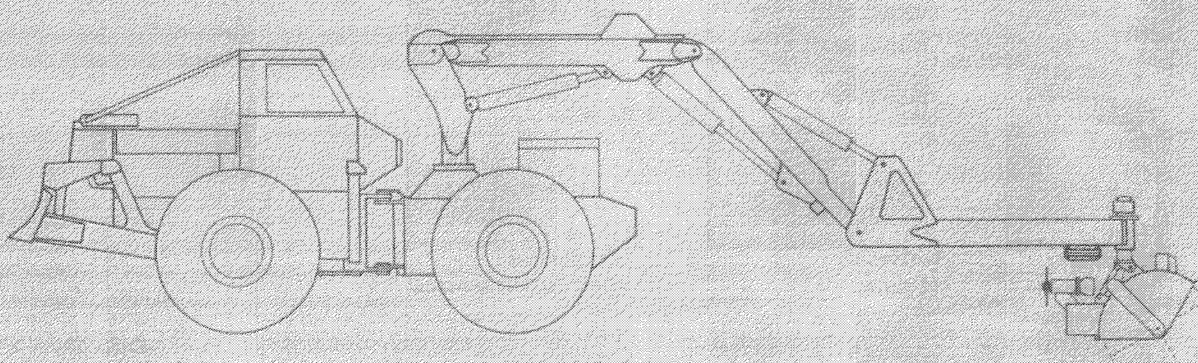
FERIC FOREST ENGINEERING RESEARCH INSTITUTE OF CANADA
INSTITUT CANADIEN DE RECHERCHES EN GÉNIE FORESTIER

Technical Report No. TR-36
January 1980

Development and Evaluation of GLFP/NESCO Boom-Mounted Flail Delimber

E. Heidersdorf



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FOREWORD

This report describes the development and evaluation of the second prototype of a boom-mounted flail delimber designed and constructed by Great Lakes Forest Products Ltd. and the Northern Engineering and Supply Company Ltd., with assistance from FERIC. Although development of this machine has now been terminated, results of the trial may be of interest to present and prospective flail users.

The machine was the subject of both short-term and longer-term studies. The short-term evaluations describe potential productivity under measured, but limited, operating and environmental conditions. The longer-term study provides information on long-term production, mechanical availability and the causes of non-productive time.

Details of the study procedures and analyses, plus results of limited interest, have been omitted from this report to keep it brief. Further details of the study will be supplied on request.

All quantitative data throughout the report are given in "SI" (Système International d'Unités) units. A table for conversion to Imperial units is provided in Appendix B.

Grateful appreciation is extended to Messrs. A. Bartholomew, B. Andersson, G. Dickie and the operating personnel of GLFP, and Mr. E. Maradyn of NESCO for their cooperation and help during the study. Technical assistance provided by FERIC employee E. Vajda is also acknowledged.

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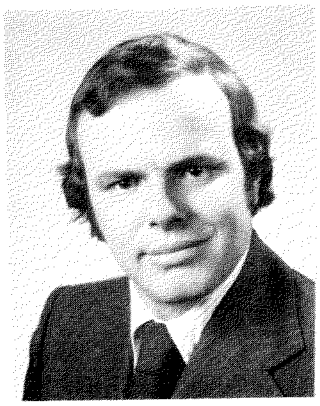


E. Heidersdorf received his B.Sc. Forest Engineering from the University of New Brunswick in 1972. That year, he joined the Woodlands Research Division of the Pulp and Paper Research Institute of Canada in Pointe Claire, Quebec. At FERIC's inception in April 1975, he joined that organization to work on machine and systems evaluations.

He is a member of the Canadian Institute of Forestry and of the Woodlands Section, Canadian Pulp and Paper Association.

SUMMARY

The development of the GLFP/NESCO boom-mounted flail forms part of the recent effort to mechanize the delimbing phase of the logging operation due to the time-consuming and dangerous nature of the work. The concept originated from Great Lakes Forest Products, and other industry members' desire for a stump-area delimber capable of effectively processing feller-buncher wood in the relatively small trees typical of large portions of Canada's boreal forest region. The design was intended to take advantage of the comparatively high potential productivity of the flail limbing concept, especially in small wood, while avoiding some of the difficulties inherent to conventional roadside flailing, notably coordination, interference and topping problems. A stump-area delimber was also considered to be silviculturally beneficial in that slash and cones would be dispersed over the cutover and not accumulate as debris at the landings and in the piles.

Basically the unit consists of a small flail head, with an integral topping device, mounted on the boom of a feller-buncher type carrier via a 3-m boom extension designed to increase reach. The machine travels in the stump area along rows of feller-buncher produced wood, delimbing the full trees from the top with successive sweeps of the boom and subsequently topping the stems. Since it is the boom and not the carrier itself which moves over the trees, control of limbing height and operator comfort are superior to front-mounted flails operating off-road.

Together with the Northern Engineering and Supply Company Ltd., GLFP built and tested the first prototype, mounted on a Drott 40 carrier, in 1977. This unit showed sufficient potential to warrant construction of a second prototype. With FERIC's aid, a second prototype, on a John Deere 743 chassis, was put into the field in June 1978. No major ergonomic shortcomings were observed on the modified John Deere 743 carrier beyond possibly the machine instability on side-hills over 10%. Target productivity was set at 36 m^3/PMH.

FERIC evaluated the second prototype operating in summer and winter conditions in August 1978 and February 1979 respectively. Moreover, shift level data were collected from July 1978 to April 1979. During both short and long term studies, productivity averaged about 20 m^3 per PMH in tree sizes averaging 0.11 to 0.14 m^3 and target productivity was only rarely approached during short, one to two hour, periods.

Availability averaged a fairly low 63% but this is not uncommon for prototypes undergoing modification and testing. Indications are that the concept is basically mechanically reliable. Though early signs were promising, chain life was only marginally superior to conventional flailing, averaging about 50 hours. However, the "third-link" problem inherent to conventional flails was totally eliminated. This was presumably due to the increased control of limbing height and low flail rpm. The circular topping saw, though fairly light, proved mechanically sound with only periodic saw-tooth changes required. Topping efficiency was 88% in summer and 83% in winter.

Constraints imposed by the other phases of the feller-buncher/flail/grapple skidder system were the major cause of lower than anticipated flail performance. The flail requires single layers of wood, as in windrows, to maximize flailing action and consequently productivity. Since windrowed wood limits grapple skidder performance, the feller-bunchers attempted to produce fan-shaped bunches, close at the butt for the skidder and spread at the top for flailing. However, bunches were often tight with overlapping stems which decreased chain penetration and thus productivity and limbing quality.

In summer, delimbing of jack pine and white spruce proved troublesome, possibly due to the low, 200 to 250 rpm, flailing speed. Black spruce quality was adequate except in tight bunches. Winter delimbing of all species was excellent, though productivity did not increase. Limbing standards vary with subsequent handling, but for most operations additional manual clean-up at the landing would be required during summer months. Limbing quality might be improved with changes in the system, but whatever the system, increased quality reduces flail productivity.

