CHAPTER 8

RESULTS OF THE EXPERIMENTS ON FUEL-CONSUMPTION MEASUREMENT AT STEADY-STATE SPEED

8.1 FUEL CONSUMPTION ON TANGENTS (FC-1)

The experiment of fuel consumption measurement at steady-state speed was the largest experiment carried out with the PICR test fleet. It consisted of approximately 30.000 measurements on twenty-five test sections with different characteristics. The nine vehicles specified in Table 8.1 were used in this experiment; they were run on the test sections at a constant speed, from a minimum of 10 km/h to a maximum of 120 km/h (car on negative grades), in different combinations of speed and gear.

For the analysis of variance the factors and levels shown in Table 8.2 were considered, where the load was determined according to the maximum loads recommended for each type of vehicle (Zaniewski, Plautz e Morais), and the roughness varied from 23 QI to 118 QI, on paved roads, and from 48 QI to 225 QI on unpaved roads. The dependent variable was the average fuel consumption (in mililiters/second), obtained from the three measurements carried out for each combination of the different levels of factors shown in Table 8.2. Analysis of variance was employed to evaluate the influence of each of the main factors and their interactions, and for identification of those which had a significant effect on fuel consumption. This identification served as the basis for formulating equations capable of explaining the variation in fuel consumption as a function of the independent variables associated with the significant factors.

After the more significant independent variables were identified, a non-linear regression procedure was used to estimate their coefficients. Thus the equations for the prediction of fuel consumption were developed for the seven classes of vehicles studied (Zaniewski, Morais e Moser, 1979).

Table 8.3 presents the equations obtained, as well as the determination coefficients and the mean square errors for each equation. Figures 8.1 to 8.5 illustrate the form of the equations and the magnitude of each of the main effects evidenced by the analysis of field data. Figure 8.1 shows the fuel consumption of each type of vehicle as a function of operating speed when the vehicles were running half loaded on a paved, level, well maintained surface (roughness

TABLE 8.1 - MAIN SPECIFICATIONS OF TEST-FLEET VEHICLES

TYPE	CAR	UTILITY	BUS	LIGHT TRUCK		HEAVY TRUCK		SEMI TRAILER	
MAKE	VOLKSWAGEN	VOLKSWAGEN	MERCEDES BENZ	FORD		MERCEDES BENZ		SCANIA TRACTOR	TRAILER
DIMENSION	1300	KOMBI	O-362	F-400	F-4.000	L-1113	L-1113-C MUNK	L-110-38S	
DIMENSION (m)									
Ground clearance	0.152	0.200	0.273	0.200	0.200	0.279	0.279	0.300	
Total height	1.500	1.912	2.945	1.890	1.890	2.454	2.454	2.013	
Width	1.540	1.746	2.500	2.030	2.030	2.350	2.350	2.403	
Distance between axles	2.400	2.400	5.500	4.030	4.030	4.200	4.200	3.800	8.750
Front overhang	0.760	1.130	2.310	0.750	0.750	1.100	1.100	1.480	0.900
Rear overhang	0.910	0.867	2.800	2.200	2.200	3.850	4.600	...	2.600
Total length	4.070	4.397	10.860	8.980	6.980	9.150	9.900	16.630	12.250
MOTOR									
Fuel	Gasoline	Gasoline	Diesel	Gasoline	Diesel	Diesel	Diesel	Diesel	
Type	Horiz.Opp.		In line	V	In line	In line	In line	In line	
Number of cilinders	4	4	6	8	4	6	6	6	
Bore (mm)	77	83	97	92	105	97	97	127	
Stroke (mm)	69	79	128	84	120	128	128	145	
Displacement (cc)	1.285	1.493	5.675	4.457	4.163	5.675	5.675	11.000	
Compression Ratio	6.6	6.6	17	73	17,8	17	17	16	
Torque/RPM (m.kgf)	9.1/2.600	10.3/2.600	37/2.600	33.5/2.200	29.2/1.600	37.0/2.000	37/2.000	79/1.200	
Horse Power	48/4.600	60/4.600	147/2.800	169/4.400	102/3.000	147/2.800	147/2.800	285/2.200	
TRANSMISSION RATIO									
1st gear	3.8	3.8	8.02	6.40	5.30	8.02	8.02	13.51	
2nd gear	2.06	2.06	4.77	3.09	2.85	4.77	4.77	10.07	
3rd gear	1.32	1.32	2.75	1.69	1.56	2.75	2.75	7.55	
4th gear	0.87	0.89	1.66	1.00	1.00	1.66	1.65	5.66	
5th gear	-	-	1.00	-	-	1.00	1.00	4.24	
6th gear	-	-	-	-	-	-	-	3.19	
7th gear	-	-	-	-	-	-	-	2.38	
8th gear	-	-	-	-	-	-	-	1.78	
9th gear	-	-	-	-	-	-	-	1.34	
10th gear	-	-	-	-	-	-	-	1.00	
Differential	4.375	4.375	4.875	5.140	4.630	4.875	4.875	4.710	

SOURCE: Vehicle owner's manuals.

