FERIC *FOREST ENGINEERING RESEARCH INSTITUTE OF CANADA*
INSTITUT CANADIEN DE RECHERCHES EN GÉNIE FORESTIER

Analysis of Felling Butt-Damage in Interior British Columbia

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Technical Note TN-76

June, 1984

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PREFACE

In 1982 and 1983, FERIC published two reports on non-shear felling machinery in British Columbia. The first was Special Report SR-19, which contained results of a survey of 14 types of non-shear felling heads. Much of that report was subjective and included the comments of many users. The second publication, Special Report SR-19A, was a follow-up to the first. It contained measured information on the damage levels of many of the types identified earlier, as well as including other felling techniques (handfalling, some shears) for comparative purposes.

Both reports were restricted to study cooperators, member companies, and manufacturers and distributors of the products. Although the survey report was rapidly outdated by changes in machine types, numbers, locations and production performance, the butt-damage report contained data useful for industry managers. In January and February of 1984, FERIC made further measurements of butt-damage levels. The scope of felling techniques was expanded to include directional saw fellers, two more shears, two Koehring circular saws (previously unavailable in B.C. during the winter months) and additional Harricana and Denis circular-saw buncher heads.

This report includes previous data and the new data collected in 1984.

The intent of this report is:

(1) to report the measured butt-damage levels of trees felled by various techniques; and

(2) to comment on machine design features related to butt damage -- but this report does not constitute a complete engineering evaluation of the various machine styles.

FERIC gratefully acknowledges the cooperation of all staff members of the contractors and companies involved in these studies. The authors also wish to thank FERIC staff members for their assistance, particularly Pat Forrester who conducted the field studies, and Kristi Knox who checked, illustrated and arranged the manuscript for final publication.

Information in this report is given in metric units. Imperial units may occasionally be shown in parentheses. Appendix I contains a list of common conversion factors.

AUTHORS

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TABLE OF CONTENTS

LIST OF TABLES AND FIGURES

FIGURE		PAGE

SUMMARY

All styles of non-shear felling machines should significantly decrease butt damage and lumber loss as compared to shears. A reduction in the percent lumber loss by a factor of 4 to 10 can usually be expected. Based on the assumption that a mill will be cutting 2 X 6 (loss at the mill depends on the size of lumber sawn), the percent volume loss for non-shear machines winter-tested ranged from 0.12% to 1.86%, with 75% of these machines producing less than 1% loss. The four shears studied showed volume losses between 3.5 and 4.5 percent.

Results from a specific machine will also depend on stand conditions and on the operator. Among the stand conditions, tree size was found to have the greatest effect on butt-damage results; small trees usually exhibit larger proportional lumber losses. Species, frost depth, tree lean and other stand characteristics also affect damage levels.

The operator is important and can affect the amount of damage caused by a machine. However, we believe that a machine can be designed so that it produces minimum losses without placing excessive demands on the operator.

Several excellent and several poor design features were identified among the machines investigated. For a machine which will minimize butt damage:

- do not use shears;
- leave the tree free during the cutting process;
- design the cutting device so it is less sensitive to binding;
- design machine so that the stump will tend to split (not the log) when bending is applied to open the kerf; and
- eliminate any opportunity for the operator to apply uncontrolled stress to the tree during cutting.

Damage levels are already fairly low for most non-shears presently working in B.C. but the potential for further improvements exists by applying any of the above recommendations.

SOMMAIRE

Comparativement aux engins munis de cisaille, tous les types d'engins d'abattage sans cisaille devraient permettent de diminuer considérablement la perte de bois résultant des dommages causés à la bille de pied. On peut généralement s'attendre à réduire par un facteur de 4 à 10 le pourcentage de perte en bois. Reposant sur l'hypothèse que l'usine produira des 2 x 6 (la perte de bois à l'usine dépend des dimensions du bois scié) le pourcentage de perte en volume de bois pour les engins d'abattage sans cisaille, mis à l'essai en hiver, variait de .12% à 1.86% (75% de ces engins produisant une perte inférieure à 1%). Les quatres cisailles étudiées donnaient des pertes en volume allant de 3.5 à 4.5 pourcent.

Pour une machine donnée, les résultats dépendront également des conditions du peuplement et de l'opérateur. Parmi les conditions du peuplement, on a trouvé que le diamètre de l'arbre est celle qui exerce le plus d'influence sur les dommages causés à la bille de pied, les petits arbres donnant généralement une perte de bois proportionnellement plus forte. L'essence, la profondeur du gel, l'inclinaison de l'arbre ainsi que d'autres caractéristiques du peuplement affectent également le niveau des dommages.

L'opérateur est important et peut avoir un effet sur la gravité des dommages causés par une machine. Nous croyons toutefois possible de concevoir une machine qui produirait des pertes minimales, sans pour autant exiger toute l'attention d'un opérateur.

Parmi les machines étudiées, nous avons observé plusieurs caractéristiques de conception excellentes et plusieurs autres médiocres. Pour obtenir d'une machine le minimum de dommages causés à la bille de pied, nous recommandons:

- de ne pas se servir de cisailles;
- de laisser l'arbre libre au cours du processus d'abattage;
- de concevoir le dispositif de coupe de façon à ce qu'il soit moins sensible au coincement;
- de concevoir la machine de façon à ce que la souche ait tendance à fendre (et non la bille) lorsqu'on applique un effort de flexion pour ouvrir le trait de scié; et
- d'éliminer le risque que l'opérateur applique sur l'arbre une contrainte non contrôlée au cours de l'abattage.

La plupart des têtes d'abattage sans cisaille que l'on rencontre actuellement en Colombia-britannique ne causent que peu de dommages à la bille de pied, mais l'application de l'une ou l'autre des recommandations ci-dessus permettra d'autres améliorations.

INTRODUCTION

Non-shear mechanical felling is increasing in importance in British Columbia as more forest products companies refuse sheared wood because of unacceptable lumber losses. Interior B.C.'s lumber-based economy, combined with normal winter temperatures ranging from -10 degrees to -25 degrees Celsius, has focused industry attention on reducing wood-damage levels as one means of obtaining higher end-product recovery and value. Interior B.C. is unique in North America, and probably the world, because of the number of different felling machines that have been used specifically to combat wood-damage losses.

In October 1982, FERIC published a restricted report (SR-19) that identified 14 different types of heads at various levels of development. This was only a partial list because some large-capacity (91 cm) directional saw fellers were excluded. Some head designs received little industry support and are no longer manufactured. However, new designs have replaced those which faded. In February 1984, FERIC's Western Division was approached by two more manufacturers who would like to enter the non-shear market. Even excluding these, there are still approximately 15 types of non-shear felling heads, at various stages of development, available for the Interior B.C. market.

Obviously, confusion and difficulties have accompanied the introduction of non-shear technology. A purchaser is faced with a complex array of questions which must be answered before a purchase is made -- questions like suitability for expected conditions of tree size and terrain, expected productivity, purchase price, reliability, parts and service support, stump heights and operating costs. Many of these factors influence the choice of any piece of equipment, but two things have combined to make the introduction of non-shear felling in Interior B.C. somewhat extraordinary. These are the large number of relatively unproven designs available, and the fairly short time scale (8-14 months) of the widespread industry changeover from shear heads.

Given the problems and the time scale, it is unlikely that harvesting cost reductions have been realized by many forest companies. In many cases the reverse has occurred because contractors have negotiated higher rates to cover expensive purchase prices (compared to shears) and new categories of operating costs (possible carrier hydraulic modifications, increased stock of replacement cutting devices, cutter lubrication, sharpening and increased maintenance).

It therefore seems necessary to examine the basic reason that these devices were introduced -- to reduce wood damage so that more of what is harvested is available for conversion to income-producing product. Are these devices "saving" wood? If so, how much compared to widely-used handfallers and shears? Can anything be done to "save" more wood?

FERIC's studies on butt-damage levels were established to answer these questions. The objectives of these studies were:

(1) to determine quantitatively the wood loss resulting from butt damage caused by various felling methods;

(2) to investigate the different felling methods and determine the causes of butt damage; and

(3) to make recommendations so that future designs or modifications of non-shear heads result in minimum damage.

The remainder of this report is divided into three sections. The first section is fairly short and contains the results of the studies. The second identifies factors which have been observed to influence butt-damage levels. The third section contains conclusions drawn from this study.

DATA COLLECTION AND BUTT-DAMAGE RESULTS

TABLE 1 gives a description of all felling systems FERIC has measured in British Columbia. All studies were conducted in Interior B.C. winter conditions (January to early March). One machine was measured in 1982 and several were examined in 1984, but most of the studies were conducted in 1983. The felling systems are arranged in alphabetical order in TABLE 1. Included are a handfaller, 4 shears and a variety of non-shear heads, both buncher and director styles. For simplicity, the names given in the last column of TABLE 1 will be used in the rest of the report when referring to a particular machine.

