)
90.5	2.4 (1.8 to 2.9)	.9 (.5 to 1.2)	.2 -.4 to .9)
<b>0.030 inch</b>			
10.6	8.6 (5.8 to 10.6)	3.3 (2.1 to 4.5)	-1.0 -2.1 to .1)
18.3	6.6 (5.3 to 7.7)	2.1 (1.5 to 2.5)	-1.0 -1.7 to -.2)
90.5	4.2 (3.6 to 5.1)	1.0 (.6 to 1.4)	-.6 -1.2 to .0)
<b>0.045 inch</b>			
10.6	11.6 (8.4 to 14.7)	4.0 (2.3 to 5.2)	-1.1 (-2.9 to .4)
18.3	9.1 (7.2 to 10.5)	2.6 (1.8 to 3.1)	-1.0 (-2.0 to -.1)
90.5	5.8 (3.7 to 6.7)	1.2 (.7 to 1.8)	-.5 (-1.5 to .2)
<b>0.060 inch</b>			
10.6	12.8 (7.1 to 17.6)	5.1 (3.3 to 6.9)	-1.3 (-3.4 to .0)
18.3	10.5 (8.2 to 12.8)	2.9 (2.1 to 3.8)	-2.0 (-3.3 to -.9)
90.5	7.7 (5.4 to 9.2)	1.3 (.7 to 2.2)	-.8 (-1.7 to -.1)

<sup>1</sup> Clearance angle 15°; cutting velocity 5 inches per minute.

<sup>2</sup> The first number in each entry is the average cutting force; the numbers following in parentheses are maximum forces (average of five).

<sup>3</sup> The first number in each entry is the average cutting force; the numbers following in parentheses are minimum and maximum forces (average of five).

<sup>4</sup> A negative normal force indicates that the knife tended to lift the workpiece; force was positive when the knife pushed the workpiece.

**TABLE 8C.--TOOL FORCES WHEN ORTHOGONALLY CUTTING BLACK OAK ACROSS THE GRAIN IN THE 90-90 DIRECTION<sup>1</sup>**

Depth of cut and moisture content (percent)	Rake angle, degrees		
	20	30	40
-----Pounds per 0.1 inch of knife-----			
<b>PARALLEL FORCE<sup>2</sup></b>			
<b>0.015 inch</b>			
10.7	21.6 (28.6)	17.7 (24.1)	14.5 (19.3)
18.3	16.4 (20.6)	13.2 (16.9)	11.9 (15.5)
99.4	14.8 (17.9)	11.1 (13.9)	8.9 (11.7)
<b>0.030 inch</b>			
10.7	37.9 (50.2)	32.0 (42.2)	24.2 (31.2)
18.3	30.0 (36.5)	23.6 (28.6)	19.8 (25.1)
99.4	24.1 (28.6)	17.6 (20.9)	14.4 (18.4)
<b>0.045 inch</b>			
10.7	44.1 (55.3)	37.4 (47.5)	30.7 (38.2)
18.3	37.0 (46.5)	31.0 (38.9)	24.4 (31.8)
99.4	32.1 (37.7)	22.2 (26.6)	18.2 (22.9)
<b>0.060 inch</b>			
10.7	49.8 (63.2)	45.9 (60.7)	34.9 (45.5)
18.3	46.6 (58.5)	37.2 (45.1)	29.4 (36.5)
99.4	38.9 (46.8)	27.2 (32.4)	22.6 (28.3)
<b>NORMAL FORCE<sup>3,4</sup></b>			
<b>0.015 inch</b>			
10.7	2.0 (0.7 to 3.6)	-0.7 (-2.1 to 1.2)	-2.7 (-4.4 to -1.0)
18.3	1.3 (.5 to 2.1)	-.7 (-1.7 to 1.0)	-2.0 (-3.3 to -.8)
99.4	.8 (.2 to 1.2)	-.7 (-1.5 to .3)	-1.9 (-3.0 to -.8)
<b>0.033 inch</b>			
10.7	2.6 (.4 to 5.4)	-3.0 (-5.6 to .8)	-5.4 (-8.6 to -2.7)
18.3	1.2 (.2 to 3.3)	-2.4 (-4.4 to -.6)	-4.8 (-6.9 to -3.1)
99.4	.7 (-.2 to 1.4)	-1.7 (-2.7 to -.5)	-4.0 (-5.4 to -2.0)
<b>0.045 inch</b>			
10.7	3.5 (.1 to 7.1)	-4.0 (-7.1 to .9)	-7.5 (-11.2 to -3.1)
18.3	1.8 (-.3 to 3.6)	-3.5 (-6.1 to -.4)	-6.8 (-10.0 to -4.0)
99.4	.9 (-.7 to 2.7)	-2.7 (-4.1 to -1.3)	-5.2 (-7.0 to -3.1)
<b>0.060 inch</b>			
10.7	4.6 (.5 to 8.9)	-4.4 (-8.9 to 1.7)	-9.1 (-12.6 to -4.3)
18.3	2.0 (-.4 to 4.9)	-5.3 (-7.7 to -1.2)	-8.7 (-11.6 to -4.2)
99.4	1.0 (-.9 to 2.6)	-3.5 (-5.0 to -1.8)	-6.8 (-10.0 to -3.2)

<sup>1</sup> Clearance angle 15°; cutting velocity 5 inches per minute.

<sup>2</sup> The first number in each entry is the average cutting force; the numbers following in parentheses are maximum forces (average of five).

<sup>3</sup> The first number in each entry is the average cutting force; the numbers following in parentheses are minimum and maximum forces (average of five).

<sup>4</sup> A negative normal force indicates that the knife tended to lift the workpiece; force was positive when the knife pushed the workpiece.

**TABLE 9A.--TOOL FORCES WHEN ORTHOGONALLY CUTTING BLACKJACK OAK VENEER  
IN THE 0-90 DIRECTION<sup>1</sup>**

Depth of cut and moisture content (percent)	Rake angle, degrees		
	50	60	70
-----Pounds per 0.1 inch of knife-----			
<b>PARALLEL FORCE<sup>2</sup></b>			
<b>0.015 inch</b>			
11.7	3.9 ( 8.9)	4.4 ( 8.9)	<b>3.7 ( 7.1)</b>
19.2	<b>2.9 ( 6.2)</b>	5.8 (11.9)	<b>2.9 ( 5.5)</b>
82.5	<b>2.1 ( 5.1)</b>	4.2 ( 8.4)	<b>2.4 ( 4.6)</b>
<b>0.030 inch</b>			
11.7	<b>5.8 (14.5)</b>	4.6 ( 9.9)	4.9 (10.6)
19.2	<b>4.4 ( 9.3)</b>	3.6 ( 6.9)	3.9 ( 7.4)
82.5	<b>4.0 ( 7.4)</b>	2.8 ( 5.4)	3.2 ( 5.9)
<b>0.045 inch</b>			
11.7	<b>6.7 (15.9)</b>	<b>5.4 (12.6)</b>	<b>6.0 (14.0)</b>
19.2	<b>5.2 (10.1)</b>	4.3 ( 8.6)	<b>4.8 ( 8.3)</b>
82.5	<b>4.6 ( 9.1)</b>	3.6 ( 7.6)	<b>3.9 ( 7.3)</b>
<b>0.060 inch</b>			
11.7	7.9 (19.3)	<b>6.4 (14.3)</b>	7.2 (15.5)
19.2	6.0 (12.0)	<b>5.6 (10.6)</b>	5.8 (10.8)
82.5	5.3 (11.2)	<b>4.6 ( 8.8)</b>	4.6 ( 7.6)
<b>NORMAL FORCE<sup>3,4</sup></b>			
<b>0.015 inch</b>			
11.7	<b>-0.2 (-1.3 to 1.5)</b>	<b>-0.5 (-2.3 to .9)</b>	<b>0.5 (-0.6 to 1.6)</b>
19.2	<b>.0 (-.9 to 1.7)</b>	<b>-.6 (-2.3 to 1.1)</b>	<b>-.2 (-.8 to .8)</b>
82.5	<b>-.1 (-.8 to .6)</b>	<b>-1.0 (-3.2 to .3)</b>	<b>.1 (-.5 to .8)</b>
<b>0.030 inch</b>			
11.7	<b>-.5 (-2.2 to 1.6)</b>	<b>-.4 (-2.0 to .9)</b>	<b>-.5 (-2.1 to .8)</b>
19.2	<b>-.9 (-2.0 to .3)</b>	<b>-.8 (-1.8 to .5)</b>	<b>-1.2 (-2.4 to .2)</b>
82.5	<b>-.8 (-2.0 to .3)</b>	<b>-.8 (-2.0 to -.1)</b>	<b>-.9 (-1.8 to .1)</b>
<b>0.045 inch</b>			
11.7	<b>-.5 (-2.9 to 2.1)</b>	<b>-.9 (-2.8 to .5)</b>	<b>-.8 (-2.9 to 1.2)</b>
19.2	<b>-1.0 (-2.6 to .4)</b>	<b>-1.3 (-3.0 to .2)</b>	<b>-1.5 (-3.0 to .2)</b>
82.5	<b>-1.1 (-2.6 to .2)</b>	<b>-1.3 (-2.9 to -.3)</b>	<b>-1.4 (-2.6 to .1)</b>
<b>0.060 inch</b>			
11.7	<b>-.9 (-4.2 to 1.4)</b>	<b>-1.0 (-3.0 to .8)</b>	<b>-1.4 (-4.0 to .7)</b>
19.2	<b>-1.5 (-3.2 to .1)</b>	<b>-1.8 (-3.9 to -.1)</b>	<b>-2.3 (-3.8 to .0)</b>
82.5	<b>-1.3 (-2.7 to .0)</b>	<b>-1.7 (-3.7 to .0)</b>	<b>-2.2 (-3.4 to -.4)</b>

<sup>1</sup> Clearance angle 0°; cutting velocity 5 inches per minute.

<sup>2</sup> The first number in each entry is the average cutting force; the numbers following in parentheses are maximum forces (average of five).

<sup>3</sup> The first number in each entry is the average cutting force; the numbers following in parentheses are minimum and maximum forces (average of five).

<sup>4</sup> A negative normal force indicates that the knife tended to lift the workpiece; force was positive when the knife pushed the workpiece.

**TABLE 9B.--TOOL FORCES WHEN ORTHOGONALLY CUTTING BLACKJACK OAK PARALLEL TO THE GRAIN IN THE 90-0 DIRECTION<sup>1</sup>**

Depth of cut and moisture content (percent)	Rake angle, degrees		
	10	20	30
-----Pounds per 0.1 inch of knife-----			
<b>PARALLEL FORCE<sup>2</sup></b>			
<b>0.015 inch</b>			
11.6	19.0 (22.7)	15.2 (18.2)	10.1 (14.6)
19.2	12.1 (13.8)	10.6 (12.2)	7.3 ( 9.0)
80.8	9.2 (10.7)	6.9 ( 8.4)	4.5 ( 6.0)
<b>0.030 inch</b>			
11.6	33.2 (41.9)	31.3 (36.0)	17.8 (27.6)
19.2	24.9 (29.1)	20.8 (24.1)	12.2 (16.5)
80.8	17.2 (20.1)	12.3 (15.3)	7.4 ( 9.8)
<b>0.045 inch</b>			
11.6	48.1 (56.4)	40.0 (46.2)	19.9 (38.2)
19.2	31.7 (39.3)	27.1 (30.1)	15.5 (19.9)
80.8	23.8 (27.6)	17.2 (21.4)	10.1 (13.0)
<b>0.060 inch</b>			
11.6	57.7 (73.4)	53.7 (63.0)	20.4 (50.7)
19.2	42.3 (48.6)	35.7 (40.2)	16.8 (25.5)
80.8	30.6 (36.1)	22.7 (27.7)	11.9 (15.7)
<b>NORMAL FORCE<sup>3, 4</sup></b>			
<b>0.015 inch</b>			
11.6	5.3 ( 4.0 to 6.4)	1.7 (1.1 to 2.3)	-0.3 (-0.8 to 0.2)
19.2	3.4 ( 2.5 to 4.1)	1.3 ( .8 to 1.5)	-.3 ( -.6 to .1)
80.8	2.5 ( 1.8 to 3.2)	.8 ( .5 to 1.1)	-.2 ( -.5 to .4)
<b>0.030 inch</b>			
11.6	9.0 ( 6.6 to 10.7)	2.9 (2.2 to 3.7)	-1.1 (-2.6 to .8)
19.2	5.9 ( 4.3 to 7.1)	1.7 (1.1 to 2.3)	-.9 (-1.4 to -.3)
80.8	4.0 ( 3.0 to 4.8)	1.0 ( .5 to 1.4)	-.6 (-1.0 to -.2)
<b>0.045 inch</b>			
11.6	11.5 ( 8.4 to 14.1)	3.3 (2.0 to 4.6)	-1.4 (-3.8 to .9)
19.2	7.5 ( 5.7 to 9.2)	2.1 (1.4 to 2.7)	-1.2 (-1.8 to -.6)
80.8	5.3 ( 4.0 to 6.2)	1.1 ( .6 to 1.7)	-1.0 (-1.5 to -.5)
<b>0.060 inch</b>			
11.6	13.7 (10.2 to 17.1)	4.2 (2.4 to 5.8)	-1.4 (-5.1 to 1.2)
19.2	9.5 ( 7.1 to 11.0)	2.6 (1.9 to 3.1)	-1.5 (-2.8 to -.3)
80.8	6.3 ( 4.7 to 7.6)	1.2 ( .5 to 1.8)	-1.2 (-1.9 to -.6)

<sup>1</sup> Clearance angle 15<sup>0</sup>; cutting velocity 5 inches per minute.

<sup>2</sup> The first number in each entry is the average cutting force; the numbers following in parentheses are maximum forces (average of five).

<sup>3</sup> The first number in each entry is the average cutting force; the numbers following in parentheses are minimum and maximum forces (average of five).

<sup>4</sup> A negative normal force indicates that the knife tended to lift the workpiece; force was positive when the knife pushed the workpiece.

**TABLE 9C.--TOOL FORCES WHEN ORTHOGONALLY CUTTING BLACKJACK OAK ACROSS THE GRAIN IN THE 90-90 DIRECTION<sup>1</sup>**

Depth of cut and moisture content (percent)	Rake angle, degrees		
	20	30	40
-----Pounds per 0.1 inch of knife-----			
<b>PARALLEL FORCE<sup>2</sup></b>			
<b>0.015 inch</b>			
10.9	17.3 (25.6)	15.4 (21.8)	12.2 (17.1)
17.7	16.5 (21.5)	12.9 (16.9)	
89.2	11.9 (15.4)	10.1 (12.4)	11.7 (15.0)
<b>0.030 inch</b>			8.4 (11.1)
10.9	31.5 (41.9)	27.7 (35.4)	20.6 (28.2)
17.7	31.7 (38.5)	22.2 (26.9)	17.7 (21.9)
89.2	21.3 (25.4)	16.4 (19.3)	14.3 (18.2)
<b>0.045 inch</b>			
10.9	33.8 (49.2)	33.3 (46.6)	25.5 (35.7)
17.7	36.7 (43.9)	29.9 (36.3)	23.8 (30.0)
89.2	28.0 (34.9)	21.1 (25.9)	18.3 (25.2)
<b>0.060 inch</b>			
10.9	40.5 (55.4)	40.9 (51.7)	34.1 (45.4)
17.7	43.1 (52.9)	35.4 (43.3)	28.2 (36.1)
89.2	33.7 (42.2)	26.9 (32.8)	22.3 (28.6)
<b>NORMAL FORCE<sup>3,4</sup></b>			
<b>0.015 inch</b>			
10.9	1.4 (-0.2 to 4.1)	-0.4 (-2.0 to 1.8)	-2.4 (-4.3 to -0.1)
17.7	1.3 (.3 to 2.8)	-.9 (-2.0 to .1)	-2.5 (-3.8 to -1.1)
89.2	.5 (-.1 to 1.3)	-.9 (-1.8 to .0)	-1.7 (-2.6 to -.7)
<b>0.030 inch</b>			
10.9	2.1 (-1.5 to 7.9)	-1.7 (-4.8 to 3.7)	-5.2 (-8.5 to -1.3)
17.7	1.0 (-.7 to 4.8)	-2.4 (-4.0 to -.6)	-4.7 (-6.4 to -2.6)
89.2	.3 (-.7 to 1.8)	-1.9 (-3.1 to -.3)	-3.9 (-5.7 to -1.7)
<b>0.045 inch</b>			
10.9	2.0 (-2.2 to 8.9)	-2.8 (-7.2 to 3.7)	-7.2 (-11.3 to -3.2)
17.7	1.2 (-.8 to 4.4)	-4.2 (-6.7 to -1.8)	-6.8 (-9.2 to -4.1)
89.2	.6 (-.9 to 3.3)	-2.8 (-4.4 to -.6)	-5.2 (-7.7 to -3.3)
<b>0.060 inch</b>			
10.9	2.6 (-2.6 to 11.6)	-3.7 (-8.1 to 4.2)	-9.1 (-14.0 to -2.7)
17.7	1.2 (-2.1 to 5.0)	-5.2 (-9.0 to -2.4)	-8.6 (-12.1 to -4.2)
89.2	.7 (-1.5 to 4.2)	-3.8 (-5.9 to -.8)	-6.7 (-9.2 to -3.7)

<sup>1</sup> Clearance angle 15°; cutting velocity 5 inches per minute.

<sup>2</sup> The first number in each entry is the average cutting force; the numbers following in parentheses are maximum forces (average of five).

<sup>3</sup> The first number in each entry is the average cutting force; the numbers following in parentheses are minimum and maximum forces (average of five).

<sup>4</sup> A negative normal force indicates that the knife tended to lift the workpiece; force was positive when the knife pushed the workpiece.

**TABLE 10A.--TOOL FORCES WHEN ORTHOGONALLY CUTTING CHERRYBARK OAK VENEER  
IN THE 0-90 DIRECTION]**

Depth of cut and moisture content (percent)	Rake angle, degrees		
	50	60	70
-----Pounds per 0.1 inch of knife-----			
<b>PARALLEL FORCE<sup>2</sup></b>			
<b>0.015 inch</b>			
11.4	3.8 ( 9.3)	<b>4.6 (11.6)</b>	<b>3.5 ( 7.8)</b>
18.8	3.3 ( 8.1)	<b>2.9 ( 5.9)</b>	6.5 (14.0)
93.4	2.1 ( 5.0)	<b>2.4 ( 4.5)</b>	4.7 ( 9.6)
<b>0.030 inch</b>			
11.4	<b>5.5 (15.3)</b>	<b>5.5 (14.3)</b>	4.5 (10.6)
18.8	4.4 ( 9.9)		3.5 ( 6.8)
93.4	3.0 ( 7.3)	4.1 (8.0)	2.5 ( 5.4)
<b>0.045 inch</b>			
11.4	6.1 (17.8)	<b>6.7 (18.3)</b>	<b>6.2 (14.7)</b>
18.8	5.2 (12.6)		4.7 ( 8.7)
93.4	3.8 ( 8.8)	4.7 (9.9)	3.2 ( 7.0)
<b>0.060 inch</b>			
11.4	<b>7.9 (21.7)</b>	7.9 (20.4)	6.8 (15.9)
18.8	6.7 (15.0)	5.1 (12.0)	5.0 ( 9.5)
93.4	4.6 (11.1)	4.3 ( 9.5)	3.8 ( 7.9)
<b>NORMAL FORCE<sup>3,4</sup></b>			
<b>0.015 inch</b>			
11.4	<b>0.5 (-0.9 to 3.1)</b>	<b>1.2 (-0.4 to 3.2)</b>	<b>-0.1 (-1.6 to 1.6)</b>
18.8	.5 (-1.0 to 2.9)	-.1 (-.9 to 1.6)	.0 (-2.5 to 2.4)
93.4	.3 (-.4 to 1.5)	.0 (-.8 to .9)	<b>-1.0 (-2.4 to 1.3)</b>
<b>0.030 inch</b>			
11.4	.6 (-1.9 to 5.2)	.8 (-1.1 to 3.6)	<b>1.4 (-.3 to 3.6)</b>
18.8	.3 (-1.6 to 3.1)	-.9 (-2.5 to .9)	-.1 (-1.5 to 2.0)
93.4	-.1 (-1.1 to 1.3)	-.5 (-1.6 to .6)	.4 (-.6 to 1.8)
<b>0.045 inch</b>			
11.4	.7 (-1.9 to 5.1)	.7 (-1.5 to 3.9)	.2 (-2.0 to 3.0)
18.8	-.1 (-1.9 to 2.4)	-1.1 (-2.8 to .7)	-.7 (-2.7 to 1.8)
93.4	-.2 (-1.3 to 1.3)	-.7 (-2.2 to 1.3)	-.3 (-1.5 to 1.3)
<b>0.060 inch</b>			
11.4	.8 (-1.9 to 5.9)	.9 (-2.3 to 4.9)	.2 (-2.5 to 3.3)
18.8	-.2 (-2.2 to 2.7)	-1.3 (-3.8 to .8)	<b>-1.3 (-3.6 to 1.1)</b>
93.4	-.5 (-2.1 to 1.6)	-.9 (-2.8 to .7)	-.5 (-1.9 to 1.2)

1 Clearance angle 0°; cutting velocity 5 inches per minute.

2 The first number in each entry is the average cutting force; the numbers following in parentheses are maximum forces (average of five).

