Session 2
Paper (b)

FERIC RESEARCH IN LOGGING TRUCK CHARACTERISTICS

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INTRODUCTION

As the distance between the wood fibre resource and the mills continues to increase, and the cost of equipment, labour and petroleum products escalates each year, the task of improving the efficiency of wood transport continues to be a major concern of The Forest Engineering Research Institute of Canada (FERIC). Wood transport often forms more than 25% of the total delivered wood cost, and petroleum products make up more than 20% of that transport cost. By far the largest share of the wood is moved by trucks. There are notable exceptions including rail-haul, river drive, lake-tow, and barge-haul, but these respond to specific local needs. Costly fleet and system decisions are often made on non-scientific, subjective rules-of-thumb. There is a definite need for sound parameters on which to design transportation systems and management procedures to maximize productivity and minimize costs.

The aim of this presentation is to provide an overview of the research into Secondary Transportation being carried out by FERIC's Eastern division. It is necessary to underline the long range strategy and illustrate the step by step logic to achieve this. It should be apparent that the research can "pay its way". If FERIC's advice, requiring little or no capital cost, is implemented by industry the total transport cost per unit of production can be reduced.

ON-ROAD TRANSPORTATION RESEARCH PROGRAMME

In searching for means to reduce costs, and improve efficiency of wood transportation, FERIC has been following a chronological strategy to quantify the interrelationships between the truck, the driver, the road, the weather and other variables. Fuel consumption is one immediate, handy measurement criterium to show the return for this research expenditure in terms of $/tonne/km. This has been used as a common denominator to offer immediate, tangible savings to the forest industry.

Transportation in the forest industry is subject to very special operating conditions. It was therefore necessary first to investigate these operating factors and to establish what happens when they interrelate. This was started in 1981.

In 1983 and 84 the theoretical testing methods were established and verified, and in 1984 an on-board recording system was assembled, debugged and made operational. Some interesting results have been obtained from in-shop truck roller-dynomometer measurements. Of more particular interest is the analysis of data collected on public and private logging roads. The first data analysed show a marked influence of the driving technique, road macro- and micro-design and machine specification on the energy consumption performance and machine durability.

FERIC REPORTS

A series of reports is being published under the overall title of "Analysis of Productivity and Cost of Forestry Transportation". Part I, published in July 1982 was entitled "Pilot Study to Determine the Factors for Analysis of Commercial Vehicle Power Consumption and Road Performance". Part II was published in April 1984 and entitled "Theoretical Analysis of the Impact of Vehicle Operating Conditions on Power Losses, and Experimental Determination of the Resistance Forces Attributable to Oil Churning". Part III is called "Determine the Influence of Road Surface and Air Resistance on Energy Losses in Logging Trucks".

The compilation and analysis of field data is continuing. These reports, Part IV entitled "Determine Relationship between Driveline Friction Losses and Applied Torque", and Part V "Obtain and Analyse the Duty Cycle of Trucks" are presently being prepared.

TRADITIONAL TRUCK-ABILITY RULES

Truck salesmen have been using time-honoured coefficients to assist industry in specifying truck fleets during the last 35 years. These parameters were purported to be Gospel for multi-axle tractor trailer haul units in forestry applications, even though they were derived from a two-axle truck on pavement. There has long been a serious need to re-examine these parameters as they affect industry's decision-making.

RESEARCH OBJECTIVES

FERIC's objectives in Secondary Transportation can be listed as follows:

- To identify and quantify the conditions (parameters) upon which the productivity and cost of wood transportation depends.
- To classify these parameters according to their cost-benefit impact.
- To create a data bank or library of information which will allow simulation of the optimum transportation system for a specific situation.
- In cooperation with industry to apply, monitor and verify these findings under actual operating conditions.
- To identify the hazardous conditions in on-highway wood haul and offer solutions to minimize the potential of spills and upsets.