The QM Shear was originally chosen in 1983 for comparison purposes as it has probably been the most widely-used shear in British Columbia. The Forano shear was specifically chosen in 1984 because of several verbal industry reports that this head produced little or no wood damage.

Butt-damage data collection and analysis followed a procedure defined by FERIC's Western Division in 1981. The procedure, nicknamed the "Bicycle Wheel Method", allows one to calculate wood volume losses attributable to felling damage from measurements taken on logs at the felling site. The losses thus calculated approximate actual lumber losses in the mill. FERIC Technical Note TN-52 fully describes the method.

TABLE 1. Description and Location of Felling Systems Studied.

Felling System	Year Studied	Max. Stump Diameter cm (in)	Carrier	Location	Abbreviated Name
Anda Feller Buncher	*	61 (24)	Drott 50	Ft. St. James	Anda
Drott Auger Feller Buncher		61 (24)	Drott 50	Prince George	Auger
Dag Chainsaw Director		51 (20)	Komatsu D65	Ft. St. James	Dag
Denis Feller Buncher		51 (20)	Drott 40	Fraser Lake	Denis 1
Denis Feller Buncher	1984	51 (20)	Drott 40	Mackenzie	Denis 2
Dika Feller Buncher		71 (28)	Caterpillar 235	Prince George	Dika Buncher
Dika Feller Director	1984	91 (36)	Caterpillar D6	Prince George	Dika Director
Forano Feller Buncher	1984	51 (20)	Drott 40	Vanderhoof	Forano 1
Forano Feller Buncher	1984	51 (20)	Drott 40	Vanderhoof	Forano 2
Hand Faller		N/A	N/A	Prince George	Hand Faller
Harricana Feller Buncher		56 (22)	Caterpillar 225/235	Ft. St. James	Harricana 1
Harricana Feller Buncher		51 (20)	Drott 40	Kamloops	Harricana 2
Harricana Feller Buncher	1984	51 (20)	Caterpillar 225	Mackenzie	Harricana 3
Hultdins Felling Saw		61 (24)	TJ 520 Clambunk	Telkwa	Hultdins
Koehring Feller Buncher	1984	56 (22)	Koehring 266	Fraser Lake	Koehring 1
Koehring Feller Buncher	1984	51 (20)	Hitachi U-122	Mackenzie	Koehring 2
Kockums Feller Buncher	1982	55 (22)	Drott 40	Princeton	Kockums 1
Kockums Feller Buncher		55 (22)	John Deere 693-B	Princeton	Kockums 2
Northwood/FERIC Feller Director		91 (36)	FMC	Prince George	NW/FERIC FD
Ösa 670 Feller Buncher		56 (22)	Ösa	Houston	Ösa
QM Feller Director	1984	74 (29)	Caterpillar D6	Vanderhoof	QM Saw Director
QM Shear (Snipper)		71 (28)	Caterpillar D7G	Prince George	QM Shear 1
QM Shear (Snipper)		71 (28)	International 175	Prince George	QM Shear 2
RotoSaw Feller Director	1984	76 (30)	International 175	Tumbler Ridge	RotoSaw Director
Spencer Feller Buncher		48 (19)	Drott 40	Princeton	Spencer

* All unlabelled felling systems were measured in 1983.

TABLE 2 contains summarized results of the butt-damage studies. The felling systems have been ranked in order of increasing percent volume loss. Volume loss is that loss due to butt shatter in the tree (exclusive of other forms of felling breakage) expressed as a percentage of all lumber potentially recoverable from the tree. An average of 55 trees were sampled for each of the 25 studies (range: 21 to 77). Sample sizes for the Denis 2 (21 trees) and the Kockums 1 (26 trees) were smaller than preferred. Both studies were stopped early because of conditions beyond our control -- strike closure for the Denis 2 and snow closure for the Kockums 1. It is possible that the summaries for these two machines are not representative of their true performance, so the results should be interpreted with caution.

TABLE 2. Butt-Damage Summary.
(Ascending Order of % Volume Loss)

Rank	Felling System	% Volume Loss (2 x 6 basis)	No. of Trees Measured	Trees with Damage No.	%	Av. Butt Diameter cm
1	Handfaller	0.05	57	2	4	35.3
2	Spencer	0.12	44	7	16	36.1
3	Koehring 2	0.15	64	5	8	33.2
4	Harricana 2	0.17	68	9	13	28.0
5	Harricana 1	0.20	57	9	16	31.5
6	Dag	0.41	50	17	34	30.4
7	Dika Buncher	0.45	54	22	41	34.6
8	Osa	0.49	56	16	29	27.1
9	Denis 2	0.56	21	6	29	31.7
10	Dika Director	0.62	65	32	49	36.1
11	Kockums 2	0.63	58	38	66	31.7
12	Hultdins	0.67	53	30	57	37.1
13	Auger	0.73	56	16	29	25.5
14	Koehring 1	0.83	64	17	27	27.7
15	Anda	0.88	75	44	59	34.5
16	Kockums 1	0.92	26	11	42	31.0
17	Denis 1	1.28	77	31	40	25.8
18	RotoSaw Director	1.30	64	49	77	31.0
19	QM Saw Director	1.43	64	22	34	25.2
20	Harricana 3	1.46	50	22	44	31.1
21	NW/FERIC FD	1.86	39	30	77	40.7
22	Forano 1 (shear)	3.34	64	57	89	25.0
23	Forano 2 (shear)	3.36	55	51	93	35.1
24	QM Shear 1	3.36	38	38	100	41.1
25	QM Shear 2	4.54	56	55	98	30.3

Detailed results by diameter classes, species and different lumber classes are available on request from FERIC.

The average lumber size is assumed to be 2 X 6. The percent volume loss is a function of the average size of lumber cut by the mill. FIGURE A illustrates the fact that the larger the lumber cut, the greater the loss from splitting. As an example, FIGURE B shows how the percent lumber loss for Kockums 2 increases as the size of the lumber increases.

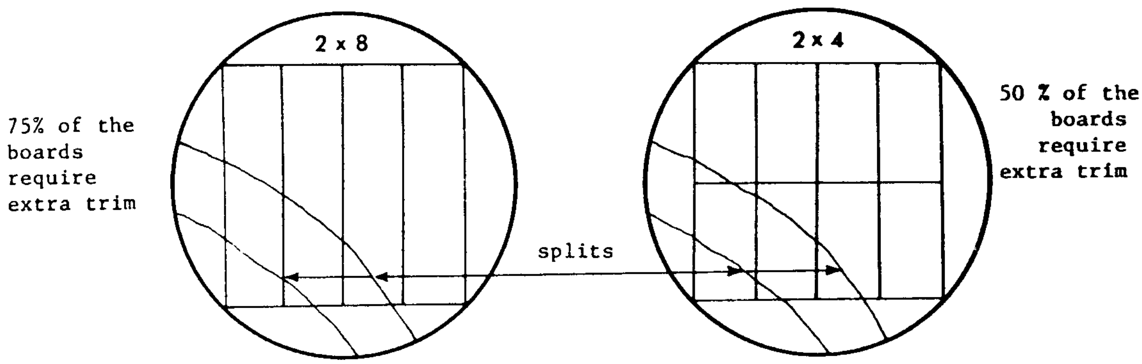


FIGURE A. The larger the lumber size the greater the percentage of boards with damage.

