FUEL CONSUMPTION AND PRODUCTIVITY OF TRUCKS COMPARED TO TRACTORS AND TRAILERS FOR HAULING SUGARCANE

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Abstract

The South African sugar industry moves about three quarters of the sugarcane crop to the mills by road transport. The recent increases in fuel costs prompted an investigation into the effects of changing vehicle size, load size and vehicle type. This paper describes the test results for trucks varying in carrying capacity from 5 to 40 tons and compares them with figures obtained previously for tractors and trailers. It is concluded that within the scope of legal loads both productivity and fuel consumption are improved most dramatically by increasing load size. The tests also showed that trucks are vastly more productive and fuel efficient than tractors and trailers when utilized as transport vehicles.

Introduction

This work was prompted by the high cost of diesel fuel and the large quantity of sugarcane transported by road transport in South Africa. The effect of changing either vehicle power or load size on the productivity and fuel consumption of transport vehicles were studied. Murray, Boevey and Meyer[1] reported results obtained from a similar series of tests carried out on tractors and trailers. This report on trucks complements the previous work and was conducted in exactly the same manner and on the same route as was done in 1980. Some modifications were made to the equipment used for measurement and additional equipment was manufactured to measure the power developed by the trucks.

A selection of trucks was chosen ranging from a small Ford D0805 truck with a maximum load of 5 t up to a Mercedes Benz 2624 "hilo" type truck with a maximum load of 40 t. In the context of this paper, "load" means gross imposed load, that is the gross vehicle mass less the mass of the prime mover. In the case of the Mercedes Benz 2624 the prime mover was the horse and in the case of the other trucks it was the chassis without body.

All the trucks were tested with loads varying from zero to the maximum legal mass and the top speed used was the legal maximum of 80 km/h.

Materials and Methods

The route travelled and the test procedure were the same as used by Murray *et al*[1] with some modifications. The fuel flow meter was modified because a considerable amount of trouble had been experienced with short circuiting the injector bleed line back to the injector pump feed. The bleed was therefore returned to the fuel flow meter, resulting in virtually trouble-free operation.

Other facilities that had to be developed were those for measuring the power developed by the trucks. Initially trucks were taken to Darling and Hodgson Automotive Services where time was hired on their rolling road dynamometer, but the relatively high cost and inconvenience of this led to the design and manufacture a rolling road which could utilize our existing hydraulic dynamometer as a power sink. For tractors there are standard test procedures and official test reports are published for most models tested according to OECD procedures. No such facility exists for wheel-testing trucks and the only specifications against which a truck's performance could be measured were those supplied by the engine manufacturers. The engine specifications obviously do not take into account losses occurring through the transmission; consequently if we were to measure power at the wheels as an estimate of what the engine was producing we would have to know what losses to expect through the drive train. The most conservative estimates for drive train losses are 10% for a single axle truck in a direct gear ratio and up to 25% for a tandem truck in an indirect gear ratio.[2] These estimates illustrate that care should be exercised before selecting a truck with six wheels, four of which are driven.

To determine drive-line losses a second dynamometer was manufactured to measure the power required to drive the transmission from the wheels. This was done by disengaging the engine with the clutch and measuring the power required to drive the whole transmission up to the clutch plate. This measurement, made at various road speeds was added to the truck's measured power, to give an estimate of the power developed at the flywheel of the engine. The procedure is not entirely satisfactory because it is based on the assumption that the torque transmission through hypoid gear reduction in the differential is reversible, which is not strictly true. Any error that is incurred exaggerates the performance of the truck. Figures 1 and 2 show the rolling road and the two dynamometers. A graphical representation of typical wheel power and rolling losses is given in Figure 3.

Results

Dynamometer test results

The results of the dynamometer tests carried out on the four trucks chosen for the road tests are given in Table 1.