TABLE 8.2 - FACTORS AND LEVELS CONSIDERED IN THE ANALYSIS OF THE FC-1

FACTORS	LEVELS
Type of Vehicle	1, 2, ..., 7 (models in the fleet)
Vehicles Repeated Within the Classes	1, 2 (Kombi, Heavy Truck)
Gross Weight	Own weight, own weight + load
Type of Surfacing	Paved, unpaved
Roughness	Paved section { Low (< 40 QI) / High (> 90 QI) Unpaved section { Low (<100 QI) / High (>140 QI)
Vertical Geometry	0-2% 3 to 5% 6 to 8% > 8% *
Direction of Grade	Positive, negative
Speed Gear	10, 20, ... V (km/h) 1ª, 2ª,... MARC

*Test section 555 with primary surfacing and 13% grade.

TABLE 8.3

CONSUMPTION EQUATIONS FOR STEADY-STATE SPEED

VEHICLE	S^2_c	R^2	
Car	0.037	0.91	$COMB = 0.142e^{(0.2287V+0.000855(V)GR+0.03782P(GR+3)+0.2695(5-MARC)+0.0001024(QI)(GR+14))}$
Utility	0.060	0.93	$COMB = 0.197e^{(0.02579V+0.001062(V)GR+0.02932P(GR+3)+0.2485(5-MARC)+0.0000785(QI)(GR+14))}$
Light Gasoline Truck	0.410	0.94	$COMB = 0.906e^{(0.0127+0.00063P+0.00699(5-MARC)+0.0000215(QI)V+0.01234GR(P)MARC)}$
Light Diesel Truck	0.140	0.90	$COMB = 1826e^{(0.0325V+0.00208(GR)V+0.0254P(GR+1)+0.2333(5-MARC)+0.001405QI)}$
Medium Truck	0.190	0.93	$COMB = 0.583e^{(0.02356+0.000491(P).(GR+1))V+(0.00594P+0.01224GR).(6-MARC)+(0.00057QI)}$
Heavy Truck	0.410	0.96	$COMB = (2.54/\sqrt{1+G})e^{(0.00505+0.00029.P(GR+1)+0.00035QI)V}$
Bus	0.170	0.92	$COMB = 0.195e^{(0.0359S+0.0044(GR)V+0.0075(P).(GR+1)+0.2781(6-MARC)+0.0002088(P)QI)}$

COMB = fuel consumption (ml/sec)

V = speed (km/h)

GR = grade (%)

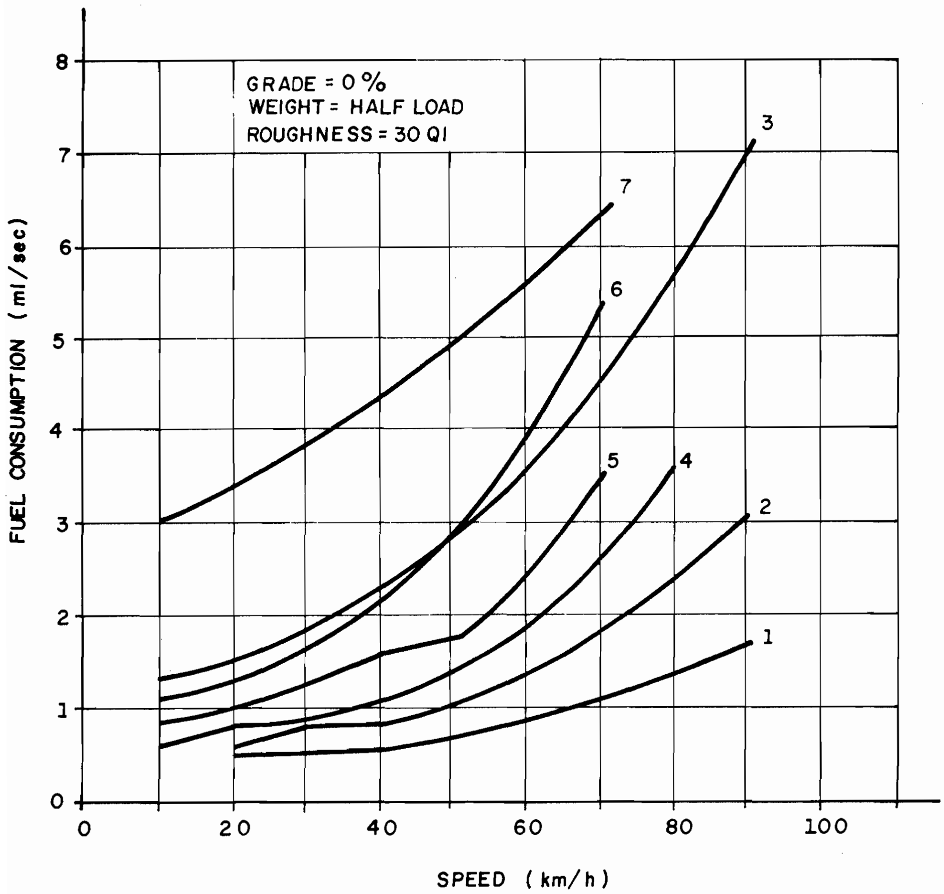
G = $|GR|$ for negative grades

0 otherwise

P = gross weight (t)

