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INSTITUT CANADIEN DE RECHERCHES EN GÉNIE FORESTIER

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A Proposed Modular Machine System for Wood Harvesting in Eastern Canada

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PREFACE

Increasing costs for wood harvesting and energy, and a growing concern to reduce ground damage created a need for a review of the development strategy of forestry machines.

In 1981 a meeting of Canadian Pulp and Paper Association Woodlands Section LOG/SMG Equipment and Systems Committee discussed the basic requirements for future logging systems and thereby created the first basis for this report.

One of the goals in this study was to work out at least one example of a new machine system that would better meet the prerequisites of future wood harvesting activities.

This paper has benefited from several penetrating critiques of the draft report at various stages. The author gratefully acknowledges these contributions from the industry and extends sincere appreciation especially to:

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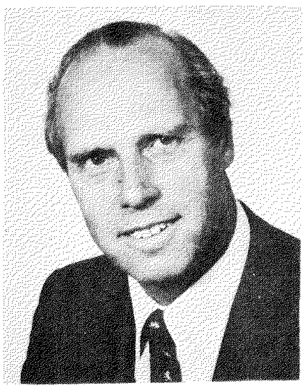

P.G. Mellgren obtained a M.Sc. degree (Mechanical Engineering) in 1946 from the Royal Institute of Technology, Stockholm Sweden. He then worked in the private industry in Sweden on machine development, from 1958 as manager engineering at SUNDS AB, a subsidiary of Swedish Cellulosa AB (pulp & paper, forestry machines) and from 1968 at Kockums AB. In 1974 he moved to Canada to market Finnish and Swedish forestry machines and joined FERIC in 1977.

He is a professional engineer and a member of l'Ordre des Ingénieurs du Québec.

TABLE OF CONTENTS

SUMMARY

A modular machine system designed to better meet the prerequisites and trends of future wood harvesting in central and eastern Canada and parts of British Columbia is proposed. It is anticipated that it will have the following features:

* A simple, light-weight design using existing, commonly available components and modules.
* High off-road mobility.
* Low ground pressure.
* High productivity.
* Improved operator safety and comfort.
* Lower investment and harvesting costs.
* Will deliver clean (carried) trees.
* Compatible with existing systems (possibility for gradual implementation).

It is hoped this presentation will stimulate readers to come up with additional ideas and concepts.

INTRODUCTION

The objective of this report is to:

a) identify trends,
b) formulate the prerequisites,
c) locate the intrinsic problems of present-day machines,
d) present improved alternatives for wood harvesting systems for central and eastern Canada and certain areas of British Columbia.

This report is intended to stimulate creativity and encourage a more open dialogue between machine user-owners and manufacturers to develop improved wood harvesting systems for the next 10 years. The great number of variables, i.e. terrain, tree sizes, climate and distances makes it extremely difficult to find optimal harvesting systems in Canada. Therefore, the cooperation of all parties involved, from the design engineer to the machine operator, is necessary.

TRENDS

At present various trends that will affect the wood harvesting systems of the future can be identified, e.g.:

1. The full tree system (trees with branches transported to roadside for processing) is gaining popularity, the reasons being:

   a) lower harvesting cost because of fewer machines working in hostile environment, (better productivity of the delimbing at roadside more than compensates for the transporting of limbs and tops).

   b) lower silvicultural costs with less slash on the ground.

   c) the opportunity for better future utilization of the biomass in step with increasing energy costs or wood fibre scarcity.

2. Forest management agreements to ensure a sustained yield from the forest will require a better integration of harvesting and silvicultrual operations which will eventually lower the total forestry costs.

3. Ground damage and rutting will no longer be acceptable for silvicultural and environmental reasons.

4. Use of the chainsaws will decline in step with the development of safer and more cost-effective machines.

5. Increased multi-stem felling of small trees with accumulator feller-bunchers.

6. Increased use of saw felling heads to eliminate butt splitting damage of sawlogs.

7. Increased use of multi-stem (e.g. dual head) stroke delimbers.

8. Demand for machines that can carry a clean load to roadside thereby eliminating the wear problems of chipper knives, grit in the pulp mill, excessive ash formation in boilers, etc. associated with wood skidded (dragged) in dirt and sand (as at present).

9. An increasing number of owner-operated machines is favoured by many forest companies.

PREREQUISITES

The following is a list of prerequisites that users of machines expect to find in wood harvesting machine systems of the future. Part of this list is the result of discussions at LOG/SMG Equipment and Systems Development Committee (CPPA) meetings.

1. High productivity of capital and labour; that is, more cost-effective machines achieved through the following:

   - shorter cycle times
   - higher reliability
   - simpler operation
   - shorter training time
   - higher spare-parts availability
   - ergonomically sound designs
   - multiple-tree capability
   - higher off-road mobility and speed

2. Greater operator safety.

3. Maximal fibre recovery and utilization.

4. Environmental compatibility, no rutting, no soil compaction.

5. Silvicultural compatibility which in most areas means facilitating reforestation by leaving minimal slash or residual trees on clear-cut sites. It is recognized that special treatment may have to be given to nutrient deficient areas.

6. Processing done at the most "controllable" (for quality and production) location to which raw material can be economically transported (to roadside, terminal, mill, etc.); that is, as few machines as possible in harsh environment.

7. Clean raw material, free of sand, grit and dirt.

8. Improved fuel economy.

9. Planning, service and supervision of the production system should be simple.

10. Possibility of sorting wood categories (species, sizes, etc.).

11. Commonality of parts.

Many of the prerequisites may be met with a standardized machine system using the same basic carrier and components for felling, forwarding, delimbing, truck loading and possibly road building to give benefits from:

* Common parts - reduced spare parts inventory.
* Simplified training of operators and mechanics.
* Lower costs through longer production series of well-proven components.

INTRINSIC PROBLEMS WITH PRESENT BASIC CARRIER CANDIDATES

Attempts to use a basic carrier has not been successful in the past. Present basic carrier candidates have not been able to meet the prerequisites of the market for all the functions.

The ubiquitous skidder is the most obvious basic carrier candidate (Fig. 1). Unfortunately the skidder has some intrinsic problems which has limited its use as a feller-buncher and delimber carrier:

- Instability.
- The large diameter tires reduce the operator's visibility.

- The loader size has to be limited because of weight restrictions resulting in low swing torque and limited reach
- A complex hose or swivel arrangement is necessary as all the hydraulic functions of the felling booms and head have to pass the swivel.

Figure 1. A typical choker skidder.

The skidder has, however, been used in the past as a feller-buncher carrier, (Fig. 2 and 3). They are examples of fairly good compromises which alleviate, to some extent, the intrinsic problems but at a cost. A reduced boom reach and an automatic lock-up of the oscillating axles improves stability. A cab location on the rear frame (Fig. 2) improves visibility at the expense of standardization. The felling heads have no accumulator for weight-stability reasons.