3 The first number in each entry is the average cutting force; the numbers following in parentheses are minimum and maximum forces (average of five).

4 A negative normal force indicates that the knife tended to lift the workpiece; force was positive when the knife pushed the workpiece.

**TABLE 10B. -- TOOL FORCES WHEN ORTHOGONALLY CUTTING CHERRYBARK OAK PARALLEL TO THE GRAIN IN THE 90-0 DIRECTION'**

Depth of cut and moisture content (percent)	Rake angle, degrees		
	10	20	30
-----Pounds per 0.1 inch of knife-----			
<b>PARALLEL FORCE<sup>2</sup></b>			
<b>0.015 inch</b>			
10.4	17.8 (21.5)	16.7 (19.3)	12.9 (16.6)
18.7			7.4 (8.4)
87.9	11.7, (13.7),	10.1, (12.0),	4.7 (6.0)
	8.5 (10.4)	6.0 (7.3)	
<b>0.030 inch</b>			
10.4	37.0 (45.0)	37.6 (41.8)	21.9 (29.7)
1a.7	23.6 (27.0)	19.8 (22.9)	14.6 (17.8)
87.9	16.9 (20.1)	11.9 (13.5)	7.2 (9.1)
<b>0.045 inch</b>			
10.4	47.9 (59.0)	45.8 (52.3)	19.5 (42.6)
1a.7	30.0 (38.1)	27.4 (30.5)	17.9 (22.1)
87.9	24.3 (30.0)	17.9 (20.2)	9.3 (11.6)
<b>0.060 inch</b>			
10.4	58.0 (72.9)	55.3 (66.8)	23.9 (49.9)
18.7	38.1 (47.5)	34.3 (36.8)	23.0 (29.5)
87.9	30.0 (34.6)	22.4 (25.7)	13.3 (16.7)

**NORMAL FORCES. 4**

<b>0.015 inch</b>			
10.4	5.1 (4.1 to 6.2)	2.0 (1.4 to 2.6)	-0.7 (-1.1 to -0.1)
1a.7	3.2 (2.6 to 3.8)	1.2 (.9 to 1.6)	-.1 (-.5 to .3)
87.9	2.4 (2.0 to 3.3)	.a (.4 to 1.4)	.o (-.4 to .5)
<b>0.030 inch</b>			
10.4	a.9 (6.1 to 11.3)	3.6 (2.6 to 4.5)	-1.7 (-2.5 to -.7)
1a.7	6.0 (4.4 to 7.0)	1.9 (1.5 to 2.3)	-.9 (-1.4 to -.4)
87.9	4.0 (3.2 to 5.0)	1.0 (.6 to 1.6)	-.2 (-.8 to .5)
<b>0.045 inch</b>			
10.4	11.3 (a.0 to 15.2)	4.1 (2.4 to 5.4)	-1.5 (-3.5 to -.1)
18.7	7.4 (5.4 to 8.9)	2.3 (1.8 to 2.9)	-1.3 (-2.1 to -.4)
87.9	5.8 (4.6 to 7.3)	1.1 (.5 to 1.8)	-.5 (-1.2 to .4)
<b>0.060 inch</b>			
10.4	14.7 (10.7 to 18.3)	4.5 (2.5 to 6.3)	-1.6 (-4.2 to .1)
18.7	9.2 (7.0 to 10.9)	3.0 (2.3 to 3.5)	-1.8 (-2.8 to -.7)
87.9	6.7 (5.2 to 8.1)	1.2 (.6 to 1.8)	-1.2 (-2.0 to -.2)

<sup>1</sup> Clearance angle 15°; cutting velocity 5 inches per minute.

<sup>2</sup> The first number in each entry is the average cutting force; the numbers following in parentheses are maximum forces (average of five).

<sup>3</sup> The first number in each entry is the average cutting force; the numbers following in parentheses are minimum and maximum forces (average of five).

<sup>4</sup> A negative normal force indicates that the knife tended to lift the workpiece; force was positive when the knife pushed **the** workpiece.

**TABLE 10C.--TOOL FORCES WHEN ORTHOGONALLY CUTTING CHERRYBARK OAK ACROSS  
THE GRAIN IN THE 90-90 DIRECTION<sup>1</sup>**

Depth of cut and moisture content (percent)	Rake angle, degrees		
	20	30	40
-----Pounds per 0.1 inch of knife-----			
<b>PARALLEL FORCE<sup>2</sup></b>			
<b>0.015 inch</b>			
9.9	25.0 (32.6)	18.1 (24.1)	15.5 (20.7)
18.6	18.0 (22.6)	13.7 (17.3)	11.0 (14.2)
96.0	13.3 (15.6)	10.6 (12.8)	8.7 (11.4)
<b>0.030 inch</b>			
9.9	40.6 (52.3)	35.4 (44.4)	27.3 (34.2)
18.6	30.7 (36.9)	23.4 (28.0)	18.4 (23.3)
96.0	24.7 (28.6)	17.5 (21.9)	14.1 (17.9)
<b>0.045 inch</b>			
9.9	48.5 (61.7)	43.2 (54.2)	32.8 (43.9)
18.6	37.9 (45.1)	29.2 (34.5)	24.2 (29.5)
96.0	32.5 (37.5)	22.5 (27.0)	18.0 (22.1)
<b>0.060 inch</b>			
9.9	63.6 (79.3)	48.2 (63.9)	40.6 (53.5)
18.6	46.2 (54.1)	35.9 (42.9)	28.3 (37.2)
96.0	39.3 (46.2)	27.3 (33.8)	21.2 (27.0)
<b>NORMAL FORCE<sup>3,4</sup></b>			
<b>0.015 inch</b>			
9.9	2.3 ( 1.0 to 3.9)	-0.4 (-1.9 to 1.8)	-2.9 ( -5.0 to -1.2)
18.6	1.5 ( .6 to 2.6)	-.5 (-1.3 to .5)	-1.9 ( -3.0 to -.3)
96.0	.7 ( -.1 to 1.6)	-.5 (-1.2 to .0)	-1.9 ( -2.7 to -.8)
<b>0.030 inch</b>			
9.9	3.3 ( .8 to 7.2)	-2.5 (-5.1 to 1.0)	-6.2 ( -8.9 to -2.6)
18.6	1.5 ( .0 to 3.6)	-2.2 (-3.7 to -.3)	-4.7 ( -6.6 to -2.6)
96.0	.4 ( -.7 to 1.7)	-2.2 (-3.4 to -.9)	-3.9 ( -5.3 to -2.4)
<b>0.045 inch</b>			
9.9	4.1 ( .8 to 7.9)	-3.2 (-6.9 to 2.2)	-8.4 (-12.2 to -3.6)
18.6	1.6 ( -.4 to 4.0)	-3.1 (-5.2 to .2)	-6.6 ( -8.7 to -3.7)
96.0	.4 (-1.1 to 1.9)	-3.2 (-4.9 to -1.5)	-5.3 ( -7.2 to -3.2)
<b>0.060 inch</b>			
9.9	4.9 ( .1 to 9.7)	-3.9 (-8.8 to 3.2)	-10.9 (-15.7 to -4.0)
18.6	2.2 ( -.5 to 4.8)	-4.5 (-7.3 to -1.6)	-8.7 (-12.1 to -4.2)
96.0	.4 (-1.3 to 2.7)	-4.2 (-6.2 to -1.9)	-6.8 ( -9.6 to -3.7)

<sup>1</sup> Clearance angle 15°; cutting velocity 5 inches per minute.

<sup>2</sup> The first number in each entry is the average cutting force; the numbers following in parentheses are maximum forces (average of five).

<sup>3</sup> The first number in each entry is the average cutting force; the numbers following in parentheses are minimum and maximum forces (average of five).

<sup>4</sup> A negative normal force indicates that the knife tended to lift the workpiece; force was positive when the knife pushed the workpiece.

**TABLE 11A. -- TOOL FORCES WHEN ORTHOGONALLY CUTTING LAUREL OAK VENEER IN THE 0-90 DIRECTION<sup>1</sup>**

Depth of cut and moisture content (percent)	Rake angle, degrees		
	50	60	70
-----Pounds per 0.1 inch of knife-----			
<b>PARALLEL FORCE<sup>2</sup></b>			
<b>0.015 inch</b>			
11.1	4.2 (10.0)	4.7 (10.8)	4.1 (8.7)
19.0	2.9 (6.5)	4.9 (12.2)	2.9 (6.3)
91.2	2.5 (5.9)	4.4 (8.9)	2.1 (4.5)
<b>0.030 inch</b>			
11.1	5.0 (13.7)	4.3 (9.2)	5.2 (12.0)
19.0	4.3 (9.3)	3.6 (7.4)	3.8 (8.0)
91.2	3.2 (8.5)	2.8 (5.9)	2.9 (6.1)
<b>0.045 inch</b>			
11.1	5.2 (15.9)	5.2 (13.4)	5.9 (13.6)
19.0	5.0 (10.9)		4.5 (9.1)
91.2	3.6 (10.1)	4.3 (9.3)	3.5 (6.9)
<b>0.060 inch</b>			
11.1	6.7 (18.5)	6.5 (16.2)	6.8 (15.4)
19.0	6.1 (13.5)	5.8 (11.4)	5.3 (11.5)
91.2	4.1 (10.3)	4.3 (9.4)	4.0 (8.1)
<b>NORMAL FORCE<sup>3,4</sup></b>			
<b>0.015 inch</b>			
11.1	0.1 (-1.2 to 2.6)	-0.1 (-1.7 to 2.2)	0.8 (-0.6 to 2.4)
19.0	.2 (-.7 to 2.0)	-.1 (-1.8 to 2.1)	.3 (-.7 to 1.8)
91.2	.2 (-.7 to 1.9)	-.6 (-2.1 to 1.3)	.3 (-.5 to 1.2)
<b>0.030 inch</b>			
11.1	.4 (-1.4 to 3.1)	.7 (-.9 to 2.6)	.3 (-2.1 to 3.6)
19.0	-.4 (-1.9 to 2.0)	-.3 (-1.5 to 1.8)	-.5 (-1.7 to 1.1)
91.2	.2 (-1.2 to 1.8)	-.6 (-1.6 to .5)	-.1 (-1.3 to 1.3)
<b>0.045 inch</b>			
11.1	.1 (-1.8 to 3.0)	.1 (-1.7 to 1.9)	.1 (-2.6 to 3.5)
19.0	-.3 (-2.1 to 1.9)	-.8 (-2.5 to 1.7)	-.8 (-2.4 to 1.2)
91.2	-.1 (-1.8 to 1.9)	-.7 (-2.3 to .6)	-.1 (-1.8 to 2.3)
<b>0.060 inch</b>			
11.1	.1 (-2.0 to 3.3)	.4 (-2.0 to 3.3)	.1 (-2.8 to 3.6)
19.0	-.6 (-2.8 to 1.8)	-1.2 (-3.3 to 1.2)	-1.5 (-3.3 to .3)
91.2	.0 (-1.6 to 2.3)	-1.1 (-3.3 to .9)	-.2 (-1.8 to 1.1)

<sup>1</sup>Clearance angle 0°; cutting velocity 5 inches per minute.

<sup>2</sup>The first number in each entry is the average cutting force; the numbers following in parentheses are maximum forces (average of five)

<sup>3</sup>The first number in each entry is the average cutting force; the numbers following in parentheses are minimum and maximum forces (average of five)

<sup>4</sup>A negative normal force indicates that the knife tended to lift the workpiece; force was positive when the knife pushed the workpiece

**TABLE 11B. -- TOOL FORCES WHEN ORTHOGONALLY CUTTING LAUREL OAK PARALLEL TO THE GRAIN IN THE 90-0 DIRECTION<sup>1</sup>**

Depth of cut and moisture content (percent)	Rake angle, degrees		
	10	20	30
-----Pounds per 0.1 inch of knife-----			
<b>PARALLEL FORCE<sup>2</sup></b>			
<b>0.015 inch</b>			
10.9	19.0 (22.3)	16.8 (19.3)	11.4 (14.3)
19.0			6.6 (8.3)
89.4	12.0 (13.5)	10.1 (11.5)	4.7 (6.1)
<b>0.030 inch</b>	8.2 (10.5)	7.0 (8.3)	
10.9	36.3 (43.2)	31.6 (35.4)	17.6 (28.9)
19.0	23.7 (29.1)	20.2 (22.2)	
89.4	15.9 (19.7)	12.8 (15.7)	12.9 (17.1)
<b>0.045 inch</b>			7.8 (10.1)
10.9	48.9 (58.0)	44.4 (48.3)	19.3 (40.6)
19.0	30.8 (39.1)	28.3 (32.0)	16.9 (23.2)
89.4	20.5 (27.9)	18.1 (21.8)	10.7 (14.6)
<b>0.060 inch</b>			
10.9	61.3 (77.5)	61.2 (64.1)	18.5 (50.1)
19.0	39.5 (50.7)	35.3 (39.9)	18.7 (31.6)
89.4	27.4 (34.7)	23.4 (28.3)	14.4 (18.0)

**NORMAL FORCE<sup>3,4</sup>**

<b>0.015 inch</b>			
10.9	5.8 (4.9 to 6.8)	2.1 (1.7 to 2.5)	-0.6 (-1.1 to 0.0)
19.0	3.5 (2.8 to 4.1)	1.2 (.9 to 1.6)	-.1 (-.4 to .5)
89.4	2.6 (1.6 to 4.0)	.8 (.4 to 1.2)	-.1 (-.5 to .4)
<b>0.030 inch</b>			
10.9	9.7 (7.6 to 11.5)	3.6 (3.1 to 4.2)	-1.3 (-2.4 to -.1)
19.0	6.1 (3.7 to 7.7)	1.9 (1.5 to 2.3)	-.7 (-1.4 to -.1)
89.4	3.7 (2.3 to 4.9)	1.1 (.6 to 1.7)	-.4 (-1.1 to .5)
<b>0.045 inch</b>			
10.9	12.7 (10.5 to 15.2)	4.5 (3.9 to 5.2)	-1.5 (-3.4 to .3)
19.0	7.6 (5.1 to 9.4)	2.4 (1.8 to 2.9)	-1.2 (-2.0 to -.5)
89.4	4.6 (3.0 to 6.3)	1.2 (.7 to 1.8)	-.8 (-1.4 to -.1)
<b>0.060 inch</b>			
10.9	15.4 (11.6 to 18.9)	6.2 (5.4 to 7.0)	-1.5 (-4.4 to .1)
19.0	9.9 (6.8 to 12.4)	2.8 (2.1 to 3.5)	-1.4 (-2.6 to -.7)
89.4	6.0 (4.4 to 7.8)	1.4 (.8 to 2.1)	-1.4 (-2.2 to -.7)

<sup>1</sup>Clearance angle 15°; cutting velocity 5 inches per minute.

<sup>2</sup>The first number in each entry is the average cutting force; the numbers following in parentheses are maximum forces (average of five).

<sup>3</sup>The first number in each entry is the average cutting force; the numbers following in parentheses are minimum and maximum forces (average of five).

<sup>4</sup>A negative normal force indicates that the knife tended to lift the workpiece; force was positive when the knife pushed the workpiece

**TABLE 11C.--TOOL FORCES WHEN ORTHOGONALLY CUTTING LAUREL OAK ACROSS THE GRAIN IN THE 90-90 DIRECTION**

Depth of cut and moisture content (percent)	Rake angle, degrees		
	20	30	40
-----Pounds per 0.1 inch of knife-----			
<b>PARALLEL FORCE<sup>2</sup></b>			
<b>0.015 inch</b>			
10.7	23.4 (29.2)	21.2 (27.6)	16.0 19.3
18.6	18.3 (21.8)	12.1 (15.6)	10.8 14.2
94.4	14.1 (17.6)	12.1 (15.0)	8.3 11.0
<b>0.030 inch</b>			
10.7	36.5 (48.6)	33.4 (41.6)	28.1 (35.1)
18.6	33.6 (39.9)	23.9 (29.5)	18.5 (22.2)
94.4	24.8 (30.3)	16.9 (21.1)	13.5 (16.9)
<b>0.045 inch</b>			
10.7	47.9 (59.1)	43.0 (53.7)	34.2 (40.5)
18.6	42.1 (47.7)	30.8 (37.3)	23.5 (29.4)
94.4	32.3 (39.7)	22.9 (29.1)	17.2 (22.7)
<b>0.060 inch</b>			
10.7	49.5 (70.5)	48.1 (63.0)	43.8 (54.7)
18.6	50.9 (58.9)	39.3 (46.3)	30.2 (38.0)
94.4	39.4 (49.4)	28.1 (35.1)	20.8 (27.0)
<b>NORMAL FORCE<sup>3,4</sup></b>			
<b>0.015 inch</b>			
10.7	2.2 ( 0.6 to 4.7)	-0.5 (-2.0 to 1.6)	-2.5 ( -3.9 to -0.7)
18.6	1.4 ( .8 to 2.6)	-.2 (-1.2 to .8)	-1.9 ( -3.0 to -.7)
94.4	.8 ( .1 to 1.9)	-.8 (-1.7 to .0)	-1.7 ( -2.6 to -.6)
<b>0.030 inch</b>			
10.7	3.2 ( .7 to 7.2)	-1.8 (-4.6 to 2.6)	-5.9 ( -8.3 to -3.0)
18.6	1.4 ( .2 to 3.1)	-2.4 (-4.1 to -.6)	-4.6 ( -6.5 to -2.4)
94.4	.5 ( -.9 to 1.6)	-2.0 (-3.1 to -.6)	-3.7 ( -5.2 to -1.7)
<b>0.045 inch</b>			
10.7	4.5 ( .8 to 9.2)	-2.9 (-6.0 to 2.8)	-7.9 (-10.7 to -3.8)
18.6	1.5 ( .0 to 3.9)	-3.8 (-5.7 to -1.6)	-6.7 ( -8.9 to -3.1)
94.4	.5 (-1.1 to 2.1)	-3.2 (-4.7 to -1.1)	-5.1 ( -7.7 to -2.6)
<b>0.060 inch</b>			
10.7	5.7 ( 1.5 to 10.2)	-2.8 (-7.7 to 4.6)	-10.4 (-14.2 to -4.6)
18.6	1.4 ( -.7 to 3.9)	-5.2 (-8.1 to -1.3)	-8.7 (-12.0 to -4.2)
94.4	.3 (-1.9 to 2.2)	-4.3 (-6.3 to -1.6)	-6.6 (-10.0 to -3.2)

<sup>1</sup>Clearance angle 15°; cutting velocity 5 inches per minute.

<sup>2</sup>The first number in each entry is the average cutting force; the numbers following in parentheses are maximum forces (average of five)

<sup>3</sup>The first number in each entry is the average cutting force; the numbers following in parentheses are minimum and maximum forces (average of five).

<sup>4</sup>A negative normal force indicates that the knife tended to lift the workpiece; force was positive when the knife pushed the workpiece.