QI = roughness index

MARC = vehicle gear



1 - CAR

2 - UTILITY

3 - LIGHT GASOLINE TRUCK

4 - LIGHT DIESEL TRUCK

5 - BUS

6 - HEAVY TRUCK

7 - SEMI - TRAILER

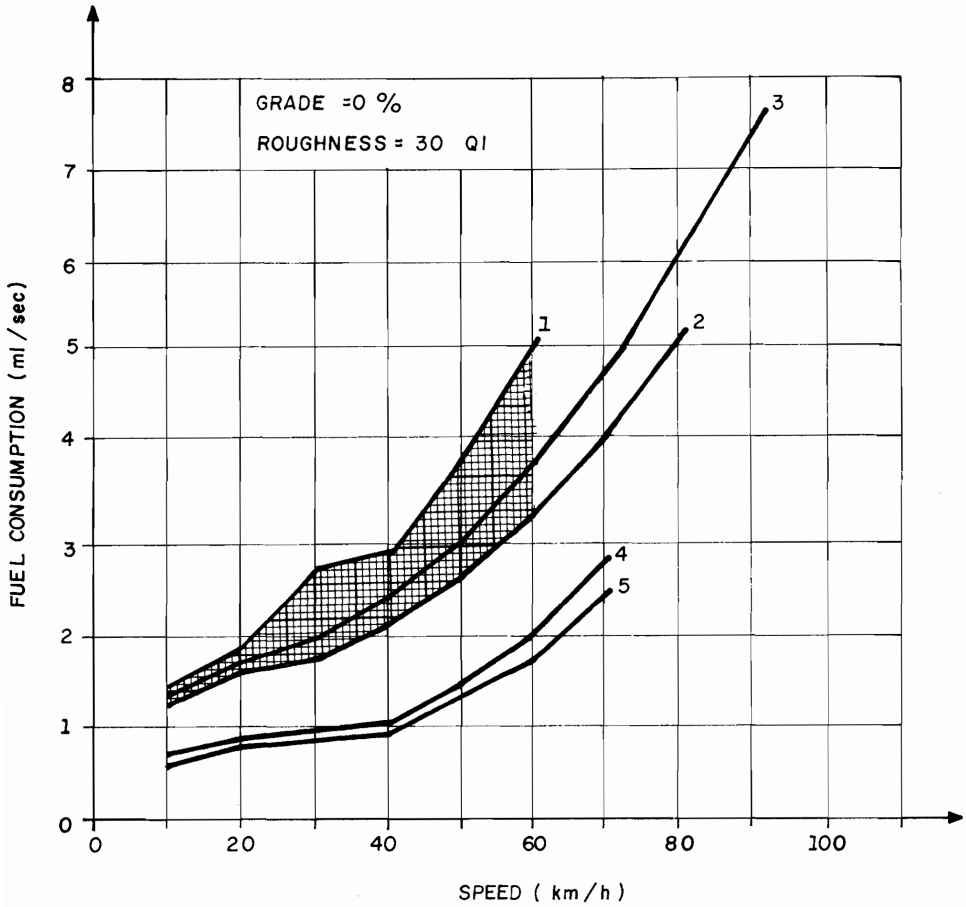
FIGURE 8.1 - EFFECT OF SPEED ON FUEL CONSUMPTION

of 30 QI). For each speed, the highest gear which the vehicle could use was employed on the test section. Therefore, each curve in Figure 8.1 represents the curve of lowest fuel consumption for each vehicle. The positions of the curves in the figure indicate a general tendency for fuel consumption to increase with increasing vehicle weight, except for the light gasoline truck, whose fuel consumption surpasses that of the medium truck when travelling at low speeds. However, for speeds in excess of 50 km/h the tendency mentioned above holds.

Figure 8.2 shows fuel consumption as a function of speed. For this purpose the equations used were those for light gasoline trucks and diesel trucks when travelling on level roads with roughness of 30 QI. Besides this, Figure 8.2 shows the effects, on fuel consumption, of the variation of load and of the use of different gears for the same speed. Curves 1 and 2 show the effect of gears on fuel consumption in an empty light gasoline truck. It can be noted that at speeds of less than 20 km/h this effect is not so great as at speeds between 20 km/h and 60 km/h. Curves 2 and 3, like curves 4 and 5, illustrate the effect of load on fuel consumption; these curves indicate that the effect of load variation on fuel consumption is greater for light gasoline trucks than for light diesel trucks, particularly at speeds over 40 km/h. Curves 2 and 5, like curves 3 and 4, show the difference in consumption between both types of fuel and indicate a clear advantage for light diesel trucks over light gasoline trucks. In the same conditions, the volume of diesel fuel consumed is as much as 50% less than the volume of gasoline consumed.

