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

Technical Report No. TR-57

May 1984

The Use of High Flotation Tires for Skidding in Wet and/or Steep Terrain

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PREFACE

This report describes FERIC's four-year program aimed at introducing high-flotation logging tires to extend the range and capabilities of conventional skidders. Our program, coupled with the efforts of several tire manufacturers and the forest industry in Canada and the United States, has resulted in a new breed of wide, high-flotation tires capable of significantly improving skidder performance in a number of applications. The reader is cautioned that the results presented are specific to the test tires, machines and operations, and thus, should only be applied with discretion.

Details of the study procedures and analyses, plus results of limited interest, have been omitted from this report for the sake of reasonable brevity. Further details of the study will be supplied on request.

All tire dimensions are presented in Imperial units to conform with the standard tire sizing policy used in North America. All other 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.

The authors would particularly like to thank the following companies for their help and cooperation and their willingness to take the first chance:

John Deere Ltd.
Rolligon Corp.
Spruce Falls Power & Paper Co. Ltd.
Tundra Industrial Equipment Ltd.

Grateful appreciation is also extended to the other companies, and their personnel, that gave their support to the program:

Abitibi-Price Inc.
Firestone Canada Inc.
Goodyear Tire and Rubber Co.
Great Lakes Forest Products Ltd.
St. Regis (Alberta) Ltd.
Timberjack Inc.
United Tire & Rubber Co. Ltd.

Technical assistance provided by FERIC employees D. MacGregor, B. McMorland, M. St-Amour and summer student P. Zundel is also acknowledged.

Per G. Mellgren is a registered professional engineer (M.Sc.M.E.) and Ernest Heidersdorf is a graduate forest engineer (B.Sc.F.E.). P.G. Mellgren initiated FERIC's involvement with the wide-tire concept and was instrumental in its application by the tire manufacturers. E. Heidersdorf was in charge of all FERIC testing, the analyses of the results and preparation of the final report.

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SUMMARY

Adequate flotation of off-road vehicles (i.e. the avoidance of excessive sinkage) has long been a problem, particularly on the low strength soils which underlie large portions of the forest area throughout Canada. Harvesting these wet areas in summer with conventional, narrow logging tires has proved environmentally unacceptable and costly because of bogged down machines, reduced loads and excessive ground disturbance. Efforts to solve this problem with tracked vehicles have had only limited success, mainly because of high track and undercarriage maintenance costs.

To help resolve these problems, FERIC initiated a search for a dependable high-flotation tire that could be used to improve the performance of existing machines in soft-ground conditions. Testing commenced in 1980 with FERIC's introduction of 68 in.-wide Rolligon tires to skidding operations in the black spruce swamps of Northern Ontario's Clay Belt. Ground conditions in this area consist of a thin root mat overlying deep organic soils of negligible shear and compression strength. It was hoped that the large footprint of the wide tires would keep the machines from breaking through the root mat.

The spectacular initial results led to a four-year testing and development program by FERIC, the forest industry and several tire manufacturers. This program has culminated in a new breed of wide, flexible, low-pressure, high-flotation tires capable of significantly improving skidder performance both in soft-ground and steep-slope applications. Such tires are presently manufactured by Rolligon Corp. (68-in. wide), United Tire (50-in. width), Firestone (50 in.) and Goodyear (43 in. available, 50 in. pending) with approximately 100 already in service in Canada by 1983.

The success of the new wide, high-flotation tires stems from a number of advantages that they have demonstrated over conventional, narrow skidder tires, notably:

+ Productivity increases of up to 60% in wet ground. There are also indications of lesser, though significant, improvements in performance on rough and steep terrain.

+ Fuel savings per unit volume of up to 40% depending on the ground.

+ Substantial reductions in ground disturbance (rutting) on sensitive soils even after repeated passes.

+ Less soil compaction providing improved regeneration and higher future growth rates.

+ The possibility of using smaller machines to do an equivalent job.

+ A smoother ride for man and machine.

+ Improved stability and thus safety on sidehills owing to the tire width.

+ Increased access to conventionally inaccessible timber because of the improved flotation and stability. This improved access can also mean less idle time for the skidder fleet and a reduced need for expensive specialized equipment.

Naturally, along with the benefits come a number of tradeoffs, notably:

- The price of the tires is double or more that of conventional tires.

- The wide tires' performance in deep snow is questionable. Moreover, the tires are more susceptible to puncture in cold weather. Therefore, a change of tires with season may be required.

- The tire width places increased stress on the axles and final drives, possibly necessitating their reinforcement especially on smaller size-class skidders.

- The increased vehicle width may affect manoeuverability, garage size and ease of freighting.

- The use of wide tires may require specialized equipment and facilities for tire maintenance.

- Their life, though appearing promising, remains as yet unproven.

Prospective users must weigh these advantages and disadvantages before choosing what is right for their particular conditions, needs and applications. However, there is no doubt that in the right application, the use of the new breed of wide, high-flotation tires can improve the range and capabilities of conventional skidders substantially.

INTRODUCTION

The performance of off-road vehicles often depends on their flotation, that is, their ability to move on the soil surface without excessive sinkage. This machine characteristic is especially vital on the low strength soils, typically peats, clays and silts, which underlie large portions of the forest area throughout Canada.

Historically, these soft ground areas have been largely harvested in the winter months when the ground is frozen. However, where such areas represent a significant proportion of a company's operating limits, this traditional practice poses a number of problems and costs because of the reduced logging season, notably: increased planning, difficulties in wood delivery scheduling and maintaining a uniform species mix for the mill, increased inventories, seasonal employment and subjugation to the whims of the weather.

Harvesting these wet areas in summer with machines equipped with conventional, narrow logging tires has proved costly because of excessive ground disturbance and low productivity, i.e. reduced loads and travel speeds (Fig. 1).

Figure 1. Excessive Sinkage with Conventional Tires.

Efforts to solve this problem with tracked vehicles have had limited success. Where speed is required, as in skidding, track and undercarriage maintenance costs have generally been high because of the inherent lack of drive-line overload protection, the large number of moving wear parts, and the rough ride over stumps and other obstacles typically associated with tracked carriers.

FERIC's evaluation of the McColl ACCUFOR concept (a high speed, all-terrain Accumulator Forwarder) suggested the need for a low-pressure, high-flotation tire to help resolve these problems. Thus in 1979, FERIC initiated a search for such a tire that could be used to improve the performance of existing machines.

This effort has led to a four-year testing and development program by FERIC, the forest industry and the tire manufacturers resulting in a new breed of high-flotation skidder tires. The skidder was chosen as the base machine because of its importance to the Canadian forest industry and the need for improved performance in soft-ground conditions. Moreover, the skidder afforded readily available populations throughout Canada for testing in a diversity of conditions.

Though the main thrust of this program was to improve skidder performance in soft ground, certain features of these new tires indicated potential for other applications. Thus, the program was expanded to include testing in these situations. This report incorporates the results of FERIC's entire four-year testing and development program, both in soft ground and in alternate applications.

Much of the testing may not be considered overly scientific because of limitations in sample sizes and uniformity of test conditions. However, the forest environment is regretfully not a test bench and thus, we faced the constraints of weather and availability of machinery and suitable ground conditions. The results did however provide valuable insights to the development program. The test results are presented in some detail to show the development progression and to allow the reader to make his own best conclusions.

TIRE THEORY (DIAMETER VS WIDTH?)

Increasing the diameter and/or width, i.e. the footprint*, of tires increases the tractive pull of a vehicle and also reduces the sinkage and rutting. However as Bekker states, "The form of the ground contact area (footprint) and its orientation to the direction of motion are as important in producing high thrust and low slip as are the size of that area and the load. Narrow, long contact areas (large, narrow wheels and tracks) are in most cases more efficient and "mobile" than wide, short footprints with the same area. This fact explains the generally better performance of single tires compared to duals, and tells why skis are long and narrow." [2].

Thus, increasing tire diameter would appear to be the most effective manner to enlarge the footprint. However, for a certain off-road vehicle size, the diameter of the tires or machine height is limited for stability as well as practical reasons, especially on skidders with the frequent need for mounting and dismounting.

The Scandinavians have attempted to overcome this problem by developing bogey forwarders with six to eight or even up to sixteen tracking tires to get mobility and low ground pressure. This concept permits the use of smaller, narrow tires needed by machines which must often travel on public roads and are thus restricted to maximum vehicle widths of about 2.6 metres. However, the bogey designs are heavy, complicated and expensive.

In Canada, there are no real width restrictions as the machines work nearly 100% of the time off-road in clear-cut operations. Thus, FERIC looked to wider tires as a solution to the flotation problem.

Wide tires had been experimented with in the early 1960's but had been discarded for a number of reasons:

1. They were expensive to develop and manufacture.
2. The heavy tire designs made the machines sluggish and put considerable stress on the axles and final drives.
3. The thick-walled designs led to high rolling resistance.
4. The tires were more susceptible to puncture from sharp obstacles because of the large contact area.
5. The market and interest were limited.

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* For simplicity of comparison, the nominal (rated) footprint area of a tire can be approximated by the expression R·B, where R is the tire radius and B is tire width. This expression assumes a standard sinkage of 7% of the outer tire diameter [9].

However, FERIC felt that the practicality of wide tires deserved a second look because of a number of factors emerging in the last few years, notably:

1. A growing silvicultural and environmental awareness and concern about the negative effects of ground disturbance and soil compaction.

2. An increased interest in reducing fuel consumption (i.e. lowering rolling resistance) because of escalating fuel prices.

3. Recent developments in the techniques and materials available for tire fabrication indicated the possibility of manufacturing light-weight, thin-walled, penetration-resistant wide tires.

TIRE SEARCH

Our studies of mobility problems convinced us that the first step had to be the development or adaption of wider tires to existing 4-wheel skidders to improve their performance in areas where conventional, narrow logging tires experienced difficulties, notably soft ground. Better tires would then possibly lead to the development of improved off-road machines as a second long-term development program.

Thus in 1979, FERIC initiated a search for a wide tire that would be adaptable to existing skidders. A number of criteria were considered to be vital in this selection.

1. The tires had to be much wider than conventional tires. At that time, the widest conventional skidder tires available were 34 inches, but 18.4-in. and 23.1-in. wide tires were most commonly used. A doubling of this width was required to get adequate skidder trafficability in certain wet ground conditions as will be discussed later in the report.

2. The tire walls had to be fairly flexible yet penetration resistant. A rigid and stiff carcass means high internal friction or hysteresis friction losses adding to the rolling resistance of the tire.

3. A tire and mounting design that would allow for low inflation pressures was considered desirable to maximize the footprint area for a given load and improve ride comfort.

The only tires available meeting these requirements and seemingly adaptable to skidders were those made by Rolligon Corporation of Stafford, Texas (Fig. 2). For close to 20 years, Rolligon Corp. has developed and manufactured off-road vehicles used in geophysical exploration and pipeline construction work. Their tires were specifically developed for these vehicles.