Unfortunately the estimate of the power at the flywheel was in most cases rather lower than expected, although the trucks

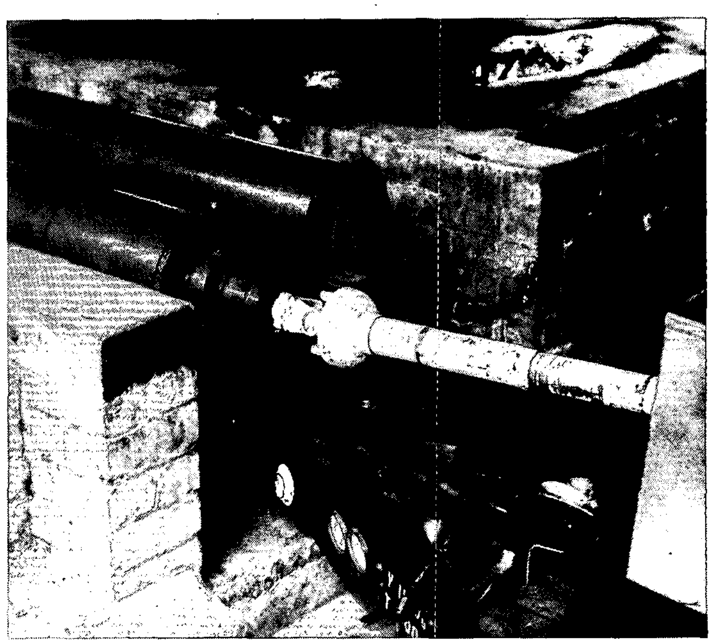

FIGURE 1 Attachment of the rolling road to the hydraulic pto dynamometer.

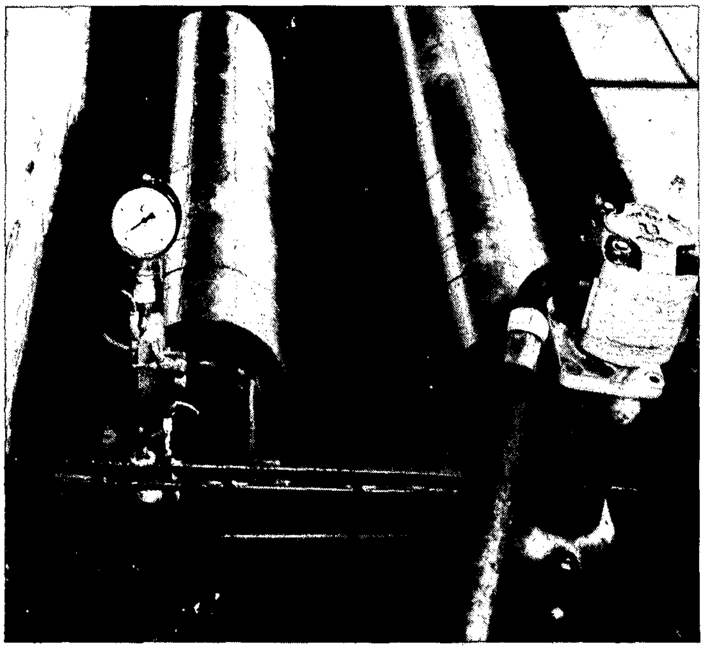

FIGURE 2 Attachment of the transmission-losses dynamometer showing: (1) the hydraulic power source, (2) the right angle drive gearbox, (3) the torque arm, and (4) the pressure cell and gauge.

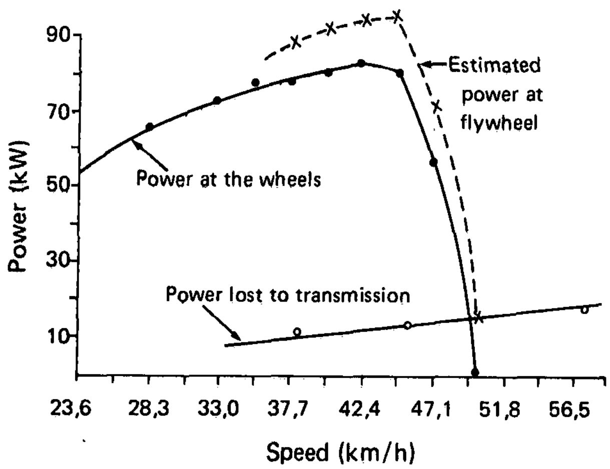

FIGURE 3 A typical power versus ground speed characteristic showing the power developed at the wheels, the power consumed by the transmission and the estimated power at the flywheel.