**TABLE 12A.--TOOL FORCES WHEN ORTHOGONALLY CUTTING NORTHERN RED OAK VENEER IN THE 0-90 DIRECTION'**

Depth of cut and moisture content (percent)	Rake angle, degrees		
	50	60	70
-----Pounds per 0.1 inch of knife-----			
<b>PARALLEL FORCE<sup>2</sup></b>			
<b>0.015 inch</b>			
10.9	2.9 ( 9.0)	3.5 ( <b>8.6</b> )	<b>3.5 ( 6.9)</b>
18.1	2.8 ( 6.6)	2.7 ( <b>5.8</b> )	<b>4.8 (11.9)</b>
91.9	2.2 ( 4.8)	2.1 ( <b>4.4</b> )	<b>3.9 ( 7.6)</b>
<b>0.030 inch</b>			
10.9	4.2 (13.1)	<b>4.2 (12.0)</b>	3.8 ( 8.6)
18.1	4.2 ( 9.8)	<b>3.6 ( 8.3)</b>	3.3 ( 6.3)
91.9	3.3 ( 8.3)	<b>3.0 ( 6.5)</b>	2.6 ( 5.3)
<b>0.045 inch</b>			
10.9	<b>4.6 (15.0)</b>	<b>5.4 (14.7)</b>	<b>5.3 (10.6)</b>
18.1	4.2 (11.6)	<b>4.4 (10.3)</b>	3.9 ( 8.3)
91.9	3.6 ( <b>9.5</b> )	<b>3.6 ( 7.3)</b>	3.1 ( 6.1)
<b>0.060 inch</b>			
10.9	<b>6.2 (18.4)</b>	5.9 (16.4)	5.9 (14.1)
18.1	<b>4.6 (12.6)</b>	5.0 (11.4)	4.6 ( 9.6)
91.9	4.7 (12.1)	4.1 ( 8.8)	3.8 ( 7.3)
<b>NORMAL FORCE<sup>3,4</sup></b>			
<b>0.015 inch</b>			
10.9	<b>0.5 (-0.7 to 2.7)</b>	<b>0.9 (-0.4 to 3.0)</b>	<b>0.6 (-0.6 to 1.6)</b>
18.1	.3 (-.7 to 1.9)	.3 (-.8 to 2.0)	<b>1.0 (-1.2 to 4.3)</b>
91.9	.2 (-.5 to 1.3)	.2 (-.4 to .8)	.4 (-1.2 to 1.9)
<b>0.030 inch</b>			
10.9	.5 (-1.1 to 3.8)	.6 (-1.0 to 3.3)	<b>1.4 (-.4 to 3.1)</b>
18.1	.1 (-1.3 to 2.3)	-.1 (-1.5 to 2.0)	.4 (-1.1 to 2.0)
91.9	.0 (-.8 to 1.5)	-.3 (-1.4 to .8)	.4 (-.5 to 1.3)
<b>0.045 inch</b>			
10.9	.8 (-1.1 to 4.2)	.4 (-1.7 to 3.1)	<b>1.7 (-.1 to 4.0)</b>
18.1	.2 (-1.5 to 2.3)	.1 (-2.0 to 2.5)	.1 (-1.7 to 2.3)
91.9	-.1 (-1.2 to 1.7)	-.4 (-1.9 to .8)	-.1 (-1.2 to 1.0)
<b>0.060 inch</b>			
10.9	.6 (-1.4 to 4.6)	.8 (-1.2 to 4.0)	<b>1.8 (-.6 to 5.1)</b>
18.1	-.1 (-1.6 to 2.1)	.1 (-2.4 to 2.9)	-.3 (-1.8 to 1.8)
91.9	.0 (-1.5 to 1.7)	-.7 (-2.7 to .7)	-.4 (-1.7 to 1.1)

<sup>1</sup>Clearance angle 0"; cutting velocity 5 inches per minute.

<sup>2</sup>The first number in each entry is the average cutting force; the numbers following in parentheses are maximum forces (average of five).

<sup>3</sup>The first number in each entry is the average cutting force; the numbers following in parentheses are minimum and maximum forces (average of five).

<sup>4</sup>A negative normal force indicates that the knife tended to lift the workpiece; force was positive when the knife pushed the workpiece

**TABLE 12B.--TOOL FORCES WHEN ORTHOGONALLY CUTTING NORTHERN RED OAK PARALLEL TO THE GRAIN IN THE 90-0 DIRECTION<sup>1</sup>**

Depth of cut and moisture content (percent)	Rake angle, degrees		
	10	20	30
-----Pounds per 0.1 inch of knife-----			
<b>PARALLEL FORCE<sup>2</sup></b>			
<b>0.015 inch</b>			
10.4	20.1 (23.3)	17.6 (19.7)	11.9 (16.0)
17.8	13.6 (15.2)	11.9 (13.4)	8.8 (10.8)
78.9	8.8 (10.1)	8.0 (9.0)	5.8 (7.1)
<b>0.030 inch</b>			
10.4	37.2 (44.9)	31.9 (38.4)	18.9 (31.8)
17.8	25.6 (31.5)	23.4 (25.5)	15.9 (21.0)
78.9	19.9 (22.5)	15.5 (17.0)	10.5 (12.3)
<b>0.045 inch</b>			
10.4	45.2 (58.1)	40.4 (51.7)	21.4 (38.7)
17.8	32.3 (38.2)	32.9 (37.1)	17.8 (27.5)
78.9	27.1 (30.3)	21.1 (23.9)	15.4 (18.1)
<b>0.060 inch</b>			
10.4	58.9 (77.7)	47.3 (70.6)	24.9 (52.4)
17.8	44.0 (54.5)	40.9 (43.8)	20.4 (34.7)
78.9	36.4 (40.9)	27.9 (33.1)	17.5 (22.8)

**NORMAL FORCE<sup>3,4</sup>**

<b>0.015 inch</b>			
10.4	5.6 (4.5 to 6.7)	2.0 (1.4 to 2.5)	-.4 (-0.9 to 0.3)
17.8	3.5 (3.0 to 4.2)	1.3 (.9 to 1.7)	-.4 (-.8 to .1)
78.9	2.6 (1.9 to 3.1)	.9 (.6 to 1.3)	.1 (-.3 to .5)
<b>0.030 inch</b>			
10.4	9.1 (6.8 to 11.8)	3.1 (2.2 to 4.0)	-1.2 (-2.8 to -.1)
17.8	6.4 (4.9 to 7.6)	1.8 (1.1 to 2.4)	-1.3 (-2.0 to -.5)
78.9	4.2 (3.5 to 5.2)	1.0 (.6 to 1.6)	-.8 (-1.2 to -.2)
<b>0.045 inch</b>			
10.4	10.8 (8.1 to 13.5)	3.8 (2.4 to 5.2)	-1.6 (-3.5 to -.1)
17.8	7.7 (5.7 to 8.9)	2.3 (1.6 to 2.9)	-1.5 (-2.6 to -.4)
78.9	6.0 (4.8 to 7.0)	1.1 (.6 to 1.9)	-1.4 (-2.0 to -.6)
<b>0.060 inch</b>			
10.4	13.6 (9.5 to 17.8)	3.7 (1.5 to 5.7)	-2.0 (-4.7 to -.3)
17.8	10.4 (7.7 to 12.7)	2.8 (1.9 to 3.4)	-1.9 (-3.6 to -.5)
78.9	7.3 (5.8 to 8.5)	1.1 (.5 to 1.7)	-1.6 (-2.6 to -.7)

<sup>1</sup>Clearance angle 15°; cutting velocity 5 inches per minute

<sup>2</sup>The first number in each entry is the average cutting force; the numbers following in parentheses are maximum forces (average of five).

<sup>3</sup>The first number in each entry is the average cutting force; the numbers following in parentheses are minimum and maximum forces (average of five)

<sup>4</sup>A negative normal force indicates that the knife tended to lift the workpiece; force was positive when the knife pushed the workpiece.

**TABLE 12C.--TOOL FORCES WHEN ORTHOGONALLY CUTTING NORTHERN RED OAK ACROSS THE GRAIN IN THE 90-90 DIRECTION<sup>1</sup>**

Depth of cut and moisture content (percent)	Rake angle, degrees		
	20	30	40
-----Pounds per 0.1 inch of knife-----			
<b>PARALLEL FORCE<sup>2</sup></b>			
<b>0.015 inch</b>			
10.6	21.8 (27.4)	17.1 (21.7)	17.4 (22.0)
17.8	17.2 (21.3)	14.8 (17.5)	
92.3	12.8 (15.0)	10.6 (13.5)	13.0 (16.2), 8.6 (10.9)
<b>0.030 inch</b>			
10.6	34.5 (42.5)	29.4 (40.9)	24.4 (31.3)
17.8	29.9 (36.3)	21.9 (26.3)	18.3 (23.6)
92.3	23.1 (27.4)	18.3 (22.0)	14.0 (17.0)
<b>0.045 inch</b>			
10.6	37.0 (49.8)	35.0 (46.6)	29.3 (36.8)
17.8	41.4 (47.8)	29.6 (36.2)	24.5 (32.7)
92.3	31.3 (37.6)	22.7 (29.1)	17.4 (21.4)
<b>0.060 inch</b>			
10.6	45.0 (56.9)	40.8 (52.9)	36.9 (46.7)
17.8	46.1 (53.3)	36.1 (43.0)	29.2 (35.9)
92.3	36.7 (43.8)	27.6 (32.7)	20.9 (25.5)
<b>NORMAL FORCE<sup>3,4</sup></b>			
<b>0.015 inch</b>			
10.6	1.7 (0.6 to 2.9)	-0.3 (-1.5 to 1.2)	-3.5 (-5.2 to -1.7)
17.8	1.3 (.5 to 2.1)	-1.0 (-1.9 to -.1)	-2.6 (-3.8 to -1.2)
92.3	.7 (.2 to 1.3)	-.7 (-1.7 to .1)	-2.0 (-2.8 to -1.0)
<b>0.030 inch</b>			
10.6	2.3 (.5 to 4.2)	-2.0 (-4.1 to 1.2)	-5.6 (-8.0 to -2.7)
17.8	1.4 (-.2 to 2.9)	-2.5 (-3.8 to -1.0)	-4.7 (-6.5 to -2.4)
92.3	.4 (-.5 to 1.4)	-2.2 (-3.3 to -.8)	-4.0 (-5.2 to -2.5)
<b>0.045 inch</b>			
10.6	2.4 (-.2 to 5.4)	-3.0 (-5.7 to -.5)	-7.4 (-10.4 to -3.7)
17.8	1.3 (-.7 to 3.5)	-3.4 (-4.9 to -2.0)	-7.1 (-10.1 to -4.4)
92.3	.7 (-.6 to 1.8)	-3.1 (-4.6 to -1.6)	-5.2 (-7.3 to -3.3)
<b>0.060 inch</b>			
10.6	3.6 (-.1 to 8.2)	-3.6 (-6.6 to -.2)	-9.9 (-13.5 to -6.4)
17.8	1.7 (-.7 to 4.7)	-4.3 (-7.0 to -1.6)	-8.3 (-11.5 to -4.9)
92.3	1.3 (-.5 to 2.9)	-4.0 (-6.0 to -2.2)	-6.8 (-9.0 to -3.8)

<sup>1</sup>Clearance angle 15°; cutting velocity 5 inches per minute.

<sup>2</sup>The first number in each entry is the average cutting force; the numbers following in parentheses are maximum forces (average of five).

<sup>3</sup>The first number in each entry is the average cutting force; the numbers following in parentheses are minimum and maximum forces (average of five).

<sup>4</sup>A negative normal force indicates that the knife tended to lift the workpiece; force was positive when the knife pushed the workpiece.

**TABLE 13A.--TOOL FORCES WHEN ORTHOGONALLY CUTTING POST OAK VENEER IN THE 0-90 DIRECTION**

Depth of cut and moisture content (percent)	Rake angle, degrees		
	50	60	70
-----Pounds per 0.1 inch of knife-----			
<b>PARALLEL FORCE<sup>2</sup></b>			
<b>0.015 inch</b>			
11.6	3.8 ( 9.6)	4.0 ( 8.0)	3.6 ( 5.9)
19.5	3.0 ( 6.0)	2.5 ( 5.1)	5.9 (11.0)
78.5	2.4 ( 4.3)	2.1 ( 4.3)	4.8 ( 8.8)
<b>0.030 inch</b>			
11.6	5.6 (13.4)	5.1 (11.9)	4.6 ( 9.0)
19.5			3.2 ( 5.4)
78.5	4.5 ( 8.9)	3.8 ( 7.6)	2.8 ( 4.9)
<b>0.045 inch</b>			
11.6	3.4 ( 6.4)	3.1 ( 6.5)	
19.5	6.2 (17.4)	6.3 (13.7)	5.4 (10.9)
78.5	5.5 (11.1)		4.4 ( 7.2)
<b>0.060 inch</b>			
11.6	4.0 ( 8.5)	4.8 (10.2)	3.5 ( 6.2)
19.5		3.7 ( 8.1)	
78.5	7.7 (18.4)	6.6 (17.6)	6.9 (14.4)
	6.5 (12.3)	5.6 (10.7)	5.5 ( 9.1)
	5.0 ( 9.5)	4.4 ( 9.4)	4.0 ( 7.3)

**NORMAL FORCE<sup>3,4</sup>**

<b>0.015 inch</b>			
11.6	-0.3 (-1.4 to 1.2)	0.2 (-1.0 to 1.3)	-0.6 (-1.6 to 0.8)
19.5	-.3 (-1.2 to 1.4)	-.5 (-1.3 to .9)	-.7 (-2.7 to 1.7)
78.5	-.1 (-.7 to .8)	-.2 (-1.0 to .7)	.0 (-2.0 to 1.9)
<b>0.030 inch</b>			
11.6	-.3 (-2.1 to 1.7)	-.4 (-2.2 to 1.1)	.3 (-1.2 to 1.9)
19.5	-.8 (-2.0 to .5)	-1.1 (-2.2 to .4)	-.5 (-1.4 to .5)
78.5	-.6 (-1.4 to .4)	-.8 (-1.8 to .2)	.1 (-.6 to .9)
<b>0.045 inch</b>			
11.6	-.7 (-2.6 to 1.8)	-.9 (-3.0 to 1.2)	-.3 (-2.3 to 1.3)
19.5	-1.1 (-2.5 to .6)	-1.6 (-3.2 to .3)	-1.4 (-2.7 to .3)
78.5	-.8 (-2.1 to .4)	-1.1 (-2.5 to .3)	-.6 (-1.5 to 1.0)
<b>0.060 inch</b>			
11.6	-.9 (-3.4 to 1.4)	-1.0 (-3.9 to 1.9)	-.7 (-2.8 to 2.1)
19.5	-1.2 (-3.2 to .7)	-1.9 (-3.6 to .0)	-1.6 (-3.6 to .8)
78.5	-1.1 (-2.9 to .4)	-1.2 (-2.9 to .5)	-.9 (-2.2 to .7)

<sup>1</sup>Clearance angle 0°; cutting velocity 5 inches per minute.

<sup>2</sup>The first number in each entry is the average cutting force; the numbers following in parentheses are maximum forces (average of five)

<sup>3</sup>The first number in each entry is the average cutting force; the numbers following in parentheses are minimum and maximum forces (average of five).

<sup>4</sup>A negative normal force indicates that the knife tended to lift the workpiece; force was positive when the knife pushed the workpiece

**TABLE 13B.--TOOL FORCES WHEN ORTHOGONALLY CUTTING POST OAK PARALLEL TO THE GRAIN IN THE 90-0 DIRECTION<sup>1</sup>**

Depth of cut and moisture content (percent)	Rake angle, degrees		
	10	20	30
-----Pounds per 0.1 inch of knife-----			
<b>PARALLEL FORCE<sup>2</sup></b>			
<b>0.015 inch</b>			
11.3	18.0 (20.3)	16.7 (20.4)	10.2 (13.6)
19.7		9.9 (11.2)	5.9 (7.4)
79.6	12.1 (14.1),	7.4 (8.7)	4.9 (5.9)
<b>0.030 inch</b>	8.8 (10.8)		
11.3	32.6 (40.4)	31.8 (36.1)	15.3 (22.1)
19.7	22.3 (26.8)	17.2 (20.1)	
79.6	17.4 (21.4)	11.6 (14.1)	10.7 (14.3)
<b>0.045 inch</b>			7.0 (9.7)
11.3	40.8 (55.9)	38.9 (46.9)	19.4 (36.5)
19.7	31.6 (38.0)	24.0 (27.5)	
79.6	23.8 (31.5)	15.8 (19.3)	13.0 (15.2)
<b>0.060 inch</b>			9.5 (12.3)
11.3	52.3 (73.2)	45.9 (57.7)	21.2 (40.7)
19.7	38.3 (50.1)	28.8 (35.0)	15.5 (21.0)
79.6	29.8 (38.0)	18.0 (23.6)	12.4 (15.4)
<b>NORMAL FORCE<sup>3,4</sup></b>			
<b>0.015 inch</b>			
11.3	4.8 (3.5 to 5.8)	1.8 (1.3 to 2.4)	-0.6 (-1.1 to 0.0)
19.7	3.5 (2.6 to 4.1)	1.2 (.8 to 1.6)	.1 (-.6 to .8)
79.6	2.4 (1.7 to 3.1)	.8 (.5 to 1.3)	.0 (-.3 to .4)
<b>0.030 inch</b>			
11.3	8.2 (5.8 to 10.7)	2.9 (2.0 to 3.7)	-1.1 (-2.0 to .1)
19.7	5.4 (4.0 to 6.6)	1.6 (1.0 to 2.0)	-.8 (-1.4 to -.2)
79.6	4.1 (3.0 to 5.3)	1.1 (.6 to 1.6)	-.4 (-.8 to .3)
<b>0.045 inch</b>			
11.3	10.3 (6.9 to 13.5)	3.4 (2.0 to 4.6)	-1.5 (-3.2 to -.4)
19.7	7.4 (5.4 to 9.2)	2.0 (1.3 to 2.6)	-1.1 (-1.5 to -.4)
79.6	5.0 (3.4 to 6.1)	1.3 (.6 to 1.9)	-.5 (-1.0 to .2)
<b>0.060 inch</b>			
11.3	11.8 (7.6 to 18.1)	3.9 (1.9 to 5.6)	-1.7 (-4.1 to .1)
19.7	8.8 (5.8 to 11.5)	2.0 (1.3 to 2.8)	-1.3 (-1.9 to -.6)
79.6	6.1 (4.2 to 7.5)	1.4 (.9 to 2.1)	-.6 (-1.3 to .1)

<sup>1</sup> Clearance angle 15°; cutting velocity 5 inches per minute.

<sup>2</sup> The first number in each entry is the average cutting force; the numbers following in parentheses are maximum forces (average of five).

<sup>3</sup> The first number in each entry is the average cutting force; the numbers following in parentheses are minimum and maximum forces (average of five).

<sup>4</sup> A negative normal force indicates that the knife tended to lift the workpiece; force was positive when the knife pushed the workpiece.

**TABLE 13C.--TOOL FORCES WHEN ORTHOGONALLY CUTTING POST OAK ACROSS THE GRAIN IN THE 90-90 DIRECTION<sup>1</sup>**

Depth of cut and mixture content (percent)	Rake angle, degrees		
	20	30	40
-----Pounds per 0.1 inch of knife-----			
<b>PARALLEL FORCE</b>			
<b>0.015 inch</b>			
10.0	24.5 (32.1)	18.0 (23.3)	17.1 (22.1)
19.5	16.4 (20.6)	14.1 (18.1)	9.7 (12.5)
83.1	15.4 (18.5)	11.4 (14.1)	8.5 (11.2)
<b>0.030 inch</b>			
10.0	40.7 (50.1)	35.2 (44.5)	28.5 (38.1)
19.5	31.2 (38.0)	23.0 (29.1)	17.2 (22.1)
83.1	23.6 (27.5)	18.3 (21.9)	13.7 (17.3)
<b>0.045 inch</b>			
10.0	48.3 (61.1)	43.4 (56.4)	36.2 (48.0)
19.5	39.2 (48.0)	31.4 (39.1)	23.0 (30.1)
83.1	34.7 (41.4)	23.1 (29.3)	18.4 (22.9)
<b>0.060 inch</b>			
10.0	51.2 (65.2)	51.3 (67.6)	45.0 (60.1)
19.5	45.9 (55.0)	37.7 (45.4)	28.5 (36.4)
83.1	41.6 (50.6)	29.2 (34.6)	22.1 (29.0)
<b>NORMAL FORCE<sup>3,4</sup></b>			
<b>0.015 inch</b>			
10.0	1.6 ( 0.2 to 4.3)	-0.8 ( -2.0 to 0.8)	-3.2 ( -5.0 to -1.3)
19.5	1.1 ( .3 to 1.8)	-.9 ( -1.9 to .8)	-2.0 ( -3.0 to -.9)
83.1	.5 ( -.1 to 1.2)	-.9 ( -1.6 to -.2)	-2.1 ( -3.0 to -.9)
<b>0.030 inch</b>			
10.0	1.3 ( -.9 to 4.7)	-4.2 ( -6.5 to -.9)	-7.6 ( -11.4 to -4.6)
19.5	.8 ( -.6 to 2.6)	-2.6 ( -4.7 to -.3)	-4.6 ( -6.3 to -2.3)
83.1	.3 ( -.5 to 1.2)	-2.4 ( -3.5 to -.9)	-4.1 ( -5.6 to -2.4)
<b>0.045 inch</b>			
10.0	1.5 ( -1.5 to 7.5)	-5.6 ( -8.4 to -.9)	-10.7 ( -15.0 to -6.6)
19.5	.9 ( -.9 to 3.4)	-4.0 ( -6.5 to -.7)	-6.8 ( -9.6 to -3.8)
83.1	.2 ( -1.7 to 1.7)	-3.4 ( -5.2 to -1.8)	-5.7 ( -7.6 to -3.3)
<b>0.060 inch</b>			
10.0	2.0 ( -2.6 to 7.8)	-7.4 ( -11.9 to -2.5)	-13.7 ( -19.4 to -7.1)
19.5	1.3 ( -1.4 to 4.3)	-5.3 ( -8.3 to -2.0)	-8.6 ( -12.4 to -4.7)
83.1	.3 ( -2.1 to 2.7)	-4.5 ( -6.6 to -2.5)	-6.8 ( -9.6 to -4.0)

<sup>1</sup> Clearance angle 15°; cutting velocity 5 inches per minute.

