tions and the following equation represents the best fit on the functions tried.

$$S=59.3+7.3\left[18.6-(G-3.8)^{2}\right]^{.5}-3.25C+.56L+.240\ L^{G/2.6}$$

where S = mean spot speed

L = station (1, 2, 3, 4, 5)

1 is equivalent to 2000 meters up a negative grade

2 is equivalent to 1500 meters up a negative grade

3 is equivalent to 1000 meters up a negative grade

4 is equivalent to 500 meters up a negative grade

5 is equivalent to the bottom of a negative grade

C = new vehicle class (1, 2, 3, 4, 5, 6)

G = grade in percent

The equation is graphically presented in Figures 5, 6, and 7.

Effect of the Speed-Limit Enforcement Program

Free-speed data from four negative grade sections have been collected with the radar units in view before and after the speed-limit law. The four sections have grades of 1.3%, 3.6%, 6.0%, and 6.1%. As a preliminary examination, it is possible to compare the effects of the speed-limit law on the speed patterns of the four sections.

Analysis of the results indicates that the speeds measured after the speed-limit law are significantly lower than those measured before the law. The effect of the law is much more pronounced on the steeper grades where speeds are in general higher.

Conclusions - A large mass of free-speed data was collected within three months after initiation of the speed-limit law with the radar visible. The preliminary analysis of these data indicates the speed-limit law has reduced speeds significantly on negative grades when the radar units are visible. Recommendations are being considered now for further work, so that adjustments can be made on these reduced speeds.