TABLE 1

Results of power measurements made on the four trucks tested

Vehicle	Power at wheels (kW)	Rolling power (kW)	Estimated power at flywheel (kW)	Expected* power at flywheel (kW)	Deviation of measured power %
Ford D0807	30,0	12,0	42,0	49,5 (55)	− 15
Mitsubishi FK 115	61,7	17,0	78,7	76,5 (85)	+ 3
MAN 14-192	100,0	13,0	113,0	128,0 (143)	− 12
Mercedes Benz 2624	114,0	18,7	132,7	161,0 (179)	− 18

* The figure in brackets is the power expected from the engine without any accessory loss.

were either brand new or supposed to be in very good condition. Considerable efforts were made to calibrate all the equipment as accurately as possible to ensure that the measured results were not in error by more than five per cent. One should therefore not view the trucks under test against the manufacturer's specifications but rather against the measured figures.

Confirmation of the validity of the estimated power is the calculation of specific fuel consumption (sfc) for various trucks. This ranged from 0,29 ℓ/kWh for the Mitsubishi to 0,40 ℓ/kWh for the MAN. These figures are within the range to be expected for a diesel engine. The MAN which gave the worst measurement of sfc was a new truck with very tight transmission. During the course of our test it appeared to loosen up considerably.

Road test results

Fuel consumption

The quantity of diesel fuel consumed per unit of transport effort* is expressed in terms of ℓ/t km, as was demonstrated by Murray *et al.*[1] The variation of this parameter, as change in load takes place, does not follow the same trend for trucks as it did for tractors in that there is no marked change in the gradient of the curve at any particular load. Consequently the approximations by Murray *et al*[1] of simplifying each curve to two straight lines is not justified for trucks. Another relationship was sought and it was found that regressing ℓ/t km against $\frac{1}{\text{load}}$ provided the best statistical fit, indicated by the correlation coefficients of the resulting regression equations in Table 2.

TABLE 2

Regression equations for calculating specific fuel consumption from the load size for three vehicles and three road gradients

Vehicle	Road gradient %	Regression equation	R^2
Ford D0805	3,5	Y = 1,06 + 15,34 (L)	0,98
	5,0	Y = 4,09 + 9,98 (L)	0,98
	8,0	Y = 3,47 + 15,96 (L)	0,89
Mitsubishi FK 115	3,5	Y = 0,89 + 24,55 (L)	1,00
	5 & 8	Y = 1,98 + 24,91 (L)	1,00
MAN 14-192	3,5	Y = 2,79 + 16,42 (L)	0,93
	5 & 8	Y = 4,15 + 9,21 (L)	0,96

Y = specific fuel consumption (ℓ/t km × 100)
L = reciprocal of load (t^{-1})

* Transport effort is defined as product of the load and the distance the load travelled and thus has units of t km.

Neither the data measured for the Bell 1206 tractor nor those for the MB 2624 truck fitted this type of relationship because the specific consumption increased on gradients for which the analysis was done, for loads of 20 t and more. This was because significantly lower gear ratios had to be chosen to negotiate the hills (see Figure 4).

The data for the MAN and Mitsubishi showed no measurable difference in fuel consumption on the 5% and 8% gradients. The regression coefficients for the three trucks on the three gradients are not similar enough to justify approximation by taking a mean, indicating that the fuel consumption of the various trucks was not affected at the same rate by increases in load. For big trucks specific fuel consumption improved by up to 15% when loads were increased from 5 to 10 t but only by 6% when increasing the load from 10 to 15 t. For the