The multi-stem capability of the flail should have given it productive advantages over single-stem delimbers, but this potential was not realized, even with lower limbing quality. The low productivity, coupled with marginal limbing quality in summer, resulted in GLFP and NESCO terminating development of the machine in September 1979.

Required limbing standards and the cost of manual clean-up dictate the level of flailing intensity. Depending on economics, it is conceivable that the potential optimal use of the boom-mounted flail concept is as a rough prelimber, enjoying high productivity and leaving the majority of branches in the stump area. However, productivity will have to be raised to at least the target level for the flail to be cost competitive.

INTRODUCTION

In conventional tree-length logging, delimbing is the most time-consuming and dangerous part of the cutter's work. Thus in recent years, considerable effort and expense has been expended in attempting to mechanize this phase of the operation. A large number of mechanical delimbers, both roadside and stump-area, have been developed. Some have enjoyed relative success; others have failed as it rapidly became apparent that delimbing presented one of the greatest challenges to mechanization.

Starting in the early 70's, flail-type delimbers, which beat off the branches with revolving chains on a rotating drum, have gained considerable industry interest. Normally mounted on a wheeled carrier, the flail unit is driven over piles of full trees, usually at roadside landings but sometimes in the stump area. Due to their multi-stem capability, flails exhibit high potential productivity compared to single stem delimbers especially in small wood, but at certain costs, notably reduced limbing quality.

This report describes the development and evaluation of a boom-mounted flail, the GLFP/NESCO delimber. The unit was designed to take advantage of the high productivity of the flail concept while avoiding some of the problems inherent to conventional flailing.

BACKGROUND

Developed by Great Lakes Forest Products Ltd. (GLFP) and the Northern Engineering and Supply Company Ltd. (NESCO), the test unit was essentially designed to operate in the stump area. GLFP had experimented with conventional flails, both at the roadside and at the stump, but generally with unsuccessful results. At the stump, front-mounting of the flail attachment on conventional flails did not allow for adequate limbing-height control in rough terrain. Moreover, the necessity for continuous machine movement during limbing resulted in operator discomfort and fatigue. GLFP and NESCO's concept called for mounting the flail attachment on the boom of a feller-buncher type carrier, with the boom, and not the carrier itself, moving the flail over the full trees. Thus off-road capability would be increased through improved control of the flailing head and reduced requirements for machine movement.

In designing a stump-area delimber, GLFP hoped for a number of advantages over conventional roadside flailing, or for that matter, many other roadside delimbing systems. These benefits included:

1. Reduced coordination and interference problems typically associated with roadside flailing. While the conventional flail has generally proved to be productive whenever it could be applied, it has proven difficult to place enough skidders working to a single landing to keep it productively employed.

2. By incorporating a topping device into the design, eliminate the 35¢ to 70¢/m^3 subsequent manual topping required in conventional flailing.

3. Reduced landing size and cost. Skidding would be the same as for conventional tree-length operations.

4. Silvicultural benefits from slash and cone dispersal in the cutting area. Also problems of debris accumulation at the landing and in the piles are eliminated.

5. Possible production advantages through the skidding of tree lengths as opposed to full trees.

The first prototype, mounted on a used Drott 40 tracked carrier, was built and tested during the summer and fall of 1977. FERIC appaised the machine during this trial and decided that the concept held sufficient potential to warrant FERIC's involvement in the construction of a second prototype. A second prototype, on a John Deere 743 chassis, was put into the field in June 1978 and operated until the end of September 1979 when development was terminated. This report describes tests of this second unit.

The machine was evaluated operating in summer and winter conditions in August 1978 and February 1979 respectively. Moreover, shift level data were collected from July 1978 to April 1979.

MACHINE DESCRIPTION

The GLFP/NESCO delimber basically consists of a small chain flail with an integral tree topping device, mounted on the boom of a John Deere 743 carrier (Figure 1). The first prototype had been mounted on a Drott 40 carrier, but this chassis proved inadequate in terms of mobility and boom control. The choice of the John Deere carrier involved a number of trade-offs, but it was considered the most suitable readily available unit. The carrier was essentially standard with the only major modifications being calcium weighting of the tires for increased stability and a second hydraulic reservoir and pump for independant hydraulic power to the flail attachment. Fuel consumption during the trial averaged 18 ℓ per productive machine hour (PMH). Carrier specifications are available from the manufacturer on request.

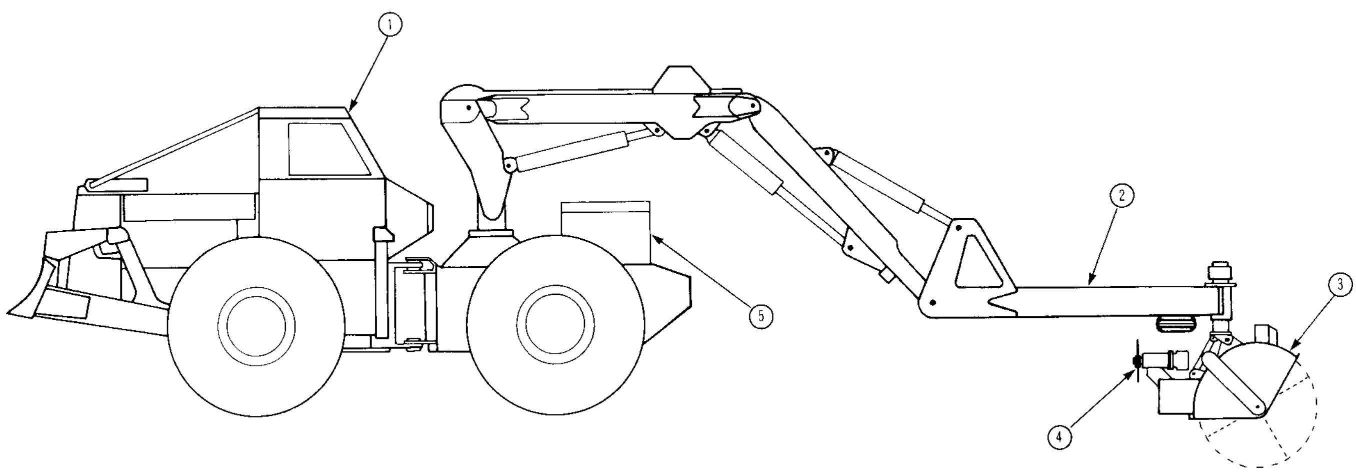


Figure 1. The GLFP/NESCO Delimber.
The main components are:
1) John Deere 743 carrier.
2) 3-m boom extension.
3) Flail unit with 1.2-m drum.
4) 66-cm topping saw.
5) Reservoir for attachment hydraulics.

Effective limbing stroke was increased through a 3-m boom extension (weight: 680 kg). At the end of the extension, the flail attachment (weight: 950 kg), rotatable through about 270°, consists basically of a 1.2-m rotating drum in a protective shroud (Figure 2). Drum drive is sprocket and chain, hydraulically powered, and drum speed can be varied through the use of different sized sprockets. During the trial, drum speed averaged about 200-250 rpm. The 66-cm diameter slasher-type topping saw is hydraulically driven and can be raised and lowered.