Figure 2. Rolligon Tires (68 inches wide).

The tire is effectively an air-filled flexible roller having:

- Low inflation and footprint pressures;
- Flexible tire surface and sidewalls;
- Extreme deflection at operating loads and pressures;
- Low skin stresses in tire surface; and
- Uniform penetration resistance, including side walls.

Though the design had never been tested in logging operations, these characteristics appeared to be desirable for logging applications. Of the various models available, their 54 x 68-18 tire* with a V-6** penetration resistance appeared most readily adaptable to existing skidders. The 54-in. tire diameter, about 20% less than that of conventional skidder tires, was not considered to be ideal in terms of ground clearance, but represented a compromise allowing for the use an off-the-shelf tire without undue modification.

FERIC purchased five such Rolligon tires in January 1980 for the first wide tire tests. Rolligon Corp. modified these tires for us somewhat by increasing the sidewall strength for better penetration resistance and improved torque transfer capability.

PERFORMANCE TESTING

PART A - WET GROUND

Site (The Clay Belt)

In 1980, FERIC introduced the Rolligon tires to the Clay Belt in Northern Ontario on the limits of Spruce Falls Power & Paper Co. Ltd., Kapuskasing, Ontario who had agreed to cooperate in the trial. Large portions of this extensive area consist of black spruce swamps in which a thin root mat overlies deep organic soil commonly referred to as "black muck" (Fig. 3).

The surface root system (spruce, ferns, grasses, etc.) reinforces the top peat layer forming a thin mat that has a much higher shear and compression strength than the underlying soil. For example, the compression strength or ground bearing capacity of a Muskeg type A (Radforth Classification) root mat may vary from 35-70 kPa. Meanwhile, the compression strength

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* In North America, tires are commonly sized by a three number code. The first number indicates the tire diameter in inches, the second number represents the tire width in inches and the third number gives the diameter of the bead opening in inches. Thus a 54 x 68-18 tire is 54" in diameter, 68" wide and has an 18" diameter bead opening.

** All Rolligon tires were available in three different grades of penetration resistance: standard, V-2 and V-4. The Vidar (KEVLAR) V-6 penetration resistance, developed for the FERIC tests, is equal to a 30 ply rated nylon tire. KEVLAR, a DuPont registered trademark, is an aramid organic fibre with very high tensile and fatigue strength, as well as many other attractive properties. This is the material commonly used in bulletproof vests.

Figure 3. Test Site (Clay Belt).

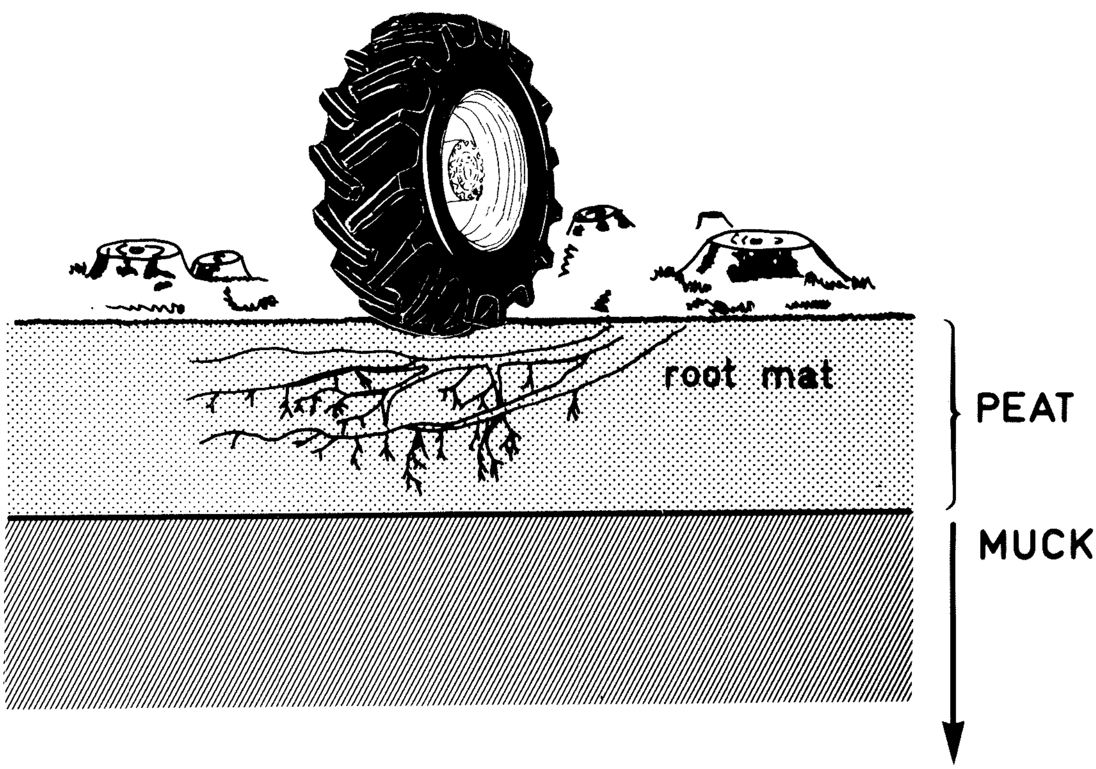


Figure 4. Soil Profile.

of the "black muck" is virtually nil. Thus, the ground pressure of machines working in this area in the summer should be less than about 35 kPa so that the machines stay on the root mat at all times (Fig. 4).

However, skidders with conventional, narrow tires normally have a rated footprint pressure of over 50 kPa, even when unloaded. Thus, they frequently break through the root mat resulting in reduced productivity because of decreased travel speeds, bogged down machines and diminished loads. They also cause silviculturally and environmentally unacceptable ground disturbance, particularly close to the landings (Fig. 5).

Figure 5. Ground Disturbance (Rutting) Caused by Skidders with Conventional Tires.

As Gemmel stated "... Wheeled skidders (with regular tires) obliterate seedbed microsites and planting chances by exposing muck and clay to the fluctuations of weather (spring frost, wet spring, dry summer, wet fall and fall frost). Wheeled skidders produce ruts which block lateral drainage which tends to cause puddling. In turn, this encourages the development of bullrushes, sedges and alder, none of which at this point of time produce good pulping fibre. A major problem, therefore, and a major obstacle blocking the successful melding of harvesting and silviculture in the Clay Belt is the destruction of site during logging." [5]. The severity of the problem is emphasized by the fact that of the black spruce forest in the Clay Belt, which represents 80% of the productive forest in the area, 50% overlies deep organic soils and an additional 30% overlies shallower organic soils.

This was the scenario that we were trying to resolve with our wide tire program. Hopefully, the substantial increase in tire width (e.g. double) would keep the equipment on the root mat.

1980

In 1980, FERIC's Rolligon tires were shipped to Spruce Falls Power & Paper Co. Ltd. in Kapuskasing.

Test Track Comparison

The initial tests were designed to assess the relative performance of the Rolligon tires as compared to other tire designs over measured test tracks. After some preliminary testing with a John Deere 640-B skidder, it was decided to use the somewhat smaller John Deere 540-B (67 kW net SAE) for the actual tests to get a fair comparison with the existing fleet of skidders in the area (67-kW class). The local John Deere distributor, Tundra Industrial Equipment Ltd., agreed to participate in the study and supplied the test skidder. All tests were conducted with the same skidder, only the tires were changed. The inboard planetaries unique to John Deere skidders greatly facilitated the mounting and dismounting of the Rolligon tires, otherwise complicated by their small 18-in. bead opening.

Trelleborg AB, Trelleborg, Sweden supplied a set of Trelleborg 422 600-34/14 SB tires and John Deere Ltd. loaned a set of United Tire 68 x 34-26 tires to the trial. The Trelleborg tires were chosen for study because their width (23.5 in.) approximated that of the more common conventional tires and because their rounded shoulder profile was supposedly conducive to operation in soft ground. The United tire represented the widest conventional tire available at that time. Figure 6 shows these tires. Table 1 provides fuller details of the three tires studied.

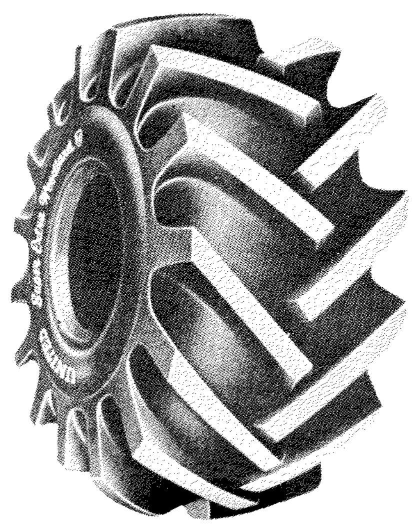


Figure 6. Trelleborg Tire United Tire

Table 1: Test Tire Description.

Tires	Trelleborg 422 600-34/14 (65x23.5-34)*	United 68x34-26	Rolligon 54x68-18
Overall diameter D, in.	65	68	54
Width B, in.	23.5	34	68
Footprint $\frac{D}{2} \cdot B$**, in^2	764	1156	1836
Footprint pressure rating at a load of 2400 kg per tire, kPa	48	32	20
Inflation pressure, kPa	115-170	115-170	48
Penetration resistance	14 ply rated nylon	16 ply rated nylon	30 ply rated nylon
Weight of tire + rim, kg	391	431	390

* See first footnote p. 6.
** See footnote p. 3.

The tests were conducted in August 1980. The selected test area was a wet black spruce swamp, clearcut with a JD 693-B Feller Buncher on tracks and skidded with the Rolligon-tired skidder to minimize ground disturbance. Parallel test tracks [distance = 200 m + semi-circle (17-34 m) + return 200 m] were established in this area. There was some minimal rutting from previous traffic by skidders with conventional tires, but the test tracks were as uniform as possible.

Each test consisted of measuring travel time and fuel consumption over a set test track. The fuel consumption was measured using a spring balance to weigh a separate 9-litre fuel tank before and after each run. The following variable conditions were assessed for all the tires.

1. Machine in both forwarder and skidder configurations. In the forwarder configuration, a counter-weight was mounted on the rear butt plate under the fairlead to provide equal axle loads of about 4800 kg each (Fig. 7). The skidder configuration involved pulling the <u>same</u> $3\text{-}m^3$ load of tree lengths for all such tests.