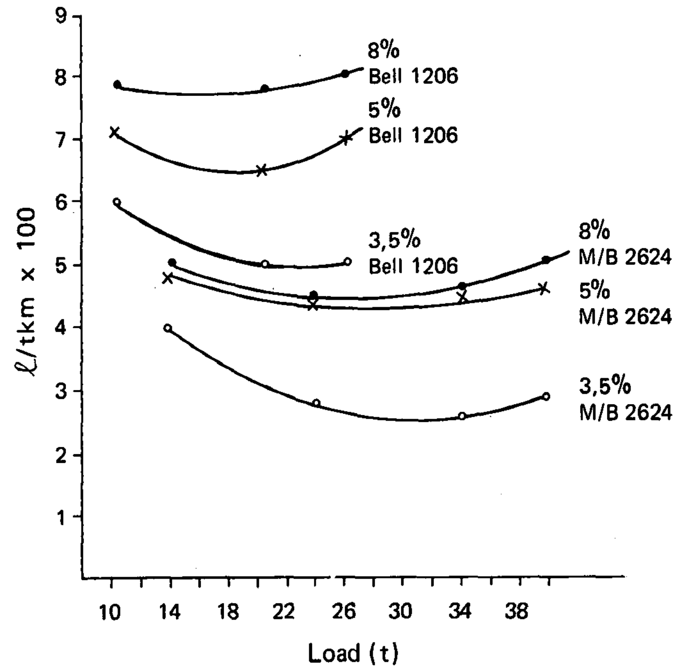

FIGURE 4 Specific fuel consumption (ℓ/t km × 100) versus load (ℓ) for three road gradients for the Mercedes Benz 2624 truck and the Bell 1206 tractor. This graph illustrates the increase in specific fuel consumption for these two vehicles at very heavy loads.

smaller truck a 33% improvement in ℓ/t km resulted from increasing the load from 2 to 5 t and a 16% improvement was recorded when the load was increased from 5 to 10 tons. Large improvements in specific fuel consumption can therefore be obtained by increasing load size.

Using the procedure described by Murray *et al*[1] it was not possible to find a simple relationship between ℓ/t km and the available power of each truck as measured on three different slopes and for three loads. However, it was possible to establish a reliable relationship between the ratio of the load to the maximum measured power and specific fuel consumption (ℓ/t km) for each vehicle (see Table 3).

The regression coefficients in Table 3 are remarkably similar indicating that virtually for all truck sizes fuel consumption (ℓ/t km) improves at the same rate with reduced power to mass ratio. This emphasises the value of using large loads.

Productivity

The productivity of a transport vehicle is determined by the speed of travel, its payload and cycle distance, but generalized observations can be made by analysing the change in speed for a variation of load size and road gradient for each vehicle size. The regression equations relating speed to load for each vehicle on a 5% gradient are listed in Table 3 along with the correlation coefficients. Each is a linear equation expressing speed y as a function of load (t) and is of the general form. $y = a + b(t)$ where the units of y would be km/h. The integral $F(t) = \int y\ dt$, however, would have units of t km/h which is a measure of productivity and would be of the form $F(t) = a(t) + \frac{1}{2}b(t^2) + c$. Since this is a quadratic function in terms of t, it has an extreme value. The regression coefficients in Table 3 are negative at a value of t such that $y = 0$. Therefore the value of $t = t$ (optimum), such that $y = 0$, represents the load at which each vehicle would be most producive.

The calculated values of t (optimum) for the four trucks and the Bell 1206 tractor are given in Table 4 with $F(t)$ equations for each vehicle.

The regression coefficients in the equations are not at all similar for the various trucks, indicating that increasing load does not have a similar effect on all vehicles, as was the case for tractors reported by Murray *et al.*[1]

The characteristics of the truck's gearing play a major role in the range of the regression coefficients from 1,23 km/h per ton change in load to 4,7 km/h per ton change in load. The $f(t)$ equations indicate that productivity is more rapidly improved by the addition of one ton to a fairly small load than by the addition of one ton to a large load. This re-emphasises the importance of ensuring a substantial load at all times.

The effects of increasing truck power for a given load are illustrated by the regression equations of Table 5.