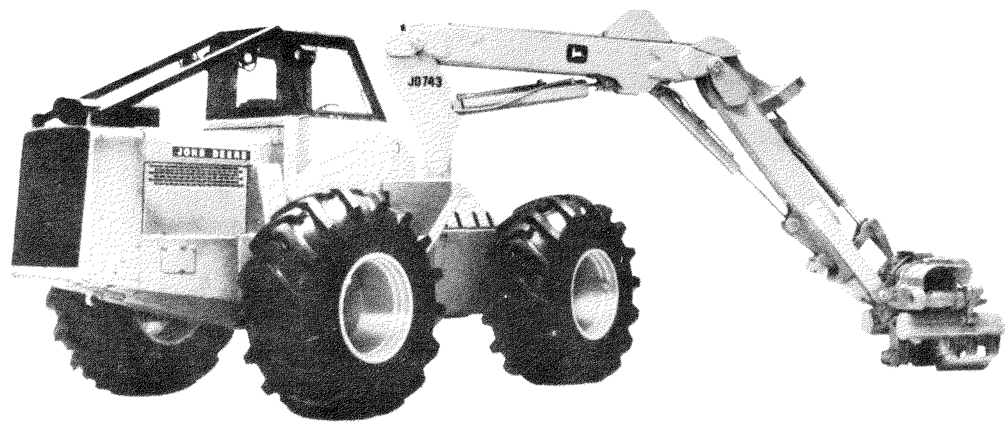

Figure 2. Feller-Buncher.

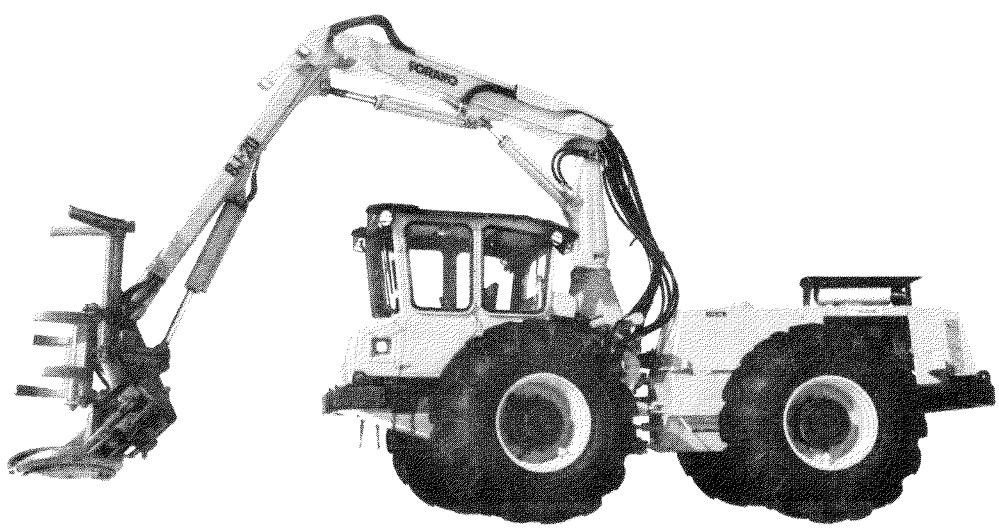

Figure 3. Feller-Buncher.

The skidder in its present configuration has insufficient stability to carry a stroke delimber attachment.

Large two-axle feller-forwarders have good stability but suffer from some inherent problems that have limited their use as basic carriers:

- High ground pressure.
- Too expensive because of their large size and weight for use as a delimber carrier.
- A number of controls of the hydraulic system and all the controls of the engine have to pass through the swing mast or turntable.
- The engine is too large to be fuel-efficient solely for delimbing.

A new feller-forwarder design has eliminated some of the inherent problems.

Excavator carriers (tracked) have been used for years as basic machines for feller-bunchers (Fig. 4). In most cases, they can out-perform feller-bunchers based on wheeled skidder chassis, because of better stability, visibility and reliability.

The excavator track undercarriage working in the stump area suffers, however, from the following drawbacks:

- Short track life (1-2 years), as it is not designed to travel over stumps and rough ground.
- Slow speed, both off- and on-road, which means that the machines inconveniently have to be refuelled and serviced in the stump area when operating far from the road.
- Require expensive, inconvenient low-bed trailer hauling for fairly short distances between job sites.

More standardization would have resulted in sacrificing productivity for some of the functions. Consequently, we must continue searching for the ideal basic carrier that would meet the prerequisites for all the wood harvesting functions. The ideal basic carrier may be too difficult to find and we may have to be content with the best possible compromise.

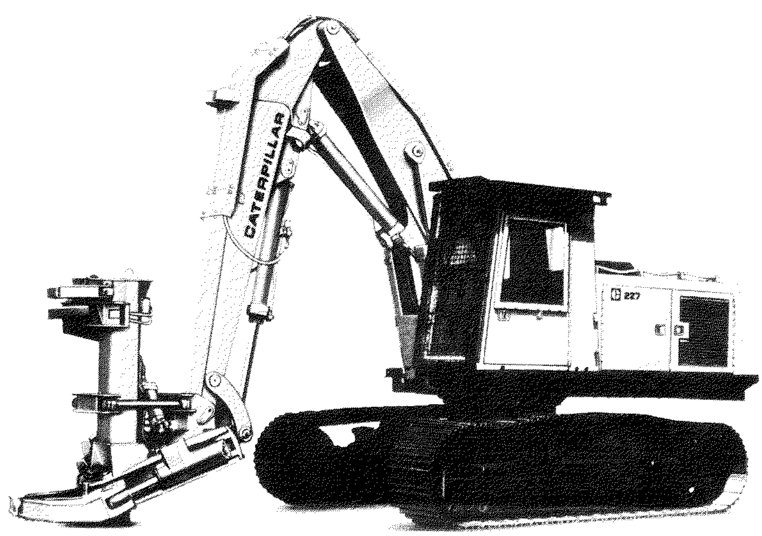

Figure 4. A typical feller-buncher on excavator track undercarriage.

SINGLE- OR MULTI-FUNCTION MACHINES

Before taking a closer look at the prerequisites of basic carriers for the future it might be interesting to review the question: should single- or multi-function machines be used?

In Canada, there has been a clear trend away from multi-function machines in recent years:

1. Multi-function machines tend to be too complex to suit the Canadian market. The problems of servicing these machines are also compounded by the long distances mechanics need to travel.

2. The small tree sizes in eastern Canada require machines with multi-stem capability in order to get economical productivity. It is extremely difficult to design a simple, reliable, multi-stem, multi-function machine such as a feller-delimber, delimber-forwarder, etc.