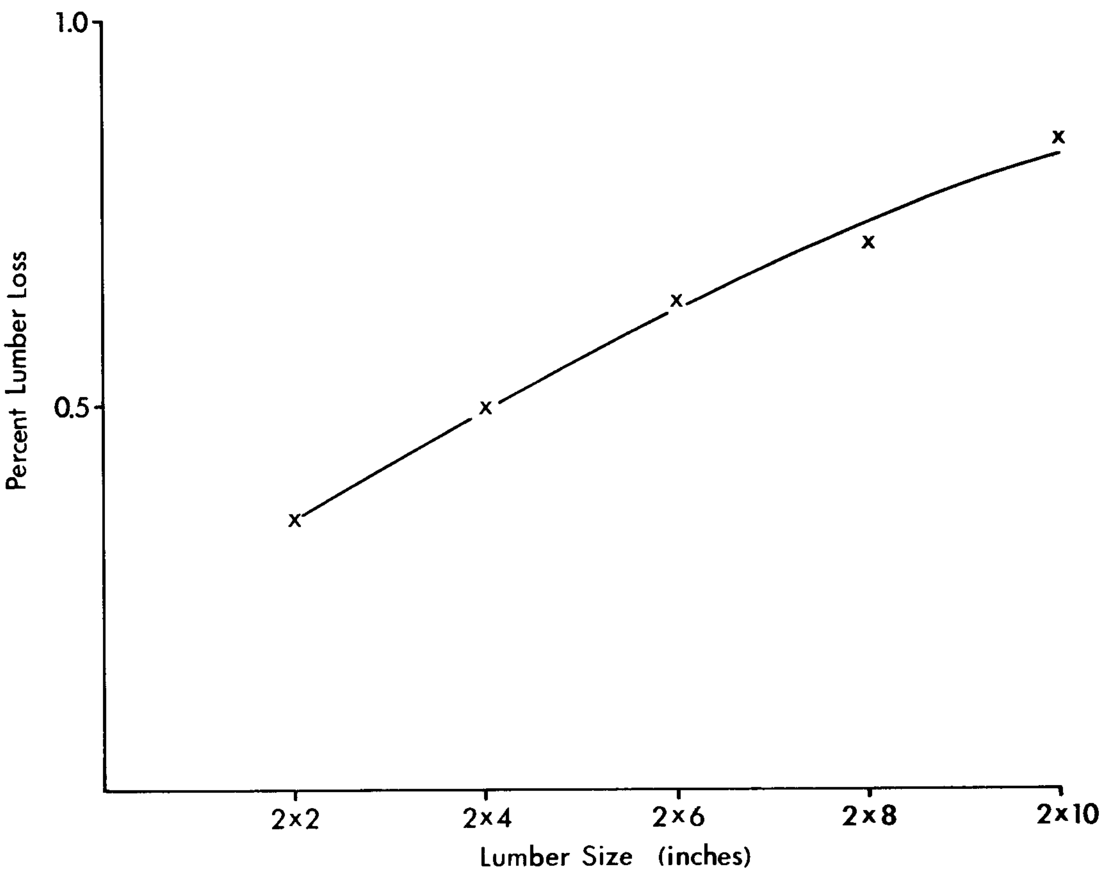


FIGURE B. Percent lumber loss increases as lumber size increases (example - Kockums 2).

The rankings in TABLE 2 illustrate that handfalling causes the least damage and that the four shears studied cause the greatest losses. Among the non-shear buncher heads, the single-blade circular saws are near both the low and high ends of the range. The results presented in TABLE 2 should be interpreted carefully. They represent damage observed for a system with a given operator in a very specific set of stand, terrain, weather and other conditions, and should not be taken as an absolute characterization of the system's performance in all conditions.

FACTORS INFLUENCING BUTT DAMAGE

In addition to the collection of butt-damage data on felled trees, FERIC also carried out an engineering investigation of most of the systems studied in 1983 to determine the causes of butt damage and how they can be avoided. Three major factors affect the damage results:

- stand characteristics;
- operator; and
- machine.

Each one will have an effect on the amount of butt damage. After discussing these factors, we will elaborate on the details of machine design since it represents the main potential for systematic butt-damage reduction.

Stand Characteristics

Tree size - This is a major factor affecting wood loss from shatter. Usually, small trees result in a larger percent volume loss than large trees. As an example, FIGURE C shows how wood loss decreases as the tree size increases for a typical machine. TABLE 2 showed 20 data sets for mechanical non-shear felling. Most of those (15) had higher percent losses in their smaller-diameter trees. The term "smaller diameter" varied somewhat between systems -- it generally refers to trees less than 30 cm butt diameter. Of the remaining five heads, the two Denis and Koehring 1 showed no particular pattern related to tree diameter; the Kockums 1 and the QM Saw Director showed the highest percent volume loss in their larger tree sizes, a reversal of the usual pattern.

To further illustrate the usual trend of decreased wood loss with increased tree size, we recomputed the data for the Auger and the QM Shear 1. The Auger was chosen as it worked with the smallest average butt diameter of the non-shear buncher heads, and the QM Shear 1 because it had the largest average butt diameter of all systems studied. From the Auger sample, we eliminated all trees smaller than 25 cm. As a result, the average butt diameter increased to 31.2 cm and the percent wood loss dropped to 0.67 percent. For the QM Shear 1, we eliminated all trees larger than 42.5 cm; the average butt diameter decreased to 30.5 cm and the percent wood loss increased to 4.09 percent.

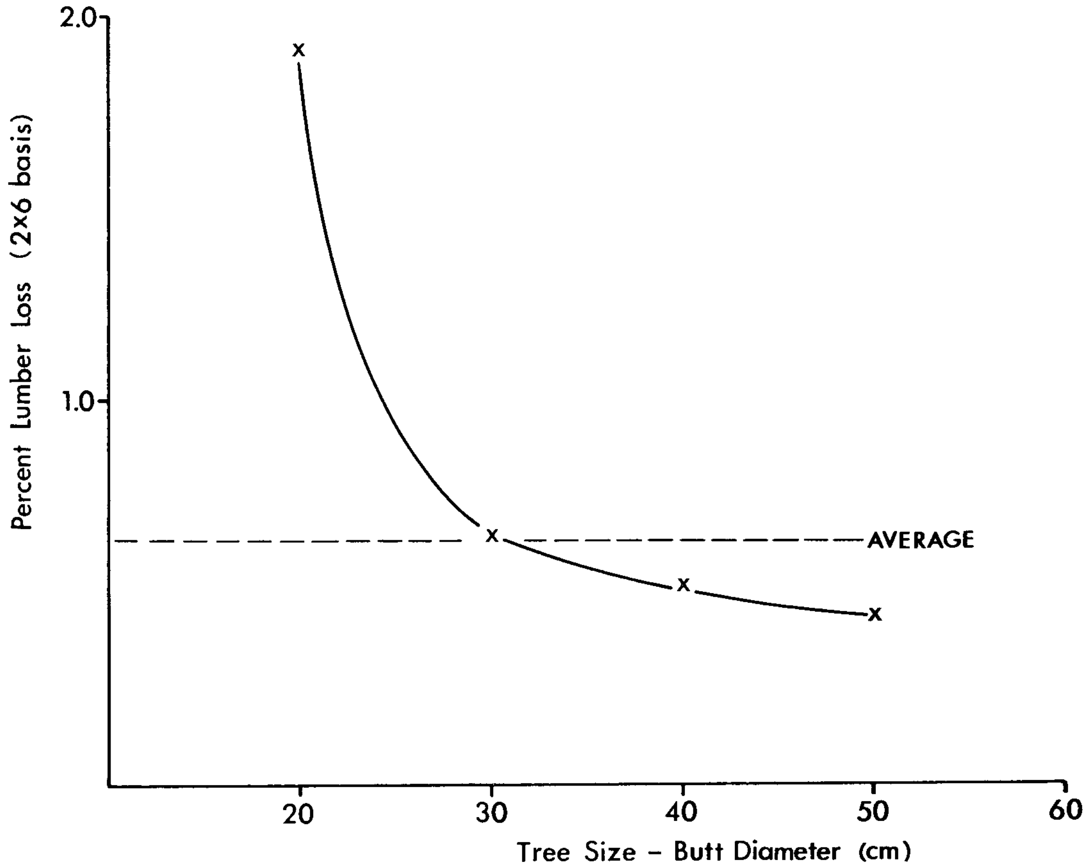


FIGURE C. Percent lumber loss decreases as tree size increases (example - Kockums 2).

Because they worked in large wood, QM Shear 1, NW/FERIC FD, Hultdins, Dika Director and Spencer are favoured in the ranking. On the other hand, the Forano 1, Auger and Osa are penalized because of the small wood they cut.

At least two factors explain why damage is greater in small trees. First, they are bent more easily by feller bunchers, and bending causes higher stresses to be applied to the uncut wood. This will usually result in greater splitting. Secondly, percent volume loss is a function of the percentage of the cross section that is damaged by cracks. As shown in FIGURE D, a crack appearing 5 cm from the edge of the log will affect a larger percentage of the area of a small log (a) than of a large log (b). Assuming the two splits run the same length up the tree, log (a) will have a greater percent volume loss.

Trees too large for a machine usually cause felling difficulties and end up being damaged. Oversized trees were excluded from our samples.

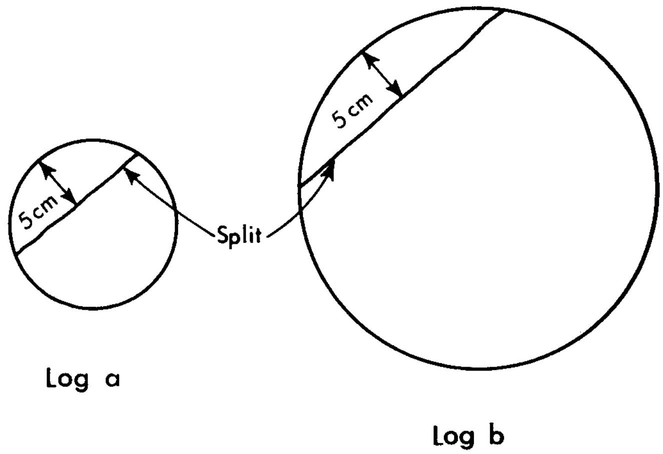


FIGURE D. Similar splits result in greater lumber loss in small logs.

Tree species - Four species were found in our investigation: Lodgepole Pine, Balsam, Engelmann Spruce and Douglas-fir.

Douglas-fir definitely showed less loss than the other three species. Pine and spruce showed comparable damage. Balsam appeared to show slightly more damage than pine or spruce. This ranking by species is exactly what can be expected when comparing their strength (TABLE 3).