Up to 18 chains (two banks of 5 and two banks of 4) can be attached to the drum with bolts. Additional chain could be stored inside the drum and played out as necessary. Chain type and configuration varied during the trial as discussed on page 18.

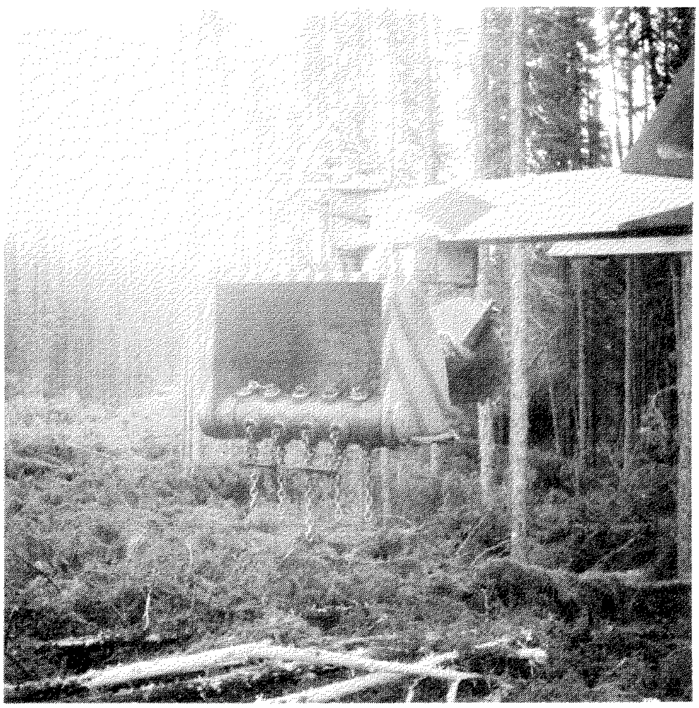


Figure 2. Flail and Topping Attachment.
Note "axe-heads" on inner chains for increased limbing efficiency in summer.

OPERATION

The Mark II GLFP/NESCO delimber was operating on a single shift out of Camp 602 on Great Lakes' limits north of Thunder Bay, Ontario. The harvesting system was basically comprised of a Drott 40 feller-buncher, the chain flail and a John Deere 640 grapple skidder (Figure 3).

It had been hoped that felling would be conducted with a Hydro-Ax "swather", but development delays with this machine necessitated the sharing of Drott 40's with a neighbouring limb-and-skid operation. This caused substantial problems to the trial operation as discussed later in the report.

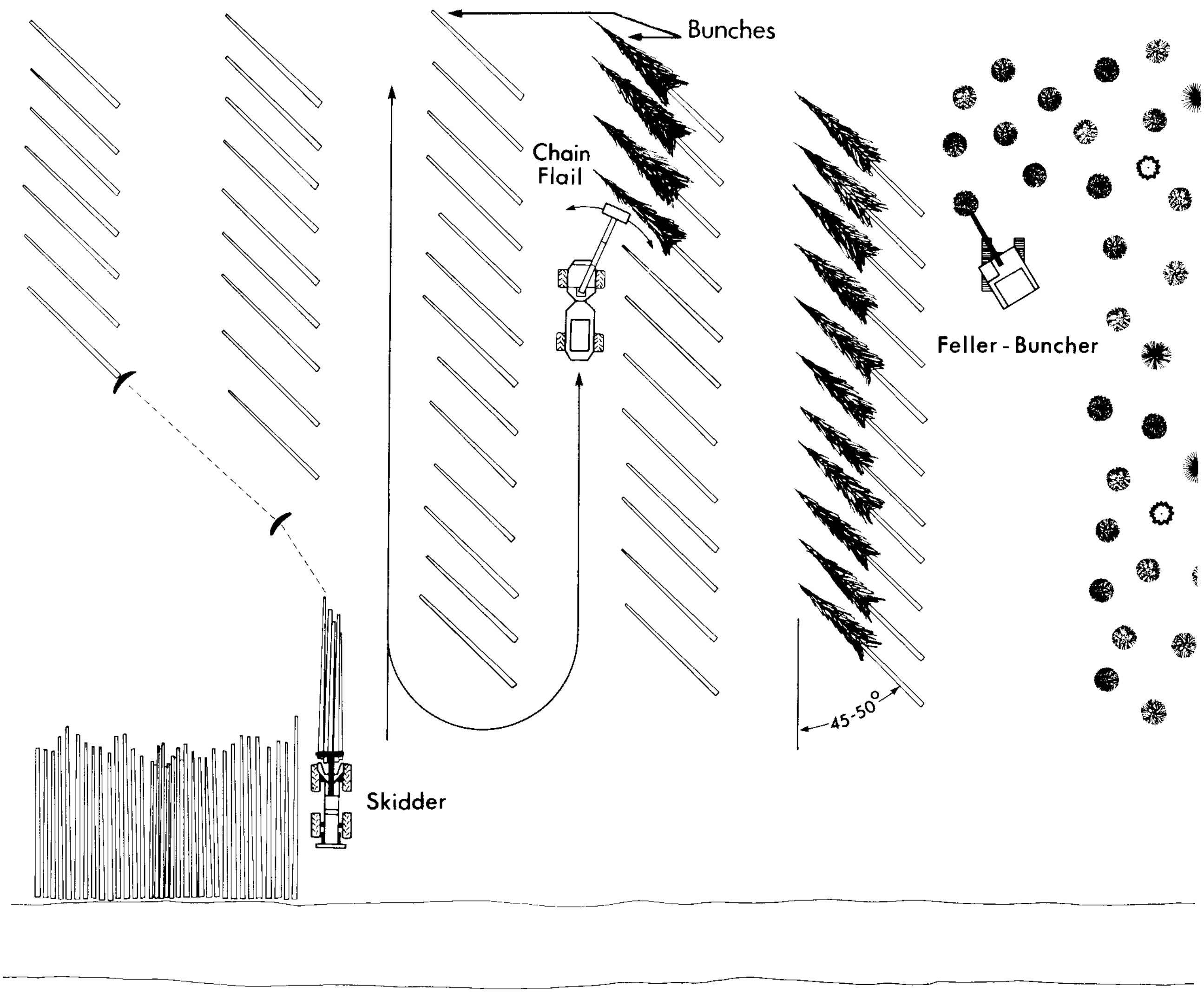


Figure 3. Normal Operating Pattern for Feller-Buncher/Flail/Skidder System. Note that single stems in diagram represent bunches of trees.

The Drotts placed the felled full trees in bunches or windrows with the butts directed toward the landing area and the tops angled to the flail's direction of travel, so as to allow a 3-m path between rows for the flail's passage.

The flail carrier could theoretically travel over the tops but with a resultant decreased limbing efficiency and an increased occurrence of breakage in winter conditions.