ACHIEVEMENTS TO DATE

Some of the results which are interesting and immediately applicable are:

- Usage of synthetic versus standard lubricating oils and greases. Fuel savings have been shown through the use of synthetic oils in cold weather.
- Insulation of the rear axles to prevent heat loss and maintain optimum oil temperatures decreases oil churning losses through improved viscosity. Both of the above items bring significant reduction in energy consumption, with corresponding improvement in life and operating cost of driveline components.
- Major oil companies are showing more interest in synthetic oils. FERIC has the instrumentation and expertise to quantify the cost/benefit of new, more expensive oils. Reports will be available on this type of testing shortly.
- Optimum tire inflation pressures have been identified according to best fuel consumption on different roads.
- Tire configuration has been shown to have a highly significant impact upon power requirements, and further study is warranted.
- Reduction in technical travel speed as well as reduction in engine power can significantly reduce fuel cost without adverse effect on daily production.
- Road surfaces (micro deviations) have been globally measured. Detailed measurements are provided for in FERIC's new instrumentated test truck.
- Hills and curves (road profile or macro-deviations) have a highly significant impact on power demands, and new instrumentation is being refined to measure road profile on-the-fly.
- The study of all these factors provides means to significantly improve fuel consumption, if operators choose to apply some of the suggestions.

FUTURE RESEARCH

Future areas to be researched include:

- More detailed measurements of engine parameters and detailed study of data already taken.
  - Engine optimum thermal condition (coolant system related to fan and radiator cross section, crankcase oil, propellant fuel and ambient temperatures) is known to influence significantly the energy consumption.
- Automatic transmission vs mechanical transmission. This has long been a question mark when purchasing or replacing trucks. Several member companies are interested in such a study.
- Measurements of air pressure and air temperature have been taken before and after the turbo-charger to relate the boost pressure to power demand. The air temperature is also measured after the after-cooler. It could prove out that these simple measurements may be so directly related to power demand and therefore to fuel consumption that many other expensive measurement techniques become obsolete.

DRIVER'S MANUAL

We anticipate producing a Drivers Manual in 2 to 3 year's time which will be based upon the scientific evaluation of the best driving techniques measured from a large number of professional drivers.

SIMULATION

A data bank of measurements of many variables in different situations are being accumulated. New systems, or changes to existing systems could be simulated for a specific set of conditions. Examples are traffic flow and truck/loader interface. It is exciting to consider, say in five years time, a computer simulation of a haul for a proposed new operation before the first blaze is made to locate the centre line of the main road. All of the "what if I shave down this hill? What if I spend money on crushed rather than pit-run gravel? What if I were to pave the road?" questions could be considered; the cost to improve road standards is well known and FERIC would be able to show the benefit for the additional expenditure.

EARLY FIELD TESTING

A start was made in 1981 to isolate and quantify the various power requirements and power losses. A truck was used for a test bench, on the road, without the aid of sophisticated instrumentation. A standard, simple technique called the inertia, or coast-down method was utilized. Coefficients for tire rolling resistance, air resistance, oil churning losses, driveline friction and engine losses were established for logging conditions. These were related to fuel consumption (power requirements) for different temperatures, lubricants, tire pressures and road surfaces.

The explanation of the inertia, or energy balance technique can be over-simplified af follows:

It takes a given amount of energy to get from A to B. This force is composed of:

- driveline friction plus oil churning losses;
- tire rolling resistance;
- road grade resistance;
- air resistance;
- engine loss;
  - inside engine (mechanical friction)
  - outside engine (all parasitical equipment - includes heat).

THE COASTDOWN TECHNIQUE

The inertia method of quantifying power requirements has been known since the apple fell on Isaac Newton's head. One important, basic part of FERIC's trucking studies uses what Newton figured out, plus a formula developed by FERIC applying this law to rolling vehicles, and makes measurements for specific situations of interest to the logging transportation industry.

The total energy required to overcome inertia, and accelerate to a given velocity while overcoming all the other obstacles in the way is equal to coasting down to a stop from that same velocity in exactly the same set of circumstances. That makes sense, so now let's try to separate out and quantify the various power losses acting upon the vehicle coasting down.

ELEVATED COAST DOWN

A. Let's first eliminate the influence of air resistance and rolling resistance. Take the vehicle inside the shop and lift up the back (drive) wheels. We will calculate the power losses in the drive line. There is a constant, or initial force of oil churning resistance plus another one related to velocity. Call one a velocity-independent and the other a velocity-dependent coefficient of oil churning. We want to quantify the losses according to source, and this has to be done by subtraction.

1. **Transmission only**

   Unhook the drive shaft in front of the front differential. Rev. up the engine to a given road velocity (measured from the transmission), step on the clutch, put the shifter into neutral, and let out the clutch. Measure the time it takes to roll to a stop. A very strict, repeatable procedure is used, and timing must be very accurate.