FUEL CONSUMPTION

The fuel-consumption experiments will provide the data re-

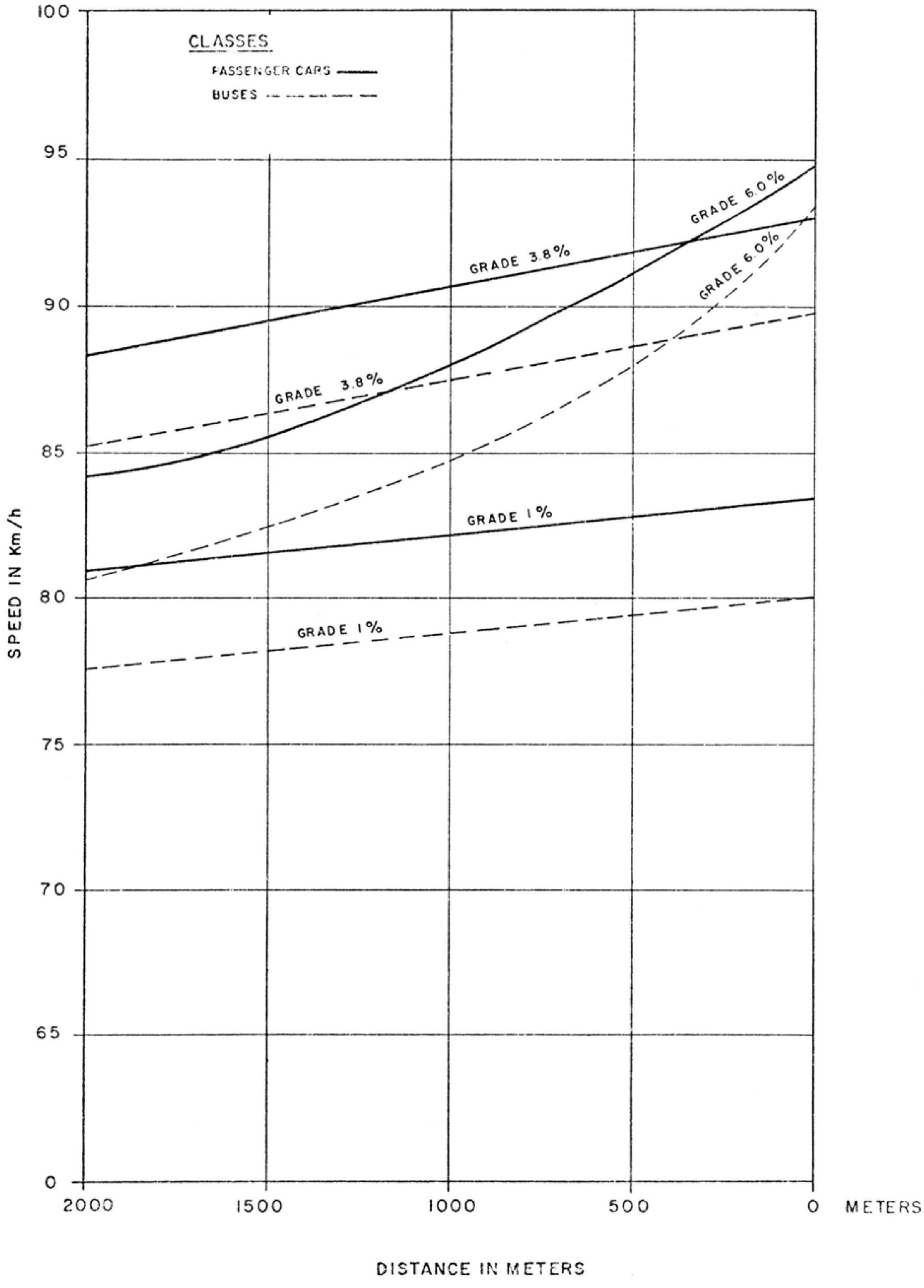

Figure 5 - Preliminary Relationships Between Speed and Distance on Negative Grades Between 1 and 6 Percent for Passenger Cars and Buses