2. For each machine configuration, measurement in both 2nd and 3rd gear with 3-4 repetitions per gear.

3. Engine speed governed to 2000 rpm for all tests.

4. Each tire/machine configuration tested on a different test track to avoid compounded ground disturbance.

Exceptions:

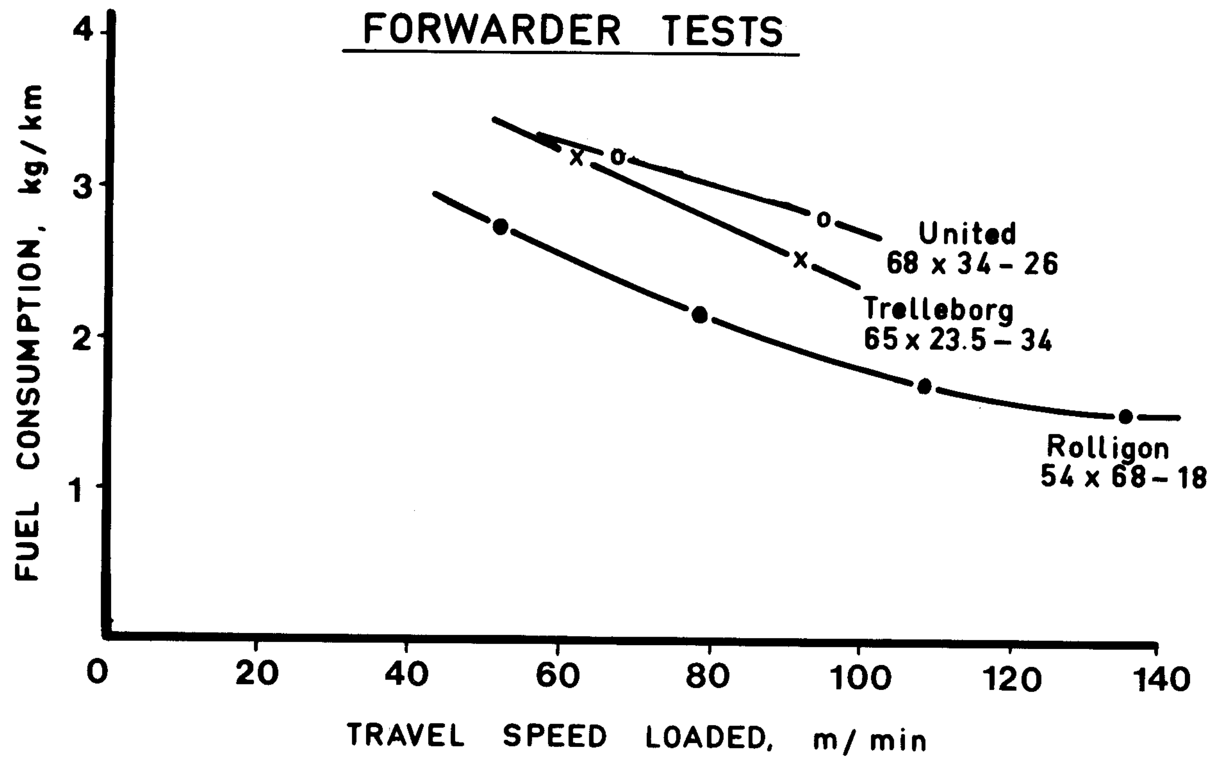
1. Trelleborg tires tested only in forwarder configuration.

2. Rolligon tires also tested in 4th and 5th gear in forwarder configuration (tests conducted in September 1980).

Figure 7. Machine Configurations. Note the counterweight used to simulate forwarder operation and the 9-L jerry can used for fuel consumption measurements. Rolligon tires at left, United tires at right.

The results of the track tests are summarized in Figure 8. There was no significant difference between skidding and forwarding (carrying) a comparable load.

At comparable speeds, the Rolligon tires showed a 20-25% fuel saving with no appreciable ground disturbance. When they could travel, the Trelleborg tires performed somewhat better than the United tires because of reduced rolling resistance, but they were more prone to bogging down because of their high ground pressure. In actual fact, the Trelleborg tires never completed more than three passes over the same track without getting stuck. The United tires also caused considerable rutting because of their aggressive tread design.



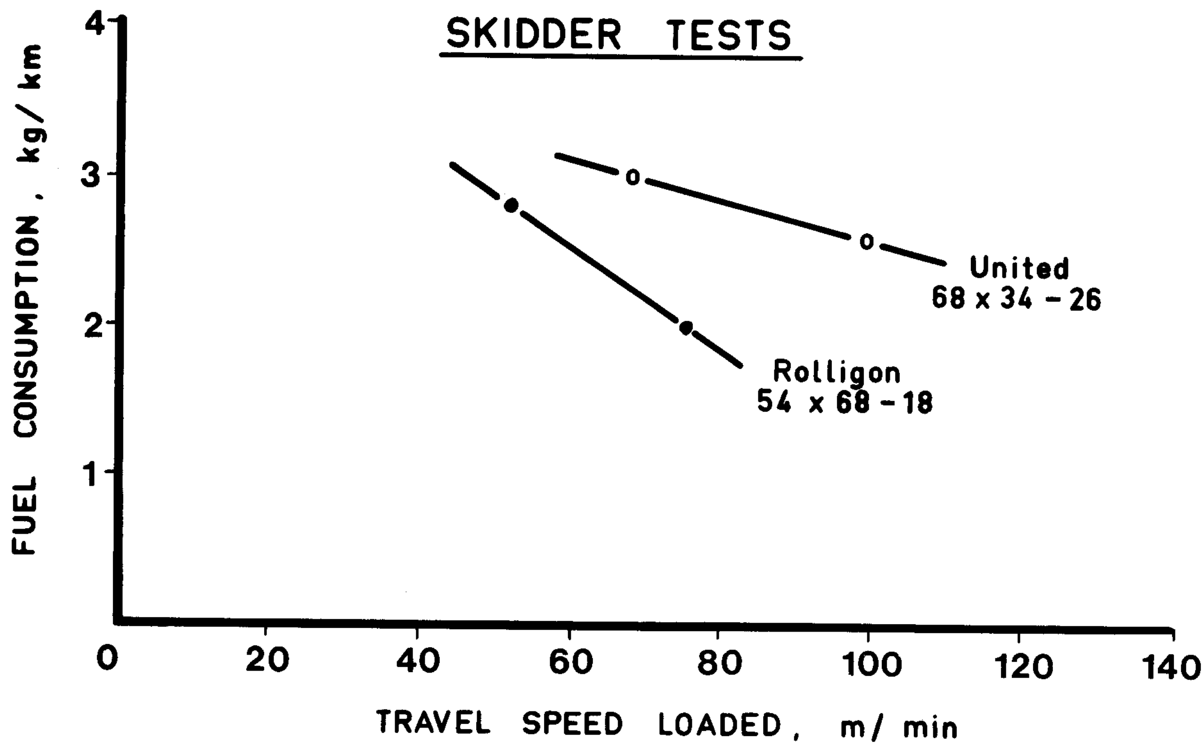


Figure 8. Test Track Results (Fuel Consumption vs Speed).

In any particular gear, the Trelleborg and United tires traveled faster than the Rolligons because of their larger diameter. However, the high flotation and smoother ride of the Rolligon tires permitted the use of 4th and 5th gear, thus leading to a higher speed overall. Travel speed on logging machines is usually controlled by operator preference and not by machine limitations. Flexible tires absorb much of the shocks instead of transmitting them to the operator. Also, increased tire width reduces angular roll thereby decreasing the acceleration forces on the operator's body. The potential for increased travel speed may also lead to further fuel consumption savings because of the aquaplaning effect during high speed travel in wet conditions (i.e. reduced rolling resistance).

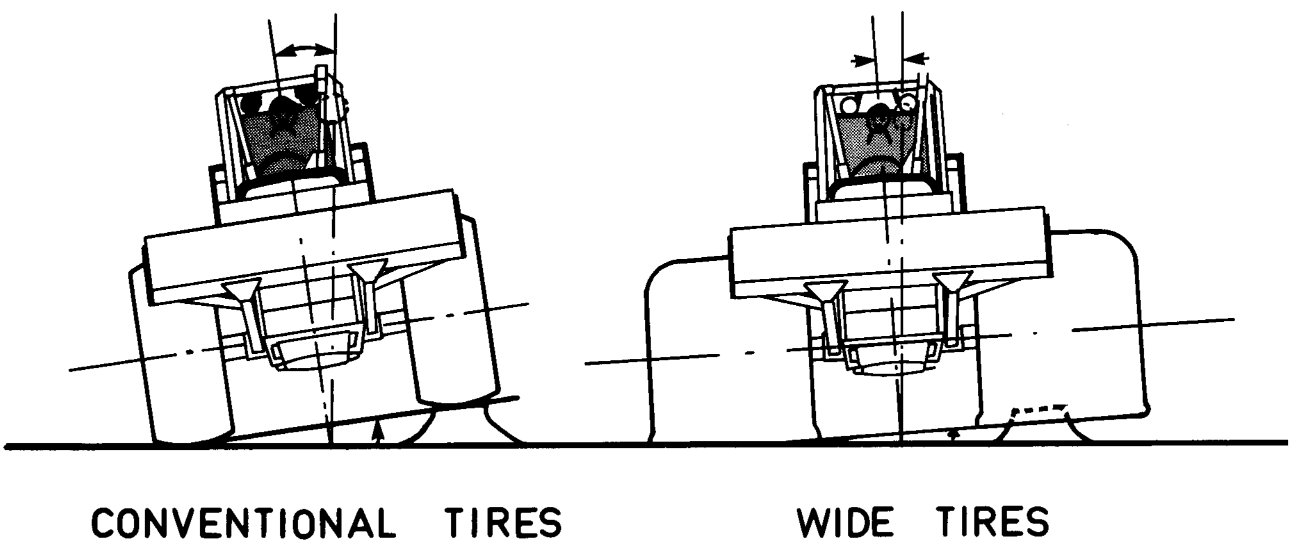


Figure 9. Improved Ride Comfort with Wide, Flexible Tires. Note reduction in angular roll.

Practical Skidding Comparison

In September/October 1980, Spruce Falls conducted a shift-level comparison of the JD 540-B with Rolligon tires and one of their "standard" machines, a Tree Farmer C5 with 71x24.5-32 tires, during regular skidding of full-tree bunches felled by a JD 693-B Feller-Buncher. Occasionally a Timberjack 230 with 30.5-inch wide tires was used instead of the Tree Farmer C5.

All machines had about 67-kW engines and worked side by side. Daily fuel usage was measured with hand-pump meters during refuelling. The operators switched machines every second day to eliminate the influence of skill differences. Ground conditions were wet, similar to those in the test track area. Table 2 provides a summary of the machines' relative performance.

Table 2: Shift-Level Performance Comparison.