Felling machines used for steep and rough terrain need maximum stability and gradeability in order to hold heavy and snow covered trees in gusting winds in an upright position. A single function machine is more logical under these conditions because the addition of another function such as delimbing will result in additional weight, reduced stability and reduced gradeability. The alternative would be a larger carrier.

Successful stroke delimbers perform one primary function: delimbing. Their design allows them to perform secondary functions also such as piling and sorting without any added components. These machines have very efficient materials handling characteristics with minimal movement of trees, stems, limbs and tops.

Transportion should be done by a single function machine, because all added functions such as felling or delimbing reduce payload, gradeability and stability. It is difficult to compensate for the reduced payload with better materials-handling characteristics. Examples of single function transporters are: skidders and forwarders.

Feller-forwarders are exceptions to the rule that single function machines are more economical. These machines perform two primary functions, felling and forwarding. Despite high cost for increased width and weight in order to attain sufficient stability for carrying a felling head plus one or several trees in an upright position, it has been proven that these machines are cost-effective in certain terrains and for shorter trees (less than 18-20 m).

Despite the success of the feller-forwarders on hard grounds the general trend should be towards single-function machines for the following reasons:

* More reliable, less complicated machines.

* Better mobility with lighter machines with low ground pressure - better flexibility.

* The trend towards small contractors with limited resources and service facilities favours inexpensive, reliable, simple machines.

A NEW BASIC CARRIER

Any new basic carrier would have to meet a number of prerequisites.

The feller-buncher must reach every tree. Therefore, mobility, low ground pressure and stability are important factors affecting the productivity of feller-bunchers.

Daily servicing of the machine should preferably be carried out at the roadside or the field garage which means that the carrier should be able to travel at 3-6 km/h off-road and at least 10 km/h on the road in order to reduce non-productive travel time.

A delimber must work on the road as well as in or over ditches, which means it must have a low ground pressure. A travel speed of 10 km/h on the road would be sufficient. Good stability is a must for a delimber carrier.

The prerequisites for the loader and excavator are essentially the same as those of the delimber. The transporter has to travel fairly long distances over rough, steep or soft ground. Consequently, high mobility, flotation, traction and stability are important features.

The transporter or forwarder will determine the design and characteristics of the basic carrier as it must continuously travel and transport some 50-500 m^3/ha of wood from the stump area to the roadside efficiently.

To meet these prerequisites a new basic carrier (Fig. 6-8) with the following features is proposed:

* Four wide 68 x 50-32 tires with the option of conventional tires with snow chains or tracks in deep snow (over 75 cm).

* A simple, one-sided bogie arrangement to maintain equal wheel load distribution in rough terrain.
* Hydrostatic drive and traction steering for fast manoeuvrability.
* A wide cab with a swinging seat for comfortable driving in both directions. Positioning the operator is faster and safer than turning the machine - and reduces ground damage and tire wear.
* The centre of gravity remains at the centre of the machine whether it is loaded or unloaded, i.e. the trees are always carried with their centre of gravity at the middle of the carrier (Fig. 7).
* The carrier is very well balanced because of the position of the engine and pumps. This eliminates the need for heavy counter-weights (Fig. 13 and 14).
* The bogies can be locked in different positions in order to level the machines.
* Maximum gross vehicle weight = 10-15 tons.
* Very good ground clearance (about 1 m).
* Common components: wheels, driveline, bogies, engine, hydraulics, cab, etc. Modular design.

Figure 5. A Clam-bunk Skidder.

A NEW FORWARDER CONCEPT - THE FERIC FORWARDER

In eastern Canada skidders are presently used in 85-90% of all off-road transportation. The remaining 10-15% is transported by harvesters, feller-forwarders or forwarders of various types. The skidder, choker- or grapple-type, is a very flexible vehicle that can be used in a variety of terrains. Though the choker-skidder is a simple, reliable, inexpensive vehicle, it has some intrinsic problems that could make it less popular at some time in the future:

- The loading and unloading times are very long. (Normally 50-75% of the total time per load in "cut and skid" operations).
- The operator must dismount 2-4 times per load (time consuming, tiring and hazardous).
- The load is dragged in the mud creating problems for full-tree utilization.

Grapple skidders are suitable for larger trees and bunched trees. The operator need not dismount for loading. The grapple skidders suffer, however, from the same intrinsic dirt problems as the choker skidder. The load location, far behind the rear axle, creates a very unfavourable load distribution which greatly reduces the potential load capacity and skidder life. Moreover, it has a very low load ratio (Payload/Operating weight = 0.15-0.25 compared to that of the choker skidder which is 0.30-0.60).

The clambunk skidder, (Fig. 5) has not replaced the skidder to any large extent in eastern Canada despite many interesting features:

* Large payloads, 5-15 m^3 of tree lengths or full trees, make longer forwarding distances economical. Payload/Operating weight = 0.60-0.70.
* Self-loading.
* Carries 60-80% of the load thus delivering cleaner (average) wood for full tree chipping.

The following drawbacks may explain the reasons why so few clambunk skidders are in actual operation in Canada:

- Long loading times, 5-15 min.
- Complex loader and loading operation means long training periods (3-6 months) and low reliability (5-6 hydraulic functions on loader + 2 hydraulic functions on the clambunk).

- The machine is expensive (3-4 times the cost of a skidder).
- High ground pressure, 70-80 kPa (10-12 psi) at the front wheels.

The proposed new FERIC forwarder (Fig. 6-8) has the following features and is designed to overcome many of the inherent problems experienced with skidders:

* Carries loads of tree lengths or full trees - clean wood.

* The centre of gravity of the load can always be located in the middle of the machine between the wheels which makes it possible to carry longer trees.

* Safer on steep slopes. No need to turn. The operator drives straight uphill and downhill.

* The machine is very versatile in that it can also be used to pull trees from difficult positions to compile bunches and can carry or skid trees.

* The load grapple can lift either one tree or a full load up to nearly the vehicle weight.

* Loading and unloading takes only a few seconds, when the load is properly pre-bunched.

* Can be driven on to existing piles of full trees or tree lengths for fast unloading, permitting build-up of high piles. This eliminates the need for piling and aligning the wood with the blade as is common practice today with skidders (Fig. 8).

* Wide, low pressure tires reduce wood breakage.

* The new forwarder simply backs away from the pile after unloading whereas skidders have to drive down the vertical front of the pile; a practice which is hard on the machine and limits pile height.

* It is faster to turn the position of the operator than the machine. A swing seat with armrest controls in a wide cab permits comfortable operation in both directions with less strain on the operator and the machine, less ground disturbance, shorter travel times and no hazardous turning on steep slopes.

* For simplicity and stability only the wheels of the load side have a bogie suspension.

* An extremely simple machine with only three hydraulic functions of the loader: the main boom, jib and grapple.