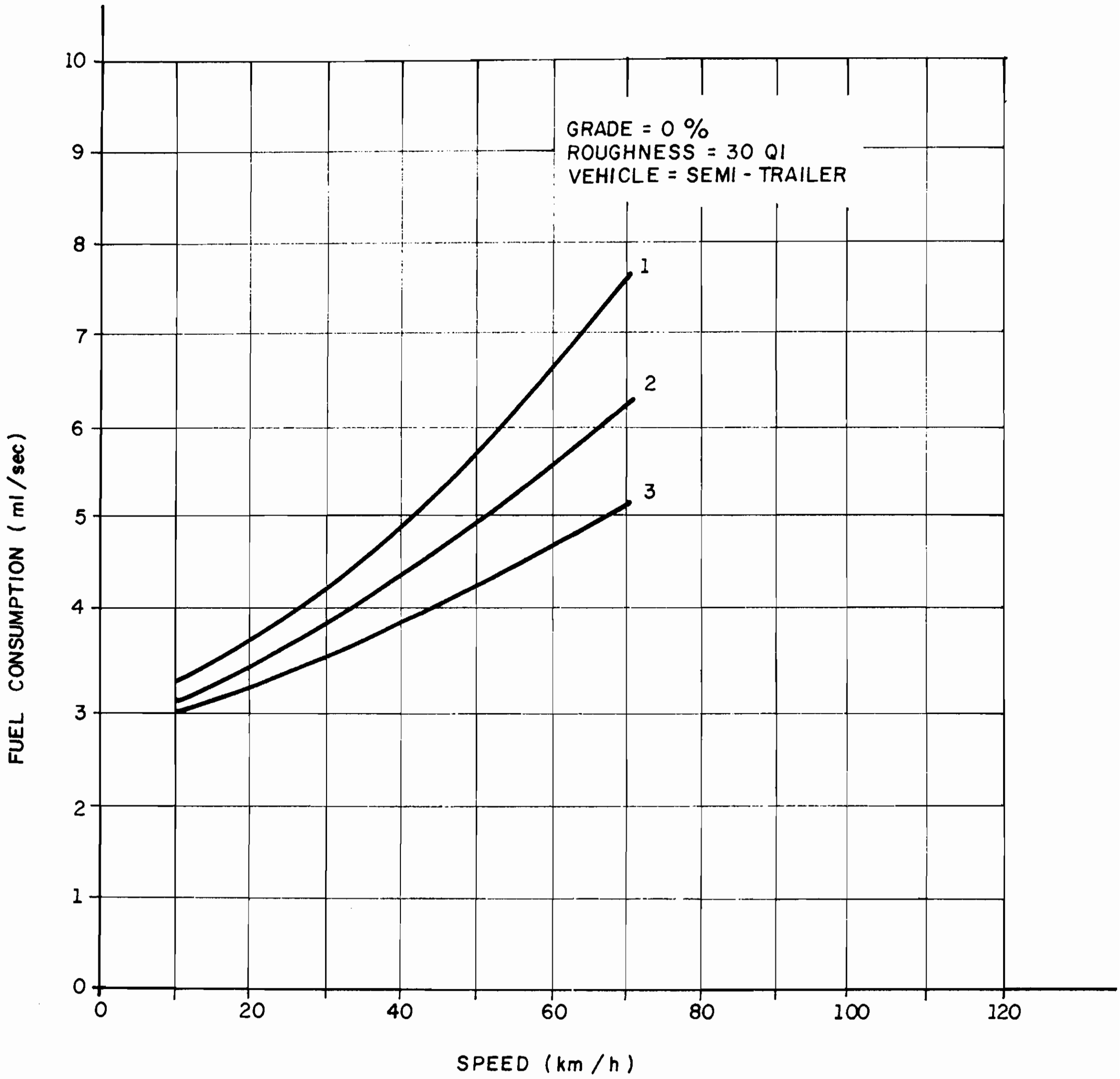
Figure 8.3 shows the effect of load/speed interaction on fuel consumption for a semi-trailer travelling on level roads with roughness of 30 QI. At low speeds the variation of weight due to the vehicle load produces little difference in the fuel consumption of trucks, whereas at higher speeds this difference is very high, reaching almost 3 ml/sec at a speed of 70 km/h, which corresponds to an increase of about 50% in fuel consumption.