	Tree Farmer C5 or Timberjack 230 with Conventional Tires	JD 540-B with Rolligon Tires	Diff.
Production, m^3	696	930	
Mandays	12	9.5	
m^3/manday	58	98	+69%
PMH (Productive Machine Hours)	76	63	
m^3/PMH	9.2	14.8	+61%
Fuel consumption, L/m^3	0.942	0.558	-41%

During the period September/November 1980, FERIC conducted an independent shift-level study to monitor the performance of the JD 540-B with Rolligon tires. Unfortunately, we were unable to simultaneously monitor a "conventional" skidder for comparison. Our figures indicated a productivity of 13.9 m^3/PMH for the unit with a fuel consumption of 0.552 L/m^3, very close to those obtained by Spruce Falls.

The spectacular gain in productivity with the Rolligon tires resulted from the increased travel speed and flotation, and the possibility to take larger loads without bogging down.

Skidder traction, and thus load size, is determined by the shear strength of the root mat and the total footprint of the tires. It can be approximated by the expression $\tau \cdot A$, where τ is the shear strength and A is the total footprint area. The shear strength of a Muskeg type A root mat may vary between 7 and 14 kPa (1-2 psi). Thus, a skidder with conventional tires, for example 71x24.5-32 (footprint area = 870 in.^{2}), will spin out, break through the root mat and possibly bog down if its traction requirements exceed 1 psi x 870 in^2 x 4 = 3480 lbs. In practice, this means it can barely start a skidload of about the same weight (1.4 - 1.7 m^3). A skidder equipped with 54x68-18 Rolligon tires (footprint area = 1836 in.^{2}) could pull a load of about 7344 lbs.

Thus in muskeg conditions, the wide, high-flotation tires can pull about double the load of conventional tires. At Spruce Falls, the common skidding practice involves using only two chokers to sling a full-tree bunch of about 14 trees (1.5 m^3). While conventional tires can only pull a single bunch, wide-tired skidders may often pick up two such bunches.

1981

In early 1981, FERIC held a meeting encompassing the forest industry, tire manufacturers and skidder manufacturers to present the positive results of the initial testing and to suggest guidelines for future development and research. That year, United Tire developed a 68x50-32 "Swamper" logging tire and Firestone supplied a 66x43-25 agricultural tire to the program.

Test Track Comparison

In August, Spruce Falls conducted track tests to evaluate the relative performance of the Firestone, Rolligon and conventional tires. All tests were conducted with the same operator, gear selection (2nd low), load size (3.3 m^3), ground conditions (very wet) and comparable track lengths (≃425 m straight). Table 3 provides a fuller description of the tires tested. Table 4 summarizes the results of the trial.

Table 3: Test Tire Description.

Tires	Conventional 71x24.5-32	Firestone 66x43-25	Rolligon 54x68-18	United "Swamper" 68x50-32
Overall diam., in.	71	66	54	68
Width, in.	24.5	43	68	50
Footprint, $in.^2$	870	1420	1840	1700
Footprint pressure rating at a load of 2400 kg per tire, kPa	42	26	20	21
Approx. weight of tire & rim, kg	375	500	400	800

Table 4: Test Track Results.

PASS NUMBER	1	2	3	4	5	6
Tree Farmer C5 with conventional tires						
Speed, km/hr	5.54	3.20	stuck			
Speed, %	100	58				
% of track filled with water*	24	28				
Timberjack 230E with Firestone tires						
Speed, km/hr	4.76	4.50	4.26	3.39	3.13	stuck
Speed, %	100	95	89	71	66	
% of track filled with water	5	-	24	-	25	
John Deere 540 with Rolligon tires						
Speed, km/hr	4.84	4.80	4.64	4.80	4.71	4.64
Speed, %	100	99	96	99	97	96
% of track filled with water	1	-	2	-	-	4

* ground water level was 20 cm below surface.

The test results clearly showed the positive effect that increased tire footprint has on improving machine mobility and reducing ground disturbance. Where conventional tires bogged down, the 68-in. wide Rolligons could make repeated passes over the same track with only a 4% decrease in travel speed and virtually no ground damage (Fig. 10). The intermediate-sized Firestone tires performed at an intermediate level. The 68x50-32 United Tire "Swamper" tires were not evaluated during this trial. Preliminary testing showed that the heavy carcass (see Table 3) and aggressive tread design caused high rolling resistance and unacceptable ground disturbance (Fig. 11). These tires were shipped back to United to shave off some of the excess rubber, thereby hopefully improving the tires' performance.

In October, FERIC conducted a repetitive pass test to compare the relative ground disturbance characteristics of the Rolligon, Firestone (66x43-25) and shaved United (68x50-32) tires. This test simply involved repeated passes over side-by-side, 50-m straight stretches. Table 5 presents the results. The ground was partially frozen at this time which explains the high level of performance by all the tires, but the findings are useful for comparative purposes.

Fig. 10. Area Logged with Rolligon Tires. Note minimal ground disturbance.

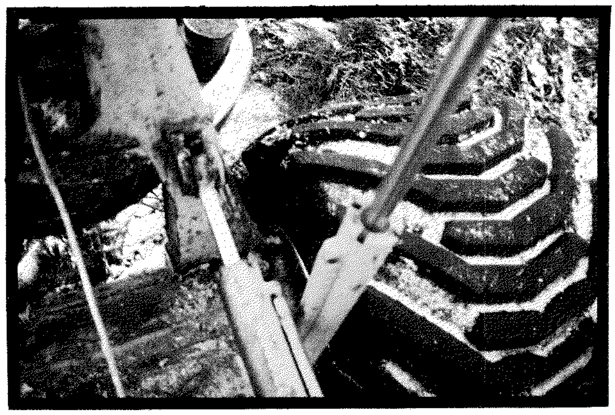


Fig. 11. United Tire 68x50-32 "Swamper" Tire. Note aggressive lugs.

Table 5: Repetitive Pass Tests.

Pass	JD 540-B with United Tires (Shaved)	TJ 230E with Firestone Tires	JD 540-B with Rolligon Tires
	% of Track with Exposed Organic Soil (Muck)		
10	58	2	2
12	stuck	-	-
14		-	-
16		-	-
18		26	4
20		50	-
22		stuck	16
24			-
26			33

This test showed the advantage of a light, flexible tire (Rolligon) over a heavy, stiff tire (United Tire) even if footprints were similar. The Firestone tire again performed to an intermediate level.

Practical Skidding Comparison

During October/November 1981, FERIC conducted a shift-level comparison of the Firestone, shaved United, Rolligon and conventional tires during regular skidding of full-tree bunches on Spruce Falls' limits. The collection of field data, supplemented by daily Servis Recorder charts, was carried out by company personnel according to uniform procedures developed by FERIC. Daily fuel usage was measured with hand-pump meters.

The results of the study are summarized in Table 6. All machines worked in close proximity to each other in wet ground conditions.

The findings again confirmed the improved flotation, speed and traction associated with wide tires. The Rolligon results were virtually identical to those experienced in 1980 (Table 2). The heavy United Tire design performed below expectations considering the large footprint area. The good fuel consumption performance of the TJ 230E equipped with the Firestone tires probably resulted partially from that machine's lighter weight and its Deutz air-cooled engine, a unit noted for good fuel efficiency.

<u>1982</u>

In 1982, United Tire introduced a new 68x50-32 tire called the "Super Muskeg". This KEVLAR-based tire was the same size as their "Swamper" tire tested in 1981, but was lighter, more flexible and had non-aggressive lugs for better travel on the root mat.

Test Track Comparison

In June, FERIC conducted comparative ground disturbance tests of the new United tires, the Rolligons and the Firestone 66x43-25 agricultural tires (Fig. 12). The test involved repetitive passes over side-by-side, 100-m straight test tracks (Fig. 13). Load size in all tests averaged 2.3 m^3. The ground was still slightly frozen and somewhat drier than in previous tests which may explain the high performance of all the tires. Table 7 summarizes the results of the trial.

Table 6: Shift-Level Performance Comparison.

	Shifts Reported	PMH	m^3 Skidded	m^3/PMH	Increase over "Conventional"	Litres Consumed	L/PMH	L/m^3	Decrease from "Conventional"
Tree Farmer C5 with conventional tires (71x24.5-32)	10	65.0	536	8.3	-	442	6.80	0.824	-
Timberjack 230E with Firestone tires (66x43-25)	10	71.0	779	11.0	+33%	394	5.55	0.506	-39%
John Deere 540-B with United Tire tires (shaved) (68x50-32)	10	69.5	695	10.0	+21%	543	7.82	0.782	- 5%
John Deere 540-B with Rolligon tires (54x68-18)	10	71.8	948	13.2	+60%	492	6.86	0.519	-37%

Figure 12. Test Tires. The United Tire 68x50-32 "Super Muskeg" tire is pictured on the left and the Firestone tire (66x43-23) is on the right.

Figure 13. Ground Disturbance Testing (Rolligon vs United).

Table 7: Repetitive Pass Tests.

Pass	JD 540-B with United "Super Muskeg" Tires	JD 540-B with Rolligon Tires	TJ 230E with Firestone Tires
	% of Track with Exposed Organic Soil (Muck)		
5	1	1	-
10	4	1	3
15	9	2	-
20	15	3	20

The performance of all three tires was considered acceptable in terms of ground disturbance.

Practical Skidding Comparison

A shift-level comparison of the Rolligon and United "Super Muskeg" tires during regular skidding of full trees on Spruce Falls' limits during June provided the results presented in Table 8. Again, the machines worked side-by-side with the operators rotating between them daily.

Table 8: Shift-Level Performance Comparison.

	JD 540-B with Rolligon Tires	JD 540-B with United "Super Muskeg" Tires
Shifts reported	9	9
PMH	63.5	58.5
m^3 skidded	963	999
m^3/PMH	15.2	17.1
Litres consumed	391	479
L/PMH	6.16	8.18
L/m^3	0.406	0.479

The findings indicated that the performance of the two tires was essentially comparable in terms of both productivity and fuel consumption.

At the same time, Abitibi-Price Inc. was testing two skidders, a TJ 230E choker and a TJ 230E grapple (Fig. 14), equipped with United "Super Muskeg" tires on their Smooth Rock Falls limit, also in the Clay Belt. FERIC monitored the performance of these machines in conditions so wet that conventionally-tired skidders absolutely could not enter the area; even the wide tires caused considerable ground disturbance. Productivity was low (4.4 and 7.4 m^3/PMH for the choker and grapple skidder respectively) and fuel consumption was high (2.05 and 1.67 L/m^3 respectively) when compared to the Spruce Falls performance, but the worth of the tires was proven by the fact that the machines could work at all.

Abitibi-Price also experimented with a 50-in. wide Goodyear mining-industry tire with a recessed tread design (Fig. 15). The treads tended to fill with muck creating inoperable "slicks". Further testing with this tire design was abandoned.

Fig. 14. Timberjack 230E Grapple Skidder with United "Super Muskeg" Tires.

Fig. 15. Goodyear 50-in. Mining Tire.

1983

In 1983, Firestone introduced a 66x50-26 high-flotation tire called the "Flotation 23° Logger" (footprint = 1650 in.^{2}). This tire had a somewhat more aggressive tread design than the United "Super Muskeg".