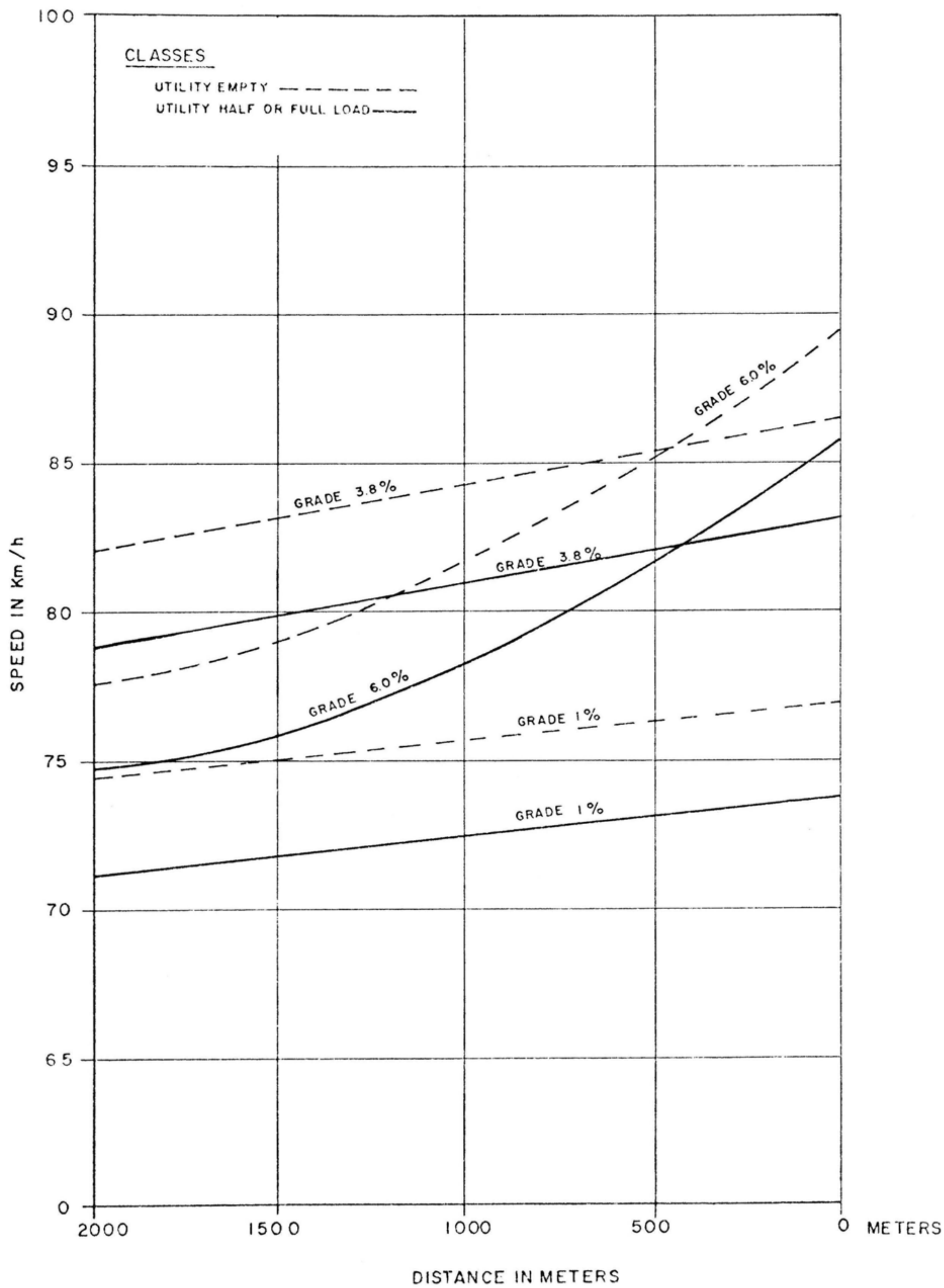

Figure 6 - Preliminary Relationships Between Speed and Distance on Negative Grades Between 1 and 6 Percent for Utility Vehicles