The flail travelled down the strip limbing the trees from the top end with successive sweeps of the boom, followed by topping (Figure 4). Depending on bunch spacing, the machine could occasionally process more than one bunch per set-up. Optimally the stems were oriented at a 45-50° angle to the line of travel to take full advantage of the boom's swing action, but the angle could be lowered in longer timber to allow sufficient passage space. Upon completion of a strip, the flail returned to the start of the next strip.

After limbing, the JD 640 skidded the tree lengths to the landing, crossing over rows to accumulate an adequate load if necessary. At the landing, additional manual delimbing was conducted if warranted.

Figure 4. The GLFP/NESCO Flail Delimbing Full Trees in Stump Area.

Terrain in the study area was generally gently rolling or flat, though there were occasional short steep pitches. In these cases, the operating layout had to be designed so that the flail worked up or down the grade since slopes over 10% presented problems in terms of side-hill stability. If the machine must work side-hills, layout should be so that the bunches being processed are always upslope from the flail with the boom then acting in a balancing manner. Side-hill stability was increased when the differential lock was engaged. Because of stability problems, the flail usually traveled with its boom fully retracted and centered. Ground bearing capacity was for the most part high, providing for good machine mobility.

Species distribution over the area averaged approximately 80% spruce, mostly black, and 20% jack pine. There were however clumps of almost pure stands of either species. There was some problem with residual standing hardwoods as discussed later in the report.

Additional information on operating conditions is provided in Tables 1, 2 and 3 in "Study Results".

Both flail operators during the August 1978 study had about 1½ months experience prior to the test and were considered relatively proficient. They normally rotated between the flail and the John Deere skidder on a weekly basis, thus increasing their interest, flexibility and overall systems awareness. During the study, in actual fact, over 90% of the sample was with a single operator. In January, 1979 a new operator replaced one of the originals and had about 2 weeks experience prior to the February study. He operated the flail for about 2/3 of the study sample and, though inexperienced, was considered equivalent to his partner.

Though fairly routine and thus possibly boring, operating the flail delimber efficiently required more skill than anticipated. Beside their hourly pay, the flail and skidder operators split a production bonus in proportion to their respective man-days worked.

STUDY RESULTS

Short Term Studies

To help assess the potential productivity of this machine, FERIC evaluated the GLFP/NESCO flail delimber under summer conditions during one week in August 1978 and, under winter conditions, in a week in February 1979. Table 1 summarizes the operating and condition factors prevalent during these tests, as well as total production during the observation periods. Table 2 provides a summary of elemental times and machine productivity.

Table 1: Operational Factors and Production

AVERAGE OPERATIONAL FACTORS	SUMMER	WINTER
Study date	August 1978	February 1979
Principal chain configuration	4"axe-heads", 10 regular	8 regular
Tree size, m^3	.11	.13
Trees per hectare*	1550	640
Volume per hectare, m^3*	182	83
Species composition, %		
Spruce	74	97
Jack Pine	26	3
Swath length, m	91	97
Swath width, m	13	15
Bunch spacing, m	4.5	5.9
Trees per bunch	8.3	5.6
Trees per set-up (i.e. cycle)	10.8	5.2
PRODUCTION		
Total trees delimbed	2175	652
Volume delimbed, m^3	248	88
Bunches	262	116
Set-ups	201	125
Swaths	13	7

* based on sample plots in study area.

Table 2: Summary of Time Elements and Productivity

TIME ELEMENT (minutes)	SUMMER			WINTER		
	Observed Produc-tive Time	Cycle Time*	%	Observed Produc-tive Time	Cycle Time*	%
Delimbing	444	2.21	64	196	1.57	70
Topping	127	.63	18	39	.31	14
Move in swath	69	.34	10	26	.21	10
Move between swaths (pro-rated)	22	.11	3	11	.09	4
Delay** (pro-rated)	35	.17	5	6	.05	2
Total time	697	3.46	100	278	2.23	100
PRODUCTIVITY						
Cycles per PMH	17			27		
Trees per PMH	187			140		
Production, m^3/PMH	21.4			18.9		

* Cycle time corresponds to time per set-up since the cycle elements repeated with each new set-up, except for "move between swaths" and "delay" which occurred only periodically.

** Delay only includes those between 0.05 min. and 15 min. Those less than 0.05 min. were included in the element in which they occurred, while those over 15 min. were not considered productive time and thus excluded from the sample.

Shift Level Study

During the period July 1978 - April 1979, FERIC monitored the GLFP/NESCO flail on a shift-level basis to gather additional information on longer-term production and mechanical performance. The collection of field data for this study was carried out by company personnel, according to uniform procedures developed by FERIC. Daily report forms for the flail, accompanied by Servis Recorder charts, were forwarded to FERIC weekly, for auditing, compilation and analysis.

Table 3 provides an operational summary of the results of the study. Table 4 indicates some of the causes of non-productive time by summarizing the repair time and frequency attributed to the various components of the GLFP/NESCO flail.

Table 3: Operational Summary

PERIOD (1978-1979)		SUMMER	WINTER	TOTAL
		July 10- Sept.12	Nov. 8- March 31	
Scheduling				
Days Reported	DY	45	96	141
Scheduled Time	HR	360.0	791.5	1151.5
Out-of-Shift Time	HR	2.5	18.0	20.5
Total Time	HR	362.5	809.5	1172.0
Shifts/Day	SH/DY	1	1	1
Machine				
Repair In-Shift	HR	67.0	149.5	216.5
Repair Out-of-Shift	HR	2.0	8.0	10.0
Service In-Shift	HR	29.5	46.5	76.0
Service Out-of-Shift	HR	-	3.0	3.0
Operations				
Non-Productive Operating Time	HR	16.0	27.5	43.5
Wait Parts	HR	2.0	118.0	120.0
Wait Mechanic	HR	1.0	9.0	10.0
Miscellaneous Delays	HR	25.5	56.0	81.5
Machine and Operations				
PMH In-Shift	HR	219.0	385.0	604.0
PMH Out-of-Shift	HR	0.5	7.0	7.5
CPPA Availability	%	72	59	63
Mechanical Availability	%	69	65	67
Utilization	%	61	49	52
Total Time Utilization	%	61	48	52
Production				
Total Production	m^3	5080	6871	11951
Trees Delimbed	TR	32528	54638	87166
Trees per PMH	TR/PMH	148	139	143
Productivity	m^3/PMH	23.1	17.5	19.5
Conditions				
Tree size	m^3	0.16	0.13	0.14
Species Composition				
Spruce	%	85	83	84
Jack Pine	%	15	17	16
Principal Chain Configuration		4 "axe-heads", 10 regular	8 regular	
Operators to Date		2	3	3
Fuel Consumption	ℓ/PMH	17	19	18