Figure 8.4 shows the effect of vertical geometry (grade) on fuel consumption for a heavy truck travelling half loaded (gross weight of 14 tons) on a paved section with roughness of 30 QI. For each speed the highest possible gear was used. Besides the effect of the grade itself, the influence of the interaction between grade and speed



1. Light gasoline truck, empty and using the lowest gear
2. Light gasoline truck, empty and using the highest gear
3. Light gasoline truck, loaded and using the highest gear
4. Light diesel truck, loaded and using the highest gear
5. Light diesel truck, empty and using the highest gear

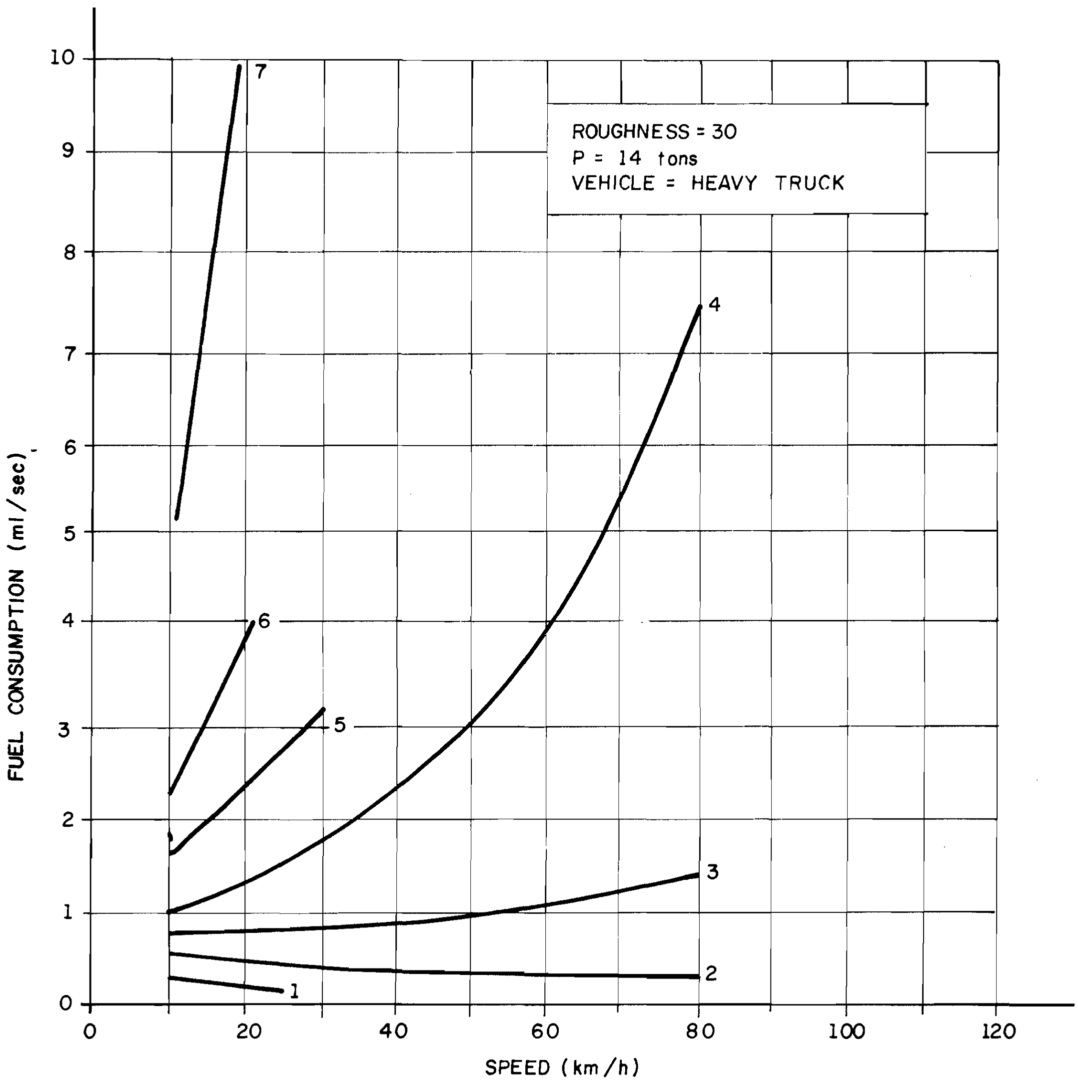
FIGURE 8.2 - EFFECT OF GEARS, LOAD AND TYPE OF FUEL ON CONSUMPTION.



GROSS WEIGHT:

1 - 40.74 tons
2 - 27.44 tons
3 - 14.14 tons

FIGURE 8.3 - EFFECT OF LOAD-SPEED INTERACTION ON FUEL CONSUMPTION



GRADE

1	-	- 13 %
2	-	- 6 %
3	-	- 3 %
4	-	0 %
5	-	+ 3 %
6	-	+ 6 %
7	-	+ 13 %

FIGURE 8.4 - EFFECT OF GRADE - SPEED INTERACTION ON FUEL CONSUMPTION.

on fuel consumption can be noted. That is, at low speeds, the influence of the grade is much smaller than at high speeds.