TABLE 3. Strength Characteristics of the Four Species Sampled.

Species	Modulus of Rupture (PSI) (Static Bending)
Douglas-fir	7500
Lodgepole Pine	5700
Engelmann Spruce	5700
Balsam	5300

Frost depth - The winters of 1982-83 and 1983-84 were both mild. The frost depth in the trees we sampled averaged 3 to 5 cm. This was much less than in other winters when it was common to find 30 cm diameter trees frozen through. Frozen wood is more brittle than unfrozen wood and butt shatter can increase with frost depth. The damage results of this study are likely lower than would be expected with colder winter temperatures.

In TABLE 2, the results for Kockums 1 were obtained during the winter of 1981-82, which was severe. This machine showed significantly more damage than a similar machine (Kockums 2) evaluated in February 1983 in the same area. Differences in the amount of frozen wood help to explain the variation in percent volume loss from one year to the next. However, Kockums 1 was one of the two systems from which a smaller-than-preferred sample size was obtained. Some of the differences between the machines may also be related to this.

Tree lean and other stand characteristics - Leaning trees, odd-shaped stumps, large and low branches, trees growing side by side, rough and steep terrain, deep snow and any other stand characteristics that increase felling difficulties will contribute to damage.

Stand characteristics varied between machines in our study. The 1984 studies on Harricana 3 showed damage levels approximately 7 times greater than measurements made on two Harricanas the previous year. Harricana 3 worked on an 18% slope (in travel direction), steeper than that of any other buncher measured during butt-damage studies. Species was 100% decadent balsam, differing from all other studies which were predominantly pine and spruce. The frost pattern also differed from other studies, except the already-noted Kockums 1. Both an outer ring and an inner core of frost were present, suggesting that fully-frozen trees began to thaw, but started to freeze again before thawing was complete.

After the Harricana 3 study was completed, it was determined that saw-feed problems may have influenced some of the sample trees. (The felling machine was under strike closure when FERIC's study crew arrived. Damage measurements were taken on trees felled several days before.) Although the study crew did not note damage that could be specifically related to the saw feed alone, this potential source of damage cannot be eliminated.

It is highly probable that some combination of the above factors, along with a recently-trained operator, caused the measured damage levels. The damage is considered remarkably high since the Harricana does not grab the tree until after it has been severed.

The Koehring 1 also showed damage higher than the expected 0.1 to 0.2 percent volume loss. In this case, neither stand/terrain factors nor operator inexperience were considered to have influenced the recorded values (flat ground in pine and spruce, with an experienced operator). Although adequate detail was not collected at this operation, it is possible that operator technique is responsible.

Machine Operator

Operators' techniques affect butt damage from a felling machine. Most of the operators appeared to be proficient, but we noted techniques used by some operators that led to increased damage. Many of the techniques were developed to overcome a machine problem. For example, many machines required the operator to bend the tree in order to keep the kerf open and prevent the cutter from binding. Also, the sidetilt feature was not always used because operators felt they were under pressure to produce.

Production versus quality will require compromise but the designer must strive to build a machine which will minimize damage and maximize production without requiring extra skill from its operator.

Machine Design Features

As shown by the ranking in TABLE 2, there was a fairly large spread in the results rising from the hand faller through the non-shears and peaking with the shears. The type and arrangement of the felling head components will determine how much damage is created. The machine design is the most important factor to investigate when studying butt damage because it is the factor that can be more easily controlled and improved.

In order to organize our analysis of the felling machine's design features, we have divided the felling cycle into the following five work elements. Each element can contribute to butt damage:

(1) positioning head on tree;
(2) cutting;
(3) kerf opening;
(4) supporting the tree weight after cutting; and
(5) holding the tree (feller buncher) or pushing/directing the tree (feller director) while it is being severed.

In some cases two or more of the above elements are performed by the same mechanism (i.e. the grab arms on the Anda hold the tree and also support the tree weight). Butt damage can occur during any of these elements if they are not properly executed. If any element causes the tree to be stressed (as shown in FIGURE E) during the cutting phase, damage is unavoidable.

(1) Positioning the head on the tree - To avoid damage, positioning should not bend or deflect the tree. For all the feller-director type machines, such as the Dag, the Dika Director, the Hultdins, the NW/FERIC FD, the QM Saw Director, the RotoSaw Director and the QM tractor-mounted shears, positioning the head only involves placing the machine around the tree base. This operation cannot stress the tree in any way and does not contribute to damage.

Though the RotoSaw Director does not pre-stress the tree, one design feature used in the positioning phase appears to cause unnecessary damage. Welded to the inside rear of the head, about 10 cm above the cut line, is a metal strip that extends into the head opening about 8 cm at head center and tapers off towards the sides. This strip is sharply pointed and was intended to dig into the tree trunk, above the cut, in order to stabilize the head during the cutting cycle.

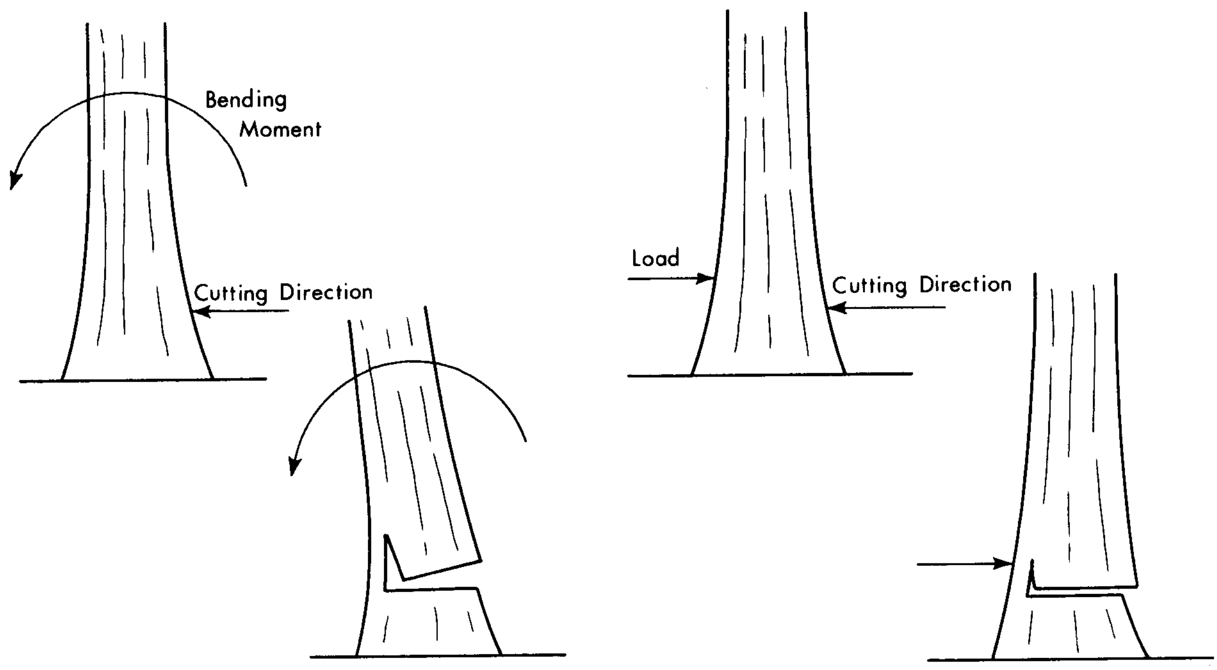


FIGURE E. Bending moment and/or loads perpendicular to the tree during the cutting phase result in butt damage.

Forty percent of the Roto-saw measured trees were damaged solely by the stabilizer. This was not superficial damage; the resulting lumber would require trimming to eliminate splits. We recomputed the results for this machine on the following basis -- if the tree was damaged only by the stabilizer, we classed the tree as damage free. The result of "eliminating" the stabilizer was that the average volume loss was reduced from the 1.3 percent shown in TABLE 2 to 0.77 percent. The stabilizer appears to add about 70% to the damage levels.

Based on this study and discussions with users, the manufacturer cut back (by about two-thirds) the amount that this strip extends into the head opening. The manufacturer informed all users of this change. This modification should result in less tree damage.

For feller bunchers such as the Kockums, Drott, Anda, Forano, Osa, Dika and Denis, it is critical that the head be aligned to the tree. If head positioning is not perfect, bending and shear stresses will be applied to the tree when the grab arms are closed and damage will result. Unfortunately, aligning the head takes time and reduces production. Fore and aft head alignment is available on all buncher heads using the "bucket" cylinder on the boom. Sidetilt is used to align the other direction. The Denis 1, Drott and Dika we studied did not have sidetilt on the felling head. (Denis 2 was equipped with sidetilt.) The Drott and Denis 1 mounted on Drott carriers could be aligned sideways using the cab leveller. However, operators may not spend the time to be careful with every tree, so side-leaning trees often were bent and stressed by the grab arms (FIGURE F). In addition, in the case of the Denis 1, fixed "horns" at the top of the mast prevent the operator from tucking side-leaning trees against the mast (FIGURE G). As the tree is cut, it is pulled inside the horns, pinching the saws and causing butt damage. The sidetilt option now available for the Denis head would eliminate most of this problem.