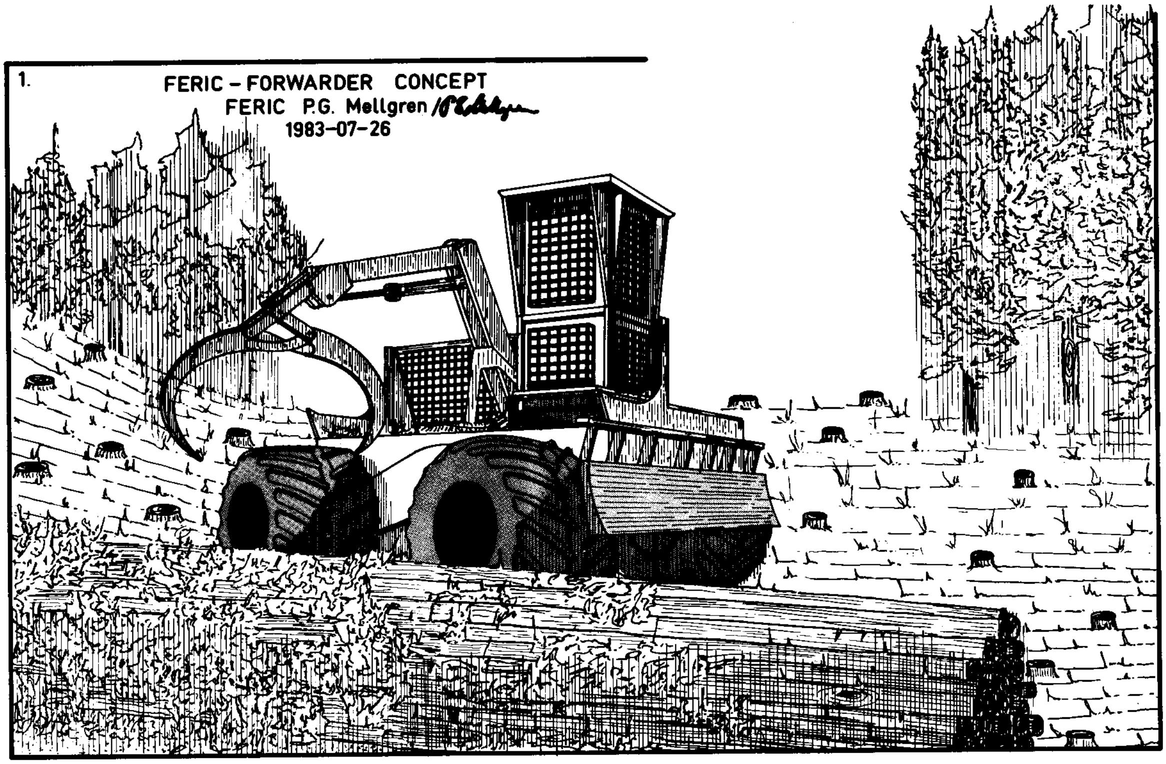

Figure 6. FERIC Forwarder, loading.

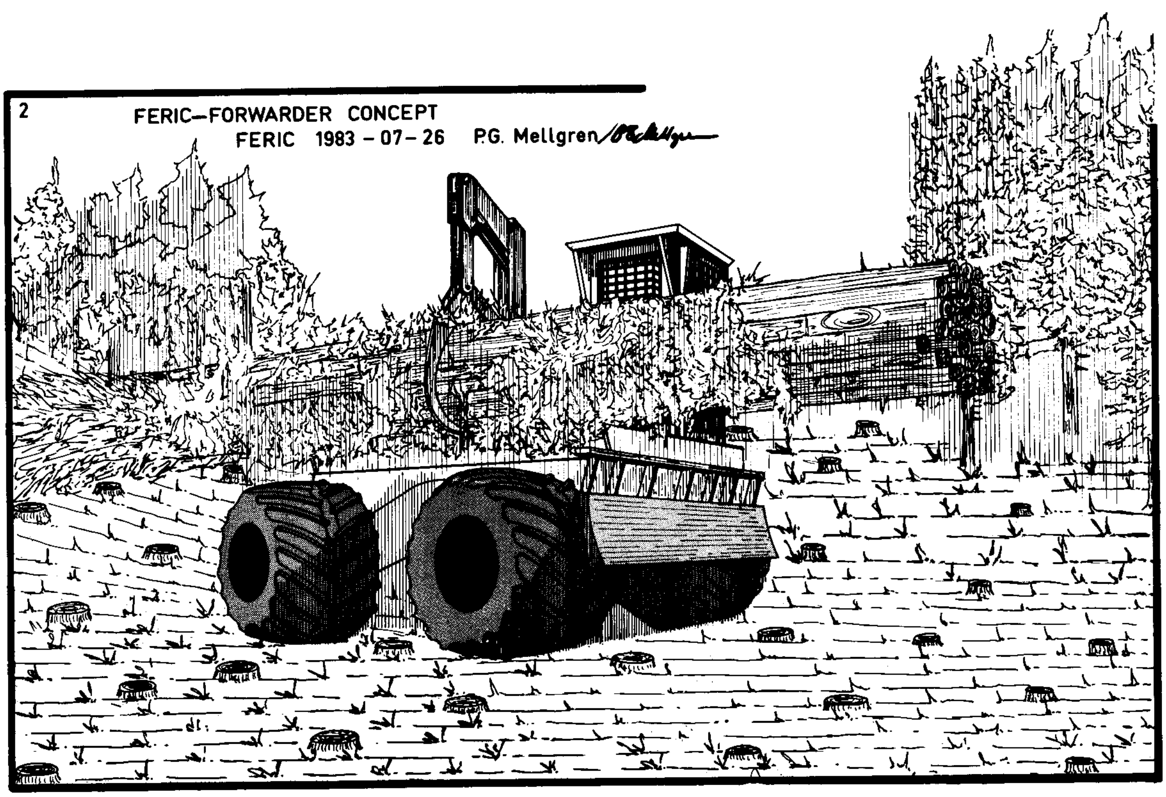

Figure 7. FERIC Forwarder, transporting.