<sup>2</sup> The first number in each entry is the average cutting force; the numbers following in parentheses are maximum forces (average of five).

<sup>3</sup> The first number in each entry is the average cutting force; the numbers following in parentheses are minimum and maximum forces (average of five).

<sup>4</sup> A negative normal force indicates that the knife tended to lift the workpiece; force was positive when the knife pushed the workpiece.

**TABLE 14A.--TOOL FORCES WHEN ORTHOGONALLY CUTTING SCARLET OAK VENEER IN THE 0-90 DIRECTION'**

Depth of cut and moisture content (percent)	Rake angle, degrees		
	50	60	70
-----Pounds per 0.1 inch of knife-----			
<b>PARALLEL FORCE<sup>2</sup></b>			
<b>0.015 inch</b>			
11.0	3.8 (11.9)	4.8 (10.3)	4.2 ( 8.5)
18.8	3.1 ( 6.8)	3.0 ( 5.5)	5.6 (11.2)
92.3	2.2 ( 5.0)	2.4 ( 5.3)	2.3 ( 4.5)
<b>0.030 inch</b>			
11.0	5.1 (15.1)	5.4 (14.1)	5.1 (12.5)
18.8	4.3 ( 9.5)	4.1 ( 8.7)	3.7 ( 6.8)
92.3	3.3 ( 7.2)	3.4 ( 7.3)	2.9 ( 5.7)
<b>0.045 inch</b>			
11.0	5.7 (16.5)	6.3 (17.7)	5.9 (13.0)
18.8	4.9 (11.5)	5.0 (10.7)	4.5 ( 9.2)
92.3	3.9 ( 7.9)	3.5 ( 7.6)	3.5 ( 7.1)
<b>0.060 inch</b>			
11.0	6.8 (19.2)	7.3 (17.2)	7.4 (16.9)
18.8	6.0 (13.4)	5.6 (12.7)	5.2 (10.5)
92.3	4.5 ( 9.7)	3.9 ( 8.6)	3.9 ( 7.7)
<b>NORMAL FORCE<sup>3,4</sup></b>			
<b>0.015 inch</b>			
11.0	1.1 (-1.2 to 4.5)	1.5 (-0.2 to 3.7)	0.7 (-0.6 to 2.0)
18.8	.4 (-.8 to 2.3)	.5 (-1.0 to 2.8)	.2 (-1.8 to 2.8)
92.3	.1 (-.6 to 1.0)	-.2 (-1.1 to 1.0)	.3 (-.4 to 1.6)
<b>0.030 inch</b>			
11.0	.3 (-1.7 to 5.5)	.6 (-1.9 to 5.0)	.9 (-1.5 to 3.8)
18.8	-.1 (-1.7 to 2.5)	-.4 (-2.0 to 1.3)	-.1 (-1.4 to 1.8)
92.3	-.3 (-1.4 to 1.3)	-.8 (-2.0 to .8)	-.4 (-1.4 to .8)
<b>0.045 inch</b>			
11.0	.5 (-1.6 to 5.6)	.7 (-1.8 to 5.2)	.9 (-1.6 to 4.1)
18.8	-.2 (-1.9 to 2.0)	-.8 (-2.9 to 1.3)	-1.1 (-2.9 to 1.3)
92.3	-.4 (-1.9 to 1.2)	-1.1 (-2.7 to .5)	-.8 (-2.2 to .5)
<b>0.060 inch</b>			
11.0	.7 (-1.9 to 5.4)	1.2 (-2.4 to 5.2)	.7 (-2.1 to 4.9)
18.8	-.2 (-2.2 to 2.8)	-1.2 (-3.8 to 1.5)	-1.5 (-3.5 to 1.0)
92.3	-.4 (-2.3 to 1.5)	-1.0 (-2.9 to .8)	-.9 (-2.6 to .8)

<sup>1</sup> Clearance angle 0°; cutting velocity 5 inches per minute.

<sup>2</sup> The first number in each entry is the average cutting force; the numbers following in parentheses are maximum forces (average of five).

<sup>3</sup> The first number in each entry is the average cutting force; the numbers following in parentheses are minimum and maximum forces (average of five).

<sup>4</sup> A negative normal force, indicates that the knife tended to lift the workpiece; force was positive when the knife pushed the workpiece.

**TABLE 14B. --TOOL FORCES WHEN ORTHOGONALLY CUTTING SCARLET OAK PARALLEL TO THE GRAIN IN THE 90-0 DIRECTION<sup>1</sup>**

Depth of cut and moisture content (percent)	Rake angle, degrees		
	10	20	30
-----Pounds per 0.1 inch of knife-----			
<b>PARALLEL FORCE<sup>2</sup></b>			
<b>0.015 inch</b>			
10.3	19.8 (23.8)	15.4 (18.8)	10.4 (16.0)
18.2	11.4 (13.1)	9.1 (10.8)	7.4 ( 9.2)
88.7	8.9 (11.2)	7.1 ( 8.6)	4.6 ( 5.7)
<b>0.030 inch</b>			
10.3	34.6 (41.9)	28.5 (36.2)	15.2 (27.0)
18.2	24.5 (29.0)	20.1 (23.2)	13.9 (18.1)
88.7	17.0 (19.8)	12.7 (15.6)	7.8 (10.5)
<b>0.045 inch</b>			
10.3	44.5 (59.2)	38.8 (50.5)	18.2 (38.7)
18.2	29.8 (36.3)	22.3 (30.6)	19.7 (23.1)
88.7	22.4 (27.9)	17.6 (21.7)	10.3 (15.4)
<b>0.060 inch</b>			
10.3	54.4 (74.3)	50.9 (64.7)	25.7 (51.7)
18.2	42.8 (49.7)	35.8 (38.7)	21.8 (26.7)
88.7	28.6 (36.9)	21.6 (26.2)	11.9 (11.5)
<b>NORMAL FORCE<sup>3,4</sup></b>			
<b>8.015 inch</b>			
10.3	5.7 (4.3 to 7.3)	1.9 (1.2 to 3.4)	-0.4 (-1.0 to 0.6)
18.2	3.1 (2.3 to 4.1)	1.1 ( .6 to 1.5)	-.1 ( -.6 to .4)
88.7	2.7 (1.8 to 4.1)	1.0 ( .5 to 1.5)	.4 ( -.3 to .8)
<b>0.030 inch</b>			
10.3	8.4 (6.0 to 10.9)	2.9 (1.6 to 4.1)	-1.1 (-2.1 to .2)
18.2	6.2 (5.0 to 7.4)	1.9 (1.2 to 2.4)	-.9 (-1.5 to -.2)
88.7	4.1 (3.1 to 5.4)	1.2 ( .6 to 2.0)	-.3 ( -.8 to .3)
<b>0.045 inch</b>			
10.3	11.0 (7.3 to 14.3)	4.0 (2.6 to 5.3)	-1.3 (-3.3 to .2)
18.2	7.4 (5.4 to 9.0)	1.3 (1.6 to 2.9)	-.8 (-2.8 to -1.0)
88.7	5.0 (3.7 to 6.8)		.0)
<b>0.060 inch</b>			
10.3	12.4 (8.2 to 19.1)	5.0 (3.3 to 6.6)	-1.6 (-4.4 to .9)
18.2	9.8 (7.0 to 11.5)	2.7 (1.8 to 3.2)	-2.0 (-2.6 to -1.2)
88.7	6.4 (3.8 to 8.5)	1.3 ( .6 to 2.4)	-1.0 (-1.9 to -.2)

<sup>1</sup> Clearance angle 15°; cutting velocity 5 inches per minute.

<sup>2</sup> The first number in each entry is the average cutting force; the numbers following in parentheses are maximum forces (average of five).

<sup>3</sup> The first number in each entry is the average cutting force; the numbers following in parentheses are minimum and maximum forces (average of five).

<sup>4</sup> A negative normal force indicates that the knife tended to lift the workpiece; force was positive when the knife pushed the workpiece.

**TABLE 14C.--TOOL FORCES WHEN ORTHOGONALLY CUTTING SCARLET OAK ACROSS THE GRAIN IN THE 90-90 DIRECTION<sup>1</sup>**

Depth of cut and moisture content (percent)	Rake angle, degrees		
	20	30	40
-----Pounds per 0.1 inch of knife-----			
<b>PARALLEL FORCE<sup>2</sup></b>			
<b>0.015 inch</b>			
10.6	23.0 (31.3)	21.4 (28.5)	17.2 (21.8)
18.2	17.3 (20.8)	14.6 (17.8)	11.8 (15.8)
94.5	14.1 (17.5)	10.1 (12.2)	9.6 (12.0)
<b>0.030 inch</b>			
10.6	38.1 (49.2)	35.4 (44.5)	27.1 (34.9)
18.2	29.8 (36.8)	21.5 (25.8)	18.6 (23.3)
94.5	23.7 (27.7)	17.0 (21.0)	14.2 (18.3)
<b>0.045 inch</b>			
10.6	41.3 (54.0)	39.8 (50.2)	34.5 (43.5)
18.2	39.5 (44.8)	29.3 (35.3)	23.0 (29.7)
94.5	30.4 (36.7)	21.1 (26.4)	18.1 (23.3)
<b>0.060 inch</b>			
10.6	47.5 (64.1)	46.9 (60.7)	43.1 (53.5)
18.2	47.1 (57.0)	32.8 (43.6)	27.9 (39.1)
94.5	34.3 (40.3)	26.9 (33.1)	22.0 (28.5)
<b>NORMAL FORCE<sup>3,4</sup></b>			
<b>0.015 inch</b>			
10.6	1.9 ( 0.2 to 2.3)	-1.2 (-2.0 to 1.5)	-3.3 ( -4.8 to -1.6)
18.2		.3)	-2.4 ( -3.6 to -1.0)
94.5	.5 ( -.2 to 1.1)	-.6 (-1.4 to .0)	-2.2 ( -3.3 to -1.2)
<b>0.030 inch</b>			
10.6	2.9 ( .9 to 5.4)	-3.1 (-5.0 to -.4)	-6.4 ( -8.9 to -3.0)
18.2	1.0 ( -.2 to 2.2)	-2.7 (-4.2 to -.9)	-5.0 ( -6.6 to -3.0)
94.5	.3 (-1.0 to 1.3)	-2.1 (-3.2 to -.8)	-4.0 ( -5.9 to -2.3)
<b>0.045 inch</b>			
10.6	3.9 ( -.5 to 8.3)	-3.2 (-6.2 to .3)	-8.8 (-11.8 to -4.9)
18.2	1.1 ( -.6 to 2.7)	-4.2 (-6.6 to -1.6)	-6.9 ( -9.5 to -3.5)
94.5	.5 (-1.0 to 1.8)	-2.9 (-4.6 to -1.5)	-5.6 ( -8.1 to -3.5)
<b>0.060 inch</b>			
10.6	4.7 ( .6 to 9.7)	-4.0 (-8.2 to 3.3)	-11.7 (-16.0 to -5.2)
18.2	1.4 (-1.2 to 3.7)	-5.5 (-9.1 to -2.2)	-9.2 (-12.9 to -3.5)
94.5	.8 (-.8 to 2.3)	-4.2 (-6.3 to -2.2)	-7.8 (-10.3 to -4.5)

<sup>1</sup> Clearance angle 15°; cutting velocity 5 inches per minute.

<sup>2</sup> The first number in each entry is the average cutting force; the numbers following in parentheses are maximum forces (average of five).

<sup>3</sup> The first number in each entry is the average cutting force; the numbers following in parentheses are minimum and maximum forces (average of five).

<sup>4</sup> A negative normal force indicates that the knife tended to lift the workpiece; force was positive when the knife pushed the workpiece.

**TABLE 15A.--TOOL FORCES WHEN ORTHOGONALLY CUTTING SHUMARD OAK VENEER IN THE 0-90 DIRECTION<sup>1</sup>**

Depth of cut and moisture content (percent)	Rake angle, degrees		
	50	60	70
-----Pounds per 0.1 inch of knife-----			
<b>PARALLEL FORCE<sup>2</sup></b>			
<b>0.015 inch</b>			
11.0	4.0 ( 9.1)	3.9 ( 8.7)	4.4 ( 9.2)
18.4	3.1 ( 5.6)	5.5 (12.5)	3.0 ( 5.7)
92.5	2.4 ( 5.4)	4.9 ( 9.3)	2.6 ( 4.5)
<b>0.030 inch</b>			
11.0	5.2 (15.0)	4.5 ( 8.8)	5.3 (10.8)
18.4	4.2 ( 9.1)	3.3 ( 6.4)	3.9 ( 7.6)
92.5	3.5 ( 8.4)	2.8 ( 5.9)	3.3 ( 6.3)
<b>0.045 inch</b>			
11.0	5.8 (16.8)	5.7 (12.9)	5.9 (13.3)
18.4	5.6 (11.4)	4.1 ( 8.6)	4.8 ( 9.0)
92.5	4.0 ( 9.6)	3.9 ( 8.4)	3.5 ( 7.4)
<b>0.060 inch</b>			
11.0	6.7 (18.5)	6.0 (15.2)	6.5 (15.8)
18.4	6.3 (13.0)	4.8 (10.0)	5.4 (10.3)
92.5	4.7 (12.1)	4.3 ( 9.2)	4.4 ( 8.4)
<b>NORMAL FORCE<sup>3,4</sup></b>			
<b>0.015 inch</b>			
11.0	0.8 (-1.1 to 3.6)	-0.5 (-2.4 to 1.4)	1.5 (-0.4 to 3.8)
18.4	.3 (-.7 to 1.8)	.4 (-1.5 to 3.0)	.6 (-.8 to 2.0)
92.5	.6 (-.4 to 2.3)	.1 (-1.4 to 1.9)	.8 (-.2 to 1.8)
<b>0.030 inch</b>			
11.0	.3 (-1.8 to 4.0)	1.2 (-.6 to 3.1)	.9 (-1.0 to 3.5)
18.4	-.4 (-1.5 to 2.1)	-.4 (-1.6 to 1.2)	.0 (-1.7 to 2.1)
92.5	.3 (-1.2 to 2.0)	.1 (-1.2 to 1.5)	.4 (-.7 to 1.6)
<b>0.045 inch</b>			
11.0	.4 (-1.8 to 5.0)	.6 (-1.3 to 3.1)	.4 (-1.4 to 3.0)
18.4	-.7 (-1.9 to 1.7)	-.4 (-2.1 to 1.8)	-.6 (-2.2 to 1.4)
92.5	.1 (-1.1 to 2.4)	-.2 (-1.9 to 2.0)	.1 (-1.4 to 1.7)
<b>0.060 inch</b>			
11.0	.5 (-2.1 to 4.6)	.3 (-1.7 to 3.0)	.5 (-1.9 to 3.8)
18.4	-.7 (-2.3 to 1.9)	-.6 (-2.6 to 1.6)	-.4 (-2.3 to 1.7)
92.5	.2 (-1.1 to 2.3)	-.5 (-2.6 to 1.8)	-.2 (-1.9 to 1.4)

<sup>1</sup>Clearance angle 0°; cutting velocity 5 inches per minute.

<sup>2</sup>The first number in each entry is the average cutting force; the numbers following in parentheses are maximum forces (average of five)

<sup>3</sup>The first number in each entry is the average cutting force; the numbers following in parentheses are minimum and maximum forces (average of five).

<sup>4</sup>A negative normal force indicates that the knife tended to lift the workpiece; force was positive when the knife pushed the workpiece.

**TABLE 15B.--TOOL FORCES WHEN ORTHOGONALLY CUTTING SHUMARD OAK PARALLEL TO THE GRAIN IN THE 90-0 DIRECTION<sup>1</sup>**

Depth of cut and moisture content (percent)	Rake angle, degrees		
	10	20	30
-----Pounds per 0.1 inch of knife-----			
<b>PARALLEL FORCE<sup>2</sup></b>			
<b>0.015 inch</b>			
10.4	19.7 (23.1)	17.4 (21.5)	11.6 (16.6)
18.8	12.3 (14.2)	8.8 (11.5)	7.3 (8.9)
88.0	9.3 (10.7)	7.0 (7.9)	4.6 (6.3)
<b>0.030 inch</b>			
10.4	35.8 (45.0)	29.1 (40.9)	16.5 (31.0)
18.8	24.5 (28.3)	20.5 (23.7)	13.8 (17.1)
88.0	17.7 (20.6)	13.3 (15.5)	8.3 (10.5)
<b>0.045 inch</b>			
10.4	43.7 (55.6)	40.1 (52.7)	20.8 (39.9)
18.8	32.5 (36.6)	25.5 (29.0)	18.4 (23.0)
88.0	25.5 (30.3)	19.2 (22.0)	11.4 (14.2)
<b>0.060 inch</b>			
10.4	51.2 (72.3)	47.2 (70.1)	20.3 (47.4)
18.8	40.3 (49.1)	34.3 (38.1)	21.0 (27.6)
88.0	31.1 (37.1)	24.8 (28.5)	14.8 (18.5)
<b>NORMAL FORCE<sup>3,4</sup></b>			
<b>0.015 inch</b>			
10.4	5.6 (4.3 to 6.5)	2.3 (1.6 to 2.8)	-0.2 (-0.8 to 0.3)
18.8	3.7 (2.5 to 4.7)	1.1 (.7 to 1.6)	-.1 (-.5 to .3)
88.0	2.6 (2.2 to 3.1)	1.1 (.7 to 1.4)	.3 (-.1 to .7)
<b>0.030 inch</b>			
10.4	9.6 (7.4 to 11.6)	3.5 (2.0 to 4.6)	-.9 (-2.0 to .0)
18.8	6.3 (5.4 to 7.3)	1.9 (1.3 to 2.7)	-.9 (-1.4 to -.4)
88.0	4.3 (3.5 to 4.9)	1.4 (.8 to 1.9)	-.2 (-.6 to .3)
<b>0.045 inch</b>			
10.4	11.2 (8.9 to 13.7)	4.1 (2.6 to 5.4)	-1.1 (-3.2 to .2)
18.8	7.9 (6.4 to 8.9)	2.3 (1.5 to 3.0)	-1.4 (-2.0 to -.5)
88.0	5.9 (4.7 to 7.0)	1.5 (1.0 to 1.8)	-.6 (-1.1 to .1)
<b>0.060 inch</b>			
10.4	12.5 (8.4 to 17.3)	4.4 (2.3 to 6.5)	-1.2 (-3.6 to .3)
18.8	9.8 (6.7 to 11.5)	3.0 (2.2 to 3.7)	-1.7 (-2.6 to -.7)
88.0	7.1 (5.2 to 8.4)	1.6 (.9 to 2.2)	-.7 (-1.6 to .4)

<sup>1</sup>Clearance angle 15°; cutting velocity 5 inches per minute.

<sup>2</sup>The first number in each entry is the average cutting force; the numbers following in parentheses are maximum forces (average of five).

<sup>3</sup>The first number in each entry is the average cutting force; the numbers following in parentheses are minimum and maximum forces (average of five).

<sup>4</sup>A negative normal force indicates that the knife tended to lift the workpiece; force was positive when the knife pushed the workpiece.