2. **Transmission plus front-rear differential**

   The identical procedure is repeated. The interaxle driveshaft only is removed. The results derived from timing this coast down produce a velocity-dependent and a velocity-independent oil-churning coefficient for the transmission plus the front-rear differential, so you can subtract 1) to get the front-rear differential only.

3. **Transmission plus front-rear differential plus rear-rear differential.**

   Repeat as above with all drive shafts in place, and subtract the results of 1. and 2. to get 3., the power loss due to oil churning in the rear-rear differential.

   The equation resolves to friction force to slow down versus inertia force to keep moving, or energy balance.

Prior to having access to a scanning recorder, a read-out monitor was used to measure time and engine revolutions, but the solution of the equation was long and required trial and error. Furthermore some subjective judgement was required...a curve fitted to three points.

Presently enjoying the capability of a digitized scanning instrument, an almost infinite number of points describes the velocity curve, and therefore acceleration (deceleration) may be accurately derived at any point in time, so the solution is simpler, more accurate, and verifies earlier conclusions.

ON-THE-ROAD COAST DOWNS

B. Having calculated oil churning losses from the elevated coast-downs, now we go on-the-road to measure:
   1. the rolling resistance coefficient, and
   2. air drag coefficient.

The theory upon which the on-the-road coast downs is based is the same energy balance theory as used for the elevated coast downs. There are simply two ways of processing the measurements, the newer way easier and more accurate than the earlier method.

If the vehicle is coasted down from a known velocity on a level, flat and uniform surface, the total of the air drag coefficient plus the rolling resistance coefficient may be calculated, because the oil churning losses already calculated may be subtracted. Any effect of grade not eliminated by choosing flat road is cancelled out by coasting down in both directions.

1. The rolling resistance may be isolated and quantified by removing one or more axles from the trailer, and removing part of the load, so that each of the axles in contact with the road carries the same weight as before. The difference may be calculated by repitition as above, and prorated.

   Two measurements are usually required to gather the information for the "old-method". Measure the on-road coast down time from 80 km/hr to 60 km/hr, and then do it again from 20 km/hr to 0 km/hr. A time and velocity is recorded in each case for the start, mid-point and end of test

2. The air drag coefficient may be derived by subtracting the results of total rolling resistance from the total, at various travel velocities.

Thus, in summary, there is a grand total which is made up of oil churning losses (already calculated by the elevated coast down technique) + rolling resistance (which is made up of starting rolling resistance, and a rolling resistance which is related to velocity) + air drag (which is dependent on the frontal area of the vehicle, and has almost no effect at low speeds, but has a dramatic, increasing effect with high speeds).

These measurements were repeated for different road surfaces in summer and winter, single tires vs dual tires on the trailer, different air pressures in the tires, different tire types, different gross loading and with different gear oils.

EARLY INSTRUMENTATION

In all cases, a made-to-measure digital monitor displaying RPM, velocity, time and distance, fuel consumption, and up to six diverse temperatures was used. The read-outs from the various life-support systems were manually recorded for:

fuel consumption/fuel temperature
fuel consumption/water and oil temperature

In every case, a volumetric measurement of fuel consumption was also taken at a constant speed for diverse engine rpm in direct gear.

DRIVE TRAIN FRICTION LOSSES RELATED TO APPLIED TORQUE

What has not been accounted for? Gears rub against gears, causing power losses due to friction, which are somehow related to increasing torque and the lubricating qualities of the oils. Enter: one highly accurate strain-gauge type torque meter.

The torque meter was introduced in place of one of the drive shafts. The inertia method was again used, along with other measurements allowed by better tools. Parameters were produced which were more detailed, but which agreed closely with earlier FERIC studies.

Ordinarilly, engine friction losses cannot be measured without a special engine dyno. In this case however, by using the torque meter, the engine was calibrated in-frame, with all its parasitic jewellry, not in a lab. This was a real measurement for that particular engine against the normal marketing-oriented information provided by the manufacturer.

IN-SHOP ROLLER DYNO

The instrumented truck was placed on a shop roller-dynomometer. Power measurements were taken from the torque meter, not from the dynomometer. The dyno itself was simply used to change power demands to the driving wheels when required.

The solution by subtraction resembles the elevated coast downs, but this time power losses due to applied torque may be isolated from simple oil churning losses.

The measurement procedure is as follows:

1. With the truck transmission removed, and the torque meter coupled directly to the engine, direct 1:1 torque was measured at various engine rpm. Fuel consumption was recorded for each test.