The regression coefficients are very similar for all road gradients and loads except for the 15 t loads. In the load range up to 10 *t* one could therefore expect the speed to change by 0,6 km/h per kW change in power. This variation on an average speed of 45 km/h represents a 1,3% change in speed per 1 kW change in power.

TABLE 3

Regression equations for calculating specific fuel consumption from the ratio of the available power to the load being drawn for four vehicles and three road gradients

Vehicle	Road gradient %	Regression equation	R^2
Ford D0805	3,5	Y = 1,8 + 0,43 (X)	0,95
	5,0	Y = 5,3 + 0,59 (X)	1,00
	8,0	Y = 5,6 + 0,57 (X)	0,99
Mitsubushi FK 115	3,5	Y = 0,89 + 0,34 (X)	0,96
	5,0	Y = 2,36 + 0,41 (X)	0,94
	8,0	Y = 4,16 + 0,26 (X)	0,92
MAN 14-192	3,5	Y = 0,51 + 0,48 (X)	1,00
	5,0	Y = 3,74 + 0,37 (X)	1,00
	8,0	Y = 2,99 + 0,42 (X)	1,00
Mercedes Benz 2624	3,5	Y = 1,45 + 0,36 (X)	1,00
	5,0	Y = 4,09 + 0,34 (X)	1,00
	8,0	Y = 4,93 + 0,32 (X)	0,97

Y = specific fuel consumption (ℓ/t km)
X = ratio of available power (kW) to load (t) (kW/t)

TABLE 4

Regression equations to calculate speed from the load size, productivity equations and optimum load size for five vehicles

Vehicle	Regression equation	R^2	Optimum load (t)	Productivity equation
Mercedes Benz 2624	y = 65,7 – 1,23 (t)	0,95	52	F(t) = 65,7 (t) – 0,82 (t²) + c
Bell 1206	y = 44,3 – 1,37 (t)	0,97	32	F(t) = 44,3 (t) – 0,69 (r²) + c
M.A.N. 14 192	y = 114,4 – 4,68 (t)	0,77	24	F(t) = 114,3 (t) – 2,34 (t³) + c
Mitsubushi FK 115	y = 86,7 – 3,86 (t)	0,97	23	F(t) = 86,7 (t) – 1,93 (r²) + c
Ford D0805	y = 68,3 – 4,16 (t)	0,98	16	F(t) = 68,3 (r) – 2,08 (r²) + c

y = speed (km/h) F(t) = ∫ y. dt which is the productivity (t km/h) c = constant of integration t = load (t)

TABLE 5

Regression equation for calculating speed from the maximum available flywheel power for three load sizes and three road gradients

Road gradient %	Load (t)	Regression equation	R^2
3,5	5	y = 41,0 + 0,50 (p)	1,00
	10	y = 20,7 + 0,57 (p)	0,98
	15	y = 29,6 + 0,31 (p)	1,00
5,0	5	y = 22,6 + 0,60 (p)	1,00
	10	y = 3,72 + 0,60 (p)	0,97
	15	y = 18,7 + 0,23 (p)	0,97
8,0	5	y = 22,6 + 0,60 (p)	1,00
	10	y = −2,2 + 0,61 (p)	0,99
	15	y = 10,8 + 0,29 (p)	0,97

y = speed km/h
p = maximum available power at the flywheel (kW)