Test Track Comparison

FERIC discontinued their testing program in the Clay Belt in 1983 because the merits of wide tires in soft ground had been proven, a number of alternative tires were available, and all that remained to be monitored was the long-term experience with such tires, best assessed by industry users.

However, Spruce Falls did evaluate the relative ground disturbance performance of the new Firestone "Flotation 23^{o} Logger" (Fig. 16) and the United "Super Muskeg" (68x50-32).

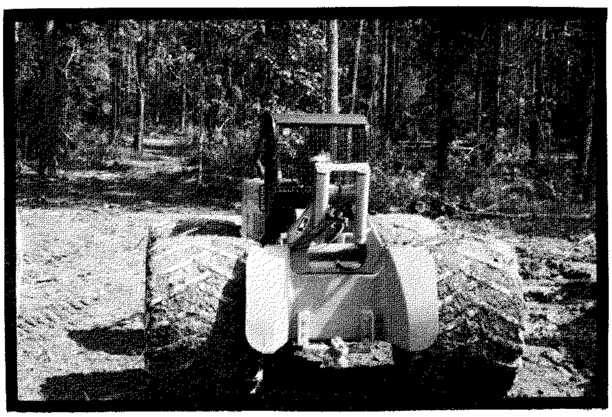


Figure 16. Firestone 66x50-26 "Flotation 23^{o} Logger".

In August 1983, Spruce Falls laid out three concentric ovals to measure the relative flotation of the two tires after repetitive passes. Load size was the same for all tests. Table 9 presents the findings of this trial.

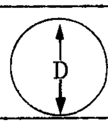
Table 9: Relative Ground Disturbance (Different Skidders).

Test Tracks (straight, D, curve)	JD 540-B with United "Super Muskeg" Tires	JD 540-B with United "Super Muskeg" Tires	TJ 240A with Firestone 66x50-26 Tires
Footprint, in.^{2}	1700	1700	1650
Number of passes	10	15	10
% of straight track with ruts >25 cm deep	0	0	0
Curve diameter D, m	30	55	43
% of curved track with ruts >25 cm deep	36.0	59.5	62.7

There was no appreciable ground damage on the straight portions of the tracks for either tire. Both tires caused considerable damage on the curved portions of the track because of the increased shear stress transmitted to the root mat during turning, but the Firestone tires created 74% more rutting than the United tires for the same number of passes. However, the poorer performance by the Firestone tires on curves could not be directly attributed to the tires themselves since differing skidder features also influence turning performance, as will be discussed later in the report.

Therefore, the test was repeated with both tires mounted on the same skidder model, a Timberjack 350. This time, concentric circular test tracks were used to assess relative ground disturbance. The results of this trial are summarized in Table 10.

Table 10: Relative Ground Disturbance (Same Skidder).

Test Track 	TJ 350 with United "Super Muskeg" Tires	TJ 350 with Firestone 66x50-26 Tires
Number of passes	10	10
Load size, m^3	2.90	2.11
Track diameter D, m	46	61
% of track with ruts >25 cm deep	69.7	74.9

Thus, the United tires caused somewhat less ground disturbance after repeated passes than the Firestone tires even though the Uniteds were pulling 37% more load on a tighter turn. Since the tires' footprints are essentially comparable, this probably results from the United tires' less aggressive lugs and shoulders and their somewhat greater flexibility.

PART B - ALTERNATE APPLICATIONS

While the main thrust of the wide tire development and testing program was to improve skidder performance in soft ground, it quickly became apparent that this new breed of tire possibly had potential for application in other areas. Their improved ride comfort may be beneficial in rough ground; in theory, they provide good traction and improved stability on slopes; and their low ground-pressure should prove advantageous on sensitive sites.

To test these theories, FERIC in 1982 purchased a set of United Tire 68x50-32 "Super Muskeg" tires for comparison with conventional practice in a number of potential applications across Canada. This section of the report describes that testing.

Great Lakes Forest Products Ltd. (Flat, Firm Ground)

In 1982, Great Lakes Forest Products Ltd., Thunder Bay, Ontario agreed to a cooperative trial to assess the performance of the wide tires under their operating conditions. Timberjack Inc. supplied a set of 5128 wide track axles to the trial.

Practical Skidding Comparison

The tests were conducted at Camp 328, northwest of Ignace, Ontario during September/October. The shift-level performance of a Timberjack 350 equipped with the United 68x50-32 "Super Muskeg" tires was compared to that of a TJ 350 with standard tires, in this case 65x18.4-34's (Fig. 17). Terrain in the harvesting area was gently rolling with some short steeper pitches (Fig. 18). The ground was firm, consisting mostly of sand and gravel with some rock outcrops (Classification*: 1.2.2). Both machines were skidding tree lengths as close together as possible. Operators were rotated daily to eliminate bias. Table 11 presents the results of the shift-level performance comparison.

Fig. 17. Comparison Machines.

Fig. 18. United 68x50-32 Tires in Operation.

* See footnote p. 29.

Table 11: Shift-Level Performance Comparison.

	TJ 350 with United Tires (68x50-32)	TJ 350 with Conventional Tires (65x18.4-34)
Shifts reported	13	12
PMH	75.5	68.5
m^3 skidded	837	831
m^3/PMH	11.1	12.1
Litres consumed	500	435
L/PMH	6.62	6.35
L/m^3	0.597	0.523

The results indicated that there was no concrete benefit in using wide tires in the relatively easy, firm ground encountered. Such terrain probably does not necessitate the use of high-flotation tires.

However, a number of operational constraints also may have adversely affected the relative performance of the wide tires. These are mentioned here as a warning to other potential users. Skid distance only averaged 82 m during the trial. This short distance, combined with the crews' work pattern, meant that only 20% of the total work cycle was spent in travel. As the proportion of travel decreases, the benefits of wide tires become less visible.

Company policy restricted load size because of continuing mechanical problems with the TJ 350 winch. Thus, any possible gain in traction with the wide tires could not be exploited. Finally, it had been hoped that the wide tires might improve travel speed because of improved ride comfort. However, the 3-speed, automatic transmissions on the TJ 350's did not provide enough speed/torque options to fully utilize this potential.

Overall, even though the results of the trial were negative, many valuable insights were gained.

Scarification Trials

The United "Super Muskeg" tires, mounted on a Timberjack 380, were also briefly tested in a patch-scarification operation during October. The performance of the wide-tired skidder was compared with that of another TJ 380 equipped with 30.5 in.-wide tires and chains all around while pulling a Bräcke scarifier (Fig. 19). The test area was undulating with much surface rock. Heavy rain fell during the entire trial.

Figure 19. Scarification Test Machines. The United "Super Muskeg" tires are pictured on the left and the standard (30.5 in.) tires with chains are shown on the right.

In the test, scarification productivity was 70% higher (1.7 ha/PMH vs 1.0 ha/PMH) with the wide tires than with the normal tire configuration. However, the FERIC observers felt that this difference resulted from operator differences and was not tire related. Actually, both tire configurations appeared essentially equal in terms of pulling capability. The wide tires had some advantage in accessing the blocks over wet ground and ride comfort (operator's opinion). On the other hand, they were more prone to sideslip on sidehills when riding over wet windfalls, and residual poplar and birch posed a problem because of tire width.

During scarification, there was considerable cutting damage to the outer rubber surface on the "Super Muskeg" tires caused by sharp rocks (Fig. 20). Though this type of damage is not overly serious in itself and caused no further problems during subsequent operation, it may indicate a potential problem when operating in rocky terrain, especially during scarification which typically necessitates straight-line travel with frequent spin-outs. For tires working in rocky terrain, a more cut-resistant rubber quality and somewhat larger lugs should be considered.

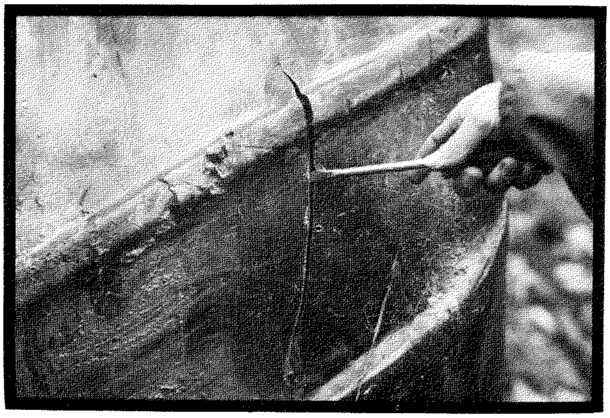


Fig. 20. Surface Cutting from Scarification in Rocky Terrain.

St. Regis (Alberta) Ltd. (Rough Ground and Slopes)

In 1983, FERIC shipped their wide tires to St. Regis (Alberta) Ltd. in Hinton to assess their performance on both rough and steep terrain, mostly on clayey soils. Timberjack Inc. again supplied a set of 5128 wide track axles to the trial.

FERIC, in cooperation with St. Regis, conducted a number of tests comparing the relative skidding performance of the United "Super Muskegs" to St. Regis' conventional 67x23.1-26 tires (footprint = 774 in.^{2}) both with and without chains depending on the application. Toward the end of the trial, FERIC replaced their "Super Muskeg" tires with a set of the newly-developed United "Super Swamper" tires and several of the tests were repeated. These tires, also 68x50-32, have somewhat more aggressive lugs than the "Super Muskegs" (Fig. 21).

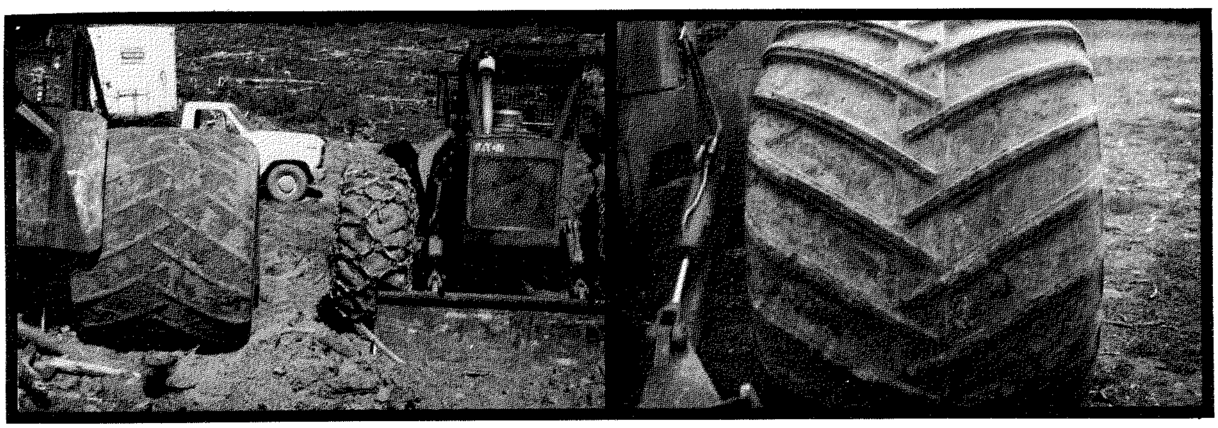


Figure 21. Test Tires. The United "Super Muskeg" (68x50-32) is pictured on the left along with the conventional 67x23.1-26 tire. The "Super Swamper" (68x50-32) is shown on the right.