**TABLE 15C.--TOOL FORCES WHEN ORTHOGONALLY CUTTING SHUMARD OAK ACROSS THE GRAIN IN THE 90-90 DIRECTION<sup>1</sup>**

Depth of cut and moisture content (percent)	Rake angle, degrees		
	20	30	40
-----Pounds per 0.1 inch of knife-----			
<b>PARALLEL FORCE<sup>2</sup></b>			
<b>0.015 inch</b>			
10.4	28.6 (36.8)	20.0 (25.7)	16.6 (21.9)
17.5	18.2 (21.7)	14.0 (18.7)	11.3 (14.2)
90.8	13.6 (15.8)	11.8 (13.8)	9.5 (11.3)
<b>0.030 inch</b>			
10.4	41.0 (51.2)	36.8 (43.0)	26.5 (33.2)
17.5	30.6 (36.7)	23.0 (27.6)	17.3 (22.4)
90.8	24.5 (29.3)	18.0 (20.8)	14.7 (17.3)
<b>0.045 inch</b>			
10.4	48.8 (59.1)	42.4 (53.0)	33.9 (42.5)
17.5	38.6 (44.7)	29.9 (36.2)	23.3 (30.2)
90.8	31.2 (36.5)	23.7 (27.4)	18.6 (21.9)
<b>0.060 inch</b>			
10.4	59.1 (75.8)	52.2 (68.5)	40.2 (53.2)
17.5	45.5 (53.5)	35.3 (43.9)	26.9 (35.9)
90.8	36.9 (42.1)	28.8 (33.1)	22.3 (26.8)
<b>NORMAL FORCE<sup>3,4</sup></b>			
<b>0.015 inch</b>			
	0.4 to 3.4)	-0.6 (-1.8 to 0.7)	-3.3 (-4.6 to -2.1)
10.4	1.0 (.8 to 2.0)	-.9 (-2.2 to .0)	-2.1 (-3.1 to -1.2)
90.8	.7 (.1 to 1.2)	-.8 (-1.4 to -.2)	-2.0 (-2.9 to -1.2)
<b>0.030 inch</b>			
10.4	2.4 (.5 to 4.5)	-3.4 (-5.2 to -.6)	-6.3 (-8.8 to -3.6)
17.5	1.4 (.2 to 2.8)	-2.3 (-4.1 to -.9)	-4.5 (-6.3 to -2.7)
90.8	.5 (-.4 to 1.6)	-2.0 (-3.0 to -1.0)	-4.0 (-5.4 to -2.6)
<b>0.045 inch</b>			
10.4	3.0 (.5 to 6.1)	-4.0 (-7.0 to -1.3)	-8.9 (-12.1 to -5.1)
17.5	1.2 (-.3 to 3.2)	-3.7 (-5.9 to -2.0)	-6.7 (-9.9 to -3.4)
90.8	.6 (-.8 to 1.8)	-3.1 (-4.5 to -1.6)	-5.7 (-7.4 to -3.9)
<b>0.060 inch</b>			
10.4	3.7 (.9 to 7.4)	-5.5 (-9.4 to -1.4)	-11.5 (-14.7 to -6.4)
17.5	1.5 (-.2 to 4.1)	-4.7 (-7.1 to -2.4)	-8.4 (-12.5 to -3.9)
90.8	1.1 (-.5 to 2.6)	-4.3 (-6.3 to -2.1)	-7.2 (-9.7 to -4.7)

<sup>1</sup>Clearance angle 15°; cutting velocity 5 inches per minute.

<sup>2</sup>The first number in each entry is the average cutting force; the numbers following in parentheses are maximum forces (average of five).

<sup>3</sup>The first number in each entry is the average cutting force; the numbers following in parentheses are minimum and maximum forces (average of five).

<sup>4</sup>A negative normal force indicates that the knife tended to lift the workpiece; force was positive when the knife pushed the workpiece.

**TABLE 16A.--TOOL FORCES WHEN ORTHOGONALLY CUTTING SOUTHERN RED OAK VENEER  
IN THE 0-90 DIRECTION'**

Depth of cut and moisture content (percent)	Rake angle, degrees		
	50	60	70
-----Pounds per 0.1 inch of knife-----			
<b>PARALLEL FORCE'</b>			
<b>0.015 inch</b>			
11.2	4.4 (11.0)	4.7 (10.6)	4.1 ( 7.5)
19.4	3.1 ( 7.6)	2.6 ( 5.0)	6.1 (12.9)
91.3	2.4 ( 5.2)	2.2 ( 4.5)	4.6 ( 7.9)
<b>0.030 inch</b>			
11.2	6.1 (16.3)	<b>6.4 (14.5)</b>	<b>4.7 (10.0)</b>
19.4	4.6 (10.2)	3.8 ( 7.5)	<b>3.4 ( 6.1)</b>
91.3	3.8 ( 8.2)	3.4 ( 7.6)	<b>2.5 ( 5.1)</b>
<b>0.045 inch</b>			
11.2	7.1 (18.8)	7.2 (15.2)	6.1 (12.3)
19.4	5.5 (11.8)	5.3 (11.1)	4.2 ( 7.4)
91.3	4.2 (10.1)	4.0 ( 8.6)	3.3 ( 7.1)
<b>0.060 inch</b>			
11.2	<b>7.8 (21.9)</b>	8.1 (18.1)	6.4 (14.1)
19.4	<b>6.3 (13.2)</b>	6.0 (11.9)	4.9 ( 8.4)
91.3	<b>4.8 (11.8)</b>	4.7 ( 9.7)	4.0 ( 7.8)
<b>NORMAL FORCE<sup>3,4</sup></b>			
<b>0.015 inch</b>			
11.2	<b>0.4 (-1.1 to 3.0)</b>	<b>0.8 (-0.9 to 2.3)</b>	<b>-0.4 (-2.2 to 0.9)</b>
19.4	<b>.0 (-1.1 to 2.0)</b>	<b>-.3 (-1.1 to .8)</b>	<b>.5 (-2.1 to 3.9)</b>
91.3	<b>.1 (-.5 to 1.2)</b>	<b>-.1 (-1.0 to .9)</b>	<b>-.5 (-2.1 to .8)</b>
<b>0.030 inch</b>			
11.2	<b>.2 (-1.5 to 2.7)</b>	<b>.3 (-1.9 to 3.1)</b>	<b>.3 (-1.5 to 1.7)</b>
19.4	<b>-.5 (-1.8 to 1.6)</b>	<b>-1.2 (-2.4 to .1)</b>	<b>-.1 (-1.3 to 1.1)</b>
91.3	<b>-.3 (-1.6 to 1.3)</b>	<b>-.8 (-2.1 to .8)</b>	<b>.1 (-1.0 to 1.1)</b>
<b>0.045 inch</b>			
11.2	<b>.3 (-3.0 to 4.9)</b>	<b>-.1 (-2.7 to 3.1)</b>	<b>.2 (-2.0 to 2.5)</b>
19.4	<b>-.9 (-2.5 to 1.1)</b>	<b>-1.2 (-3.3 to 1.1)</b>	<b>-1.1 (-2.3 to .4)</b>
91.3	<b>-.4 (-1.6 to 1.1)</b>	<b>-.7 (-2.9 to 1.2)</b>	<b>-.3 (-1.5 to .9)</b>
<b>0.060 inch</b>			
11.2	<b>.8 (-2.3 to 6.5)</b>	<b>-.2 (-3.7 to 3.0)</b>	<b>-.8 (-3.4 to 1.8)</b>
19.4	<b>-1.0 (-3.1 to .7)</b>	<b>-1.5 (-4.1 to 1.2)</b>	<b>-1.6 (-2.8 to .1)</b>
91.3	<b>-.2 (-1.7 to 1.5)</b>	<b>-1.2 (-3.3 to 1.2)</b>	<b>-1.1 (-2.6 to .4)</b>

1 Clearance angle 0°; cutting velocity 5 inches per minute.

2 The first number in each entry is the average cutting force; the numbers following in parentheses are maximum forces (average of five).

3 The first number in each entry is the average cutting force; the numbers following in parentheses are minimum and maximum forces (average of five).

4 A negative normal force indicates that the knife tended to lift the workpiece; force was positive when the knife pushed the workpiece.

**TABLE 16B.--TOOL FORCE  
TO THE GRA**

Depth of cut and moisture content (percent)	
<b>0.015 inch</b>	
10.9	1
19.5	1
89.1	1
<b>0.030 inch</b>	
10.9	3
19.5	2
89.1	1
<b>0.045 inch</b>	
10.9	4
19.5	3
89.1	2
<b>0.060 inch</b>	
10.9	5
19.5	4
89.1	

**TABLE 17A.--TOOL FORCES WHEN ORTHOGONALLY CUTTING WATER OAK VENEER IN  
0-90 DIRECTION<sup>1</sup>**

Depth of cut and moisture content (percent)	Rake angle, degrees		
	50	60	70
Pounds per 0.1 inch of knife			
<b>PARALLEL FORCE<sup>2</sup></b>			
<b>0.015 inch</b>			
10.7	3.7 ( 9.5)	3.3 ( 7.3)	4.2 ( 10.0)
18.7	2.8 ( 6.9)	2.5 ( 5.5)	4.5 ( 11.0)
102.6	1.9 ( 4.8)	1.8 ( 4.0)	3.7 ( 9.0)
<b>0.030 inch</b>			
10.7	4.5 (13.4)	4.1 ( 9.5)	3.7 ( 9.0)
18.7	3.9 ( 9.1)	3.3 ( 7.4)	2.8 ( 7.0)
102.6	3.0 ( 6.8)	2.9 ( 5.7)	2.2 ( 5.0)
<b>0.045 inch</b>			
10.7	6.0 (16.6)	4.7 (11.6)	4.7 (11.0)
18.7	4.8 (10.4)	4.6 ( 9.6)	3.4 ( 8.0)
102.6	3.5 ( 8.1)	3.3 ( 6.9)	3.0 ( 7.0)
<b>0.060 inch</b>			
10.7	6.7 (18.0)	5.6 (13.7)	5.0 (12.0)
18.7	5.2 (11.7)	5.1 (10.2)	4.3 ( 9.0)
102.6	3.9 ( 9.6)	3.7 ( 8.5)	3.4 ( 8.0)
<b>NORMAL FORCE<sup>3,4</sup></b>			
<b>0.015 inch</b>			
10.7	0.8 (-0.7 to 3.2)	0.4 (-0.8 to 1.3)	0.0 (-1.9 to 1.5)
18.7	.5 (-.7 to 2.5)	-.1 (-1.0 to 1.2)	-.1 (-1.9 to 1.5)
102.6	.2 (-.5 to 1.7)	-.1 (-.8 to .4)	-.4 (-2.0 to 1.1)
<b>0.030 inch</b>			
10.7	.4 (-1.1 to 3.5)	-.2 (-1.6 to 1.4)	.8 (-.9 to 2.3)
18.7	-.1 (-1.4 to 2.0)	-.4 (-1.9 to 1.3)	-.2 (-1.2 to 0.7)
102.6	-.1 (-1.1 to 1.7)	-.6 (-1.6 to .6)	.1 (-.6 to .6)
<b>0.045 inch</b>			
10.7	.4 (-1.6 to 3.0)	-.3 (-2.3 to 1.5)	.0 (-1.8 to 1.8)
18.7	-.4 (-2.0 to 1.8)	-.7 (-2.5 to 1.2)	-.5 (-1.8 to 0.7)
102.6	-.1 (-1.5 to 1.9)	-.7 (-2.1 to .7)	-.3 (-1.6 to 0.9)
<b>0.060 inch</b>			
10.7	.5 (-2.3 to 4.1)	-.4 (-2.3 to 1.4)	-.3 (-2.6 to 1.0)
18.7	-.8 (-2.6 to 2.0)	-1.2 (-3.3 to .6)	-.7 (-2.2 to 0.8)
102.6	-.2 (-1.8 to 1.6)	-.8 (-2.8 to 1.2)	-.4 (-1.8 to 0.9)

1 Clearance angle 0°;  
2 The first number following in parentheses are maximum forces (average of five);  
3 The first number following in parentheses are minimum and maximum forces (average of five);  
4 A negative normal force was positive when the knife pushed the workpiece.

1 Clearance angle 0°; cutting velocity 5 inches per minute.  
2 The first number in each entry is the average cutting force; the number following in parentheses are maximum forces (average of five).  
3 The first number in each entry is the average cutting force; the number following in parentheses are minimum and maximum forces (average of five).  
4 A negative normal force indicates that the knife tended to lift the workpiece; a positive normal force was positive when the knife pushed the workpiece.

**TABLE 16C.--TOOL FORCES WHEN ORTHOGONALLY CUTTING SOUTHERN RED OAK ACROSS THE GRAIN IN THE 90-90 DIRECTION<sup>1</sup>**

Depth of cut and moisture content (percent)	Rake angle, degrees		
	20	30	40
-----Pounds per 0.1 inch of knife-----			
<b>PARALLEL FORCE<sup>2</sup></b>			
<b>0.015 inch</b>			
10.6	25.4 (33.0)	21.0 (26.3)	17.5 (23.7)
18.7	13.7 (18.4)	13.2 (16.7)	10.8 (13.8)
91.9	14.5 (17.5)	11.0 (14.0)	8.9 (11.5)
<b>0.030 inch</b>			
10.6	43.0 (52.5)	37.0 (46.6)	26.9 (33.8)
18.7	31.0 (36.7)	25.7 (30.7)	18.9 (22.5)
91.9	25.3 (30.2)	17.1 (21.9)	14.0 (17.7)
<b>0.045 inch</b>			
10.6	54.5 (65.4)	43.1 (52.3)	36.0 (47.2)
18.7	39.6 (46.0)	30.2 (37.6)	23.1 (30.5)
91.9	36.0 (43.3)	23.6 (29.2)	18.2 (23.4)
<b>0.060 inch</b>			
10.6	59.3 (73.0)	50.9 (64.2)	42.3 (53.6)
18.7	44.1 (52.8)	39.4 (50.9)	28.4 (37.3)
91.9	39.2 (49.6)	29.5 (40.1)	21.1 (28.5)
<b>NORMAL FORCE<sup>3,4</sup></b>			
<b>0.015 inch</b>			
10.6	2.2 ( 0.9 to 3.8)	-1.1 (-2.3 to 0.6)	-3.7 (-5.5 to -1.5)
18.7	1.1 ( .4 to 2.6)	-.8 (-1.6 to .4)	-2.0 (-2.9 to -1.1)
91.9	.5 ( .0 to 1.1)	-.7 (-1.6 to .2)	-2.0 (-2.8 to -1.0)
<b>0.030 inch</b>			
10.6	2.9 ( 1.3 to 6.1)	-3.0 (-5.6 to -.6)	-6.7 (-9.2 to -3.3)
18.7	1.0 (-.1 to 2.8)	-2.6 (-4.6 to -.9)	-4.8 (-6.5 to -2.9)
91.9	.5 (-.4 to 1.5)	-2.0 (-3.3 to -.7)	-3.9 (-5.5 to -2.2)
<b>0.045 inch</b>			
10.6	3.4 ( .0 to 7.2)	-4.1 (-6.5 to -.2)	-9.4 (-13.4 to -4.1)
18.7	1.3 (-.6 to 4.0)	-3.9 (-6.4 to .6)	-6.6 (-9.6 to -3.2)
91.9	.6 (-1.2 to 2.2)	-3.2 (-5.0 to -1.4)	-5.4 (-7.9 to -3.0)
<b>0.060 inch</b>			
10.6	4.8 ( .0 to 11.6)	-5.0 (-9.1 to -1.3)	-11.0 (-15.5 to -2.1)
18.7	1.4 (-1.0 to 4.9)	-5.5 (-9.4 to -1.0)	-8.5 (-13.0 to -3.6)
91.9	1.3 (-.8 to 3.1)	-4.7 (-6.7 to -1.8)	-7.0 (-9.9 to -3.2)

<sup>1</sup> Clearance angle 15°; cutting velocity 5 inches per minute.

<sup>2</sup> The first number in each entry is the average cutting force; the numbers following in parentheses are maximum forces (average of five).

<sup>3</sup> The first number in each entry is the average cutting force; the numbers following in parentheses are minimum and maximum forces (average of five).

<sup>4</sup> A negative normal force indicates that the knife tended to lift the workpiece; force was positive when the knife pushed the workpiece.

**TABLE 17A.--TOOL FORCES WHEN ORTHOGONALLY CUTTING WATER OAK VENEER IN THE 0-90 DIRECTION'**

Depth of cut and moisture content (percent)	Rake angle, degrees		
	50	60	70
-----Pounds per 0.1 inch of knife-----			
<b>PARALLEL FORCE<sup>2</sup></b>			
<b>0.015 inch</b>			
<b>10.7</b>	3.7 ( 9.5)	3.3 ( 7.3)	4.2 ( 7.9)
<b>18.7</b>	2.8 ( 6.9)	2.5 ( 5.5)	4.5 (10.6)
<b>102.6</b>	1.9 ( 4.8)	1.8 ( 4.0)	3.7 ( 6.9)
<b>0.030 inch</b>			
<b>10.7</b>	4.5 (13.4)	4.1 ( 9.5)	3.7 ( 8.6)
<b>18.7</b>	3.9 ( 9.1)	3.3 ( 7.4)	2.8 ( 6.0)
<b>102.6</b>	3.0 ( 6.8)	2.9 ( 5.7)	2.2 ( 4.6)
<b>0.045 inch</b>			
<b>10.7</b>	6.0 (16.6)	4.7 (11.6)	4.7 (11.1)
<b>18.7</b>	4.8 (10.4)	4.6 ( 9.6)	3.4 ( 7.1)
<b>102.6</b>	3.5 ( 8.1)	3.3 ( 6.9)	3.0 ( 5.5)
<b>0.060 inch</b>			
<b>10.7</b>	6.7 (18.0)	5.6 (13.7)	5.0 (12.3)
<b>18.7</b>	5.2 (11.7)	5.1 (10.2)	4.3 ( 8.7)
<b>102.6</b>	3.9 ( 9.6)	3.7 ( 8.5)	3.4 ( 6.5)
<b>NORMAL FORCE<sup>3,4</sup></b>			
<b>0.015 inch</b>			
<b>10.7</b>	<b>0.8 (-0.7 to 3.2)</b>	0.4 (-0.8 to 1.3)	0.0 ( <b>-1.9 to 2.0</b> )
<b>18.7</b>	.5 ( <b>-0.7 to 2.5</b> )	-.1 (-1.0 to 1.2)	-.1 (-1.9 to 1.6)
<b>102.6</b>	.2 ( <b>-0.5 to 1.7</b> )	-.1 ( <b>-0.8 to .4</b> )	-.4 (-2.0 to 1.1)
<b>0.030 inch</b>			
<b>10.7</b>	.4 ( <b>-1.1 to 3.5</b> )	-.2 (-1.6 to 1.4)	.8 ( <b>-.9 to 2.6</b> )
<b>18.7</b>	-.1 ( <b>-1.4 to 2.0</b> )	-.4 (-1.9 to 1.3)	-.2 (-1.2 to 1.6)
<b>102.6</b>	-.1 ( <b>-1.1 to 1.7</b> )	-.6 (-1.6 to .6)	.1 ( <b>-.6 to 1.2</b> )
<b>0.045 inch</b>			
<b>10.7</b>	.4 ( <b>-1.6 to 3.0</b> )	-.3 (-2.3 to 1.5)	.0 (-1.8 to 2.4)
<b>18.7</b>	-.4 ( <b>-2.0 to 1.8</b> )	-.7 (-2.5 to 1.2)	-.5 (-1.8 to 1.1)
<b>102.6</b>	-.1 ( <b>-1.5 to 1.9</b> )	-.7 (-2.1 to .7)	-.3 (-1.6 to .7)
<b>0.060 inch</b>			
<b>10.7</b>	.5 ( <b>-2.3 to 4.1</b> )	-.4 (-2.3 to 1.4)	-.3 (-2.6 to 2.4)
<b>18.7</b>	-.8 ( <b>-2.6 to 2.0</b> )	-1.2 (-3.3 to .6)	-.7 (-2.2 to 1.5)
<b>102.6</b>	-.2 ( <b>-1.8 to 1.6</b> )	-.8 (-2.8 to 1.2)	-.4 (-1.8 to 1.1)

1 Clearance angle 0°; cutting velocity 5 inches per minute.

2 The first number in each entry is the average cutting force; the numbers following in parentheses are maximum forces (average of five).

3 The first number in each entry is the average cutting force; the numbers following in parentheses are minimum and maximum forces (average of five).

4 A negative normal force indicates that the knife tended to lift the workpiece; force was positive when the knife pushed the workpiece.

**TABLE 17B.--TOOL FORCES WHEN ORTHOGONALLY CUTTING WATER OAK PARALLEL TO THE GRAIN IN THE 90-0 DIRECTION<sup>1</sup>**

Depth of cut and moisture content (percent)	Rake angle, degrees		
	10	20	30
-----Pounds per 0.1 inch of knife-----			
<b>PARALLEL FORCE<sup>2</sup></b>			
<b>0.015 inch</b>			
10.4	20.6 (25.7)	17.7 (20.1)	11.6 (15.6)
18.4	13.6 (14.9)	12.2 (14.0)	8.3 (10.0)
95.5	9.6 (11.0)	7.0 (8.7)	5.8 (7.5)
<b>0.030 inch</b>			
10.4	34.9 (41.8)	35.7 (40.1)	17.0 (32.1)
18.4	25.2 (29.4)	22.6 (25.2)	16.1 (19.7)
95.5	17.7 (20.8)	14.0 (16.3)	10.0 (12.1)
<b>0.045 inch</b>			
10.4	48.8 (59.9)	44.8 (52.3)	17.9 (43.5)
18.4	29.9 (38.2)	32.5 (37.1)	22.0 (28.7)
95.5	25.2 (29.7)	20.3 (22.9)	13.3 (16.7)
<b>0.060 inch</b>			
10.4	61.3 (80.0)	58.4 (67.7)	19.4 (58.3)
18.4	39.6 (51.2)	40.3 (44.4)	17.9 (36.8)
95.5	32.9 (38.3)	23.6 (27.2)	17.0 (23.2)
<b>NORMAL FORCE<sup>3,4</sup></b>			
<b>0.015 inch</b>			
10.4	6.1 (4.6 to 7.6)	2.1 (1.6 to 2.5)	-0.1 -0.8 to 0.4)
18.4	4.0 (3.2 to 4.7)	1.5 (1.1 to 1.8)	.0 -.3 to .4)
95.5	2.6 (2.0 to 3.0)	1.0 (.5 to 1.8)	.0 -.5 to .5)
<b>0.030 inch</b>			
10.4	9.3 (7.7 to 10.9)	3.3 (2.3 to 4.2)	-1.1 -2.5 to .3)
18.4	6.1 (4.5 to 6.9)	2.0 (1.5 to 2.6)	-.8 -1.4 to .2)
95.5	3.9 (2.9 to 5.0)	1.0 (.4 to 1.8)	-.7 -1.1 to .0)
<b>0.045 inch</b>			
10.4	12.1 (8.5 to 15.7)	3.8 (2.6 to 5.1)	-1.2 -3.3 to .6)
18.4	8.1 (5.5 to 9.8)	2.5 (1.8 to 3.1)	-1.3 -2.4 to -.1)
95.5	5.4 (4.0 to 6.5)	1.0 (.4 to 2.0)	-1.0 -1.8 to -.1)
<b>0.060 inch</b>			
10.4	14.6 (10.5 to 19.5)	4.6 (2.1 to 6.5)	-1.0 -4.6 to 1.1)
18.4	9.8 (6.7 to 12.5)	3.1 (2.3 to 3.8)	-1.3 -3.4 to .3)
95.5	6.0 (5.1 to 7.2)	1.0 (.3 to 1.9)	-1.4 -2.8 to -.2)

<sup>1</sup> Clearance angle 15°; cutting velocity 5 inches per minute.