Table 4: Repair Summary

Reasons for Repair Components	Active Repair Time (HR)	Reasons for Repair Components	Active Repair Time (HR)
JD 743 CARRIER			
		Saw Housing	
Power Plant	22.5 (2)	Saw Arm and Mount	9.0 (2)
Power Train		Saw Blade	5.5 (5)
Differentials		Link Arm	.5 (1)
Planetaries		Drum Drive Assembly	
Axles		Drive Chain	.5 (1)
Tires & Rims	16.0 (1)	Chain Tensioner	
Other		Sprockets	10.5 (2)
Chassis or Supporting		Other	2.5 (1)
Structure	1.5 (1)	Flail Drum	6.5 (3)
Hydraulics		Flail Chains	31.0 (8)
Main Lift Cylinder		Pins and Connectors	
Secondary Lift Cylinder	1.5 (1)	Chain Pins	2.5 (2)
Shear Tilt Cylinder		Other	23.5 (6)
Hoses & Fittings	8.0 (2)	Bearings	
Other	28.0 (4)	Head Rotate	
Felling Boom		Drum Rotate	
Swing Assembly	4.5 (1)	Other	
Mast		Hydraulics	
Main Boom		Reservoir	
Secondary Boom	2.0 (1)	Head Rotate Motor	10.0 (2)
Controls	1.5 (2)	Drum Rotate Motor	
Electrical	16.0 (4)	Saw Rotate Motor	1.5 (2)
Other	1.5 (1)	Saw Arm Cylinder	1.0 (1)
		Relief Valves	
		Solenoid Valves	.5 (1)
FLAIL ATTACHMENT		Flexible Hoses	4.5 (3)
Boom Extension	.5 (1)	Fittings	1.0 (2)
Head Rotate Shaft		Pump	3.5 (1)
Flail Housing	6.0 (2)	Other	
		Other	3.0 (2)
		Total Repair Hours	226.5(68)

* (.) = number of repairs (repair frequency)

DISCUSSION

Productivity

Overall the GLFP/NESCO flail's productivity, both short-term and long-term, averaged some 20 m^3 per PMH. Of the productive time, roughly 80% was spent in limbing and topping, with the rest being moving and delay. The majority of delays observed during the detailed study periods resulted from boom obstruction, pieces of wood jamming in the saw or flail housing and personal delays.

Company policy was to leave unmerchantable hardwoods standing wherever possible. While this did not overly influence conventional operations, it did reduce flail productivity. The standing residuals sometimes obstructed boom swing thereby decreasing limbing efficiency, and in fact, preventing delimbing of occasional bunches. Oversized trees left by the Drott, sharp hummocks or rock outcrops had a similar effect. Due to its mode of operation, the flail must essentially be considered a clearcut machine, though increased care in placing the stems during the feller-buncher operation may allow for some residuals. In this case, feller-buncher productivity may however decline.

The long term study indicated no significant difference in performance in spruce and jack pine. Productivity in predominantly spruce stands averaged 19.7 m^3/PMH, while that in jack pine stands averaged 18.7 m^3/PMH. However, there may have been some difference in limbing quality.

It had been anticipated that machine productivity would increase in winter due to the increased ease of removing frozen branches. In actual fact, during both the short- and long-term studies, productivity decreased slightly in winter though limbing quality was vastly improved. In the detailed studies, reduced stand volume and density in winter, with resultant smaller bunches, decreased cycle volume by approximately 50% negating the 1/3 reduction in cycle time. Also, inexperience of the new operator may have been a factor. In the long term, the difference in average tree size helps explain the productivity trend. Moreover, the operators may have spent more time in the winter removing that "last branch".

Availability

During the trial period, the CPPA availability of the GLFP/NESCO flail averaged 63%, with 55% of the repair downtime attributable to the flail attachment and the other 45% to the John Deere carrier.

Since the unit was a prototype and thus subject to considerable experimentation, a significant proportion of the repair downtime involved modification. Major modification conducted during a shut-down in September-October 1978 was excluded from the study data due to the difficulty in obtaining reliable reporting. These modifications included:

i. Case-hardening of chain mounting points;

ii. replacement of stops (limiting flail head rotation) on boom extension with airplane tire bumper;

iii. adjustment of bumper pads on flail head to match airplane tire bumper;

iv. reinforcement of flail housing side covers (bent when pads hit stops);

v. installation of cross-over relief valve to reduce pressure build-up when flail head rotation stopped.

However, other periodic modifications, mainly to the chain configuration and sprockets controlling drum rotation speed, were reported as repair downtime. If this modification time, totalling 54 hours, is excluded from repair, overall availability rises to 68%.

The machine's availability dropped from 72% in the summer period to 59% in winter, the only difference being high waiting for parts time in the winter. Mechanical availability, which excludes the operational factors, wait for parts and mechanic, remained almost unchanged. With the unit being a prototype, unavailability of parts presented occasional problems since some components had to be custom made and the manufacturer was more than 250 km from the operation. On the other hand, wait for mechanic delay was negligible since a mechanic was assigned full-time to the prototype.

System Considerations

During the trial, considerable effort was spent in determining the optimum bunch configuration and stem orientation to maximize system efficiency. Windrowing maximized feller-buncher and flail productivity, as well as limbing quality, but drastically reduced the grapple skidder's performance due to the difficulty in gathering adequate loads. Tightly bunched wood benefitted the skidder, but minimized the flail's productivity and limbing quality. The tradeoff adopted was fan-shaped bunches, tight at the butts for the grapple skidder and spread at the tops to allow the flail access for delimbing and topping. Also such bunches were similar to those anticipated for the Hydro-Ax "swather", the feller eventually expected to complement the flail.

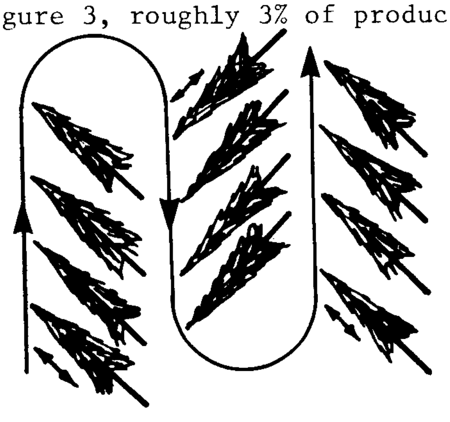
As mentioned earlier, the trial operation shared Drotts with a neighbouring limb-and-skid operation. This presented some problems, both in wood supply and proper bunch arrangement. Occasionally a number of feller-bunchers would be down, creating competition for wood and possible shortages resulting in decreased flail utilization. Moreover, the flail's wood was supplied by a number of different operators, some possibly unfamiliar with the proper bunching technique, especially since it differed from that of the limb-and-skid operation. The resulting variation in bunch configuration significantly affected the performance of the latter phases of the operation. Based on a limited sample during the August 1978 study, Drott production averaged 125 trees/PMH while attempting fan-shaped bunches; comparable to Drott production with conventional bunching practice. The similar felling rates reflect the Drott operators lack of care in preparing proper fan-shaped bunches for the delimber.

Not only is proper bunch arrangement important in felling, but also stem orientation. For most eastern Canadian tree sizes, tops angled 45^{o}-50^{o} to the flail's line of travel maximize the effect of the boom swing arc, while allowing the flail an adequate path between rows for travel. With longer trees the angle could be reduced. During the August study, the flail was doing some clean-up work with the stems oriented at 90^{o} to its line of travel. For this sample, productivity fell to 12.7 m^3/PMH due to the increased adjustment of boom position required for limbing.