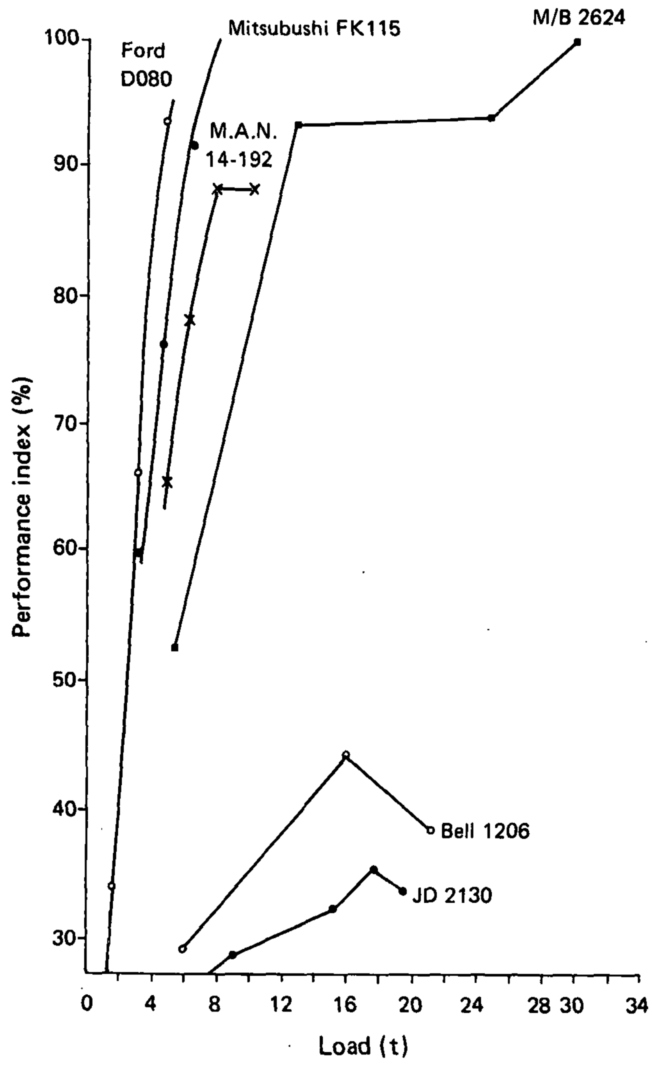

FIGURE 5 The performance index expressed as a percentage for the four trucks tested compared to that measured for the Bell 1206 and the John Deere 2130 tractors at various loads.

Tractor and trailers compared to trucks

The comparison of different transport vehicles must be made on the basis of their productivity and fuel consumption. A performance index was calculated which weights productivity (t km/h) and specific fuel consumption $\left(\frac{t\ km}{\ell}\right)$ equally. These two parameters were combined to produce an index of performance illustrated in Figure 5 which has units of $\frac{t\ km}{\ell\ h}$. It is not convenient to compare one index with another directly, and therefore they have been rated on a scale from 0 to 100%.

All indices are expressed as percentages of the highest value recorded. It can be seen that the most productive tractor and the Bell hauler compare unfavourably with the trucks. The fuel consumption (ℓ/t km) and productivity (t km/h) are both better for trucks than for tractors. The relatively poor performance of the tractors may be related to two factors. The first is the relatively unsophisticated design of tractor transmissions for the speeds attained in transport situations. Secondly, tractors have a poor selection of gear ratios for road transport speeds so that relatively little of their available power is utilized.

Conclusion

Tractors and trailers seem to be outclassed by trucks in transport productivity and fuel consumption. The minimum specific fuel consumption for tractors and trailers, measured by Murray *et al* was 5,0 ℓ/t km × 100 and the most commonly recorded value was 10 ℓ/t km × 100. For trucks the maximum value for specific fuel consumption was 7 ℓ/t km × 100 with the average value being about 4 ℓ/t km × 100. The maximum speed attained by the tractors was 30 km/h but their average speed was about 16 to 18 km/h. The trucks operated at an average speed of 40 to 45 km/h and the performance of the Bell hauler fell between those of the trucks and the tractors.

Conceivably the performance of trucks could be improved by paying more attention to the power available from them. The trucks tested were representative of the best maintained trucks in the industry and even they appeared to be unable to produce their specified power. However, their efficiency in converting diesel fuel to power was relatively good.

Considerable improvements in both tractor and truck performances could be effected by training drivers to use their vehicles to maximum advantage without causing damage.

Acknowledgements

Grateful acknowledgement is made to Darling and Hodgson Automotive Services for the help they gave us and for the use of their dynamometer. Thanks must go to Hultrans and The Tongaat Group for making trucks and a semi-trailer available for the test, to MAN Bus and Bodies who loaned new vehicles for our tests, and to Mr E Meyer for his help and enthusiasm throughout the duration of these tests.

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