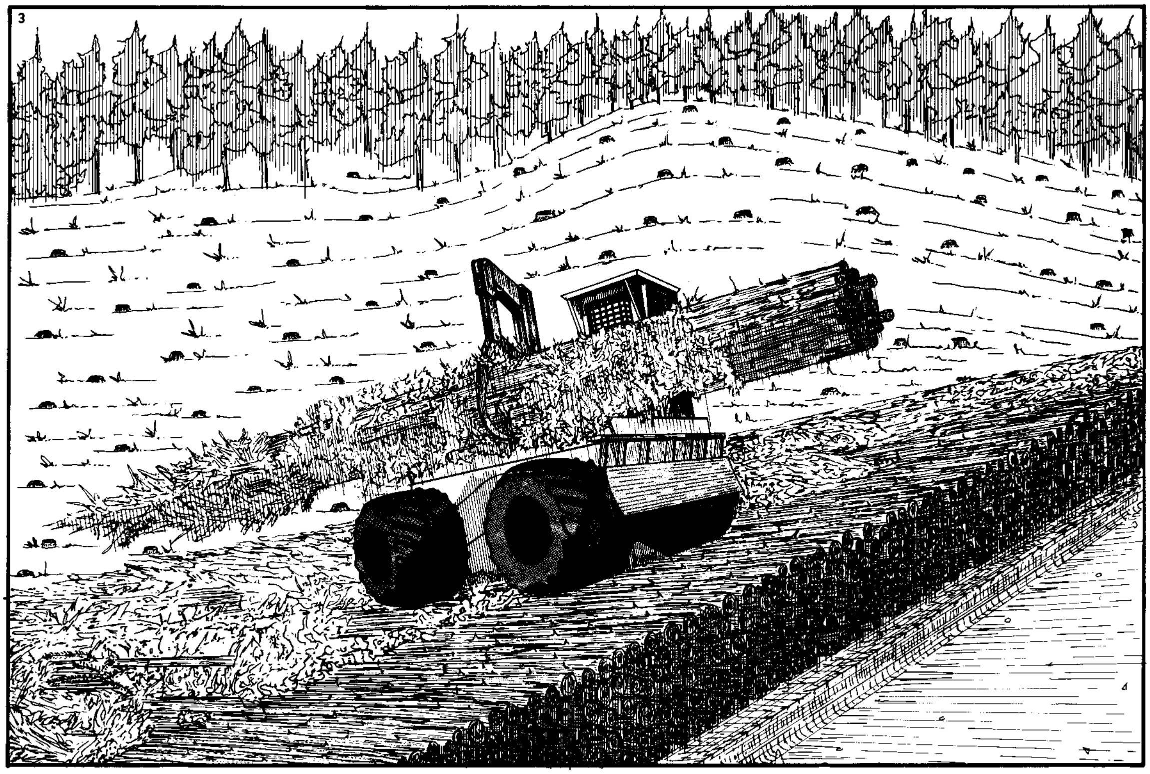

Figure 8. FERIC Forwarder, unloading.

* Better fibre recovery - no dropped trees as with grapple skidders.

* The operator will intentionally steer the wheels of the cabin side of the machine around obstacles to get a more comfortable ride. The bogie-suspended wheels on the other side can easily drive over obstacles and still have all four wheels on the ground.

Naturally, the carrier concept is the result of a number of compromises and has a few inherent drawbacks:

- The machine is wider than a skidder with regular tires which may create manoeuvering problems in mixed stands with residual trees.

- Visibility and load size with very branchy trees may, at times, be reduced.

- Performance in deep snow (without changing tires) needs to be studied.

ECONOMIC ANALYSIS OF THE FERIC FORWARDER

One of the main advantages of the FERIC forwarder is its short loading and unloading time and the fact that it does not have to turn around before loading and after unloading. The operator simply swings his seat 180° and drives in the opposite direction. A grapple skidder operator has to turn his machine 180° before picking up his load and after unloading, which is time-consuming. Furthermore, the operator has to use his dozer-blade to align the butts and make a higher pile as there is usually insufficient landing space. The decisive factor in the choice of the FERIC forwarder would be the transport cost compared to that of the choker skidder, grapple skidder or clambunk skidder.

To calculate the production per Productive Machine Hour (PMH) and transport cost for comparison with current machines we have to make a number of assumptions based on actual tests with existing machines transporting tree bunches. The assumed approximate price of the FERIC forwarder has to be considered as the price we are aiming for. Loading time includes turn around for skidders. Unloading time includes turn around and pile.

Table 1. Assumptions for Comparison Analysis

Machine	Tires	Travel speed km/h	Loading time minutes	Unloading time minutes	Load size m^3	Cost of unit approx. $
FERIC forwarder	Wide	5	1	1	3	140 000
FERIC forwarder	Wide	5	2	1	4	140 000
Grapple skidder	Wide	5	2	2	2	100 000
Choker skidder	Wide	5	4	4	3	80 000
Clambunk skidder	Regular	4	6	1	7	240 000

Figure 9 and 10 summarizes the following calculation of the productivity of the machines.

Table 2. Productivity Comparison

Vehicle	FERIC forwarder 3 m^3/load 5 km/h 83.5 m/min			Grapple skidder 5 km/h 83.5 m/min			Choker skidder 5 km/h 83.5 m/min			Clambunk skidder 4 km/h 67 m/min		
Distance 2 x m	100	200	400	100	200	400	100	200	400	100	200	400
Travel time, min	2.4	4.8	9.6	2.4	4.8	9.6	2.4	4.8	9.6	3	6	12
Load/Unload time, min.	2	2	2	4.0	4.0	4.0	8	8	8	7	7	7
Total time/load, min.	4.4	6.8	11.6	6.4	8.8	13.6	10.4	12.8	17.6	10	13	19
Load/PMH	13.6	8.8	5.2	9.4	6.8	4.4	5.8	4.7	3.4	6.0	4.6	3.16
Load size, m^3	3	3	3	2	2	2	3	3	3	7	7	7
m^3/PMH	41	26.4	15.6	18.8	13.6	8.8	17.5	14.1	10.2	42	32.2	22.0

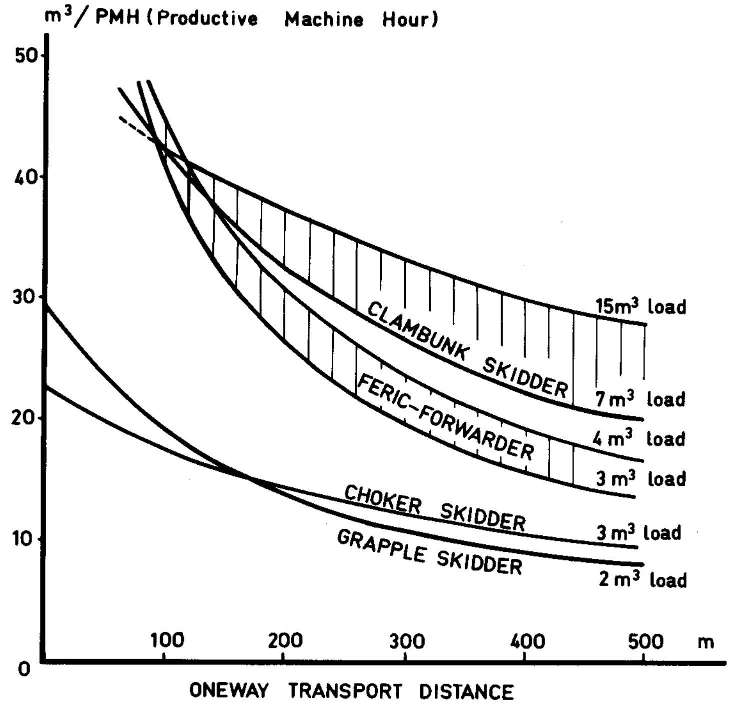

Figure 9. Comparative Productivities - m^3/PMH.