One limitation of the GLFP/NESCO flail is the difficulty in processing the trees from the opening cut of a face. These trees are either placed, as on the trial operation, with the tops in the standing timber and thus inaccessible to the flail, or behind the feller-buncher with resultant poor stem orientation for both flail and skidder. During the study, this problem necessitated a subsequent clean-up where the skidder pulled the trees out of the treeline for delimbing, followed by a reskidding to the landing. This double handling greatly reduced skidder productivity. Flail productivity also decreased slightly because of the travel time required to return to an area previously completed.

Company policy called for separating spruce and jack pine during felling. This presents no major difficulty in stands with a fairly even mix, but where one species greatly predominates, the resulting small, scattered bunches of the lesser species reduce both limbing and especially skidding productivity.

In the flail's normal operating pattern, illustrated in Figure 3, roughly 3% of productive time is spent moving between swaths since the machine must travel back to the start of each strip. The layout shown to the left would reduce the flail's moving time and distance, but the bunch orientation would hinder subsequent skidding since every second row is facing in the wrong direction.



Quality of Delimbing

When assessing mechanical delimbers, productivity must be weighed against the quality of the delimbing job performed. Chain flail type delimbers have typically exhibited high levels of productivity, but usually, with much lower limbing quality than single-stem delimbers, especially in the summer months. Limbing performance with flails may be increased but at the cost of production and increased wood damage.

Overall, at the productivity levels observed, delimbing quality with the GLFP/NESCO flail was comparable to that of conventional flail operations with possibly a marginal improvement due to the increased control of the flail mechanism. Also, the ability to rotate the head allows for increased angular access to the branches. Limbing standards vary with the subsequent treatment and end use of the trees, but for most eastern Canadian operations, the quality of delimbing with the GLFP/NESCO flail in summer would require some additional manual clean-up to be considered acceptable. In summer, GLFP employed a man with a chainsaw for additional delimbing on the piles at the landing.

Limbing performance with the GLFP/NESCO flail was dependant on a number of factors including bunch arrangement, conditioning, species, season and chain configuration (see "Chain Experience").

Since windrowing was precluded due to subsequent skidding problems, the creation of proper single-layer, fan-shaped bunches with the Drotts was vital in terms of both flail productivity and limbing quality. On tight bunches with overlapping stems, the flail's chains got inadequate penetration for effective delimbing of the lower levels of the bunch. Also the chains do not provide the vital lifting action for good limbing quality. The flail operator could break up bunches to get access to those limbs trapped beneath the pile, but naturally, production suffered.

Ideally, in summer conditions, at least a 2-week lag factor between the felling-bunching and limbing phases of the system would have been desirable to allow some drying-out or seasoning of the stems. This was not possible because of the competition for Drott time described earlier and full trees were usually processed within a day or two of felling. This problem was compounded by unusually wet weather conditions during the trial period.

Limbing technique varied slightly with species due to the differing natural growth pattern of the branches themselves. Limbing action is increased if the chains strike in the crotch of the branching angle. Thus for spruce, the head should be rotated so that the chains strike the underside of the branches, whereas the reverse holds true for jack pine.

With proper stem layout, delimbing quality in black spruce was sufficient, even in summertime, as to require no additional clean-up at the landing. Virtually all branches were removed, especially in smaller-diameter timber. However, as mentioned previously, limbing performance dropped drastically with improper bunching practice. On the larger limbed jack pine, branch stubs up to 25 cm often remained. This may have been partially due to the drum's relatively low rpm even though branches up to 8 cm were removed if struck properly. In white spruce, with its large and fairly flexible branches, 25-cm+ "whips" frequently were left. The difficulties in jack pine and white spruce would likely lead to jamming problems during subsequent handling without further clean-up. There was no balsam fir on this operation but this species has usually proved troublesome to flail-type delimbers because of the flexibility of its branches.

With frozen branches in the winter, the quality for all species after limbing and skidding was generally excellent and no further work was required at the landing. On occasion, wet heavy snow under and covering the bunches did reduce productivity and quality.

One advantage of the flail to most single-stem limbers is that it only limbs the tops where the branches are. However, depending on stem orientation, an occasional difficulty could occur when delimbing long trees with branches down to the butts. Boom reach may be inadequate to delimb the lower branches. This problem is not anticipated for most eastern Canadian conditions. Moreover, in the event of an occasional occurrence, the lower portions of the trunk could be cleaned up while processing the subsequent strip.

Figure 5 shows some examples of limbing quality with the GLFP/NESCO flail. The photos are solely meant to describe some of the problems encountered. The reader is cautioned that the photos, in general, represent "best-worst" situations for illustrative purposes, namely:

1. Well limbed, small-diameter black spruce.

2 & 3. Small, flexible black spruce branches trapped between or under stems in tight bunches. Some of these would likely be removed during skidding.