<sup>2</sup> The first number in each entry is the average cutting force; the numbers following in parentheses are maximum forces (average of five).

<sup>3</sup> The first number in each entry is the average cutting force; the numbers following in parentheses are minimum and maximum forces (average of five).

<sup>4</sup> A negative normal force indicates that the knife tended to lift the workpiece; force was positive when the knife pushed the workpiece.

**TABLE 17C.--TOOL FORCES  
GRAIN IN THE**

Depth of cut and moisture content (percent)	
0.015 inch	
10.7	18.8
18.0	15.2
105.3	13.1
0.030 inch	
10.7	35.0
18.0	29.0
105.3	21.0
0.045 inch	
10.7	38.8
18.0	35.8
105.3	28.8
0.060 inch	
10.7	47.0
18.0	39.0
105.3	35.4

**TABLE 18B.--TOOL FORCES WHEN ORTHOGONALLY CUTTING WHITE OAK PARALLEL  
TO THE GRAIN IN THE 90-0 DIRECTION<sup>1</sup>**

Depth of cut and moisture content (percent)	Rake angle, degrees			
	10	20	30	
Pounds per 0.1 inch of knife-				
<b>PARALLEL FORCE<sup>2</sup></b>				
<b>0.015 inch</b>				
10.9	19.3 (22.7)	16.2 (19.2)	5.4 (	
19.6	12.0 (14.0)	8.5 (10.1)	6.4 (	
75.1	9.4 (11.2)	6.5 ( 8.9)	4.5 (	
<b>0.030 inch</b>				
10.9	33.3 (42.7)	31.2 (34.6)	10.4 (1	
19.6	21.1 (27.7)	18.6 (21.1)	11.2 (1	
75.1	16.4 (21.1)	10.5 (12.7)	7.4 (	
<b>0.045 inch</b>				
10.9	41.0 (52.1)	40.8 (45.1)	12.0 (2	
19.6	28.0 (36.5)	24.4 (28.0)	15.5 (21	
75.1	24.4 (30.2)	14.9 (16.8)	9.5 (11	
<b>0.060 inch</b>				
10.9	50.2 (70.3)	54.8 (61.9)	12.7 (22	
19.6	35.9 (49.8)	28.2 (32.3)	18.7 (25	
75.1	30.8 (38.4)	18.1 (22.3)	11.4 (12	

**NORMAL FORCE<sup>3,4</sup>**

<b>0.015 inch</b>				
10.9	5.2 (3.4 to 6.3)	1.9 (1.3 to 2.6)	-0.4 (-0.7 to	
19.6	3.8 (2.6 to 4.3)	1.3 (.8 to 1.7)	-.1 (-.3 to	
75.1	2.8 (1.8 to 3.5)	1.1 (.5 to 1.9)	.2 (-.2 to	
<b>0.030 inch</b>				
10.9	8.5 (5.7 to 10.8)	3.0 (2.3 to 4.2)	-1.0 (-1.8 to	
19.6	5.9 (3.9 to 7.6)	2.0 (1.5 to 2.4)	-.6 (-1.0 to	
75.1	4.2 (3.0 to 5.3)	1.3 (.6 to 1.9)	-.1 (-.6 to	
<b>0.045 inch</b>				
10.9	9.5 (5.5 to 13.7)	3.9 (2.9 to 4.8)	-1.2 (-2.0 to	
19.6	7.2 (4.5 to 8.9)	2.4 (1.7 to 3.2)	-1.0 (-1.3 to	
75.1	6.1 (4.4 to 7.3)	1.5 (.6 to 2.0)	-.3 (-1.1 to	
<b>0.060 inch</b>				
10.9	11.6 (7.0 to 16.2)	5.3 (4.2 to 6.4)	-1.3 (-2.4 to	
19.6	9.1 (6.1 to 11.8)	2.9 (2.3 to 3.6)	-1.5 (-2.4 to	
75.1	7.5 (4.1 to 9.6)	1.8 (.7 to 2.8)	-.5 (-1.1 to	

<sup>1</sup> Clearance angle 15°;

<sup>2</sup> The first number in each entry is the average cutting force; the numbers following in parentheses are maximum forces (average of five).

<sup>3</sup> The first number in each entry is the average cutting force; the numbers following in parentheses are minimum and maximum forces (average of five).

<sup>4</sup> A negative normal force indicates that the knife tended to lift the workpiece; a positive normal force was positive.

**TABLE 18A.--TOOL FORCES WHEN ORTHOGONALLY CUTTING WHITE OAK VENEER IN THE  
0-90 DIRECTION<sup>1</sup>**

Depth of cut and moisture content (percent)	Rake angle, degrees		
	50	60	70
-----Pounds per 0.1 inch of knife-----			
<b>PARALLEL FORCE<sup>2</sup></b>			
<b>0.015 inch</b>			
11.5	<b>4.0 ( 8.9)</b>	4.1 ( 9.0)	4.0 ( 7.4)
19.3	3.2 ( 7.4)	2.9 ( 5.5)	5.5 (12.4)
82.1	2.0 ( 5.0)	2.0 ( 4.5)	5.3 ( 9.6)
<b>0.030 inch</b>			
11.5	<b>5.4 (13.4)</b>	<b>5.1 (12.3)</b>	4.3 (10.4)
19.3	4.5 (10.2)	4.3 ( 8.9)	3.7 ( 6.5)
82.1	3.4 ( 7.0)	2.9 ( 6.1)	2.8 ( 4.9)
<b>0.045 inch</b>			
11.5	<b>6.6 (17.6)</b>	6.4 (15.0)	5.7 (12.5)
19.3	5.5 (13.3)	5.3 (11.0)	5.2 ( 9.8)
82.1	3.9 ( 9.8)	3.4 ( 8.2)	3.3 ( 6.1)
<b>0.060 inch</b>			
11.5	7.7 (20.5)	7.1 (18.4)	<b>6.6 (15.6)</b>
19.3	6.5 (14.5)	6.4 (13.2)	<b>6.4 (12.0)</b>
82.1	4.1 ( 9.9)	4.4 ( 8.3)	<b>4.1 ( 8.5)</b>
<b>NORMAL FORCE<sup>3,4</sup></b>			
<b>0.015 inch</b>			
11.5	<b>0.2 (-1.0 to 2.1)</b>	<b>0.4 (-0.9 to 1.8)</b>	<b>-0.3 (-2.3 to 2.6)</b>
19.3	-.1 (-1.2 to 2.0)	-.3 (-1.5 to 1.2)	-.5 (-2.9 to 1.4)
82.1	.1 (-.6 to 1.2)	-.2 (-1.2 to .7)	-.9 (-3.2 to 1.4)
<b>0.030 inch</b>			
11.5	.1 (-2.1 to 2.9)	-.1 (-1.5 to 1.9)	<b>1.3 (-1.0 to 3.2)</b>
19.3	-.3 (-2.5 to 2.9)	-1.2 (-3.0 to .8)	.3 (-1.0 to 1.4)
82.1	-.2 (-1.2 to 1.4)	-.6 (-1.9 to .9)	.2 (-.5 to 1.4)
<b>0.045 inch</b>			
11.5	-.4 (-3.2 to 3.3)	-.1 (-2.3 to 2.2)	.5 (-1.6 to 3.2)
19.3	-.5 (-2.3 to 2.3)	-1.3 (-4.2 to .6)	-1.0 (-2.9 to 1.0)
82.1	-.2 (-1.6 to 1.6)	-.8 (-2.7 to .7)	-.2 (-1.5 to 1.2)
<b>0.060 inch</b>			
11.5	-.0 (-2.8 to 4.2)	.0 (-2.7 to 3.0)	-.2 (-3.3 to 3.3)
19.3	-.6 (-3.0 to 2.4)	-1.5 (-4.3 to 1.3)	-1.5 (-3.7 to 1.7)
82.1	-.5 (-2.0 to 1.1)	-1.0 (-2.9 to .7)	.1 (-1.8 to 2.0)

<sup>1</sup> Clearance angle 0°; cutting velocity 5 inches per minute.

<sup>2</sup> The first number in each entry is the average cutting force; the numbers following in parentheses are maximum forces (average of five).

<sup>3</sup> The first number in each entry is the average cutting force; the numbers following in parentheses are minimum and maximum forces (average of five).

<sup>4</sup> A negative normal force indicates that the knife tended to lift the workpiece; force was positive when the knife pushed the workpiece.

**TABLE 18B.--TOOL FORCES WHEN ORTHOGONALLY CUTTING WHITE OAK PARALLEL TO THE GRAIN IN THE 90-0 DIRECTION<sup>1</sup>**

Depth of cut and moisture content (percent)	Rake angle, degrees		
	10	20	30
-----Pounds per 0.1 inch of <b>knife</b> -----			
<b>PARALLEL FORCE<sup>2</sup></b>			
<b>0.015 inch</b>			
10.9	19.3 (22.7)	16.2 (19.2)	5.4 ( 9.3)
19.6	12.0 (14.0)	8.5 (10.1)	6.4 ( 7.6)
75.1	9.4 (11.2)	6.5 ( 8.9)	4.5 ( 5.8)
<b>0.030 inch</b>			
10.9	33.3 (42.7)	31.2 (34.6)	10.4 (15.9)
19.6	21.1 (27.7)	18.6 (21.1)	11.2 (12.8)
75.1	16.4 (21.1)	10.5 (12.7)	7.4 ( 9.6)
<b>0.045 inch</b>			
10.9	41.0 (52.1)	40.8 (45.1)	12.0 (23.5)
19.6	28.0 (36.5)	24.4 (28.0)	15.5 (21.0)
75.1	24.4 (30.2)	14.9 (16.8)	9.5 (11.5)
<b>0.060 inch</b>			
10.9	50.2 (70.3)	54.8 (61.9)	12.7 (22.2)
19.6	35.9 (49.8)	28.2 (32.3)	18.7 (25.7)
75.1	30.8 (38.4)	18.1 (22.3)	11.4 (13.7)
<b>NORMAL FORCE<sup>3,4</sup></b>			
<b>-0.015 inch</b>			
10.9	5.2 3.4 to 6.3)	1.9 (1.3 to 2.6)	-0.4 (-0.7 to 0.2)
19.6	3.8 2.6 to 4.3)	1.3 ( .8 to 1.7)	-.1 ( -.3 to .3)
75.1	2.8 1.8 to 3.5)	1.1 ( .5 to 1.9)	.2 ( -.2 to .8)
<b>0.030 inch</b>			
10.9	8.5 5.7 to 10.8)	3.0 (2.3 to 4.2)	-1.0 (-1.8 to -.3)
19.6	5.9 3.9 to 7.6)	2.0 (1.5 to 2.4)	-.6 (-1.0 to -.1)
75.1	4.2 3.0 to 5.3)	1.3 ( .6 to 1.9)	-.1 ( -.6 to .6)
<b>0.045 inch</b>			
10.9	9.5 (5.5 to 13.7)	3.9 (2.9 to 4.8)	-1.2 (-2.0 to -.4)
19.6	7.2 (4.5 to 8.9)	2.4 (1.7 to 3.2)	-1.0 (-1.3 to -.6)
75.1	6.1 (4.4 to 7.3)	1.5 ( .6 to 2.0)	-.3 (-1.1 to .2)
<b>0.060 inch</b>			
10.9	11.6 7.0 to 16.2)	5.3 (4.2 to 6.4)	-1.3 (-2.4 to -.5)
19.6	9.1 6.1 to 11.8)	2.9 (2.3 to 3.6)	-1.5 (-2.4 to -.6)
75.1	7.5 4.1 to 9.6)	1.8 ( .7 to 2.8)	-.5 (-1.1 to .2)

<sup>1</sup> Clearance angle 15°; cutting velocity 5 inches per minute.

<sup>2</sup> The first number in each entry is the average cutting force; the numbers following in parentheses are maximum forces (average of five).

<sup>3</sup> The first number in each entry is the average cutting force; the numbers following in parentheses are minimum and maximum forces (average of five).

<sup>4</sup> A negative normal force indicates that the knife tended to lift the workpiece; force was positive when the knife pushed the workpiece.

**TABLE 18C.--TOOL FORCES WHEN ORTHOGONALLY CUTTING WHITE OAK ACROSS THE GRAIN IN THE 90-90 DIRECTION<sup>1</sup>**

Depth of cut and moisture content (percent)	Rake angle, degrees		
	20	30	40
-----Pounds per 0.1 inch of knife-----			
<b>PARALLEL FORCE<sup>2</sup></b>			
<b>0.015 inch</b>			
11.2	24.6 (32.1)	20.9 (26.9)	16.1 (20.9)
18.8	16.2 (20.3)	14.1 (17.7)	10.0 (14.0)
86.3	13.9 (16.5)	11.6 (13.8)	8.8 (11.1)
<b>0.030 inch</b>			
11.2	39.6 (50.9)	31.6 (43.8)	26.7 (34.0)
18.8	29.9 (37.7)	21.4 (27.8)	17.2 (21.8)
86.3	23.4 (27.3)	17.4 (20.8)	13.2 (16.5)
<b>0.045 inch</b>			
11.2	48.7 (57.7)	43.1 (53.2)	34.3 (44.8)
18.8	34.5 (43.9)	31.0 (37.7)	20.7 (27.5)
86.3	32.8 (38.1)	23.3 (27.9)	16.9 (20.8)
<b>0.060 inch</b>			
11.2	54.6 (69.5)	48.0 (61.2)	41.1 (51.1)
18.8	42.3 (54.1)	36.3 (47.6)	26.8 (35.1)
86.3	38.6 (47.6)	28.0 (33.1)	21.0 (26.5)
<b>NORMAL FORCE<sup>3,4</sup></b>			
<b>0.015 inch</b>			
11.2	1.3 (-0.2 to 3.7)	-1.7 (-3.0 to 0.1)	-3.7 (-5.3 to -1.6)
18.8	1.0 (.3 to 1.8)	-.7 (-1.8 to .4)	-2.1 (-3.4 to -1.1)
86.3	.5 (.0 to 1.1)	-.8 (-1.6 to -.1)	-1.9 (-2.5 to -.9)
<b>0.030 inch</b>			
11.2	.9 (-1.3 to 4.6)	-3.6 (-6.2 to .7)	-7.2 (-10.0 to -4.4)
18.8	1.1 (-.3 to 3.2)	-2.3 (-4.1 to -.7)	-4.6 (-6.4 to -2.4)
86.3	.4 (-.6 to 1.3)	-1.9 (-3.2 to -.7)	-3.7 (-5.0 to -1.9)
<b>0.045 inch</b>			
11.2	1.0 (-2.4 to 3.8)	-5.5 (-8.5 to -1.2)	-9.9 (-13.4 to -4.7)
18.8	1.1 (-.8 to 4.2)	-3.7 (-6.4 to -.8)	-6.0 (-9.0 to -3.2)
86.3	.4 (-1.0 to 1.6)	-3.2 (-4.9 to -1.4)	-5.6 (-7.2 to -3.1)
<b>0.060 inch</b>			
11.2	1.0 (-2.7 to 6.2)	-6.3 (-10.8 to -.5)	-12.2 (-17.4 to -5.7)
18.8	.9 (-1.0 to 4.5)	-4.1 (-7.5 to -.1)	-8.1 (-12.3 to -3.7)
86.3	.6 (-1.4 to 2.7)	-4.1 (-6.3 to -2.2)	-6.8 (-9.0 to -3.3)

<sup>1</sup> Clearance angle 15°; cutting velocity 5 inches per minute.

<sup>2</sup> The first number in each entry is the average cutting force; the numbers following in parentheses are maximum forces (average of five).

<sup>3</sup> The first number in each entry is the average cutting force; the numbers following in parentheses are minimum and maximum forces (average of five).

<sup>4</sup> A negative normal force indicates that the knife tended to lift the workpiece; force was positive when the knife pushed the workpiece.

**TABLE 19A.--TOOL FORCES WHEN ORTHOGONALLY CUTTING SWEETBAY VENEER IN THE 0-90 DIRECTION<sup>1</sup>**

Depth of cut and moisture content (percent)	Rake angle, degrees		
	50	60	70
-----Pounds per 0.1 inch of knife-----			
PARALLEL FORCE <sup>2</sup>			
<b>0.015</b> inch			
11.3	2.2 (4.3)	2.0 (3.5)	<b>2.1 (3.2)</b>
18.7	2.1 (4.3)	1.9 (3.1)	2.9 (5.4)
150.8	1.6 (2.8)	1.5 (2.0)	2.5 (3.9)
0.030 inch			
11.3	3.3 (7.0)	2.7 (5.2)	2.5 (4.0)
18.7	2.8 (5.4)	2.5 (4.0)	2.3 (3.7)
150.8	2.1 (3.8)	1.9 (2.9)	1.7 (2.5)
0.045 inch			
11.3	3.8 (8.3)	3.3 (6.4)	3.0 (6.0)
18.7	2.9 (5.5)	3.0 (5.2)	2.9 (4.7)
150.8	2.2 (4.7)	2.3 (3.6)	2.0 (3.0)
0.060 inch			
11.3	4.0 (9.4)	3.5 (7.5)	3.4 (6.7)
18.7	3.5 (6.5)	3.4 (6.2)	3.0 (4.8)
150.8	2.6 (5.4)	2.5 (4.2)	2.3 (3.3)
NORMAL FORCE <sup>3,4</sup>			
0.015 inch			
11.3	0.1 (-0.4 to 1.1)	<b>-0.1 (-0.5 to .5)</b>	-0.1 (-0.7 to 0.6)
18.7	.6 ( -.2 to 2.0)	<b>-.2 ( -.6 to .5)</b>	-.4 (-1.4 to .6)
150.8	.2 ( -.2 to 1.1)	<b>.0 ( -.3 to .4)</b>	-.5 (-1.3 to .5)
0.030 inch			
11.3	-.1 ( -.8 to 1.2)	<b>-.5 (-1.3 to .2)</b>	.2 ( -.4 to 1.1)
18.7	-.3 ( -.9 to .8)	<b>-.5 (-1.2 to .2)</b>	.1 ( -.5 to .9)
150.8	-.1 ( -.7 to .7)	<b>-.3 ( -.8 to .3)</b>	.2 ( -.3 to .5)
0.045 inch			
11.3	-.2 (-1.2 to 1.0)	<b>-.8 (-1.9 to .1)</b>	-.2 (-1.2 to .6)
18.7	-.4 (-1.1 to .6)	<b>-.9 (-1.8 to .1)</b>	-.4 (-1.2 to .9)
150.8	-.2 ( -.8 to .5)	<b>-.6 (-1.2 to .1)</b>	-.4 ( -.8 to .1)
0.060 inch			
11.3	-.2 (-1.5 to 1.0)	<b>-.6 (-2.0 to .6)</b>	-.2 (-1.5 to 1.1)
18.7	-.4 (-1.5 to .6)	<b>-1.0 (-2.2 to .2)</b>	-1.0 (-1.9 to .1)
150.8	-.4 ( -1.2 to .5)	<b>-.7 (-1.7 to .0)</b>	-.7 ( <b>-1.4</b> to -.1)

<sup>1</sup> Clearance angle 0°; cutting velocity 5 inches per minute.

<sup>2</sup> The first number in each entry is the average cutting force; the numbers following in parentheses are maximum forces (average of five).