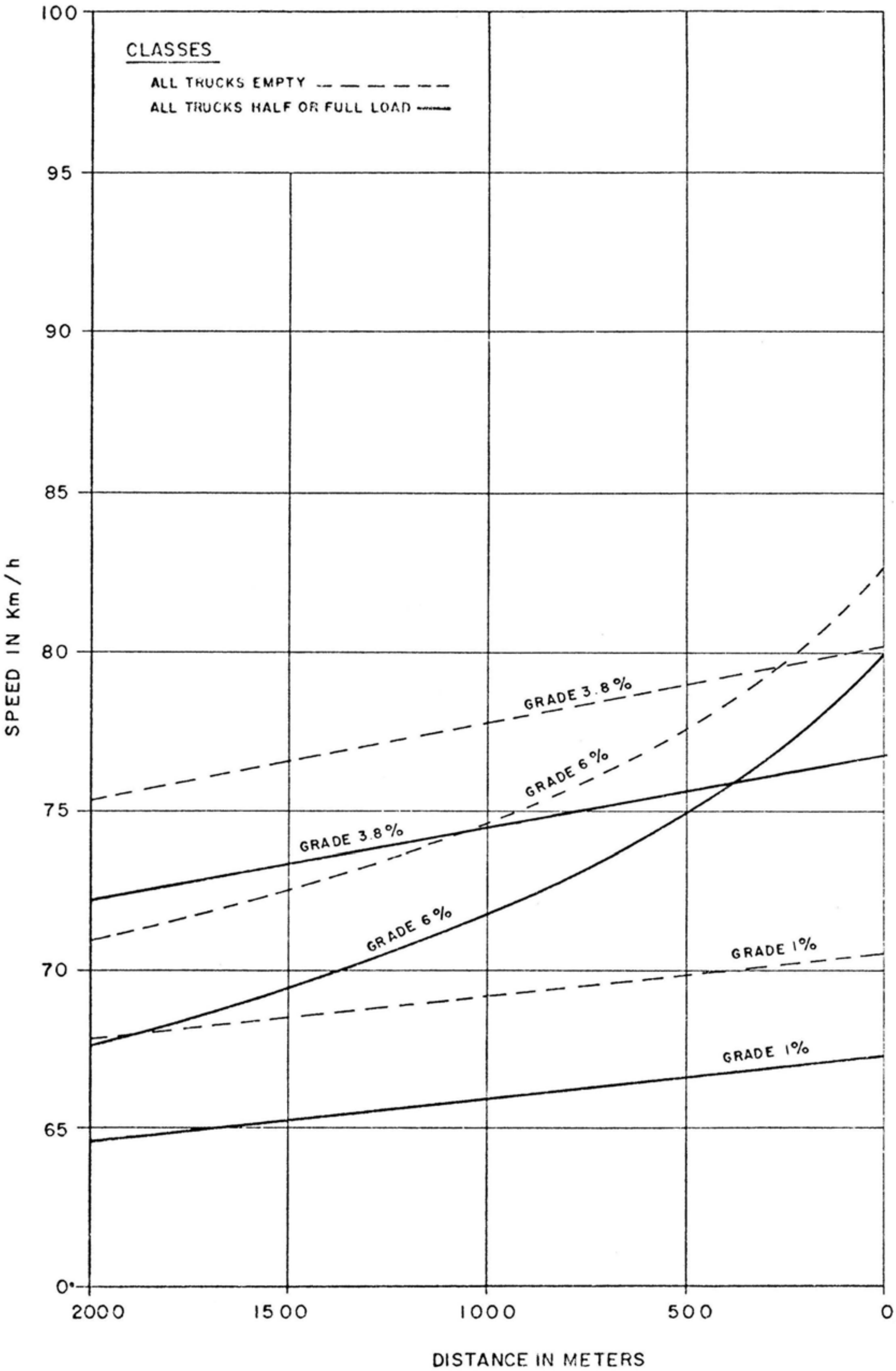

Figure 7 - Preliminary Relationships Between Speed and Distance on Negative Grades Between 1 and 6 Percent for Trucks

quired for modeling fuel consumption as a function of the roadway characteristics. Four main fuel-consumption experiments and five satellite have been defined as shown in Table 2 . One of these experiments has been completed and two are currently in progress.

Unlike the speed-measurement experiments, where the general vehicle population can be sampled for the development of relationships, fuel-consumption data must be taken from measurements made with a fleet of test vehicles. Thus the project purchased nine vehicles covering seven classes representing the types of vehicle produced in Brazil. As shown by Table 3 , the vehicles used for fuel-consumption measurements are a Volkswagen 1300, two Volkswagen Kombis, a Ford F400 (gasoline), a Ford F4000 (diesel), two Mercedes Benz L-1113/42's, a Mercedes Benz 0-362 bus, and a Scania 110/38.

Each of these vehicles has been fitted with a reservoir type fuel meter, a distance measuring instrument, and a split-second hand stopwatch.

Steady-State Fuel Consumption (FC-1)

The analysis of the steady-state fuel-consumption experiment is presented primarily to demonstrate the types of relationships which are being developed. The relationships presented are only preliminary since more data will be collected and more work is required to refine the analysis.

Fuel consumption is analyzed and discussed in units of mililiters per second. This form of the dependent variable will be used in the Time and Fuel Algorithm. In many cases, runs were made in more than one gear for a given situation. When this occurred the mean fuel consumption for all gears was analyzed.