2. Then the transmission was re-installed with the torque meter behind it, and direct gear selected. The same series of tests were repeated. This measured by a second, more sophisticated manner, the oil churning losses **plus** friction losses due to applied torque inside the transmission.

3. The above measurements were done with both rear ends turning, and then repeated with the rear drive shaft removed to disconnect the rear-rear end.

All tests were identified by type and temperature of oil.

After each measurement was done in the dyno room, a coast down was taken with the back wheels lifted to verify the oil churning losses at that temperature on that unit in the absence of air drag.

ACCOUNT FOR TIRE SLIPPAGE ON DYNO ROLLERS

In-shop coast down tests were further repeated with the wheels in contact with the dyno rollers to isolate the effect of tire slippage, and friction losses owing to the dyno itself.

ON-BOARD MODULAR DATA ACQUISITION SYSTEM

The next stage of this research programme treats the inter-relationships of the various operating factors identified and quantified. This was begun with the controlled dynamometer measurements related to temperature and other factors, as well as measurements in actual operating conditions. Further operating factor studies were carried out at the same time. An on-board modular data acquisition system was connected to all the life-support systems in the truck.

The portable recorder, acquired in 1984 is a model 2200 Megadac, which is capable to measure up to 128 channels, and capable to scan an information source up to 20,000 times per second, if necessary. It was debugged in the field on a truck rigged with captors hooked to 28 sources. Every one of these systems was scanned each 1/10 of a second. Information captured in voltage form is recorded on cassettes, which are further processed by Megadac and Hewlett-Packard equipment to transform these voltage readings into digital form for further analysis.

All of the dyno room tests were repeated again at the end of 1984 using the Megadac recorder. This replicated the earlier tests, removed human error due to manually recording digital read-outs, and required only a quarter of the time.

ROAD PROFILE ON-THE-FLY

Then on an operating road, trips were made to pick up data for later use in an attempt to derive the road profile. Fuel consumption, torque, speed, accelerator percent depression and other information was again collected. As well, the driving techniques of four drivers were measured on an identical 15 km stretch in both directions.

A five kilometer stretch of bush road was profiled vertically and horizontally every meter. This was used to test the ability of the on board string type potentiometers to measure the road profile from a moving truck. The fuel consumption recorded could be related to curves and grades. Trips were made with five different inflation pressures in the tires. Coast downs were made in both directions on this same stretch of road.

On another 500 meter stretch, coast downs were done on five different surfaces: graded and not graded, fine and rough gravel, with and without calcium stabilization treatment.

INTER RELATIONSHIPS - THE ROAD, THE MACHINE, & THE MAN

The next stage, started in 1985 was to investigate the man, machine and operating conditions interface, using the equipment mentioned above. Transport Canada has recognized that FERIC's study programme is of value to all types of truck transportation systems across Canada, and for this reason the Federal Government is participating in the cost of these studies over the next 2½ years.

Some of the preliminary developed data collected on the operational roads show a marked influence of the driving technique, road macro-space and micro-design, and machine specification on the energy consumption performance and machine durability.

Here are some of the pertinent results:

The fuel consumption on a straight and flat gravel road compared to the same road surface with a 3.75% adverse grade and 513 meters radius of curvature showed 64 HP consuming 25 litres per hour of fuel versus a requirement of 361 HP consuming 80 L/hr. fuel.

THE MOBILE LABORATORY

The instrumented FERIC tractor thus becomes a mobile laboratory. A conventional cab, 11R x 22.5 tubeless radial tires, 44,000 lb Hendrickson suspension with 60" walking beam, Caterpillar 3406, 400 HP diesel power unit, Fuller 1458LL transmission and 4.72 rear end ratio is a believable truck, on highway, or off highway. The wheel base had to be uncommonly long to accomodate a sleeper cab large enough to house the recording instrumentation, leaving room for a technician to attend the instruments in relative comfort.