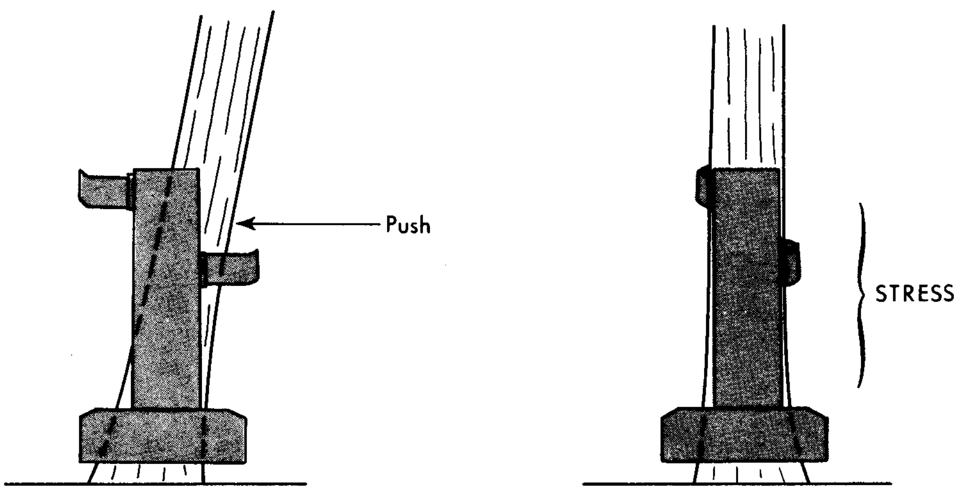


FIGURE F. Misalignment of the head results in bending stresses in the tree as the grab arms are closed.

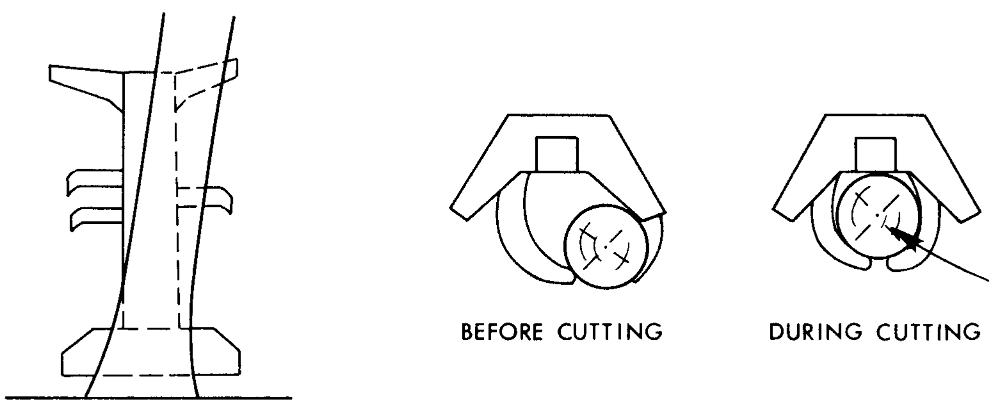


FIGURE G. Denis head. Fixed horns at the top of the mast can create cutting problems resulting in butt damage. This is accentuated if the head lacks sidetilt.

Positioning is less critical for the Spencer, Koehring and Harricana heads because no attempt is made to grab the tree before cutting starts. But, as shown in FIGURE H, stress can be applied to the tree during cutting by the Harricana and Koehring if the tree is leaning heavily towards the head, and the horns contact the tree before the cut is complete.

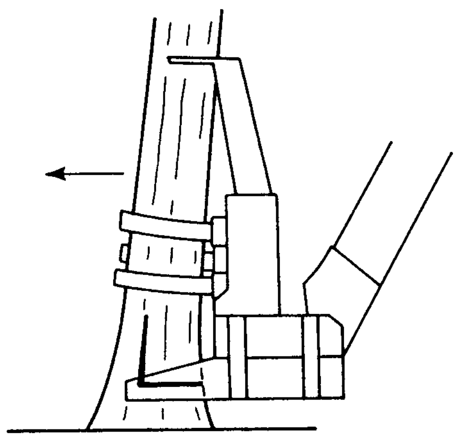


FIGURE H. Harricana head. Tree leaning toward machine can be pushed and damaged as saw is fed into the tree (grab arms are open). This also applies to the Koehring.

(2) Cutting - Four types of devices were used to fell the trees measured during these studies.

Chainsaws:	Hand faller, Spencer, Dikas (wide-kerf), Osa, Kockums, Hultdins, Anda, QM Saw Director, NW/FERIC FD.
Circular Saws:	Koehring, Harricana, Denis, RotoSaw Director.
Auger:	Drott.
Shear:	Forano, QM Tractor-Mounted Shear (snipper).

Most of the damage created by the shears can be attributed to the cutting device (the knife). Three types of damage are created by shears.

(1) Damage at the fiber level. The force exerted by a knife breaks the growth rings in tension and bending.

(2) Damage created by crushing the tree between the knife and anvil (QM Shears) or between two blades (Forano buncher head).

(3) Barberchair-type damage because of the wedging action of the knife being pushed into the tree (single-knife shears only).

Many attempts were made at improving shears to reduce damage. Ribbed, thin and pretensioned, curved, double or oblique shears did not reduce damage significantly. The best solution to the butt-damage problem seems to be the use of non-shears.

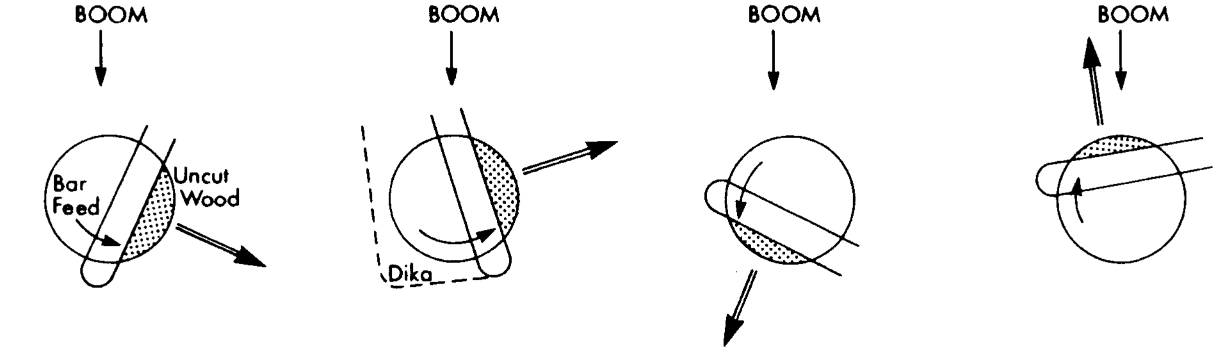
For cutting action alone, none of the non-shear cutting devices appears to be superior to the others, although the coarse chain on the Dikas occasionally tends to rip chunks out of small trees. The narrow-pitch chains and the Auger always produce a clean cut. If the circular saw is dull, the appearance of the cut can be fuzzy but the damage is only superficial.

The way the cutting device is fed into the tree determines the shape and location of the holding wood and therefore the direction most sensitive to splitting. The major types of feed are illustrated in FIGURE I. In all cases, regardless of the pivot point of the cutter or the cutter travel direction, barberchairing can be caused by applying a force IN THE DIRECTION OF CUTTER TRAVEL. This force will create a failure stress in a plane at right angles to the cutter travel direction. Type G, the Denis, creates a triangular-shaped section of holding wood as the saws extend into the tree; splitting can occur from stresses in almost any direction. Recognizing that some directions are more sensitive to damage, forces applied to the tree in that particular direction should be avoided.

<u>(3) Kerf opening</u> - A major element of the felling cycle that will result in most of the damage is keeping the kerf open to prevent the cutter from binding.

It should be noted first that some cutting devices are more susceptible to binding than others. The following list ranks, by increasing order of susceptibility to binding, the different styles we looked at:

- Auger;
- Harricana and Koehring circular saws;
- RotoSaw Director;
- Wide kerf chain (Dikas);
- Narrow kerf chain; and
- Denis twin-blade circular saw.