It is interesting to observe that curves 1 and 2 show that fuel consumption decreases as speed increases. This is attributed to the fact that for heavy trucks the engine is used as a brake to maintain low speeds on very steep negative grades, thus consuming more fuel than at higher speeds, when the engine is not used to brake the vehicle.

8.2 FUEL CONSUMPTION ON CURVES (FC-3)

The objective of this experiment was to examine the effects of short-radius curves on fuel consumption.

The data for analysis were obtained from an experiment carried out with vehicles of the PICR fleet (with the exception of the light diesel truck) on two test sections with an 8% positive grade and a riding surface of laterite gravel, one of them on a straight section and the other with two short-radius curves. The factors and levels included in the experiment are presented in Table 8.4.

TABLE 8.4 - FACTORS AND LEVELS OF THE EXPERIMENT

FACTORS	LEVELS	Nº
Loads	Empty and loaded	2
Horizontal Geometry	Curved and rectilinear sections	2
Speeds	10 to 50 km/h	5
Grades	+8% to -8%	2

In the analysis of variance of the data generated by experiment FC-3, no significant influence of horizontal curves on fuel consumption was found within the inference space of the experiment. That is, the differences observed in the fuel consumption of a given vehicle that travels at the same steady-state speed on sections which are differenciated only by their radii of curvature are not significant.

However, it is relevant to emphasize that the radius of curvature influences vehicles speeds (as shown in experiment TB-4) and, consequently, fuel consumption. But, at a given steady-state speed, consumption will be the same both on curves and straight sections.

8.3 FUEL CONSUMPTION FOR LARGE CARS (FCS-5)

Although not included in the original plans of the ICR Research, the Brazilian Transportation Planning Agency (GEIPOT) decided to undertake several experiments for measuring fuel consumption at steady-state speeds with large cars. For this purpose, two cars were used: a 6-cylinder 146-HP Opala, and an 8-cylinder 198-HP Dodge Dart (See Volume 2 of this report, Chapter 4, Table 4.4).

With these vehicles, experiments were carried out to measure fuel consumption at steady-state speeds on paved test sections with roughness below 40 QI and grades of 0 to 6%, as well as on a level test section with laterite gravel surfacing, with roughness below 100 QI, both with the vehicles empty and with a load of 350kg. After the necessary screening, the data collected were incorporated into the Project file, but at the end of 1981 they had not yet been statistically analyzed, due to time restrictions.

Table 8.5 presents a synthesis of mean fuel consumption (in ml/sec) on level sections and on positive grades of 4 to 6%, at different speeds and gears. On the positive grade of 6%, both vehicles showed a tendency to consume more fuel when empty than when loaded. However, this tendency could not be confirmed, since it was discovered only after the PICR was no longer in possession of the vehicles. Thus it is recommended that these measurements be repeated with vehicles of the same type before a definite analysis is made.

In Figure 8.5 the fuel consumption of these vehicles can be compared with that of the VW 1300 belonging to the PICR fleet. At low speeds of about 30 km/h, the differences are much lower than at high speeds.

Figure 8.6 shows the variation in fuel consumption as a function of slope steepness for the same vehicles at speeds of 40 km/h and

TABLE 8.5 - FUEL CONSUMPTION OF LARGE CARS (mℓ/sec)