THE CAPTORS

At present, the recording equipment scans the information captors listed below:

- engine revolutions per minute;
- distance travelled:
  1. from the back of the transmission and
  2. from the front wheel (free wheel);
- (velocity is derived from distance and time);
- torque, measured from a strain gauge type torque meter which replaces a section of drive shaft behind the transmission;
- accelerator pedal depression in percent;
- fuel rack opening in percent;
- front wheel angle of steer, by means of a rotational potentiometer at the power steering output shaft;
- boost air pressure:
  1. before the turbocharger and
  2. after the turbocharger;
- oil temperatures:
  1. engine crankcase;
  2. transmission;
  3. front-rear differential; and
  4. rear-rear differential;
- coolant temperature:
  1. into and
  2. out of the engine;
- air temperature:
  1. into engine (after turbocharger), and
  2. ambient temperature (under the hood);
- exhaust temperature:
  1. before and
  2. after the turbocharger;
- fuel temperature:
  1. before the fuel measuring device and
  2. close to the injectors;
- optic type volumetric fuel meter measures 78 counts/ml (2213 measurements per ounce);
- wind direction and velocity;
- air pressure on the brakes;
- road roughness wheel, equipped with:
  1. vertical axis accelerometer at the wheel hub, and
  2. linear variable distance transducer (LVDT) measuring distance between wheel and truck frame;
- three string type potentiometers, measuring the change in the articulation angle vertically and horizontally between the trailer and the tractor, near the 5th wheel;
- LVDT, measuring the rotational change of distance (derived angle) on a longitudinal vertical plane of the 5th wheel around its transverse axis;
- the system is further set up to accept at least:
  - six additional strain gauge captors which may be attached along the trailer or tractor beams, for example;
  - two inclinometers which may be set up to measure roll angle above and below the springs, on the tractor or the trailer, for example;
  - four accelerometers, amplified by an FM tape recorder to be scanned by the Megadac, at the same time recorded in real time on tape for independent analysis of analog data by other means;
  - two strain gauge load cells for measuring tension in the load tie-down system.

THE PROBLEM OF DATA COMPILATION

The system is about as limited as your imagination. One "problem" is that it collects ten mega-bytes of information in a half-day's truck time. To bring that into perspective, a respectable Personal Computer these days requires 0.64 mega-bytes of memory, and a floppy disk can store 0.36 mega-bytes. So you have to have a state-of-the-art large capacity computer and technical support system to process the collected data. It is immediately apparent that data collection can inundate the data compilation which is required before analysis can take place. The temptation is always there to become over-enthusiastic with the boundless possibilities for research projects with a space-age tool, and be frustrated with the astronomical pile of arithmetic to process with limited resources.

A computer programme has been prepared which will extract a large amount of recorded field data presently stored on cassettes and transfer this to the main computer. Now that this programme is operational, the inter-relationships between and among 28 or more variables can be quickly identified, analysed and quantified.

OTHER PROJECTS

1. Test a prototype to control axle and transmission oil temperature.

Previous work on oil churning losses related to oil temperature and viscosicity identified the optimum temperature for best fuel economy. In order to prove this point under operational conditions, a member company fabricated an insulating blanket package to prevent heat loss and therefore maintain a summer temperature in the oil inside the differential housing(s) on a haul truck during the winter of 1984-85. The temperature changes over time was monitored in this unit for several trips. The goal was achieved with very light insulation. The results have been published and circulated as a technical note.

If there is adequate industry interest, the logical next step would be for FERIC or some outside agency to design an insulating blanket for fleet use during the cold season. It would need to be "fail-safed" to prevent over-heating of oil if the weather became unseasonably warm for a day.

2. Evaluation of Self-Aligning Axles for Logging Truck Trailers

Provincial axle legislation has encouraged the use of wide axle spacing on truck/tractors and trailers. These axle configurations result in exagerated lateral resistances in tires, suspensions and trailer frames while negotiating curves. FERIC will evaluate a self-aligning unit against a standard trailer with conventional axles. Improvements are anticipated in the following areas: maintenance cost of tires and suspensions; power requirements and therefore fuel consumption; and decreased transverse vibration reducing the tendency for the load to shift and therefore reducing the chance of spills.

3. Evaluate Logging Trailer Undercarriage Systems

The self-aligning axle project outlined above is a case study for more detailed evaluation of trailer undercarriages. Further work is required to classify the types of equipment used and identify problem areas for a major in-depth study in the near future. The ultimate goal is to identify, if it exists, or suggest a design for a trailer undercarriage which would respond to the artificial parameters of most provincial axle-spacing legislation, and "live" in exteme service wood haul conditions.

CONCLUSION

This all does not move as fast as you can say it. We have some of the finest instrumentaiton available in the world and the expertise to use it. Our recently acquired computer equipment is powerful and of the latest generation. However, we still have to find cooperating companies willing for us to tie up some of their equipment for a time, and disturb their garage and production staff with unusual requests. It still requires a human being with a life-time of experience in automotive engineering to analyse the charts and graphs produced by this sophisticated instrumentation.