TYPE A

Anda
Spencer
Hultdins

TYPE B

Auger
Dika Buncher
& Director

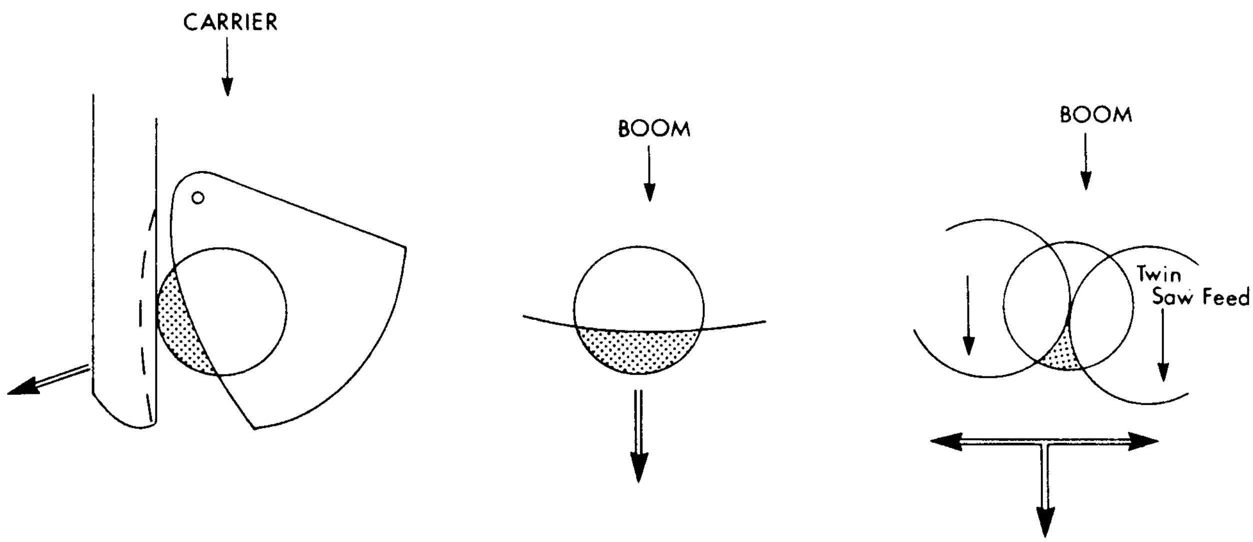
TYPE C

Osa

TYPE D

Kockums

The double arrow ⟹ shows the direction of the applied force most likely to cause barberchairing.



TYPE E

Dag (curved design)
QM Saw Director
(straight design - not shown)

TYPE F

Harricana
Koehring
NW/FERIC FD

TYPE G

Denis

FIGURE I. Seven major types of holding wood patterns can be identified for the different styles of non-shears.

The Auger has the ability to cut itself free if the kerf closes (FIGURE J). The follow-plate also helps prevent the kerf from closing. As shown in FIGURE K, the Harricana circular saw will not bind even if the kerf closes slightly. Again, the kerf is kept open by a butt support plate. The Koehring blade, though different in design, works on the same principle. The twin saws on the Denis do not have the same advantage (FIGURE L); the backs of the blades can easily be pinched when the kerf closes. If support plates were added in the areas shown in FIGURE L, it might reduce that problem.

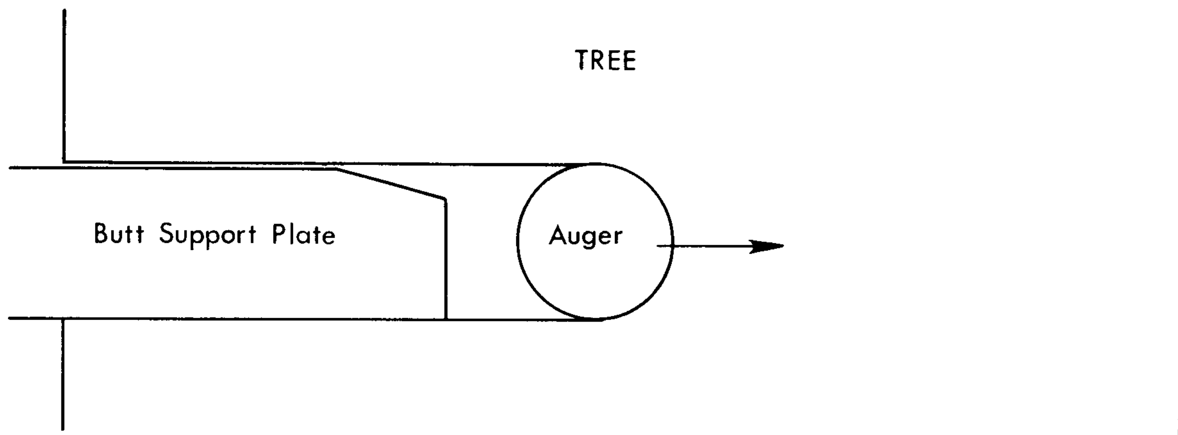


FIGURE J. Auger in cut. Auger is less sensitive to binding than most other cutters.

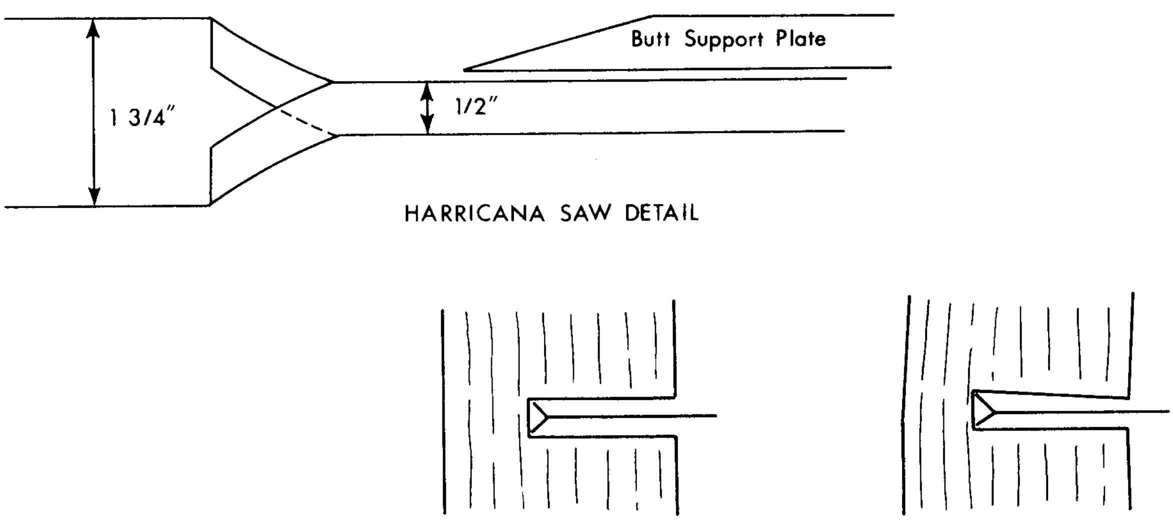


FIGURE K. Harricana circular saw does not bind even if kerf closes slightly.

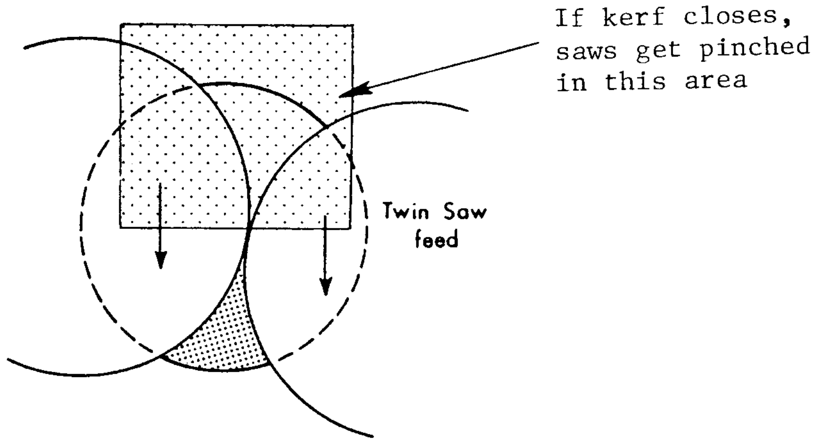


FIGURE L. Back of Denis saws get pinched if kerf closes.

With saw chains, the return side of the bar is especially vulnerable to binding when the kerf closes. Stronger chains have a better chance to cut themselves free when binding starts.

Several machines, like the Kockums and the Spencer, use a follow-up wedge to prevent the kerf from closing (FIGURE M). The wedge in itself is not strong enough and does not have enough push to force the kerf open. It also gets pinched if the kerf is not opened by other means. A very interesting solution is that used originally by Morfee Industries, and now more recently by the Dag and the QM Saw Director (FIGURE N). It combines the wedge and the bar; the kerf is automatically opened, provided enough push is applied to the bar-wedge assembly. The back of the chain is also protected and cannot get pinched. With this configuration, the amount of force applied to open the kerf is determined by the angle of the wedge and is independent of the operator's judgement. Our test on the Dag has shown that a taper angle of about 3.5 degrees prevents excessive damage.

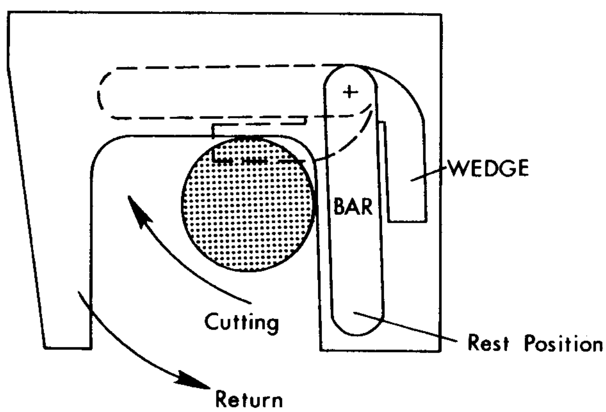


FIGURE M. Cutting cycle of Kockums showing follow-up wedge.