<sup>3</sup> The first number in each entry is the average cutting force; the numbers following in parentheses are minimum and maximum forces (average of five).

<sup>4</sup> A negative normal force indicates that the knife tended to lift the workpiece; force was positive when the knife pushed the workpiece.

**TABLE 19B.--TOOL FORCES WHEN ORTHOGONALLY CUTTING SWEETBAY PARALLEL TO THE GRAIN IN THE 90-0 DIRECTION'**

Depth of cut and moisture content (percent)	Rake angle, degrees		
	10	20	30
-----Pounds per 0.1 inch of knife-----			
<b>PARALLEL FORCE<sup>2</sup></b>			
<b>0.015 inch</b>			
10.7	12.1 15.6)	12.3 (13.2)	8.6 (11.3)
19.2	9.9 11.9)	8.4 ( 9.6)	6.9 ( 7.8)
102.7	6.3 8.5)	4.0 ( 5.7)	3.4 ( 4.5)
<b>0.030 inch</b>			
10.7	20.6 (27.7)	23.4 (25.8)	12.2 (22.1)
19.2	18.3 (24.4)	16.0 (17.8)	13.0 (15.7)
102.7	12.6 (15.9)	8.8 (11.5)	5.2 ( 7.3)
<b>0.045 inch</b>			
10.7	31.7 (41.1)	36.0 (39.5)	11.0 (29.5)
19.2	25.4 (32.7)	23.9 (25.6)	16.1 (21.3)
102.7	16.3 (23.0)	12.6 (17.0)	7.0 (10.3)
<b>0.060 inch</b>			
10.7	40.8 (50.9)	43.4 (48.2)	10.5 (34.8)
19.2	31.3 (43.7)	30.7 (33.5)	19.9 (26.1)
102.7	20.6 (27.9)	17.7 (22.3)	8.1 (11.7)
<b>NORMAL FORCE<sup>3,4</sup></b>			
<b>0.015 inch</b>			
10.7	3.6 (2.2 to 4.9)	1.7 (1.4 to 1.9)	-0.3 (-0.6 to 0.1)
19.2	3.4 (2.2 to 4.3)	1.4 (1.0 to 1.7)	.3 ( -.1 to .6)
102.7	2.7 (1.3 to 4.8)	1.1 ( .5 to 2.1)	.4 ( -.1 to 1.2)
<b>0.030 inch</b>			
10.7	5.7 (3.1 to 7.6)	2.8 (2.5 to 3.2)	-.8 (-1.5 to .1)
19.2	5.6 (3.2 to 8.0)	2.1 (1.7 to 2.6)	-.4 ( -.9 to .1)
102.7	3.3 (2.0 to 5.0)	.9 ( .5 to 1.7)	.1 ( -.4 to .7)
<b>0.045 inch</b>			
10.7	8.2 (5.0 to 11.1)	3.7 (2.7 to 4.5)	-.7 (-2.0 to .2)
19.2	6.7 (3.8 to 10.8)	2.7 (2.3 to 3.1)	-.9 (-1.5 to -.3)
102.7	4.3 (2.2 to 6.0)	1.1 ( .5 to 1.8)	-.3 (-1.0 to .2)
<b>0.060 inch</b>			
10.7	10.3 4.9 to 13.4)	5.1 4.6 to 5.7	-.6 (-2.6 to .3)
19.2	8.0 5.0 to 12.2)	3.4 2.6 to 3.8	-1.1 (-1.9 to .0)
102.7	5.6 3.0 to 8.6)	1.1 .5 to 1.8	-.5 (-1.1 to .3)

1 Clearance angle 15°; cutting velocity 5 inches per minute.

2 The first number in each entry is the average cutting force; the numbers following in parentheses are maximum forces (average of five).

3 The first number in each entry is the average cutting force; the numbers following in parentheses are minimum and maximum forces (average of five).

4 A negative normal force indicates that the knife tended to lift the workpiece; force was positive when the knife pushed the workpiece.

**TABLE 19C.--TOOL FORCES WHEN ORTHOGONALLY CUTTING SWEETBAY ACROSS THE GRAIN IN THE 90-90 DIRECTION<sup>1</sup>**

Depth of cut and moisture content (percent)	Rake angle, degrees		
	20	30	40
-----Pounds per 0.1 inch of knife-----			
<b>PARALLEL FORCE<sup>2</sup></b>			
<b>0.015 inch</b>			
11.0	16.9 (22.1)	14.5 (19.6)	11.1 (15.1)
17.6	14.5 (17.4)	11.8 (15.4)	9.4 (11.4)
146.5	9.8 (11.6)	9.5 (11.0)	6.8 ( 8.2)
<b>0.030 inch</b>			
11.0	26.1 (33.1)	22.7 (30.9)	18.6 (22.0)
17.6	25.3 (29.4)	19.0 (22.8)	14.7 (18.0)
146.5	19.0 (21.4)	15.7 (19.3)	10.1 (12.4)
<b>0.045 inch</b>			
11.0	28.6 (37.4)	27.4 (37.0)	24.5 (31.2)
17.6	29.4 (36.0)	25.7 (30.2)	19.0 (23.2)
146.5	24.6 (28.5)	19.1 (23.9)	13.2 (15.9)
<b>0.060 inch</b>			
11.0	33.6 (49.0)	29.5 (38.5)	27.6 (40.4)
17.6	31.5 (40.0)	30.6 (37.1)	22.7 (28.9)
146.5	29.2 (35.8)	22.8 (28.3)	17.4 (22.7)
<b>NORMAL FORCE<sup>3,4</sup></b>			
<b>0.015 inch</b>			
11.0	3.2 (1.4 to 6.9)	1.7 ( 0.0 to 4.3)	-0.2 (-2.2 to 1.9)
17.6	1.8 (1.1 to 3.5)	.4 ( -.4 to 1.4)	-.8 (-1.3 to .1)
146.5	.8 ( .6 to 1.3)	.1 ( -.4 to 6)	-.7 (-1.2 to -.1)
<b>0.030 inch</b>			
11.0	5.1 (2.1 to 9.4)	2.0 (-1.0 to 6.9)	-2.2 (-3.4 to .9)
17.6	2.8 (1.3 to 4.9)	-.2 (-1.5 to 1.2)	-2.1 (-3.5 to -.6)
146.5	1.1 ( .5 to 1.8)	-.8 (-2.0 to .2)	-1.8 (-2.8 to -1.0)
<b>0.045 inch</b>			
11.0	7.2 (2.6 to 13.9)	2.8 (-1.3 to 7.9)	-2.4 (-5.6 to 3.9)
17.6	3.3 ( .5 to 5.5)	-1.2 (-3.1 to 1.2)	-3.3 (-5.2 to -.6)
146.5	1.2 ( .1 to 2.3)	-1.6 (-3.0 to .0)	-2.9 (-4.5 to -1.2)
<b>0.060 inch</b>			
11.0	7.3 (1.6 to 17.9)	4.5 (-2.1 to 12.2)	-1.9 (-7.5 to 4.8)
17.6	3.0 ( .4 to 6.1)	-1.6 (-4.3 to 1.7)	-4.6 (-7.2 to -.8)
146.5	1.3 (-.8 to 3.6)	-2.3 (-4.3 to -.2)	-4.7 (-6.7 to -2.1)

<sup>1</sup> Clearance angle 15°; cutting velocity 5 inches per minute.

<sup>2</sup> The first number in each entry is the average cutting force; the numbers following in parentheses are maximum forces (average of five).

<sup>3</sup> The first number in' each entry is the average cutting force; the numbers following in parentheses are minimum and maximum forces (average of five).

<sup>4</sup> A negative normal force indicates that the knife tended to lift the workpiece; force was positive when the knife pushed the workpiece.

**TABLE 20A.--TOOL FORCES WHEN ORTHOGONALLY CUTTING SWEETGUM VENEER IN THE 0-90 DIRECTION<sup>1</sup>**

Depth of cut and moisture content (percent)	Rake angle, degrees		
	50	60	70
	-----Pounds per 0.1 inch of knife-----		
<b>PARALLEL FORCE<sup>2</sup></b>			
<b>0.015 inch</b>			
11.4	2.2 (3.5)	2.4 (3.3)	<b>3.8 (7.2)</b>
20.4	2.0 (2.8)	1.7 (2.0)	2.9 (4.9)
157.0	1.6 (2.0)	1.3 (1.6)	2.9 (4.1)
<b>0.030 inch</b>			
11.4	3.3 (5.8)	<b>3.3 (5.1)</b>	2.5 (3.6)
20.4	3.0 (4.6)	2.3 (3.4)	2.1 (2.6)
157.0	2.0 (3.2)	1.9 (2.4)	1.7 (2.0)
<b>0.045 inch</b>			
11.4	3.6 (7.5)	3.6 (6.7)	2.8 (4.9)
20.4	3.4 (5.5)	3.1 (4.3)	2.7 (3.6)
157.0	2.6 (4.3)	2.1 (3.0)	2.1 (2.6)
<b>0.060 inch</b>			
11.4	4.0 (9.6)	3.6 (8.0)	3.2 (6.2)
20.4	3.8 (6.8)	3.3 (5.5)	3.3 (4.4)
157.0	3.0 (5.0)	2.5 (4.3)	2.4 (3.5)
<b>NORMAL FORCE<sup>3,4</sup></b>			
<b>0.015 inch</b>			
11.4	<b>0.0 (-0.3 to 0.5)</b>	<b>-0.2 (-0.5 to 0.2)</b>	<b>-1.2 (-2.5 to 0.1)</b>
20.4	-0.1 (-0.4 to .3)	-0.4 (-0.7 to -0.1)	-0.5 (-1.6 to .6)
157.0	.1 (-0.1 to .3)	.0 (-0.3 to .3)	-0.5 (-1.3 to .3)
<b>0.030 inch</b>			
11.4	-0.4 (-1.1 to .3)	-0.8 (-1.4 to .0)	-0.3 (-0.7 to .3)
20.4	-0.6 (-1.0 to -0.1)	-0.9 (-1.3 to -0.5)	-0.4 (-0.6 to -0.1)
157.0	-0.3 (-0.6 to .1)	-0.4 (-0.8 to .0)	.2 (-0.2 to .4)
<b>0.045 inch</b>			
11.4	-0.7 (-1.7 to .2)	-0.8 (-2.1 to .2)	-0.7 (-1.4 to .0)
20.4	-0.8 (-1.4 to .0)	-1.3 (-1.9 to -0.5)	-0.9 (-1.3 to -0.2)
157.0	-0.4 (-1.0 to .2)	-0.7 (-1.2 to -0.1)	-0.3 (-0.7 to .2)
<b>0.060 inch</b>			
11.4	-0.7 (-2.0 to .4)	-0.9 (-2.4 to .3)	-0.8 (-1.9 to .3)
20.4	-1.0 (-1.9 to .1)	-1.5 (-2.4 to -0.2)	-1.3 (-2.0 to .1)
157.0	-0.6 (-1.3 to .2)	-0.9 (-1.6 to .0)	-0.8 (-1.2 to .1)

<sup>1</sup> Clearance angle 0°; cutting velocity 5 inches per minute.

<sup>2</sup> The first number in each entry is the average cutting force; the numbers following in parentheses are maximum forces (average of five).

<sup>3</sup> The first number in each entry is the average cutting force; the numbers following in parentheses are minimum and maximum forces (average of five).

<sup>4</sup> A negative normal force indicates that the knife tended to lift the workpiece; force was positive when the knife pushed the workpiece.

**TABLE 20B.--TOOL FORCES WHEN ORTHOGONALLY CUTTING SWEETGUM PARALLEL TO THE GRAIN IN THE 90-0 DIRECTION<sup>1</sup>**

Depth of cut and moisture content (percent)	Rake-angle, degrees		
	10	20	30
-----Pounds per 0.1 inch of knife-----			
<b>PARALLEL FORCE<sup>2</sup></b>			
<b>0.015 inch</b>			
10.9	13.5 (18.2)	12.6 (13.9)	9.2 (11.8)
20.0	8.3 (9.7)	7.4 (7.9)	6.1 (6.9)
130.0	5.8 (7.3)	4.9 (6.0)	3.5 (4.2)
<b>0.030 inch</b>			
10.9	27.7 (36.2)	24.2 (26.8)	14.1 (23.3)
20.0	15.3 (19.6)		
130.0	10.7 (14.0)	14.1 (15.7)	11.2 (13.2)
<b>0.045 inch</b>			
10.9	33.7 (45.6)	32.6 (36.7)	12.7 (34.4)
20.0	21.4 (28.6)	20.8 (22.8)	15.2 (19.0)
130.0	14.8 (20.3)	12.2 (15.4)	8.0 (10.7)
<b>0.060 inch</b>			
10.9	43.2 (56.8)	42.0 (49.9)	11.3 (40.5)
20.0	28.2 (37.3)	27.4 (31.5)	16.3 (24.9)
130.0	17.7 (25.5)	16.5 (19.6)	9.1 (12.4)
<b>NORMAL FORCE<sup>3,4</sup></b>			
<b>0.015 inch</b>			
10.9	4.3 (2.02 to 6.2)	2.1 (1.7 to 2.4)	-0.2 (-0.6 to 0.2)
20.0	2.6 (1.8 to 3.3)	1.1 (.9 to 1.5)	.2 (-.1 to .3)
130.0	2.2 (1.2 to 2.7)	.9 (.8 to 1.1)	.5 (.2 to .8)
<b>0.030 inch</b>			
10.9	7.7 (4.6 to 10.7)	3.3 (2.9 to 3.8)	-.7 (-1.5 to .0)
20.0	4.3 (2.8 to 5.3)	1.7 (1.4 to 2.1)	-.4 (-.7 to .0)
130.0	3.2 (1.9 to 4.4)	1.2 (.9 to 1.5)	.3 (-.2 to .6)
<b>0.045 inch</b>			
10.9	9.3 (5.5 to 12.5)	4.2 (3.6 to 4.8)	-.7 (-2.3 to .2)
20.0	6.0 (3.9 to 8.6)	2.3 (1.9 to 2.6)	-.7 (-1.3 to -.1)
130.0	4.0 (2.3 to 5.3)	1.3 (.9 to 1.8)	.0 (-.5 to .7)
<b>0.060 inch</b>			
10.9	11.6 (7.4 to 15.5)	5.1 (4.1 to 5.9)	-.9 (-2.6 to .0)
20.0	7.4 (4.3 to 10.3)	2.4 (1.9 to 2.9)	-.8 (-1.8 to .1)
130.0	4.8 (2.7 to 6.4)	1.5 (1.2 to 2.0)	.0 (-.6 to .9)

<sup>1</sup>Clearance angle 15°; cutting velocity 5 inches per minute..

<sup>2</sup>The first number in each entry is the average cutting force; the numbers following in parentheses are maximum forces (average of five).

<sup>3</sup>The first number in each entry is the average cutting force; the numbers following in parentheses are minimum and maximum forces (average of five).

<sup>4</sup>A negative normal force indicates that the knife tended to lift the workpiece; force was positive when the knife pushed the workpiece.

**TABLE 20C.--TOOL FORCES WHEN ORTHOGONALLY CUTTING SWEETGUM ACROSS THE GRAIN IN THE 90-90 DIRECTION<sup>1</sup>**

Depth of cut and moisture content (percent)	Rake-angle, degrees		
	20	30	40

-----Pounds per 0.1 inch of knife -----

**PARALLEL FORCE<sup>2</sup>**

<b>0.015 inch</b>			
10.6	15.9 (20.3)	13.6 (16.7)	10.0 (12.1)
19.2			7.8 (9.7)
147.9	14.0 (16.6)	10.6 (12.6)	6.9 (7.9)
<b>0.030 inch</b>	9.5 (10.8)	8.6 (10.2)	
10.6	28.0 (33.8)	21.6 (26.0)	16.4 (21.2)
19.2	24.9 (27.9)	16.8 (18.9)	12.8 (14.8)
147.9	17.4 (20.0)	14.9 (17.6)	10.3 (12.5)
<b>0.045 inch</b>			
10.6	36.1 (44.7)	31.8 (39.0)	20.7 (26.8)
19.2	32.9 (37.0)	23.2 (26.7)	17.1 (21.5)
147.9	24.2 (27.8)	18.3 (22.3)	13.0 (16.9)
<b>0.060 inch</b>			
10.6	40.7 (53.8)	36.3 (45.4)	27.5 (37.8)
19.2	36.1 (42.7)	28.7 (33.6)	21.0 (28.5)
147.9	30.0 (53.9)	22.4 (27.1)	15.3 (20.5)

**NORMAL FORCE<sup>3,4</sup>**

<b>0.015 inch</b>			
10.6	1.8 (0.7 to 2.8)	0.5 (-0.2 to 1.8)	-1.3 (-2.0 to -0.4)
19.2	1.8 (1.1 to 2.6)	.2 (-.5 to .6)	-1.0 (-1.4 to -.4)
147.9	.9 (.6 to 1.3)	.0 (-.4 to .4)	-.7 (-1.0 to -.1)
<b>0.030 inch</b>			
10.6	4.0 (1.7 to 6.0)	.2 (-1.0 to 1.7)	-3.1 -4.4 to -1.6)
19.2	2.2 (1.2 to 3.5)	-.7 (-1.8 to .4)	-2.4 -3.2 to -1.4)
147.9	.9 (.6 to 1.6)	-.8 (-1.8 to .0)	-2.0 -2.9 to -1.0)
<b>0.045 inch</b>			
10.6	5.6 (2.5 to 9.3)	-.5 (-2.7 to 2.0)	-4.3 (-6.2 to -1.8)
19.2	3.1 (1.6 to 5.0)	-1.7 (-3.2 to -.2)	-3.7 (-5.3 to -1.7)
147.9	.8 (-.2 to 1.9)	-1.5 (-2.9 to -.3)	-3.3 (-4.9 to -1.4)
<b>0.060 inch</b>			
10.6	5.2 (1.6 to 9.4)	-.1 (-2.5 to 3.4)	-5.7 (-8.9 to -1.8)
19.2	2.6 (.2 to 4.8)	-2.6 (-4.7 to -.6)	-5.2 (-7.6 to -1.7)
147.9	.6 (-1.2 to 2.2)	-2.3 (-4.5 to -.5)	-4.7 (-7.0 to -.8)

<sup>1</sup>Clearance angle 15°; cutting velocity 5 inches per minute.  
<sup>2</sup>The first number in each entry is the average cutting force; the numbers following in parentheses are maximum forces (average of five).  
<sup>3</sup>The first number in each entry is the average cutting force; the numbers following in parentheses are minimum and maximum forces (average of five).  
<sup>4</sup>A negative normal force indicates that the knife tended to lift the workpiece; force was positive when the knife pushed the workpiece.

**TABLE 21A.--TOOL FORCES WHEN ORTHOGONALLY CUTTING BLACK TUPELO VENEER IN THE 0-90 DIRECTION'**

Depth of cut and moisture content (percent)	Rake angle, degrees		
	50	60	70
-----Pounds per 0.1 inch of knife-----			
<b>PARALLEL FORCE<sup>2</sup></b>			
<b>0.015 inch</b>			
11.4	3.1 ( 5.4)	<b>2.8 ( 4.2)</b>	3.7 ( 5.7)
19.5	2.7 ( 3.8)	2.3 ( 3.4)	3.8 ( 7.5)
124.7	1.8 ( 2.5)	1.5 ( 2.1)	3.7 ( 5.4)
<b>0.030 inch</b>			
11.4	4.5 ( 7.8)	3.9 ( 6.6)	<b>3.3 ( 4.9)</b>
19.5	3.8 ( 5.5)	3.4 ( 4.8)	
124.7	2.7 ( 3.9)	2.2 ( 3.0)	2.8 ( 3.7)
<b>0.045 inch</b>			
11.4	<b>5.1 (10.3)</b>	4.6 ( 9.2)	<b>4.4 ( 7.0)</b>
19.5	4.8 ( 7.5)	4.1 ( 6.3)	<b>3.3 ( 4.7)</b>
124.7	3.0 ( 5.2)	2.8 ( 4.2)	<b>2.6 ( 3.4)</b>
<b>0.060 inch</b>			
11.4	5.7 (12.4)	<b>5.4 (10.4)</b>	<b>5.2 (10.0)</b>
19.5	5.3 ( 8.8)	4.8 ( 7.5)	4.1 ( 6.0)
124.7	3.5 ( 6.4)	3.1 ( 5.2)	3.0 ( 4.1)
<b>NORMAL FORCE<sup>3,4</sup></b>			
<b>0.015 inch</b>			
11.4	<b>-0.4 (-1.0 to 0.3)</b>	<b>-0.5 (-0.9 to .0)</b>	<b>-0.5 (-1.6 to 0.7)</b>
19.5	-.3 ( -.7 to .0)	-.7 (-1.0 to .0)	-.8 (-2.6 to .5)
124.7	-.1 ( -.3 to .2)	-.3 ( -.6 to .1)	<b>-1.3 (-2.4 to -.1)</b>
<b>0.030 inch</b>			
11.4	-.9 (-1.9 to .2)	<b>-1.1 (-2.2 to -.1)</b>	-.6 (-1.5 to .3)
19.5	<b>-1.0 (-1.6 to -.1)</b>	<b>-1.4 (-2.1 to -.6)</b>	-.8 (-1.2 to -.1)
124.7	-.5 ( -.9 to .1)	-.8 (-1.3 to -.3)	-.1 ( -.5 to .4)
<b>0.045 inch</b>			
11.4	<b>-1.1 (-2.3 to .0)</b>	<b>-1.2 (-2.6 to .1)</b>	<b>-1.1 (-2.3 to .0)</b>
19.5	<b>-1.1 (-2.3 to -.2)</b>	<b>-1.8 (-2.7 to -.5)</b>	<b>-1.5 (-2.2 to -.5)</b>
124.7	-.7 (-1.3 to .2)	<b>-1.1 (-1.8 to -.3)</b>	-.9 (-1.3 to -.3)
<b>0.060 inch</b>			
11.4	<b>-1.2 (-3.0 to .3)</b>	<b>-1.3 (-2.9 to .3)</b>	<b>-1.2 (-2.9 to .7)</b>
19.5	<b>-1.5 (-2.8 to -.2)</b>	<b>-2.0 (-3.3 to -.5)</b>	<b>-2.0 (-3.0 to -.7)</b>
124.7	-.8 (-1.7 to .2)	<b>-1.5 (-2.5 to -.3)</b>	<b>-1.3 (-2.0 to -.3)</b>

<sup>1</sup>Clearance angle 0°; cutting velocity 5 inches per minute,

<sup>2</sup>The first number in each entry is the average cutting force; the numbers following in parentheses are maximum forces (average of five).