			OPALA				DODGE			
			NEGATIVE GRADE		POSITIVE GRADE		NEGATIVE GRADE		POSITIVE GRADE	
GRADE	SPEED (kph)	GEAR	EMPTY	LOADED	EMPTY	LOADED	EMPTY	LOADED	EMPTY	LOADED
6%	30	1	1.67	1.41	2.99	2.79		1.38	2.67	2.41
	30	2	0.75	0.37	2.06	2.12	0,85		1.91	1.75
	30	3	0.37	0.37						
	40	1	2.46	2.17	4.15	4.15	2.00	1.88	3.88	3.36
	40	2	2.07	0.78	2.76	2.71	1.29	0.99	2.66	2.44
	40	3	0.38	0.33	2.16	2.12	0.66	0.33	2.11	2.11
	50	1	3.19	2.97	5.69	5.67	2.78	2.50	5.42	4.38
	50	2	1.43	1.11	3.41	3.40	1.53	1.25	3.47	3.19
	50	3	0.55	0.41	2.78	2.71	0.69	0.41	2.77	2.63
	60	2	1.83	1.50	4.52	4.32	1.66	1.49	4.02	4.10
	60	3	0.66	0.58	3.34	3.33	0.99	0.49	3.49	3.33
	70	2	2.50	1.85	5.43	5.25	2.14	1.94	5.26	5.06
	70	3	0.97	0.77	4.18	4.19	1.36	0.58	4.28	4.09
	80	2	2.55	2.32	6.53	6.16	2.66	2.22	6.43	6.22
	80	3	1.22	1.21	5.00	4.83	1.32	0.88	4.88	4.88
	90	3	1.49	1.26	5.74	5.52	1.48	1.24	5.46	5.99
	100	3	1.74	1.69	6.19	6.51	2.19	1.66	6.62	6.65
4%	30	1	1.91	1.75	2.74	2.68	1.66	1.50	2.25	2.16
	30	2	0.81	0.75	1.71	1.83	0.91	0.80	1.49	1.58
	30	3	0.50	0.33	1.34	1.37				
	40	1	2.66	2.50	4.08	3.88	2.33	2.11	3.22	3.32
	40	2	1.27	1.11	2.38	2.44	1.33	1.11	2.11	2.22
	40	3	0.72	0.50	1.72	1.88	0.88	0.66	1.66	1.77
	50	1	3.66	3.62	5.24	5.34	3.05	2.92	4.16	4.58
	50	2	1.62	1.46	2.98	3.12	1.80	1.53	2.78	2.92
	50	3	0.90	0.76	2.15	2.29	1.11	0.97	2.22	2.36
	60	2	2.01	2.00	3.75	3.90	2.17	2.00	3.51	3.68
	60	3	1.08	0.91	2.58	2.83	1.50	1.16	2.67	2.94
	70	2	2.46	2.33	4.42	4.95	2.72	2.53	4.47	4.61
	70	3	1.26	1.26	3.21	3.49	1.75	1.49	3.31	3.43
	80	2	3.00	2.87	5.33	5.70	3.32	3.11	5.56	5.56
	80	3	1.66	1.66	3.77	4.55	2.00	1.77	3.76	4.01
	90	3	2.13	2.13	4.38	5.21	2.25	1.99	4.25	4.75
	100	3	2.50	2.36	5.68	5.97	2.77	2.22	4.99	5.57
0%	30	1	2.25	2.04	2.33	2.21	1.91	1.75	1.91	1.83
	30	2	1.25	1.25	1.37	1.33	1.25	1.16	1.33	1.08
	30	3	0.75	0.75	0.87	0.83				
	40	1	3.11	2.94	3.22	3.05	2.62	2.55	2.99	2.66
	40	2	1.77	1.66	1.77	1.89	1.66	1.66	1.89	1.69
	40	3	1.16	1.27	1.33	1.33	1.22	0.99	1.22	1.11
	50	1	4.65	4.31	4.72	4.58	3.61	3.61	3.89	3.75
	50	2	2.36	2.22	2.50	2.36	2.21	2.23	2.50	2.21
	50	3	1.52	1.46	1.73	1.59	1.52	1.39	1.66	1.52
	60	2	2.75	2.83	3.00	2.92	2.67	2.83	2.77	2.67
	60	3	1.91	1.91	2.08	2.08	2.00	1.83	1.99	1.88
	70	2	3.60	3.40	3.60	3.41	3.30	3.56	3.44	3.31
	70	3	2.33	2.33	2.53	2.52	2.33	2.34	2.33	2.33
	80	2	4.66	4.11	4.88	4.44	4.01	4.23	3.99	4.00
	80	3	2.77	2.77	3.00	2.99	2.73	2.87	2.88	2.88
	90	3	3.13	3.37	3.25	3.76	3.24	3.26	3.25	3.33
	100	3	3.75	4.17	3.88	4.28	3.61	3.87	3.87	3.87