NOT TO SCALE

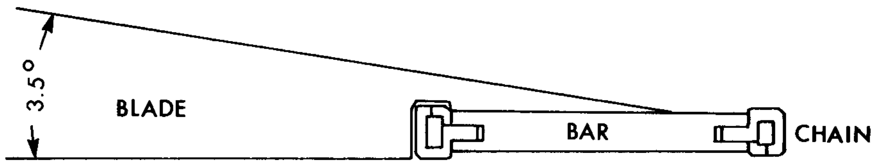


FIGURE N. Bar-wedge combination on the Dag keeps the kerf open independently of operator input.

Most of the other machines require operator input and judgement to open the kerf, and depending on the type of cutting pattern defined in FIGURE I, different actions are necessary. With machines of Type A, B and C the head has to be tilted sideways to free the chain (FIGURE O); with the Kockums (Type D) the tree must be pulled towards the machine, as shown in FIGURE P; with the NW/FERIC FD (Type F) the operator has to push the tree away from the machine to free the bar (FIGURE Q); the same is true of the Denis (Type G). Type E machines are director styles which do not have push arms to direct the tree -- they depend on the wedge angle, so there is less likelihood of operator-induced damage.

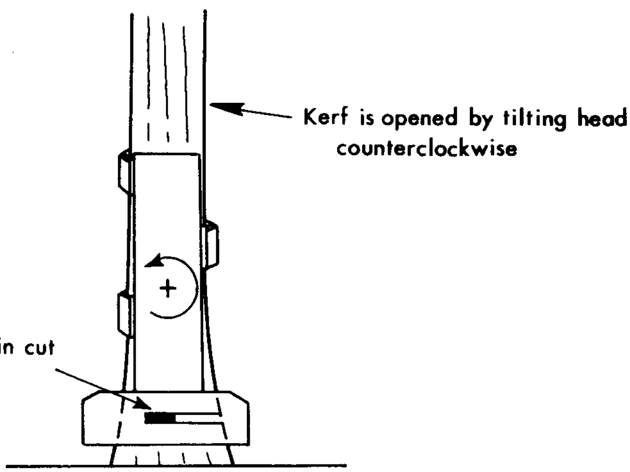


FIGURE O. Opening the kerf -- Type A, B and C machines.

It appears easier for the operator to gauge how much the tree is deflected with Type A, B and C machines, since the movement of the tree is perpendicular to the operator's line of sight. This is accomplished on the Spencer head by using the middle grab arm as a finely controlled pusher (FIGURE R), with the other arms remaining open during the cutting cycle.

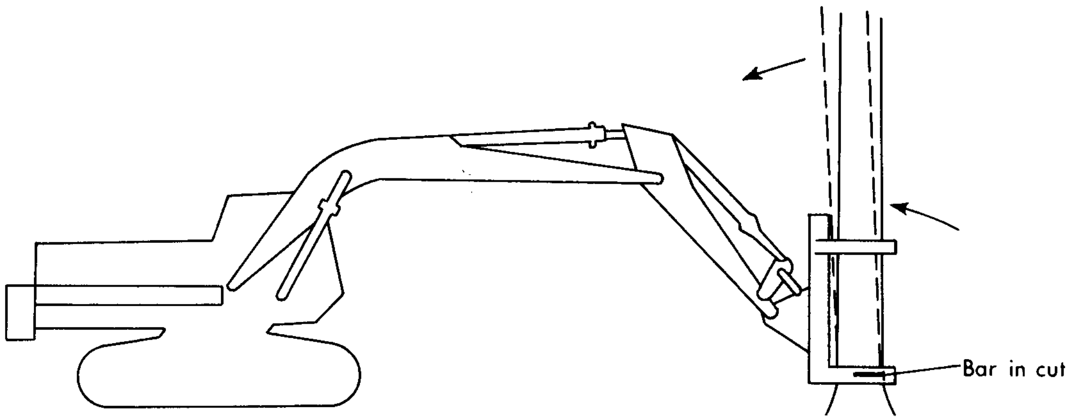


FIGURE P. Opening the kerf -- Type D machine.

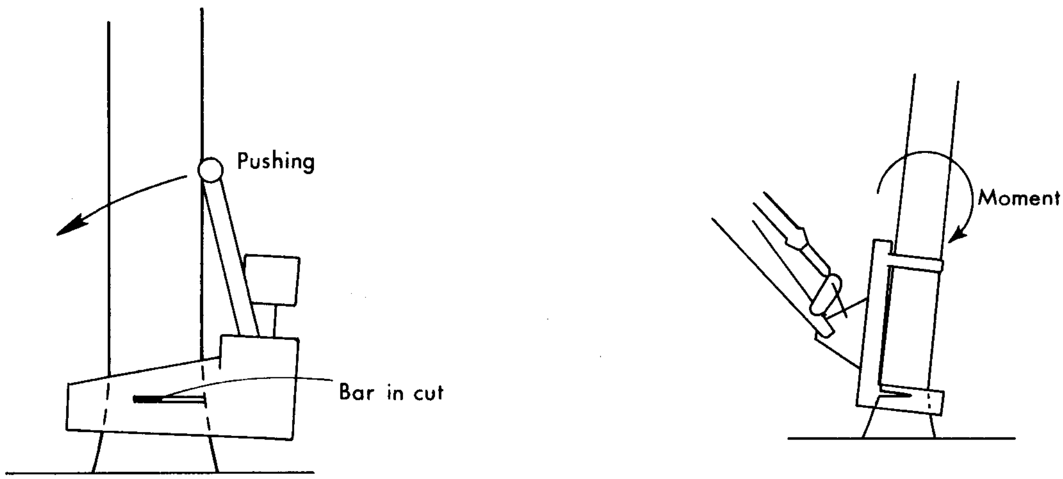


FIGURE Q. Opening the kerf -- Type F and G machines.

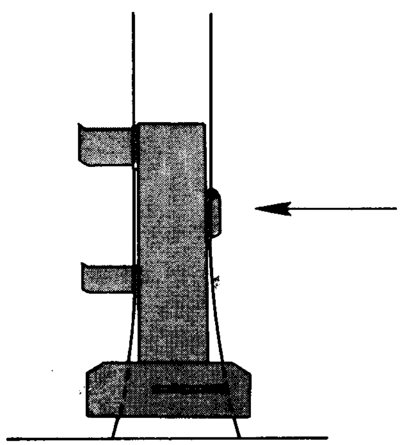


FIGURE R. Spencer uses middle grab arm to open kerf.
Other grab arms stay open during cut.

Keeping the kerf open usually requires applying loads to the tree in the direction that is most sensitive to splitting. The machine operator has difficulty in judging how much push is required and usually ends up over-pushing the tree. This is a major cause of damage.

Several solutions to this problem are possible.

(1) Use cutters that are very insensitive to binding, such as large-kerf circular saws or augers.

(2) Use a combination cutter and wedge, such as on the Dag and QM Saw Director, that eliminates the need for operator input.

(3) Encircle the tree slightly above the cut line and apply enough clamping force to prevent the butt from splitting. (FERIC has been experimenting with this idea on small log samples.)

(4) Apply the moment necessary to open the kerf in such a way that the barberchairing takes place in the stump rather than in the butt log. FIGURE S shows a simple example of how a barberchair-type of split can be created to the left or right of a notched beam. The same general idea can be used to barberchair the stump rather than the butt log. Most feller bunchers tend to split the butt log rather than the stump when a bending moment is applied to open the kerf. As an example, the Kockums is shown in FIGURE T. By changing the position of reaction points on the Kockums, the same moment applied to open the kerf could possibly be directed to split the stump instead of the tree.

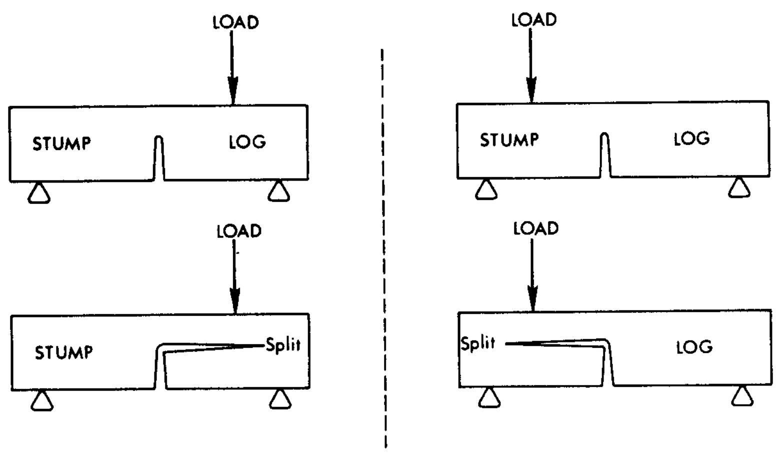


FIGURE S. The direction of splitting depends on how the load is applied to open the kerf.