<sup>3</sup>The first number in each entry is the average cutting force; the numbers following in parentheses are minimum and maximum forces (average of five).

<sup>4</sup>A negative normal force indicates that the knife tended to lift the workpiece; force was positive when the knife pushed the workpiece.

**TABLE 21B.--TOOL FORCES WHEN ORTHOGONALLY CUTTING BLACK TUPELO PARALLEL TO THE GRAIN IN THE 90-0 DIRECTION<sup>1</sup>**

Depth of cut and moisture content (percent)	Rake angle, degrees		
	10	20	30
-----Pounds per 0.1 inch of knife-----			
<b>PARALLEL FORCE<sup>2</sup></b>			
<b>0.015 inch</b>			
10.9	15.0 (20.2)	11.6 (13.4)	9.0 (12.3)
19.1	9.9 (14.8)	7.5 ( 9.0)	7.5 ( 8.9)
113.0	7.3 ( 9.6)	5.5 ( 6.5)	4.1 ( 4.6)
<b>0.030 inch</b>			
10.9	26.8 (35.3)	26.7 (30.6)	14.7 (23.1)
19.1	17.8 (24.8)		12.7 (14.7)
113.0	14.0 (18.9)	15.6 (18.4)	6.8 ( 8.0)
<b>0.045 inch</b>			
10.9	35.3 (47.7)	37.1 (41.4)	14.7 (31.2)
19.1	25.8 (34.4)	21.2 (24.2)	14.7 (18.8)
113.0	17.2 (25.2)	11.2 (14.3)	9.3 (11.0)
<b>0.060 inch</b>			
10.9	43.3 (58.7)	48.5 (52.8)	15.6 (40.7)
19.1	34.8 (43.8)	28.3 (31.0)	18.0 (22.9)
113.0	21.2 (27.4)	14.8 (19.9)	13.3 (16.3)
<b>NORMAL FORCE<sup>3,4</sup></b>			
<b>0.015 inch</b>			
10.9	4.9 (2.9 to 7.0)	1.7 (1.4 to 2.2)	-0.1 (-0.5 to 0.3)
19.1	4.2 (1.8 to 6.5)	1.3 ( .9 to 2.1)	.1 ( -.3 to .5)
113.0	3.0 (1.5 to 5.2)	1.2 ( .8 to 1.4)	.5 ( .2 to .7)
<b>0.030 inch</b>			
10.9	7.8 (4.1 to 10.3)	3.3 (2.8 to 3.8)	-.5 (-1.4 to .2)
19.1	6.4 (2.8 to 10.1)	2.0 (1.4 to 2.7)	-.3 (-.8 to .1)
113.0	4.7 (2.3 to 6.5)	1.2 ( .7 to 1.6)	.2 ( -.1 to .4)
<b>0.045 inch</b>			
10.9	9.9 (6.0 to 13.0)	4.4 (3.7 to 5.0)	-.7 (-2.3 to .5)
19.1	8.0 (4.4 to 11.4)	2.4 (2.0 to 3.2)	-.4 (-1.1 to .2)
113.0	5.4 (2.7 to 8.0)	1.2 ( .7 to 1.6)	.0 ( -.3 to .4)
<b>0.060 inch</b>			
10.9	11.3 (7.2 to 15.5)	5.7 (5.1 to 6.1)	-1.0 (-3.0 to .3)
19.1	9.9 (5.2 to 13.0)	3.2 (2.5 to 3.9)	-.9 (-1.7 to -.1)
113.0	6.3 (3.3 to 8.9)	1.2 ( .5 to 2.2)	-.6 (-1.0 to -.1)

<sup>1</sup>Clearance angle 15°; cutting velocity 5 inches per minute.

<sup>2</sup>The first number in each entry is the average cutting force; the numbers following in parentheses are maximum forces (average of five).

<sup>3</sup>The first number in each entry is the average cutting force; the numbers following in parentheses are minimum and maximum forces (average of five).

<sup>4</sup>A negative normal force indicates that the knife tended to lift the workpiece; force was positive when the knife pushed the workpiece.

**TABLE 21C.--TOOL FORCES WHEN ORTHOGONALLY CUTTING BLACK TUPELO ACROSS THE GRAIN IN THE 90-90 DIRECTION<sup>1</sup>**

Depth of cut and moisture content (percent)	Rake angle, degrees		
	20		
Pounds per 0.1 inch of knife-----			
<b>PARALLEL FORCE<sup>2</sup></b>			
<b>0.015 inch</b>			
10.4	20.1 (27.8)	17.0 (20.7)	10.9 (13.7)
19.0	15.6 (17.7)		
125.2	11.5 (13.5)	12.2 (14.2),	9.9 (11.6),
<b>0.030 inch</b>		9.5 (11.0)	7.5 (8.7)
10.4	34.4 (44.6)	27.4 (34.4)	20.5 (25.5)
19.0	30.0 (35.1)	20.5 (24.3)	15.3 (18.2)
125.2	19.8 (22.7)	15.0 (18.3)	10.9 (12.4)
<b>0.045 inch</b>			
10.4	45.9 (61.4)	37.3 (45.2)	28.3 (34.4)
19.0	37.8 (45.2)	25.6 (30.3)	20.1 (24.2)
125.2	28.1 (32.3)	19.5 (23.4)	14.1 (17.0)
<b>0.060 inch</b>			
10.4	59.5 (71.8)	46.0 (56.7)	35.9 (45.0)
19.0	45.9 (56.6)	34.4 (41.9)	25.0 (31.4)
125.2	34.2 (39.5)	24.7 (31.5)	17.5 (22.2)
<b>NORMAL FORCE<sup>3,4</sup></b>			
<b>0.015 inch</b>			
10.4	2.6 (0.8 to 7.8)	0.4 (-0.6 to 2.9)	-1.5 (-2.3 to -0.4)
19.0	1.6 (1.1 to 2.1)	-.1 (-.6 to .5)	-1.3 (-1.9 to -.7)
125.2	.8 (.6 to 1.3)	-.5 (-.5 to -.6)	-1.2 (-1.8 to -.8)
<b>0.030 inch</b>			
10.4	3.5 (.8 to 7.2)	-.7 (-2.6 to 3.3)	-4.6 (-6.2 to -1.4)
19.0	2.1 (1.3 to 3.7)	-1.3 (-2.2 to -.2)	-3.2 (-4.3 to -2.2)
125.2	.9 (.4 to 1.8)	-1.0 (-2.1 to .1)	-2.6 (-3.4 to -1.7)
<b>0.045 inch</b>			
10.4	4.6 (1.3 to 9.1)	-1.5 (-4.6 to 3.9)	-6.1 (-8.7 to -1.6)
19.0	2.3 (1.2 to 4.0)	-2.4 (-4.0 to -.5)	-4.8 (-6.7 to -2.9)
125.2	.8 (-.4 to 1.7)	-2.3 (-3.4 to -.7)	-3.9 (-5.6 to -2.6)
<b>0.060 inch</b>			
10.4	4.9 (-.2 to 12.3)	-3.1 (-6.3 to 5.4)	-8.4 (-12.7 to -3.5)
19.0	1.7 (.1 to 4.7)	-3.6 (-6.4 to -.7)	-6.9 (-9.7 to -3.3)
125.2	.6 (-.5 to 2.6)	-3.2 (-5.9 to -1.5)	-5.0 (-7.1 to -2.7)

<sup>1</sup>Clearance angle 15°; cutting velocity 5 inches per minute.

<sup>2</sup>The first number in each entry is the average cutting force; the numbers following in parentheses are maximum forces (average of five).

<sup>3</sup>The first number in each entry is the average cutting force; the numbers following in parentheses are minimum and maximum forces (average of five).

<sup>4</sup>A negative normal force indicates that the knife tended to lift the workpiece; force was positive when the knife pushed the workpiece.

**TABLE 22A.--TOOL FORCES WHEN ORTHOGONALLY CUTTING YELLOW POPLAR VENEER IN THE 0-90 DIRECTION<sup>1</sup>**

Depth of cut and moisture content (percent)	Rake angle, degrees		
	50	60	70
-----Pounds per 0.1 inch of knife-----			
<b>PARALLEL FORCE<sup>2</sup></b>			
<b>0.015 inch</b>			
10.6	1.7 (3.5)	1.6 (2.8)	<b>3.4 (5.4)</b>
18.8	1.6 (3.4)	1.4 (2.5)	<b>2.4 (5.0)</b>
180.9	1.6 (2.3)	1.2 (1.8)	<b>2.2 (3.7)</b>
<b>0.030 inch</b>			
10.6	2.2 (4.7)	1.9 (3.9)	1.9 (3.3)
18.8	2.1 (4.0)	2.0 (3.5)	2.0 (3.0)
180.9	1.8 (3.1)	1.7 (2.3)	1.5 (2.2)
<b>0.045 inch</b>			
10.6	2.6 (6.1)	2.2 (4.9)	2.3 (4.4)
18.8	2.7 (5.4)	2.3 (4.2)	2.1 (3.4)
180.9	2.1 (3.7)	1.7 (2.7)	1.8 (2.4)
<b>0.060 inch</b>			
10.6	2.7 (6.8)	2.2 (5.7)	<b>2.4 (4.7)</b>
18.8	3.1 (5.8)	2.9 (5.3)	<b>2.5 (4.1)</b>
180.9	2.2 (4.3)	<b>2.0 (3.4)</b>	<b>2.1 (3.0)</b>

**PARALLEL FORCE<sup>3,4</sup>**

<b>0.015 inch</b>			
10.6	<b>0.2 (-0.2 to 0.8)</b>	<b>0.1 (-0.4 to .6)</b>	<b>-0.3 (-1.8 to 1.2)</b>
18.8	.3 (-.1 to 1.1)	.3 (-.3 to 1.0)	.3 (-.6 to 1.4)
180.9	.5 (.0 to 1.0)	.3 (-.2 to .8)	.0 (-1.0 to .9)
<b>0.030 inch</b>			
10.6	.0 (-.6 to .5)	-.3 (-.8 to .2)	.2 (-.5 to .9)
18.8	-.1 (-.5 to .6)	-.4 (-.9 to .2)	.1 (-.4 to .7)
180.9	.1 (-.4 to .7)	-.1 (-.6 to .2)	.3 (.0 to .7)
<b>0.045 inch</b>			
10.6	-.1 (-.9 to .6)	-.3 (-1.0 to .3)	-.3 (-1.0 to .5)
18.8	-.3 (-1.0 to .5)	-.5 (-1.2 to .0)	-.4 (-.9 to .4)
180.9	.1 (-.5 to .7)	-.3 (-.9 to .2)	-.1 (-.5 to .3)
<b>0.060 inch</b>			
10.6	-.1 (-1.4 to 1.2)	-.5 (-1.6 to .4)	-.4 (-1.3 to .7)
18.8	-.4 (-1.2 to .5)	-.8 (-1.6 to .3)	-.6 (-1.2 to .1)
180.9	-.1 (-.7 to .6)	-.6 (-1.2 to .0)	-.3 (-.8 to .4)

<sup>1</sup>Clearance angle 0°; cutting velocity 5 inches per minute.

<sup>2</sup>The first number in each entry is the average cutting force; the numbers following in parentheses are maximum forces (average of five).

<sup>3</sup>The first number in each entry is the average cutting force; the numbers following in parentheses are minimum and maximum forces (average of five).

<sup>4</sup>A negative normal force indicates that the knife tended to lift the workpiece; force was positive when the knife pushed the workpiece.

**TABLE 22B. -- TOOL FORCES WHEN ORTHOGONALLY CUTTING YELLOW POPLAR PARALLEL TO THE GRAIN IN THE 90-0 DIRECTION<sup>1</sup>**

Depth of cut and moisture content (percent)	Rake angle, degrees		
	10	20	30
-----Pounds per 0.1 inch of knife-----			
<b>PARALLEL FORCE<sup>2</sup></b>			
<b>0.015 inch</b>			
10.4	9.8 (12.9)	10.1 (12.2)	6.9 (10.3)
19.2	8.6 (10.7)	6.9 (7.8)	6.4 (7.4)
124.4	6.5 (7.9)	5.6 (7.1)	4.2 (5.4)
<b>0.030 inch</b>			
10.4	20.1 (25.5)	18.6 (25.2)	10.7 (19.8)
19.2	15.4 (20.2)	13.9 (15.9)	11.7 (15.0)
124.4	12.8 (16.8)	10.2 (11.8)	7.5 (9.7)
<b>0.045 inch</b>			
10.4	28.4 (36.4)	25.8 (35.3)	6.9 (24.6)
19.2	21.0 (26.5)	20.2 (23.1)	14.3 (21.8)
124.4	16.6 (20.4)	14.7 (17.6)	8.9 (12.0)
<b>0.060 inch</b>			
10.4	37.4 (45.7)	30.5 (43.3)	6.6 (30.2)
19.2	27.3 (34.2)	26.1 (30.7)	16.9 (29.2)
124.4	20.3 (26.6)	19.4 (22.7)	10.6 (17.4)
<b>NORMAL FORCE<sup>3,4</sup></b>			
<b>0.015 inch</b>			
10.4	2.6 1.3 to 4.0	1.4 (1.0 to 2.0)	-0.3 (-0.7 to 0.0)
19.2	3.2 2.3 to 4.2	1.3 (.9 to 1.6)	.4 (.0 to 1.0)
124.4	3.6 2.3 to 4.9	1.3 (.7 to 2.0)	1.0 (.3 to 1.7)
<b>0.030 inch</b>			
10.4	4.7 2.6 to 7.0	2.3 (1.6 to 2.9)	-.7 (-1.7 to .0)
19.2	4.8 3.0 to 6.4	1.8 (1.3 to 2.4)	-.1 (-.6 to .7)
124.4	5.7 2.4 to 8.6	1.6 (1.0 to 2.5)	.8 (-.0 to 2.1)
<b>0.045 inch</b>			
10.4	6.0 2.6 to 8.8	3.4 (2.6 to 4.2)	-.4 (-2.2 to .3)
19.2	6.6 3.2 to 9.5	2.2 (1.8 to 2.7)	-.3 (-1.3 to .5)
124.4	5.8 2.6 to 8.7	1.6 (.9 to 2.3)	.5 (-.2 to 1.4)
<b>0.060 inch</b>			
16.4	8.1 3.0 to 11.7	3.4 (2.5 to 4.1)	-.5 (-2.6 to .3)
19.2	7.7 3.9 to 10.9	2.9 (2.2 to 3.8)	-.4 (-1.8 to .8)
124.4	7.2 4.0 to 8.9	1.7 (.9 to 2.5)	.7 (-.4 to 1.6)

<sup>1</sup>Clearance angle 15°; cutting velocity 5 inches per minute.

<sup>2</sup>The first number in each entry is the average cutting force; the numbers following in parentheses are maximum forces (average of five).

<sup>3</sup>The first number in each entry is the average cutting force; the numbers following in parentheses are minimum and maximum forces (average of five).

<sup>4</sup>A negative normal force indicates that the knife tended to lift the workpiece; force was positive when the knife pushed the workpiece.

**TABLE 22C.--TOOL FORCES WHEN ORTHOGONALLY CUTTING YELLOW-POPLAR ACROSS THE GRAIN IN THE 90-90 DIRECTION**

Depth of cut and moisture content (percent)	Rake angle, degrees		
	20	30	40
-----Pounds per 0.1 inch of knife-----			
<b>PARALLEL FORCE<sup>1</sup></b>			
<b>0.015 inch</b>			
10.8	12.1 (16.7)	19.8 (23.3)	7.7 (10.8)
17.7	12.3 (14.7)	9.6 (13.4)	8.2 (10.4)
165.5	8.5 (10.2)	7.8 (9.0)	5.8 (7.0)
<b>0.030 inch</b>			
10.8	18.7 (26.4)	16.7 (22.9)	12.3 (15.8)
17.7	22.1 (27.4)	15.0 (20.1)	12.3 (15.1)
165.5	15.5 (18.2)	12.8 (15.2)	8.1 (9.8)
<b>0.045 inch</b>			
10.8	24.1 (37.2)	19.1 (24.2)	17.2 (22.5)
17.7	26.2 (32.7)	20.3 (25.0)	14.7 (19.0)
165.5	21.1 (24.3)	16.3 (19.5)	10.6 (14.0)
<b>0.060 inch</b>			
10.8	28.2 (46.3)	18.9 (28.8)	20.5 (25.1)
17.7	27.4 (35.6)	24.9 (29.2)	18.8 (24.3)
165.5	25.7 (29.2)	20.4 (25.4)	12.9 (16.6)

**NORMAL FORCE<sup>3,4</sup>**

<b>0.015 inch</b>			
10.8	3.3 (1.2 to 6.9)	1.2 (-0.2 to 3.0)	-0.3 (-1.5 to 1.4)
17.7	1.6 (.9 to 2.6)	.2 (-.3 to .8)	.1
165.5	.8 (.6 to 1.2)	.3 (.0 to .8)	-.6 (-.9 to .0)
<b>0.030 inch</b>			
10.8	4.2 (1.4 to 7.0)	-.3 (-1.6 to 4.0)	-1.0 (-2.4 to .4)
17.7		.6	-1.8 (-2.8 to -.9)
165.5	1.3 (.7 to 1.7)	-.1 (-.7 to .6)	-1.1 (-2.1 to -.5)
<b>0.045 inch</b>			
10.8	3.7 (1.8 to 5.6)	-.8 (-2.4 to 5.4)	-2.1 (-4.2 to .6)
17.7		.3	-2.7 (-4.5 to -1.2)
165.5	1.4 (.5 to 2.1)	-.5 (-1.6 to .3)	-2.1 (-3.3 to -1.0)
<b>0.060 inch</b>			
10.8	5.0 (.4 to 10.7)	3.4 (-.7 to 10.4)	-2.8 (-5.9 to 1.1)
17.7	2.9 (.2 to 4.9)	-1.4 (-2.7 to -.1)	-3.8 (-6.0 to -1.5)
165.5	1.3 (.1 to 2.6)	-.9 (-2.1 to .3)	-3.0 (-4.9 to -1.2)

<sup>1</sup>Clearance angle 15°; cutting velocity 5 inches per minute.

<sup>2</sup>The first number in each entry is the average cutting force; the numbers following in parentheses are maximum forces (average of five).

<sup>3</sup>The first number in each entry is the average cutting force; the numbers following in parentheses are minimum and maximum forces (average of five).

<sup>4</sup>A negative normal force indicates that the knife tended to lift the workpiece; force was positive when the knife pushed the workpiece.







**Woodson, G. E.**

1979. Tool forces and chip types in orthogonal cutting of southern hardwoods. U.S. Dep. Agric. For. Serv. Res. Pap. SO-146, 77 p. South. For. Exp. Stn., New Orleans, La.

One-eighth to one-quarter inch thick specimens from each of 22 hardwood species were cut at 5 inches per minute **orthogonally** — as with a carpenter's plane in the three major modes, that is, planing (90-0), veneer (0-90), and crosscut (90-90) directions. Parallel and normal cutting forces for various rake angles were measured at three moisture contents and four depths of cut.