All tests were conducted with the same two Timberjack 240D skidders, one for each set of tires. Prior to the trial, the relative inherent performance of the two skidders was assessed and they were found to be comparable.

Test Track Comparison (Rough Ground)

The test area was essentially flat (2% slope). The soil was a clay loam (36% sand, 38% silt, 26% clay), but was still frozen 15 cm below the surface during testing in early June. Ground roughness was Class 3* with 1500 obstacles/ha averaging 27 cm in height and with a maximum of 86 cm (Fig. 22).

The tests were conducted on side-by-side, straight, 150-m tracks. The same operator was used for all the tests and the skidders pulled the same 3-m^3 load in each case. Speed, fuel consumption and ground disturbance (straights only) were assessed during each trip (trip = 2 passes = 150 m + turn around + 150 m return on same track ≃350 m) for each tire configuration. The fuel consumption was measured with Ruhl fuel meters mounted behind the cab of each skidder (Fig. 23).

Fig. 22. Rough Ground Test Area.

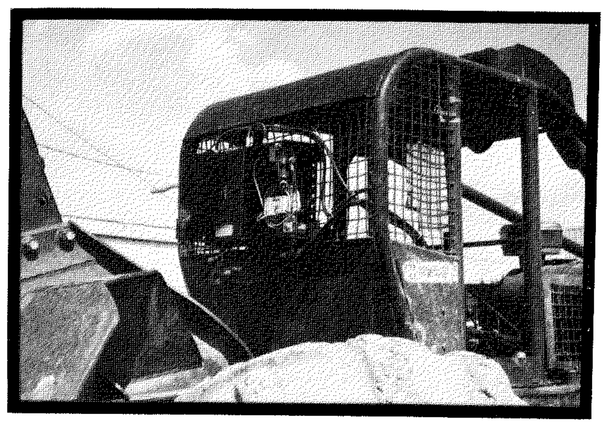


Fig. 23. Ruhl Fuel Meter.

Table 12 presents the results of the rough-ground track comparison.

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* Ground roughness classification based on:
Mellgren, P.G. 1980. Terrain classification for Canadian forestry. Canadian Pulp & Paper Association, Montreal, Québec. W.S.I. 2840. 13 p.

Table 12: Test Track Results (Rough Ground).

	TJ 240 D with Conventional Tires (67x23.1-26) NO CHAINS	TJ 240 D with "Super Muskeg" Tires (68x50-32)	Diff.
Gear 1 Low (Max. Throttle)			
Average speed, km/hr	5.17	5.97	+15%
Fuel consumption, L/km	3.62	2.35	-35%
% of track with exposed mineral soil after 20 passes	8	3	
Maximum sinkage, cm	47	25	
Gear 2 Low (Max. Throttle)			
Average speed, km/hr	7.35	8.63	+17%
Fuel consumption, L/km	2.59	2.24	-14%
% of track with exposed mineral soil after 20 passes	3	1	
Maximum sinkage, cm	42	26	

The results indicated that the wide "Super Muskeg" tires performed about 15% better than the conventional tires on rough ground in terms of both travel speed and fuel consumption. There was little change in performance with repeated passes for both tires because of the minimal ground disturbance. The poor fuel-consumption showing with the conventional tires in 1st gear, repeated during all trips, is unexplained, but may partially have resulted from somewhat poorer track conditions. The positive results with the flexible, wide tires probably resulted from increased traction and improved ride comfort allowing the operator to choose a slightly straighter route and lessening his hesitation.

The tests with the wide tires were repeated for tire inflations of 96, 76 and 55 kPa. There was no appreciable change in performance with different pressures. However, the operator commented on a marked improvement in ride comfort when tire pressure was reduced from 96 to 76 kPa, though he did not notice any additional benefit when going down to 55 kPa. Therefore, tire inflation pressure was set at around 80 kPa for all further wide tire testing during the trial.

The "Super Muskeg" tires were run in 3rd gear (8.77 km/hr) for a few trips, but the test was stopped because of operator discomfort. He declined to repeat the experience with the conventional tires.

Test Track Comparison (Slope)

Track tests similar to those conducted on rough ground were repeated on a uniform 24% slope. Track length was 130 m one-way and the Timberjack 240D's traveled unloaded. The mineral soil was again a clay loam (29% sand, 43% silt, 28% clay).

The relative performance of the conventional tires (23.1 in.-wide) with chains on the front was compared to the United "Super Muskeg" tires in late June under wet (rain previous day) conditions. The United "Super Swamper" tires were evaluated in September on the same site with wet conditions for 1st gear and 5 cm of wet snow for 2nd gear.

Table 13 summarizes the results of the test track comparison on slopes.

Under wet slope conditions, travel speed with both the "Super Muskeg" and "Super Swamper" tires was about 16% greater than that of the conventional tires with front chains. During the 2nd gear test with the "Super Swamper" tires, travel speed was only 6% higher overall because of slip on the 5 cm of snow. On those runs without excessive slip, travel speed was again improved by 15%. At this slope, there was no appreciable performance difference between the two sets of wide tires.

The wide tires' improved travel speed resulted from reduced ground disturbance (sinkage) and thus reduced slip and rolling resistance. With the conventional tires, the surface root mat was soon broken and the tires spun out and bogged down (7th pass in gear 1, 11th pass in gear 2) in the clayey soil (Fig. 24). Ground disturbance with the wide tires after 20 passes over the same ground was less than that of the conventional tires after 4 passes. On sensitive sites, this reduction in ground disturbance yields benefits not only in travel speed, but also lessens the environmental impact, particularly on oft-traveled skid trails.

For the conventional and "Super Muskeg" tires only, fuel consumption also was assessed and found to be reduced 18% with the wide tires.

Table 13: Test Track Results (Slope).

GEAR (Max. Throttle)	1 LOW					2 LOW				
TRIP NUMBER	1	2	3	5	10	1	2	3	5	10
PASSES	2	4	6	10	20	2	4	6	10	20
Conventional (Front Chains)				Stuck on 7 th Pass ↓						Stuck on 11 th Pass ↓
Speed, km/hr	3.31	3.28	3.22			5.42	5.39	5.28	5.00	
% of track with EMS*	2	7	10	10		0	4	10	26	26
Maximum sinkage, cm	48	54	56	76		26	38	42	52	56
United "Super Muskeg"										
Speed, km/hr	3.91	3.72	3.77	3.80	3.70	6.22	6.21	6.10	6.08	6.10
% of track with EMS	-	-	-	-	2	-	-	-	-	3
Maximum sinkage, cm	-	-	-	-	36	-	-	-	-	40
United "Super Swamper"							Slip		Slip	
Speed, km/hr	3.77	3.78	3.88	3.92	3.79	6.25	4.59	6.14	5.11	5.84
% of track with EMS	0	1	1	1	2	Not Assessed				
Maximum sinkage, cm	-	-	-	-	24					

* EMS = Exposed Mineral Soil

Figure 24. Slope Test Track Comparison. Note difference in ground disturbance between conventional and wide tires.

Maximum Slope Test

The purpose of this test was to assess the relative climbing ability (traction) and sidehill stability of the three sets of tires. A test track was laid up a uniform progressively steepening slope. For each tire/gear combination, the empty machine (TJ 240D) accelerated from a full stop at the bottom of the test track (18% slope) and attempted to climb as far up the slope in a straight line as possible. The travel distance to spin-out (or stall) and the slope at spin-out were recorded. For the stability test, the operator traversed the hill at progressively steeper slopes and the maximum slope at which he felt secure was recorded. The operator was a camp foreman with many years of skidding experience and, in our opinion, pushed the machines to their limit under the test conditions.

Ground conditions were wet for the "Super Muskeg" tires (morning after heavy rain the previous day), only slightly drier for the conventional tires (early afternoon of same day) and 2 cm of wet snow for the "Super Swamper" tires. Table 14 summarizes the results of the maximum slope tests.

Table 14: Maximum Slope Test Results.

TIRE	Conventional (67x23.1-26) FRONT CHAINS		"Super Muskeg" (68x50-32)		"Super Swamper" (68x50-32)	
GEAR	1 LOW	2 LOW	1 LOW	2 LOW	1 LOW	2 LOW
Ave. travel distance to spin-out, m	36.5	38.5	34	45	61	61
Slope at spin-out, %	28	28	28	34	40	40
Maximum sideslope*, %	30		40		44	

* The sideslope limits presented in Table 14 are specific to the test tires, machines and conditions. Since these limits may not necessarily apply to other situations, discretion is advised for the sake of operator safety.

The climbing ability of the conventional tires with front chains and the "Super Muskeg" tires was essentially comparable. The "Super Muskegs" had lots of rubber on the ground, but their light lugs did not grip adequately in the wet ground conditions. Traction was substantially improved with the "Super Swamper" tires, despite the dusting of snow, because of their somewhat more aggressive lugs.

Sidehill stability and thus operator safety was greatly enhanced when using the wide tires (Fig. 25). Increased machine width extends the center of gravity away from the tipping fulcrum. Also, avoiding angular roll becomes increasingly important near critical slopes. The "Super Swamper" tires performed somewhat better than the "Super Muskegs" because of their better grip. In fact, the operator felt that even steeper slopes could have been handled by the "Super Swampers" had it not been for the dusting of snow, because sideswing of the rear end was the limiting factor, not instability.