4. Stubs remaining on large-limbed jack pine.

5. Long "whips" left on white spruce.

6. Clean black spruce load requiring no further manual limbing (well arranged 7-tree bunch).

7. Poorly limbed black/white spruce load requiring additional limbing (tight 13-tree bunch).

8. Roadside piles after manual clean-up.

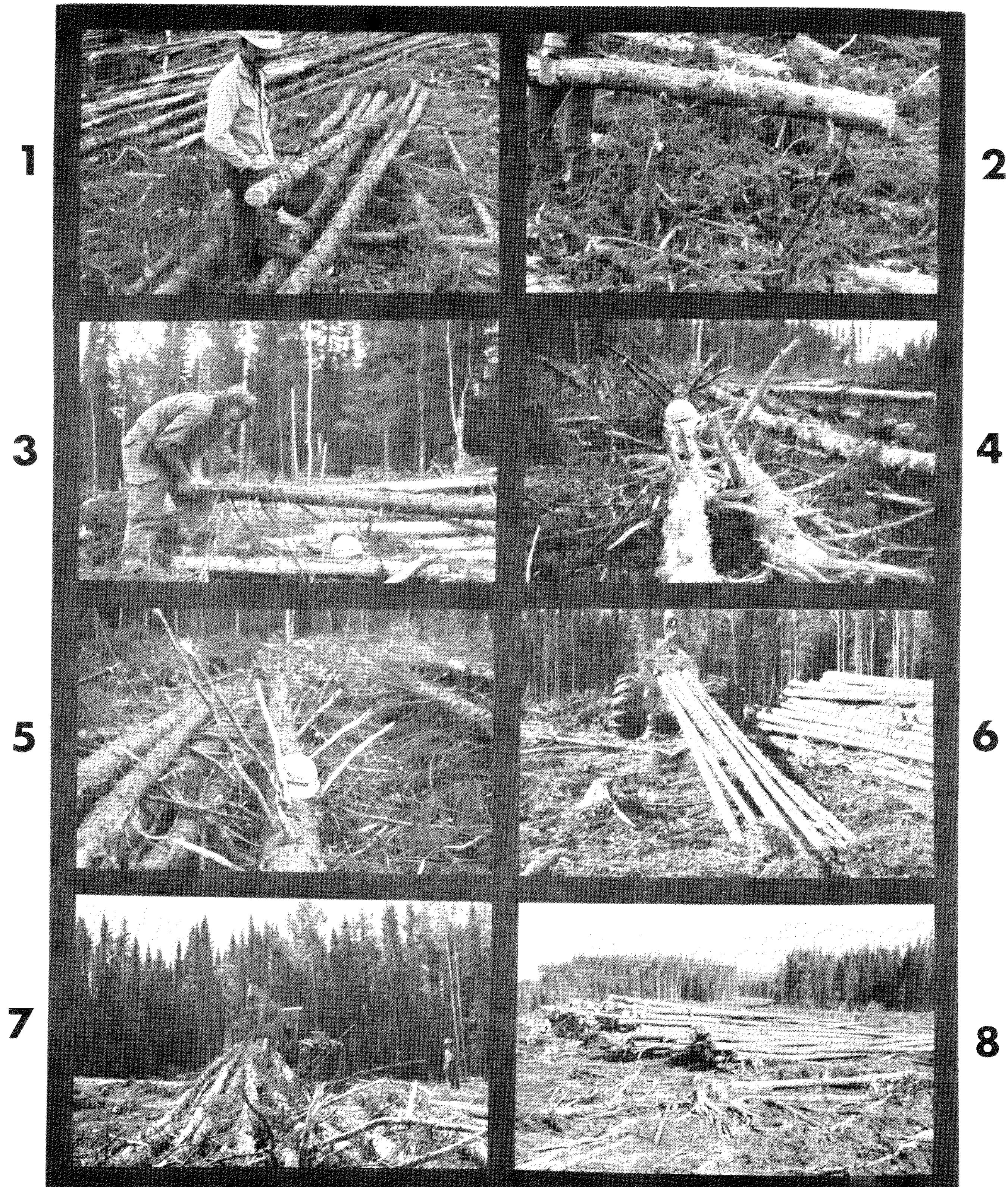


Figure 5. Examples of Limbing Quality.

Chain Experience

Chain life on conventional flail operations averages 15 to 45 hours and, with a replacement cost of $300-$400 a set, represents a major and sometimes prohibitive operating expense. During the trial of the first GLFP/NESCO prototype (Drott 40), chain life generally ran over 100 hours thus substantially reducing both the direct cost and downtime associated with the adjustment and replacement of chain. Inexplicably however, chain life for the second prototype, for the most part, averaged only about 50 hours.

However, the "third-link" problem, inherent to conventional flails, was completely eliminated, possibly due to the increased control of the flail head with regard to limbing height. With the normal chain used, standard 1.27-cm Dominion Accoloy, wear along the links was uniform. Because of this, the chains actually tended to stretch and thus had to be taken in periodically. Limited testing with some Dominion experimental chain showed that it did not warrant the added expense.

Additional chain life problems occurred a result of modification. The chain mounting points were case-hardened inside and outside with carbide rod to reduce wear. The resultant mounting points were harder than the chain itself causing increased impact wear on the second link from the pin. Also the original pin-and-cap screw arrangement holding the chains was replaced with 1.9 cm x 10 cm Grade 8 Caterpillar bolts. These are designed for strength, not hardness, and thus wore excessively. Finally, in an attempt to improve limbing efficiency, drum speed was increased to 300 rpm and hydraulic pressure was boosted from 8275 kPa to 13800 kPa. The combination of these problems reduced chain life to some 30 hr, with all trouble occurring in the pin area. The increase in drum speed did however improve limbing efficiency and quality somewhat.

There was considerable experimentation with chain configuration but normally the flail flew a full complement of 18 chains in the summer and 8 in the winter. However, some unique experiments deserve explanation. To increase summer limbing performance, "axe-heads" linked the four inner pairs of chains. These were designed to remove the branches on top of the bunch in one sweep, allowing for better penetration with the 10 normal chains (Figure 2). They also tended to clear tops and slash out of the way. The "axe-heads" worked well but inadequate strength at the welds reduced their life to one week maximum before replacement. A single bar connecting the chains would likely serve equally well.

Also, attempts were made to improve the delimbing action of the penetrating chains. Various cutters (circular and hexagonal discs, roller chain, etc.) were attached to the ends of the chains in hopes of effecting a tearing action to the sides and bottoms of the stems to complement the chains' whipping motion. The value of these could not really be assessed since it proved impossible to keep them attached more than a minute or two.

Wood damage from the chains increased with flailing intensity. For the most part, especially in winter, wood damage was not a major consideration. However, in difficult limbing situations, with resultant increased flailing intensity, considerable damage occurred on the upper stems. Brooming of tops, especially on smaller stems, was also a problem. The use of the "axe-heads" led to additional damage problems. Depending on end-use, fibre damage from flailing may be a problem in some instances.

Topping

The difficulty of manual topping in roadside piles, due largely to machine activity (skidder and flail), has frequently presented a problem in conventional flail operations. The topping feature on the GLFP/NESCO flail, however, worked very well.

In a test during the summer study, topping efficiency ran 88% with an average top diameter of 8.8 cm. In winter the percent of stems topped dropped to 83%, possibly due to the stems being buried in the snow and operator inexperience. Trees of uniform size enhanced topping since a number of stems could be topped at the same point.

Topping averaged 17% of cycle time, occurring intermittently with delimbing for any given set-up. The chains were kept rotating during topping to clear branches and tops. Limbing efficiency and quality improves once the tops are removed due to the chains increased penetrating and lifting action. Thus topping was usually done as early as possible. However, an experiment in topping before any limbing was abandoned because of problems in seeing where to top and reduced saw penetration.

The circular topping saw, though fairly light, proved mechanically reliable with only periodic saw-tooth changes required. The operator had sufficient control of saw movement to prevent undue cutting into the ground. Moreover, since topping usually followed only preliminary rough limbing, branches on the underside of the stems helped keep the tops slightly off the ground.

Carrier

Though not ideal, the John Deere 743 carrier was chosen as the most suitable readily available prime-mover for the second prototype flail. The first unit had been mounted on a used Drott 40, but this was found wanting with regard to mobility and boom control. Potential users of the boom-mounted flail concept may wish to use alternative carriers, possibly used machines presently idle. While this may reduce machine cost, some carrier features are recommended for optimal flail performance and must be considered. These include:

i. A boom reach, including extension, of 7.5 to 9 m for sufficient length to limb most boreal forest trees.

ii. Adequate boom lifting capacity to carry the flail head and extension.

iii. Good simple control of boom movement, especially height. Parallelogram, telescopic or sliding booms may have some advantage over knuckle-booms, though JD 743 proved adequate.

iv. Stability at maximum boom reach. The JD 743 was found to be somewhat unstable on side-slopes, even with calcium weighting in tires.

v. Good off-road mobility. The studies showed that the machine travelled approximately 15% of its productive time and thus speed is important, suggesting a wheeled unit. The machine must also be able to work those areas accessible to the feller-bunchers and skidders.

vi. Carrier width should not exceed 3.5 m to allow passage between rows.

vii. Hydro-static drive is preferable so that machine may move simultaneously with limbing. The JD 743 does not have this feature.