MACHINE OPERATING COST ESTIMATE

The following assumptions are made for the estimates of the comparative machine operating costs

Residual value	10%
Life - Years	6
- SMH	6 x 2250 = 13500
Interest per year	15%
Insurance per year	2%
Repair cost over life	120%
Fuel, lube, $/PMH	5
Operator cost and fringes $/SMH	15

Table 3. Transport Cost Comparison

Cost per PMH	FERIC Forw.			Grapple Skidder			Choker Skidder			Clambunk Skidder		
Total cost per unit C $	140 000			100 000			80 000			240 000		
Residual Value V	14 000			10 000			8 000			24 000		
Depreciation $	126 000			90 000			72 000			216 000		
Utilization	0.85			0.85			0.87			0.75		
Life PMH	11 500			11 500			11 700			10 100		
Life years Y	6			6			6			6		
Avg. invest. $\frac{C(Y+1)+V(Y-1)}{2Y}$	87 500			62 500			50 000			150 000		
Interest per year 15% $/year	13 100			9 400			7 500			22 500		
Insurance 2% $/year	1 750			1 250			1 000			3 000		
Repair cost over life 120%	168 000			120 000			96 000			288 000		
Depreciation $/PMH	11.00			7.85			6.15			21.40		
Interest 15%	6.88			4.90			3.85			13.40		
Insurance 2%	0.91			0.65			0.51			1.78		
Repair	14.60			10.50			8.20			28.50		
Fuel	5.00			5.00			5.00			5.00		
Operator	17.70			17.70			17.30			20.00		
Total cost $/PMH	56.09			46.60			41.01			90.08		
Transport Distance m	100	200	400	100	200	400	100	200	400	100	200	400
Production m^3/PMH	41	26.40	15.6	18.8	13.60	8.8	17.5	14.10	10.20	42	32.20	22
Cost $/$m^3$	1.37	2.12	3.60	2.48	3.43	5.30	2.35	2.92	4.03	2.15	2.80	4.10

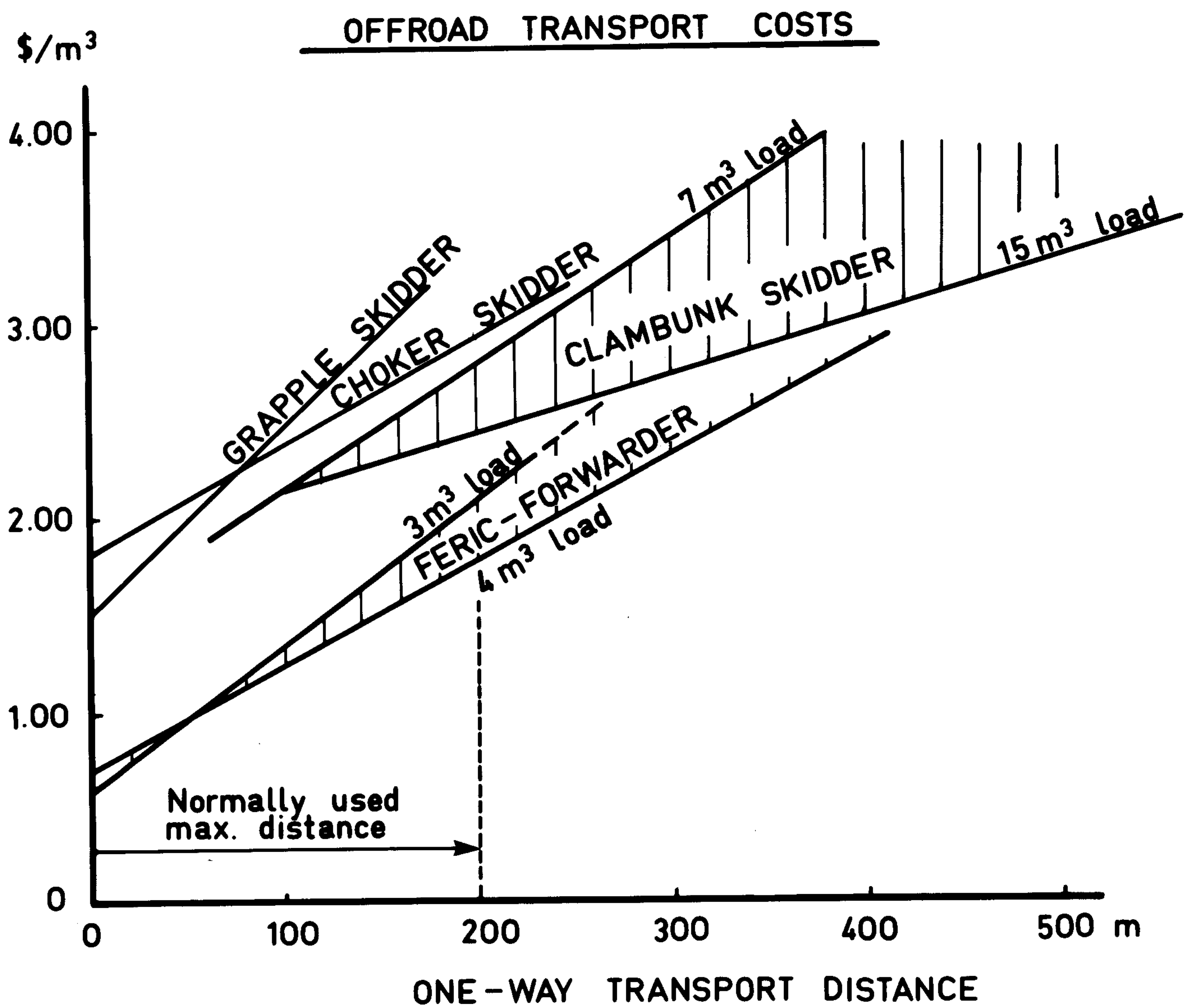

Figure 10. Comparative Transport Costs.

Figure 10 illustrates the comparative transport costs for the FERIC forwarder, and the grapple, choker and clambunk skidders.

The FERIC forwarder has the potential of reducing the transport costs by 25-50% within the normally used maximum distance of 200 m (600 ft). For distances over 200 m it is economical to take enough time to pick up 2 bunches to get a load of 4 m^3.

A clambunk skidder with a payload capacity of 10-12 tons can theoretically transport up to 15 m^3 of tree lengths. However, such large loads can increase the loading time to 15-18 min. particularly when short trees are transported. Consequently, the FERIC forwarder with a maximum payload of 4 m^3 can be economical even at transport distances of 400-500 m because of its short loading and unloading times.