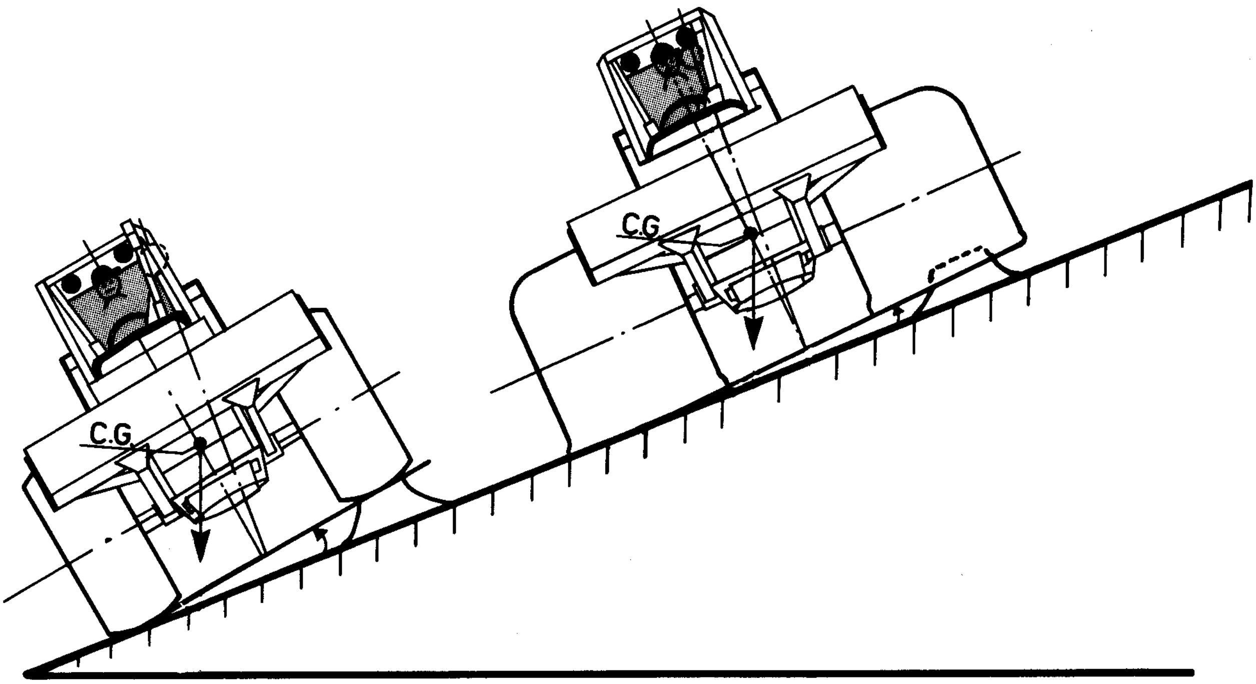

Figure 25. Improved Sidehill Stability with Wide Tires.

Practical Skidding Comparison

For a two-week period in June 1983, the performance of the two TJ 240D's (conventional tires with front chains vs "Super Muskeg" tires) was compared on a shift-level basis during conventional tree-length skidding. The machines worked as part of a three-man crew, two skidders serving a single faller. Terrain in the cut area was fairly steep (20-30% usually) with an average 300-m skid distance. The two operators rotated machines daily to eliminate bias.

Unsurprisingly, productivity for the two machines was virtually identical (32.6 trees/PMH for the conventional tires vs 31.3 trees/PMH for the wide tires or +4% for the conventional), as was the fuel consumption (6.4 L/PMH vs 6.9 L/PMH respectively or -7% for the conventional). This similarity in results was largely a function of the logging system itself. Since the three-man crew worked and were paid as a unit, the operators paced themselves to minimize congestion at the faller by alternating their coming and goings. There was no advantage to outperforming your partner and thus at the end of each day, the operators had the same number of trips and the same productivity.

Cycle Time Comparison

Since the crew structure did not allow for a meaningful comparison on a shift-level basis, the relative performance of the tires in a three-man crew was reassessed through detailed timing of the cycle time distribution during two days in late June (Fig. 26). During the test, both skidders traveled empty to the same faller up an average 12% slope with some short 30% pitches. Travel loaded distance averaged about 500 m with some 100 m of soft ground close to the landing. Load size averaged about 3 m^3. The two operators switched machines daily at lunch break to eliminate operator bias, alternating their order of usage.

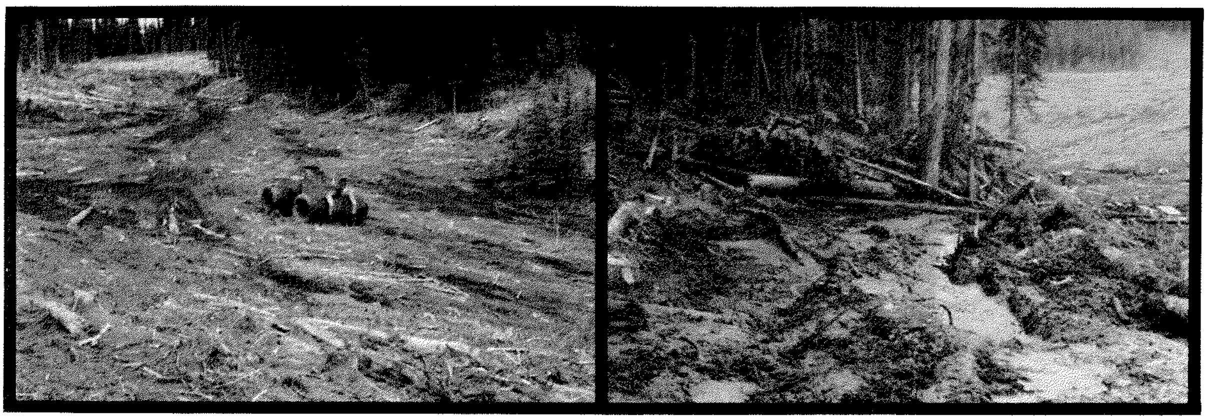

Figure 26. Test Area. Note ground disturbance caused by conventional-tired skidder particularly on skid trails.

Table 15 summarizes the results of the cycle time comparison.

As expected, there was no real difference between the two tires in total cycle time because of the operating pattern of the three-man crew. However, the use of wide tires improved machine performance during the travel portions of the cycle. Travel empty speed was increased by 10%, travel loaded speed by 11%. Also, the need for winching during travel loaded was halved. This improvement was achieved despite the fact that the operators did not use the wide tires to full advantage. They both tended to use the same skid trail and thus, the wide tires were handicapped by the ground disturbance largely caused by the conventional tires (see Fig. 26). Moreover, both took a circuitous route to avoid the soft-ground portion of the trail, even though the wide tires traversed this area several times without untoward difficulties. The operators likely did not have enough experience with the new tires for them to experiment outside their regular work pattern.

Table 15: Cycle Time Comparison (3-man crew).

MACHINE CONFIGURATION	TJ 240D with Conv. Tires (Front Chains) (67x23.1-26)		TJ 240 D with "Super Muskeg" Tires (68x50-32)		
TIME ELEMENT	Cycle Time per Load (min.)	%	Cycle Time per Load (min.)	%	
Travel Empty	4.54	14.1	4.14	12.7	
Manoeuver	0.27	0.8	0.31	0.9	
Load	8.31	25.7	9.43	29.0	
Move During Loading	0.74	2.3	0.90	2.8	
Travel Loaded (TL)	6.15	19.0	5.52	16.9	
Unload	2.57	8.0	2.72	8.4	
Pile	2.57	8.0	2.50	7.7	
Delay					
Delimb with Blade	3.63	11.2	3.67	11.3	
Winch During TL	2.24	6.9	1.11	3.4	
Other	1.28	4.0	2.26	6.9	
Total Time per Cycle	32.30	100.0	32.56	100.0	
CONDITION FACTORS					Diff.
Ave. Skid Distance, m	491		489		
Trees/Load	12.3		13.3		
Productivity, Trees/PMH	22.8		24.5		
Travel Speed Empty, km/hr	6.48		7.10		+10%
Travel Speed Loaded, km/hr	4.79		5.32		+11%
Travel Speed Loaded (winching included), km/hr	3.51		4.43		+26%

In August, the relative performance of the tires in a two-man crew (single skidder per feller) was evaluated through detailed timing of the cycle time distribution during tree-length harvesting of two side-by-side strips. The two operators switched machines daily at lunch break to eliminate operator bias. Tree size was somewhat smaller than experienced previously, and ground conditions were dry and firm. Travel empty was up a uniform 28% slope while travel loaded distance ranged to 300 m.

Under the test conditions, travel empty speed was increased by 23%, travel loaded speed by 5% with the use of wide tires. The small difference in travel loaded speed was expected considering the positive slope and the firm ground conditions. The higher travel speeds become increasingly important as the average skid distance lengthens, or in other words, as travel time represents a greater portion of the total cycle time (only 17% during study).

The use of the wide tires also had an interesting effect on total loading time. Normal practice was for the operators to push the downed trees into bunches with the skidder's blade to facilitate choking. This technique resulted in an average total loading time per load (loading time + pushing trees) of 12.12 minutes. The operators' major complaint about the wide tires was that the increased machine width did not allow them to travel easily between the treeline and the downed trees for bunching. Therefore with the wide tires, the operator simply played out his mainline without any great attempt to bunch his load and then walked back to the individual trees for choking. This method, though probably harder on the operator, resulted in average total loading time of 10.55 minutes or 13% less than the preferred practice.

Table 16 presents a summary of the cycle time comparison results.

Table 16: Cycle Time Comparison (2-man crew).

MACHINE CONFIGURATION	TJ 240D with conv. Tires (Front Chains) (67x23.1-26)		TJ 240 D with "Super Muskeg" Tires (68x50-32)		
TIME ELEMENT	Cycle Time per Load (min.)	%	Cycle Time per Load (min.)	%	
Travel Empty	2.32	10.4	1.99	9.8	
Manoeuver	0.49	2.2	0.37	1.8	
Load	8.40	37.6	9.63	47.5	
Move During Loading	1.07	4.8	0.98	4.8	
Travel Loaded	1.48	6.6	1.49	7.3	
Unload	2.18	9.8	2.57	12.7	
Pile	1.48	6.6	1.72	8.5	
Delay					
Push Trees	3.72	16.6	0.92	4.5	
Other	1.21	5.4	0.62	3.1	
Total Time per Cycle	22.35	100.0	20.29	100.0	
CONDITION FACTORS					Diff.
Ave. Skid Distance, m	123		130		
Trees/Load	26.1		25.6		
Productivity, Trees/PMH	70.0		75.6		
Travel Speed Empty, km/hr	3.59		4.41		+23%
Travel Speed Loaded, km/hr	5.00		5.27		+ 5%

WIDE TIRE USAGE CONSIDERATIONS

Alternate Skidder Tire Options

A number of wide, high-flotation skidder tire alternatives are now available to the prospective user. Each tire option has its own advantages and tradeoffs which users must match to their particular application and needs.

Rolligon Corp. supplies their 54x68-18 tire (footprint = 1836 in.^{2}) for skidder applications (Fig. 2). This KEVLAR-based tire is light (approx. 390 kg with rim), exhibits an extremely flexible carcass for good ride comfort and non-aggressive lugs for travel on the root mat. The small (54 in.) tire diameter may present ground clearance problems in certain situations. The 18-in. bead opening precludes mounting of these tires on skidders with outboard planetaries (i.e. most skidder makes except John Deere). However, Rolligon will produce a tire with a 26-in. bead opening to order. The approximate price (1984) of the Rolligon tires is Can.$12 000 each with rim.