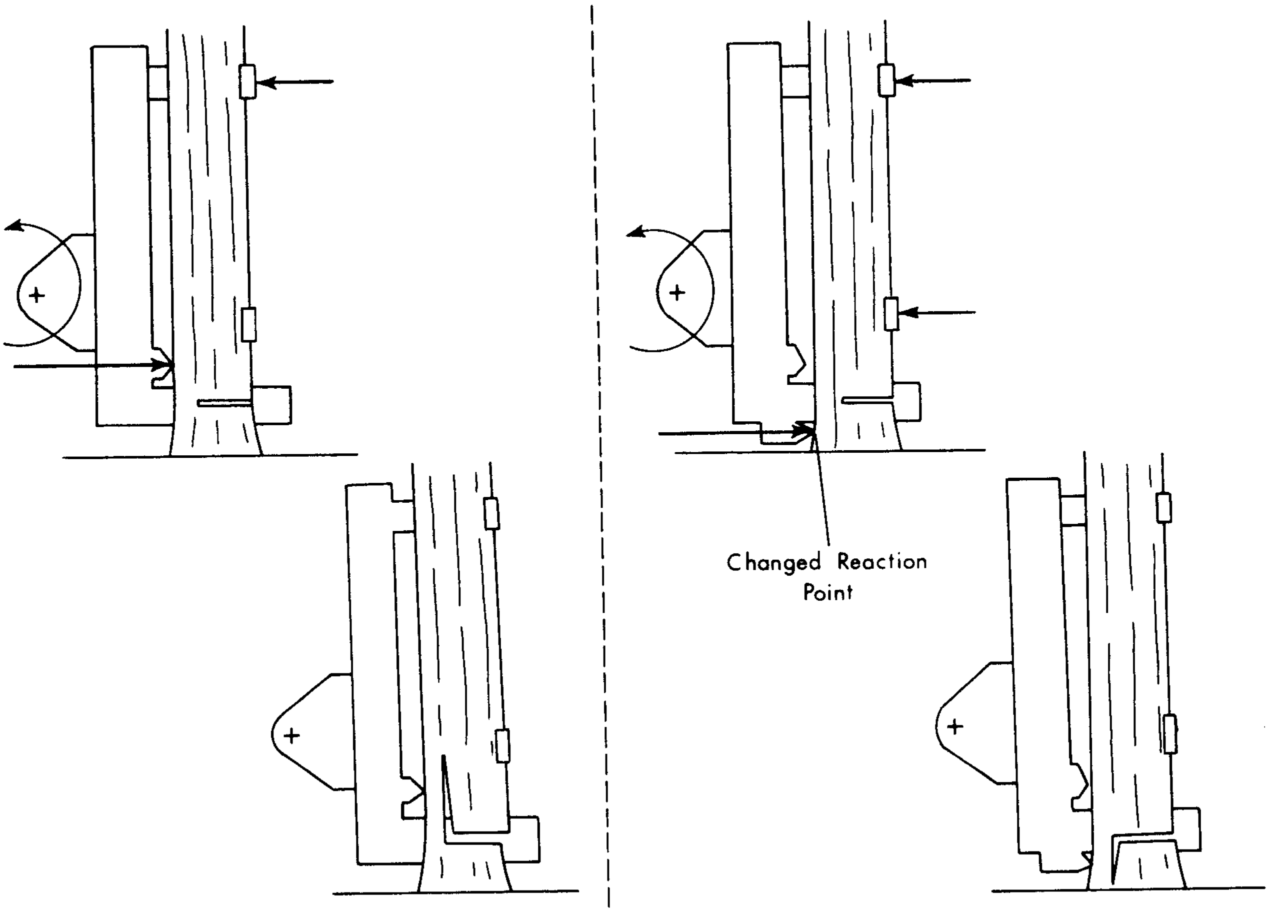


FIGURE T. Moment applied by the Kockums to open the kerf tends to split the log. Proposed modification would tend to split the stump.

(4) Supporting the tree weight - The weight of the tree is supported by the holding wood until the tree is completely cut. It then tends to crush the cutter between the butt log and the stump.

The Drott, Dikas, Harricana, Dag, Forano, Koehring, QM Saw Director, RotoSaw Director and QM Shear have support plates or bars strong enough to support the weight of the tree. On the Kockums and Spencer, the follow-up wedge is useful to protect the chain from being crushed, but cannot support the weight of large trees (FIGURE M). The NW/FERIC FD and the Hultdins are not required to support the tree. The other machines (Anda, Denis and Osa) have to rely entirely on the grab arms and the head structure to support the tree weight, and spikes are often added (by the owners) to the grab arms and tower to prevent the tree from sliding down. This need to grab the tree firmly results in stresses, in turn leading to increased damage.

(5) Holding the tree - Grabbing the tree (or pushing in the case of some feller directors) can be done before or after the tree is cut. Eight of the 20 studies on mechanized, non-shear machines were conducted on systems that do not grab the tree until cutting has been completed. Five of those eight are the top ranked (i.e. least damaging) of all the non-shear heads studied.

Non-shear heads that are required to hold the tree firmly stand a greater chance of bending or pre-stressing a tree than those that are not required to hold the tree. Damage levels can be reduced by postponing grab-arm closure until after the tree is cut, or holding the tree in such a way that it is not stressed. However, this is more easily said than done because for most machines, the grab arms are required to either keep the kerf open or to prevent the weight of the tree from crushing the cutting device. Future feller bunchers should be designed either not to hold the tree at all during cutting or not to apply bending stresses too early.

CONCLUSIONS

1. Measurements of wood-damage levels caused by various felling systems have shown that handfalling caused the least damage and shear heads caused the greatest. The 4 shear heads studied showed damage levels between 3.3 and 4.5 percent compared to 0.05 percent for the handfaller.

2. Among non-shear felling heads alone (both bunchers and directors) there was approximately a 15-fold difference between lowest and highest. Compared to the handfaller, the lowest non-shear head was 2.5 times higher; the highest non-shear head was 37 times as large.

3. Among non-shear buncher heads, the circular-saw style heads were near both the low and high ends of the range. This is considered surprising, particularly for the Koehring and Harricana styles, as their design permits the tree to be cut before it is grasped. These results indicate that the use of a circular saw cannot, by itself, be considered a guarantee of the lowest possible damage levels.

4. Stand characteristics, operator and machine design influence damage levels. It is machine design which holds the main potential for systematic butt-damage reduction. Future designs should attempt to reduce, or at least standardize, the number of operator decisions necessary for tree felling. Operators can then be instructed in the "least damage" felling procedures consistent with maintaining adequate production levels.

REFERENCES

Guimier, D.Y. and Bruce McMorland. The Bicycle-Wheel Method: A Procedure to Evaluate Butt Damage in the Woods. FERIC Technical Note No. TN-52. Vancouver, December 1981.

Guimier, D.Y. Butt-Damage Levels of Non-Shear Felling Heads in British Columbia. FERIC Special Report No. SR-19A. Vancouver, June 1983.

McMorland, Bruce. Survey of Non-Shear Feller Buncher Heads in British Columbia. FERIC Special Report No. SR-19. Vancouver, October 1982.

APPENDIX I

Conversion Factors

S.I. Unit		x	Factor	=	Equivalent
Volume					
1 cubic metre	(m^3)	x	0.3531	=	cunits
1 cubic metre	(m^3)	x	1.3080	=	cubic yards
1 litre	(L)	x	0.2200	=	Imperial gallons
1 litre	(L)	x	0.2642	=	U.S. gallons
Area					
1 hectare	(ha)	x	2.4711	=	acres
1 square metre	(m^2)	x	10.7639	=	square feet
Length					
1 centimetre	(cm)	x	0.3937	=	inches
1 kilometre	(km)	x	0.6214	=	miles
1 metre	(m)	x	3.2808	=	feet
1 metre	(m)	x	1.0936	=	yards
Proportion					
1 cubic metre/hectare	(m^3/ha)	x	0.1429	=	cunits/acre
1 (unit)/hectare	(../ha)	x	0.4047	=	.../acre
Weight					
1 metric tonne =	1000 kg				
1 kilogram	(kg)	x	2.2046	=	pounds
1 tonne	(t)	x	1.1023	=	tons (the 2000 lb "short ton")
Flow					
1 litre/second	(L/s)	x	13.1985	=	Imperial gallons/min
1 litre/second	(L/s)	x	15.8508	=	U.S. gallons/min
1 litre/minute	(L/min)	x	0.2200	=	Imperial gallons/min
1 litre/minute	(L/min)	x	0.2642	=	U.S. gallons/min
Power					
1 kilowatt	(kW)	x	1.3405	=	horsepower