A NEW FELLER-BUNCHER CONCEPT - THE SWING-SWATHER

The Swing-Swather concept is a light-weight high capacity feller-buncher that is designed for operation on relatively rock-free ground in stands of small trees (0.10-0.25 m^3/tree) Fig. 11-13.

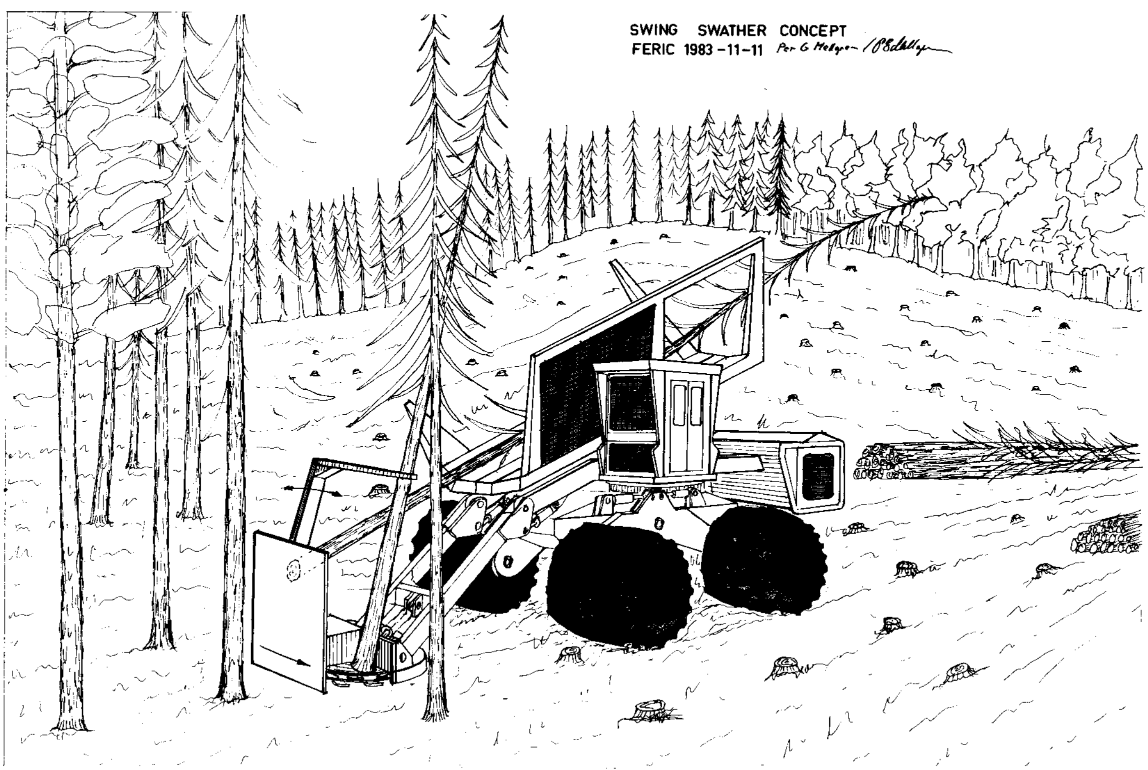

Figure 11. The Swing-Swather.

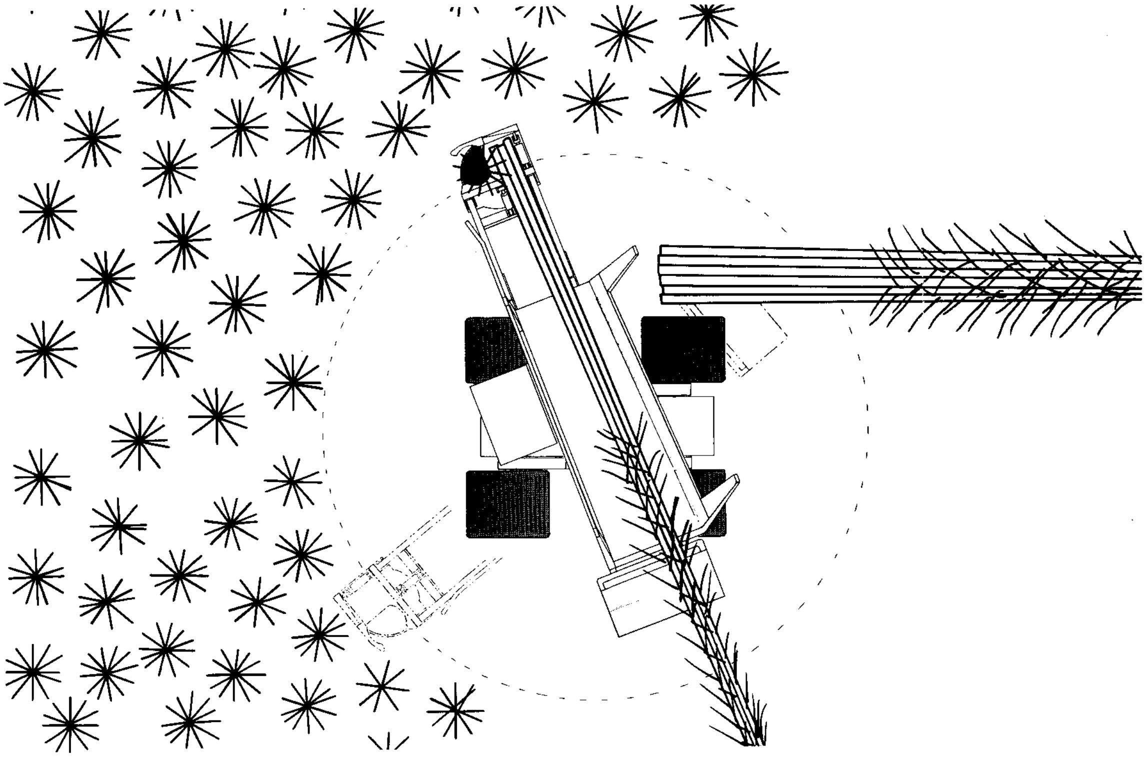

Figure 12. The Swing Swather.