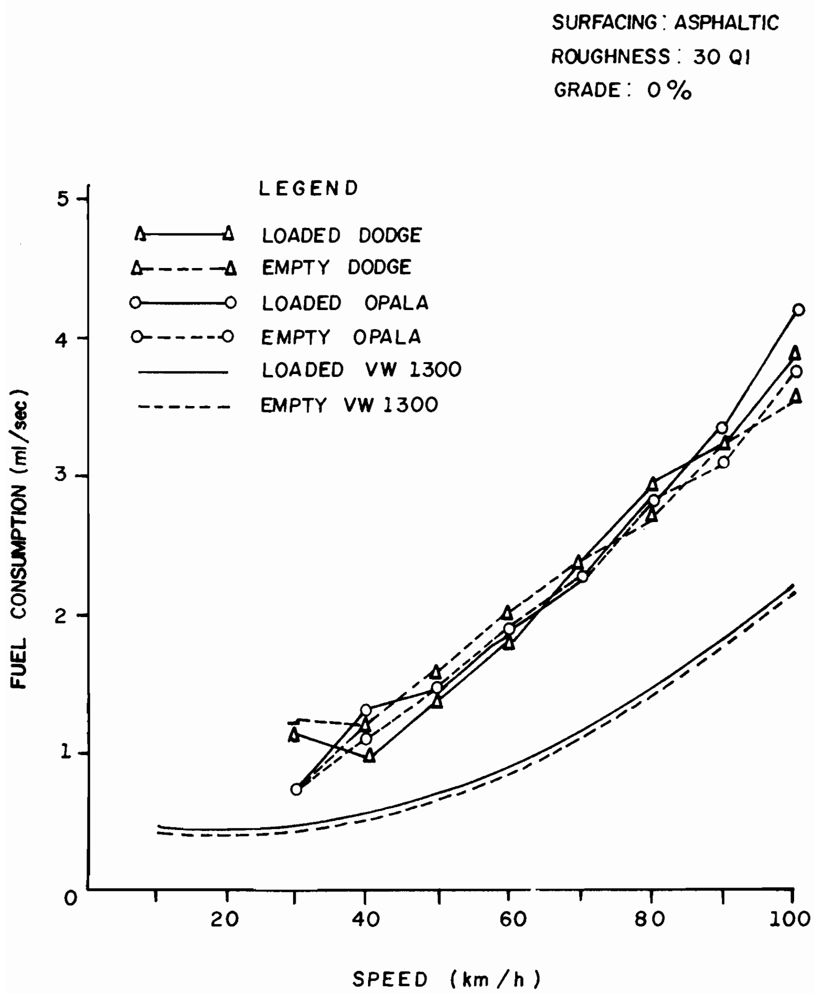


FIGURE 8.5 - FUEL CONSUMPTION OF THE VW 1300, DODGE AND OPALA AS A FUNCTION OF SPEED.

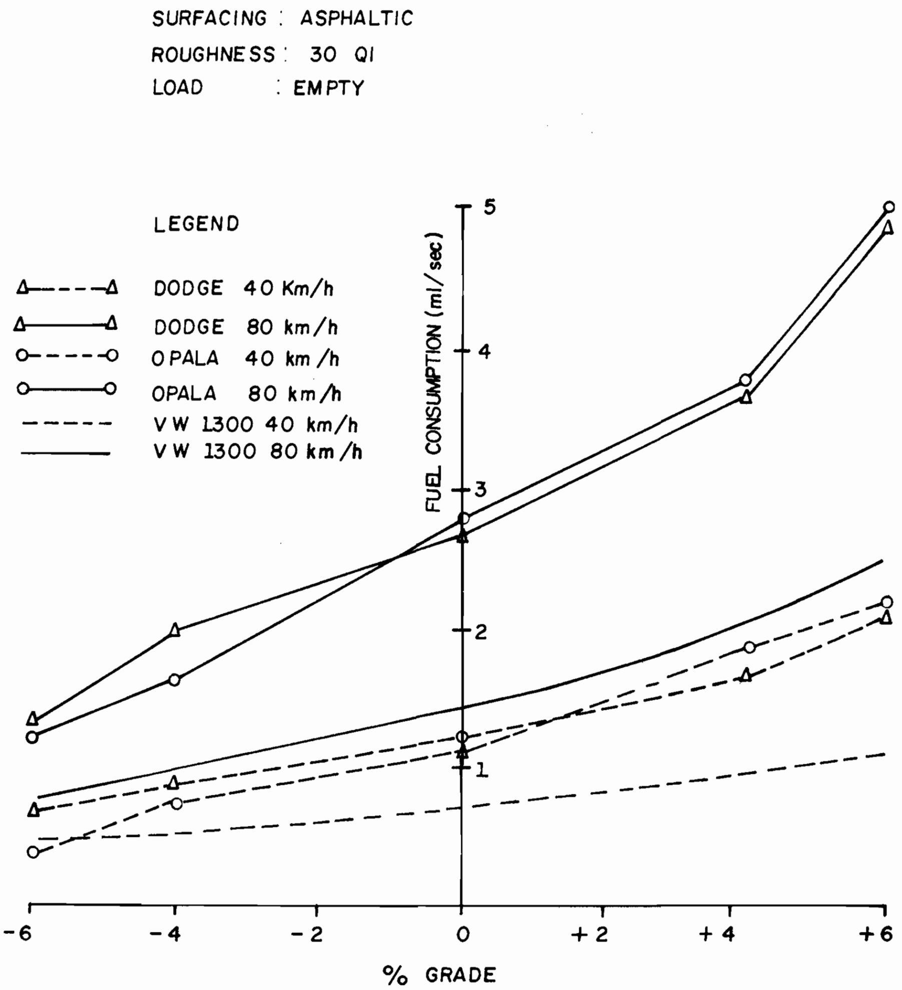


FIGURE 8.6 – FUEL CONSUMPTION OF THE VW 1300, DODGE AND OPALA AS A FUNCTION OF GRADE

80 km/h. It can be noted that the heavier vehicles, although possessing more powerful engines than the VW 1300, show a fuel consumption more sensitive to the variation in slope steepness, particularly on positive grades.