Ergonomics

No major ergonomic short comings were observed on the modified John Deere 743 carrier beyond the machine instability. There were some problems with visibility when delimbing stems close to the machine and glare, especially in winter, gave the operators some trouble.

Though a repetitious task, efficient operation of the flail required considerable skill. The "joy-stick" type controls were well located and control movement was essentially compatible with machine movement.

GLFP experimented with night operation of the flail and found additional lighting necessary. When limbing, sound levels in the cab fell within the allowable levels prescribed by the U.S. Department of Labor.

CONCLUSIONS

The development of the boom-mounted flail originated from GLFP's, and other industry members', desire for a stump-area delimber capable of effectively processing feller-buncher wood in the relatively small trees typical of large portions of Canada's boreal forest region. Since single-stem delimbers' productivity suffers drastically in small timber, the machine was designed to take advantage of the high potential productivity associated with the multi-stem capability of the flail concept, but avoid some of the difficulties inherent to conventional roadside flailing, notably coordination, interference and topping problems. To achieve acceptable limbing costs, target productivity for the Mark II prototype was set at 36 m^3 per PMH.

However, the flail's anticipated productive advantage over single-stem delimbers was not realized. In actual fact during the trial, flail productivity averaged 20 m^3 or 143 trees per PMH and the target was only occasionally approached over short, one to two hour, periods. By comparison, based on FERIC and user data, the trees-per-hour performance of the Roger delimber, basically a single-stem, roadside machine, was comparable to the flail and the Roger was working in larger wood and with 100% limbing efficiency (FERIC Technical Note TN-24). Moreover, such machines have lower capital and operating costs than expected for a "production-stage" flail and also overcome many of the logistics problems associated with roadside flailing. Given these facts, it was felt that the GLFP/NESCO flail must achieve a sustained productivity of 250 trees/PMH, in the tree conditions encountered, to be cost competitive. The low productivity experienced, coupled with marginal limbing quality in summer, resulted in GLFP and NESCO terminating development of the machine in September 1979.

The coordination and interference concerns associated with conventional roadside flailing were replaced with problems related to the interdependance of the phases of the feller-buncher/flail/grapple skidder system. The trial was designed to maximize system productivity and to evaluate the flail as a potential complement to the Hydro-Ax swather, a machine that produces bunches only. The resultant bunching practice, largely dictated by grapple skidder limitations, made the flail's performance overly dependant on proper feller-buncher technique. The flail performs best with a single layer of trees, with productivity and limbing quality drastically declining in tight bunches with overlapping stems.

In summer, limbing of jack pine and white spruce proved troublesome, possibly due to the low flailing speed. Black spruce quality was adequate except in tight bunches. Winter delimbing of all species was excellent, though productivity did not increase. Limbing standards vary with subsequent handling, but for most operations additional manual clean-up would be required during summer months. Limbing quality might be improved with changes in the system, but whatever the system, increased quality reduces flail productivity.

Though productivity was lower than hoped for, the trial did provide valuable insights for present and prospective flail users. Availability averaged a fairly low 63% but this is not uncommon for prototypes undergoing modification and testing. Indications are that the concept is basically mechanically reliable.

For the concept to be viable, productivity must be raised to at least the target level. The constraints placed on the rest of the system by the grapple skidder warrant consideration of alternate skidding methods. Clam-bunk skidders would allow for windrowing of wood but the large loads might lead to difficulties if manual clean-up is required at the landing.

Required limbing standards and the cost of manual clean-up dictate the level of flailing intensity. Depending on economics, it is conceivable that the potential optimal use of the boom-mounted flail concept is as a rough prelimber, enjoying high productivity and leaving the majority of branches in the stump area.

APPENDIX A

DEFINITION OF MACHINE TIME ELEMENTS

NORMAL SHIFT LENGTH: Nominal statement of intent for regular machine activity (e.g., 8-hour shift, 9-hour shift). It usually corresponds to operator's paid on-job time.

OVERTIME: The hours of productive work, non-productive operating time and/or active maintenance carried on outside usual shift hours.

TOTAL MACHINE TIME: The sum of Normal Shift Length and Overtime. It is the total time associated with the machine for a particular shift.

PRODUCTIVE MACHINE TIME (or PRODUCTIVE MACHINE HOURS, PMH): That part of Total Machine Time during which the machine is performing its primary function.

ACTIVE REPAIRS: Repair is diagnosis and mending or replacement of part(s) due to failure or malfunction. It also includes modifications and improvements to the machine.

SERVICE: Service is fuelling, etc., and preventive maintenance performed to retain the machine in satisfactory operational condition.

DELAY: That part of Total Machine Time during which the machine is not performing its primary function for reasons other than active maintenance. Delay time is divided into:

> NON-PRODUCTIVE OPERATING TIME: That part of Total Machine Time during which the machine's engine is running but the machine is doing something other than its primary function.
>
> WAITING FOR MECHANIC(S): That in-shift time during which the machine is down for maintenance (repair or service) but mechanic(s) are unavailable to work on it.
>
> WAITING FOR PART(S): In-shift time during which the machine is broken down and is not under repair due to the unavailability of part(s).
>
> MISCELLANEOUS DELAY: The unexplained difference between Total Machine Time and the sum of Productive Machine Time, Active and Waiting Maintenance, and Non-Productive Operating Time.

MACHINE TIME FORMULAS

$$\text{Utilization} = \frac{\text{Productive Machine Hours (In Shift)}}{\text{Scheduled Machine Hours}} \times 100$$

$$\text{Total Time Utilization} = \frac{\text{Productive Machine Hours}}{\text{Total Machine Hours}} \times 100$$

$$\text{Mechanical Availability} = \frac{\text{PMH}}{\text{PMH + (Active Repair \& Service)}} \times 100$$

("PMH, Repair and Service" includes both in- and out-of-shift)

$$\text{CPPA Availability} = \frac{\text{SMH - (Repair + Service + Wait (Parts \& Mechanic))}}{\text{SMH}} \times 100$$

("Repair and Service" includes only in-shift)

CPPA Availability, by definition, is influenced not only by machine characteristics but also by operational factors (i.e. waiting for parts or waiting for mechanic). Mechanical Availability, by definition, excludes these operational factors.

APPENDIX B

CONVERSION TABLE

1 cm	(centimetre)	0.39 inch
1 m	(metre)	3.28 feet
1 km	(kilometre)	0.62 mile
1 ha	(hectare)	2.47 acres
1 m^3	(cubic metre)	0.353 cunit
1 ℓ	(litre)	0.22 Imperial gallon 0.26 American gallon
1 kg	(kilogram)	2.20 pounds
1 kPa	(kilopascal)	0.145 pounds per square inch (psi)