United Tire now produces three KEVLAR-based 68x50-32 high-flotation tires (footprint = 1700 in.^{2}). The heavy "Swamper" tires (approx. 820 kg with rim) have a more rigid carcass and a deep aggressive lug pattern (Fig. 11). These tires were designed for areas with no root mat, such as parts of the Southeastern United States, where traction is of primary concern. However, there has been some problem with the "Swamper"s lugs plugging with mud, thus reducing traction. This line has therefore been discontinued except on special order. The 68x50-32 "Super Muskeg" tire (Fig. 12) is light-weight (approx. 500 kg with rim) with non-aggressive lugs on a flexible tire carcass for travel on the root mat. The "Super Swamper" tire (approx. 634 kg with rim) is a compromise between the "Muskeg" and "Swamper" in terms of flexibility and lug pattern (Fig. 21) and as such is well suited for operation in rough or steep terrain. Approximate unit cost of the United tires is Can.$8000 with rim.

Firestone have developed an intermediate 66x43-25 logging tire and their 66x50-26 "Flotation 23° Logger" (Fig. 16). The "Flotation 23° Logger" (footprint = 1650 in.^{2}) is constructed of nylon cord with steel belting resulting in a stiffer, but cheaper (approx. $6500 per with rim) tire. The lug pattern is comparable to that of the United "Super Swamper".

Goodyear have an intermediate 66x43-25 tire available and plan to introduce a 50-in. wide tire in 1984.

Inflation Pressure

The tire inflation pressure should be kept as low as possible (i.e. close to the compression strength of the ground) to get the maximum footprint area and thus, minimum sinkage for a given load. Moreover, reduced inflation pressure increases ride comfort with flexible tires. However, a minimum inflation pressure of 70-80 kPa is recommended to minimize the risk of slip between the tire and rim, and the possibility of bead dislocation from pressures on the sidewalls of the tire.

The various wide-tire manufacturers use differing techniques to ensure a proper beadlock between tire and rim at low inflation pressures. Rolligon pinch the bead between the rim flanges and keeper rings bolted to each rim flange. United Tire employ a series of bolts through the rim well to keep the tires pressed snugly against the flanges, while Firestone use well humps to serve the same purpose.

Tire Life

The same characteristics that contribute to the wide, high-flotation tires improved performance (i.e. light weight, flexibility and large contact area) unfortunately also tend to increase their susceptibility to tire damage, particularly on the rear tires normally subject to greater loading during skidding. However, the tire manufacturers have used the latest construction and material technology to combat this problem while retaining the tires' positive features.

The early Rolligon tires, designed largely for geophysical exploration, experienced considerable tire wear problems in the harsher logging environment. The flexible sidewalls tended to bottom out on the flanges and keeper rings during tire deflection leading to sidewall cutting on both the inner and outer surface. The light-weight rims and keeper rings were not robust enough for logging use. The problem of a high torque being transferred over a small area (18-in. bead opening) resulted in bead deformation and subsequently tire slip and sidewall tearing. Moreover, the bolts holding the keeper rings had to be tightened frequently to maintain a proper bead lock. Tire life to repair under such conditions rarely exceeded 300 hours.

Rolligon have greatly reduced these problems through improvements to both tire and rim. The ply rating of the tire has been increased to 30 ply even through the sidewall. The rims and keeper rings have been strengthened to minimize cracking. Also, the rim flanges and keeper rings have been redesigned to reduce the consequences of tire deflection and spread the torque load over a larger area. These improvements have increased tire life considerably, but a final assessment awaits additional user experience.

The United tires, being less flexible and of larger diameter, have avoided many of the tire wear problems associated with the early Rolligons. Problems still remain with sticks entering between the flanges and beads at low inflation pressures and with excessive puncturing at temperatures below freezing. Also, the surface cutting observed during our limited scarification trial at Great Lakes Forest Products raises concern about tire life during operation in rocky terrain, at least with the "Super Muskeg" tires. Nevertheless, users in soft ground conditions have obtained up to 1800 hours of operation to date without untoward tire wear. Moreover, United Tire is currently conducting an extensive R & D program aimed at improving tire reliability.

To date, there has not been enough experience with the Firestone and Goodyear tires to comment on tire wear performance, though it has appeared positive during limited testing. These manufacturers are also actively working on enhancing tire reliability.

The final conclusive answer as to the tire life of wide, high-flotation tires awaits continued, prolonged use of such tires under a variety of operating conditions. Their susceptibility to sidewall damage will likely remain a continued problem area as a tradeoff to tire flexibility. However, it would appear that their overall reliability should be <u>at least</u> comparable to that of conventional tires particularly in certain applications. Moreover, as the technology in using the new super fibers is refined, additional improvements may be anticipated.

Skidder Considerations

The use of wide tires increases the bending and shock stresses placed on the skidder axle assembly since the load forces are applied further out. To avoid failure, it may be necessary to upgrade the axles one would normally use with conventional tires, particularly on smaller size-class skidders. Again, the problem is more pronounced on the rear axle because of the increased loading. During our initial Rolligon trials at Spruce Falls, frequent axle breakages occurred on the test John Deere 540-B. Once the original axles were replaced with John Deere 640 axles, the problem was eliminated. John Deere now claim that the final drives of all their new skidder models have been upgraded so as to accommodate wide tires without conversion. At St. Regis, two rear planetaries failed on the wide tire-equipped Timberjack 240D during our trial in 1983. Timberjack Inc. no longer recommend the 5128 wide track axles used during the tests, but instead suggest their WR5 wide track axle for use with wide tires. As can be seen, the potential wide-tire user is well advised to verify his axles' adequacy for wide-tire mounting.

On sensitive soils, the use of a differential lock (no-spin) may actually decrease skidder performance while turning. On low shear strength soils (e.g. root mat), the additional shear stress transmitted by a differential lock during turning may exceed the ground's shear capacity, thus leading to increased ground disturbance and reduced turning efficiency. Therefore in such conditions, the use of skidders with automatic differential locks is not recommended. Manual differential locks that need only be activated if necessary are preferred. This fact may partially explain the poor relative performance of the Firestone 66x50-25 tires during turning in the track test described on p. 23. The Firestones were mounted on a Timberjack 240A (automatic differential lock), while the Uniteds were on a John Deere 540-B (manual lock).

Under certain conditions, the use of wide tires may allow for higher travel speeds and/or increased loads because of improved flotation, traction and ride comfort. However, these potential benefits are wasted if the skidder does not have sufficient speed ranges or adequate winch capacity to take full advantage of them.

Prospective users are advised to pay heed to these skidder/tire interrelationships to optimize overall performance in their applications.

CONCLUSIONS

In 1980, FERIC initiated a research project aimed at developing a high-flotation logging tire to extend the range and capabilities of conventional skidders. This led to the four years of testing and development described in the PERFORMANCE TESTING section of this report. Our program, coupled with the efforts of several tire manufacturers and the forest industry in Canada and the United States, has resulted in a new breed of wide, high-flotation tires capable of significantly improving skidder performance in a number of applications. These tires now are a fact with approximately 100 already in service in Canada by 1983.

The success of the new wide, flexible, high-flotation tires stems from a number of advantages they exhibit over conventional, narrow skidder tires, notably:

+ Productivity increases of up to 60% in wet ground because of their ability to stay on the root mat and the opportunity for increased loads and travel speed. There are also indications of lesser, though significant, improvements in performance on rough or steep terrain depending on the skid distance and work pattern.

+ Fuel savings per unit of volume of up to 40%, depending on the ground, because more of the work effort is translated into production.

+ Substantial reductions in ground disturbance (rutting) on sensitive soils, even after repeated passes, because of the tires' high flotation characteristics. On wet ground, this translates to a much improved regeneration chance and on slopes, to a decreased risk for erosion.

+ Less soil compaction providing improved regeneration and higher future growth rates.

+ Current users have claimed reduced wood breakage at the stump or on the pile.

+ Because of the more optimal use of the work effort, it may be possible to use smaller machines to do an equivalent job, thereby again enhancing ground disturbance performance.

+ A smoother ride for man and machine because of the tires' width, flexibility and low inflation pressure resulting in higher travel speeds and/or enhanced operator comfort and satisfaction. This feature may be of particular interest in site preparation applications.

+ Improved stability and thus safety on sidehills owing to the tire width.

+ Increased access to conventionally inaccessible timber because of the improved flotation and stability. On wet ground, this translates to a longer logging season. On slopes, it may allow for the safe harvesting of blocks too steep for conventionally-tired skidders. This was the case at St. Regis where we were able to clear a block successfully where the operators had refused to work with their conventional machines. Moreover, the improved stability and reduced ground disturbance and compaction may permit operation on sensitive sites traditionally reserved for more costly cable yarding or tracked-vehicle systems. This is the brunt of a research project currently being conducted under a federal grant by MacMillan Bloedel Research on Vancouver Island. The results of this study should be of interest to those considering steep-slope applications.

+ This increased access can also mean less idle time for the skidder fleet and a reduced need for expensive specialized equipment.

The degree to which these benefits apply to prospective users depends on their conditions and applications. However, as with most good things, along with the benefits come a number of tradeoffs, notably:

- The high initial cost of the tires. However, given the number of tire manufacturers entering into the market and a projected expanding availability of the expensive super fibres used in the tire construction, some future cost reductions may result.

- The wide tires' performance in deep snow conditions is questionable. The Rolligon tires were tested in the winter of 1980 and their performance was found to be acceptable in up to 0.3 m of snow (Fig. 27). Beyond that, the tire width and non-aggressive lugs resulted in bulldozing and spin-out. While not thoroughly tested, it is expected that the other wide tire makes would perform similarly, though some improvement might be anticipated because of their somewhat reduced width, larger diameter and more aggressive tread design. Moreover, the wide tires are more susceptible to puncture during cold weather. Therefore, the user is advised to change tires with season as he would on his car.

  An interesting application for wide tires during winter is in packing of winter roads. At Spruce Falls, production in this application is eight times that of their conventional methods because of the tire width and machine speed.

- The necessity for reinforced axles and final drives especially on smaller size-class skidders.
- The increased vehicle width may affect manoeuverability, garage size and ease of freighting.
- The use of wide tires may require specialized equipment and facilities for tire maintenance.
- Their life, though appearing promising, remains as yet unproven.

Fig. 27. Rolligon Tires in Deep Snow.

Prospective users must weigh these advantages and disadvantages before choosing what is right for their particular conditions, needs and applications. However, there is no doubt that in the right application, the use of the new breed of wide, high-flotation tires can improve skidder performance significantly, as current users can readily attest. With additional experience and development, the future of such tires should become increasingly bright not only in skidding applications, but also for other off-road equipment. Experimentation with these alternate applications will be the focus of future FERIC research.

APPENDIX A

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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 L/km (litre/kilometre)	0.354 Imperial gallon/mile 0.418 American gallon/mile
1 kg (kilogram)	2.20 pounds
1 kPa (kilopascal)	0.145 pounds per square inch (psi)
1 kW (kilowatt)	1.34 horsepower