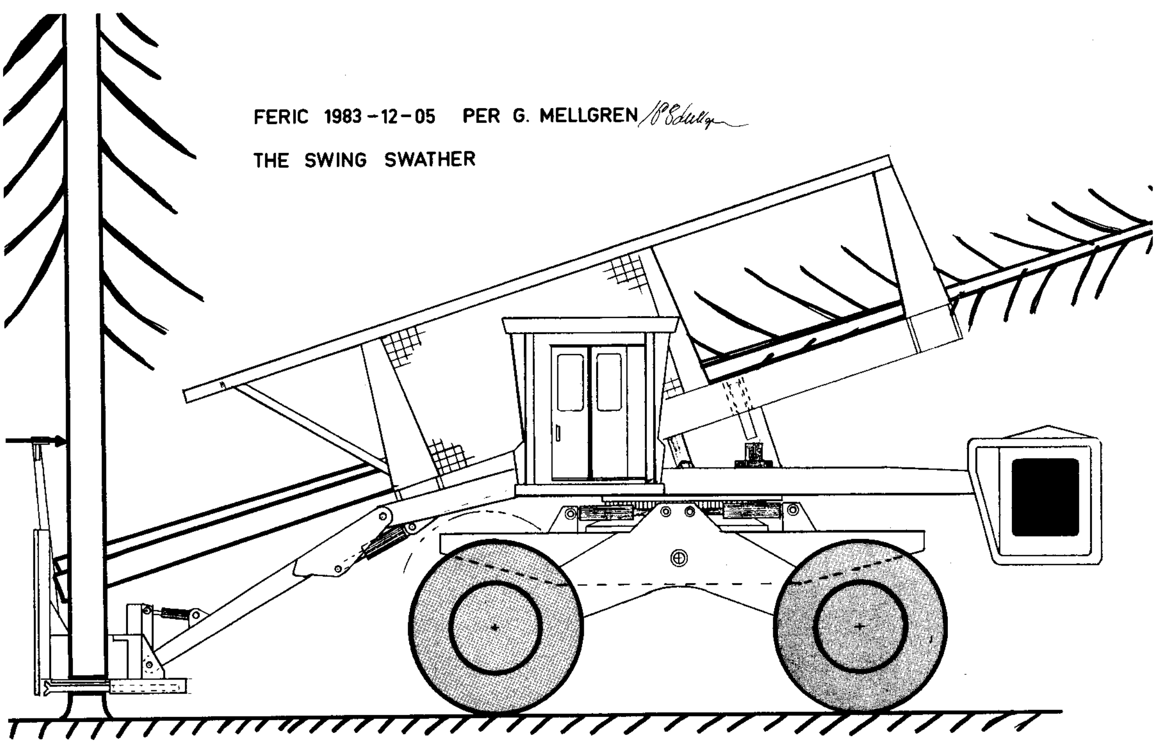

Figure 13. The Swing Swather.

The light-weight design is made possible by using a combination of features:

* First severing the tree, then push-directing the tree to fall into the accumulator basket. Thus, the swing-swather never holds the trees vertically.
* Horizontal accumulation of the trees in the basket.
* The centre of gravity of the felled trees is always near the middle of the machine. This maintains good load distribution for both the loaded or unloaded states.
* The engine, hydraulic pump drive, pumps and fuel tank module are used as counter-weights to the feller-swather head. No heavy extra counter-weights are needed as the design permits a long moment arm.
* The trees are pushed radially towards the swing centre immediately after severing. This eliminates the high twisting forces on the booms from crown contacts and entanglements between the vertical bunched trees and standing trees--a serious problem with conventional feller-bunchers.

A HIGH MOBILITY DELIMBER

Figure 14 illustrates the modular design concept of the delimber. The engine/hydraulic pump module is used as a counter-weight in balancing the tree and the extended boom in a cost-effective, weight-saving way.

The bogies are locked to the main frame with the turn-table by means of hydraulic cylinders. No extra linkages are needed to level the turntable for optimal operating conditions.

The main advantages are:

* High mobility, 10 km/h on the road for travelling to the garage for servicing and refuelling.
* Low ground pressure for work in ditches and soft ground.
* Good accessibility for service.
* Simple turn-table design—a simple swivel as there are only two hydraulic travel motors to supply.
* Light-weight carrier.
* Engine module on a long arm gives more design freedom and space for handling delimbed trees at different angles. On excavator carriers the stems have to be moved through a narrow space between the engine and the delimber boom.

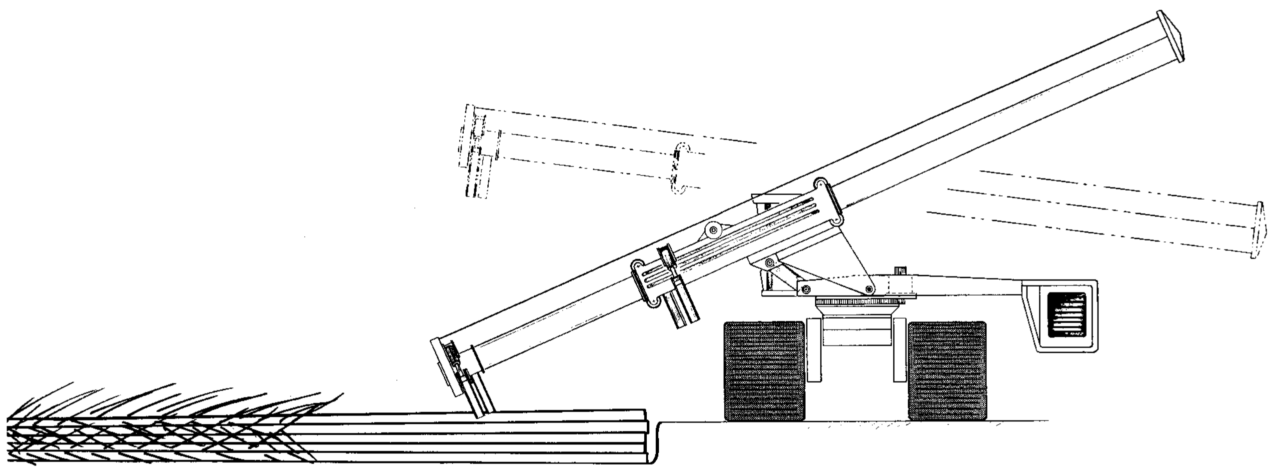

Figure 14. Delimber.

CONCLUSIONS

The proposed new modular machine system has the potential for substantially reducing the cost of clear-cut wood harvesting because of its more efficient materials handling capability.

Existing technique and components are used. What is new is a unique combination of those components into more efficient, simpler machines. Consequently, the development costs should be comparatively modest.

The proposed harvesting system uses three machines: a feller-buncher, a forwarder and a delimber. The feller-buncher can also be used as an efficient feller-forwarder, at least for short forwarding distances of 100-200 m. For short distances, it will be more economical than a feller-buncher and a forwarder provided it will be possible to design the machine for a payload of 2-3 m^3. Therefore, great care should be devoted to the design of the feller-buncher-forwarder in order to reduce the dead weight and increase the payload.

To prove the performance and stated economic advantages of the new wood harvesting machine concepts the following stepwise development program is proposed:

1. Design, manufacture, test and evaluate an experimental FERIC forwarder.

2. When the FERIC forwarder performs to expectations, design, manufacture, test and evaluate a prototype SWING-SWATHER feller-buncher and feller-forwarder. Costs can be minimized by converting the forwarder into the carrier for the Swing-Swather attachment.