Analysis Approach - It would be a difficult if not impossible task to develop one general equation for such a wide variety of conditions and for so many vehicles. Different equat-

TABLE 2 - ROAD USER COSTS AND TRAFFIC EXPERIMENTS

CATEGORY	NUMBER	TITLE	PURPOSE
FUEL CONSUMPTION MAIN EXPERIMENTS	FC-1	Steady-State Fuel Consumption	Collect data for vehicles operating at steady-state speed over tangent test sections on a variety of grades
	FC-2	Momentum	Determine the effect of momentum on fuel consumption. Important at the base of positive grades preceded by negative grades
	FC-3	Curvature	Test the effect of horizontal curvature on fuel consumption
	FC-4	Fuel Consumption Calibration	Collect independent data over long sections to verify and calibrate models developed from FC-1 to FC-3
FUEL CONSUMPTION SATELLITE STUDIES	FCS-1	Tuned vs. Untuned	Test the variability of fuel consumption due to engine condition
	FCS-2	Curvature	Similar to FC-3 but more complete coverage of curvature
	FCS-3	Sag Curves	Determine fuel consumption when sag curves are traversed
	FCS-4	Acceleration	Determine the effect of acceleration on fuel consumption when approaching a sag curve
	FCS-5	Big Cars	Determine the fuel consumption of an Opala and Dodge car at steady-state speed

TABLE 3 - TEST VEHICLE DESCRIPTION

VEHICLE	FUEL	BRAKE HORSE-POWER	TARE WGT. (KG)	GROSS WGT. (KG)	LOAD*		
					EMPTY	HALF FULL	FULL
Volkswagen 1300	Gasoline	48	780	1,160	0	130	280
Volkswagen Kombi	Gasoline	60	1,195	2,155	0	280	550
Ford F-400	Gasoline	169	2,277	6,000	150	1,730	3,510
Ford F-4000	Diesel	102	2,444	6,000	0	1,540	3,325
Mercedes Benz L - 1113/42	Diesel	147	6,395	18,500	1730	5,985	11,970
Scania 110/38 Articulated	Diesel	285	13,420	40,000	0	13,300	26,600
Mercedes Benz 0 - 362 Monobloco	Diesel	147	7,500	11,500	0	1,010	2,250

* The loads given do not include the weight of the driver and observer, which is approximately 140 kg.

ions were therefore developed for positive and negative grades and paved and unpaved roads. Four equations were developed for each vehicle, with the exceptions that the VW-1300 and the Kombis were analyzed together, and the MB 0-362 bus was not analyzed for negative grades. Thus, 18 separate regression equations were developed.

The nonlinear model that produced the lowest residual error and had the simplest form was:

$$\text{Fuel/sec} = A_0 + (A_1 + A_2 C + A_3 I)^{A_4 V} \quad (1)$$

where $A_0 - A_4$ = coefficients

C = dummy-vehicle class value (1=Volkswagen 2=Kombi)

I = interaction term which consists of a load factor, a class factor and a grade term.

V = true mean speed of the vehicle

The actual equations for the paved and unpaved situations are presented in Table 4 with the others equations.

The same procedures were used for the analysis of the bus and trucks on positive grades. It was found that although the fuel-consumption relationships for the Ford and Mercedes were similar, the relationship for the Scania was different, since it appeared more linear. For this reason two functions were tested. The nonlinear model (2) is applied to the Ford-400, the Mercedes Benz 1113, and the Mercedes Benz 0-362 bus. The linear model (3) is used for the Scania. The two functions are presented below:

$$\text{Fuel/sec} = (A_0 + A_1 L + \exp(A_2 G(1 + A_3 L)))^{A_4 V} \quad (2)$$

where A_0-A_4 = coefficients

L = dummy load value (0 = Empty, 1 = Full)

G = percent of the grade

V = true mean speed

TABLE 4 - FUEL CONSUMPTION REGRESSION EQUATIONS FOR POSITIVE GRADES

Volkswagen and Kombi Unpaved

$$F = -.53 + (1.1 + .189\ C + .0153(C + .4)(L + 1.7)\ G)^{.035\ V}$$

S = .05

Volkswagen and Kombi Paved

$$F = -.62 + (1.14 + .17\ C + .009(C + .4)(L + 2.5)\ G)^{.036\ V}$$

S = .05

Ford-400 Unpaved

$$F = .84 + (.554 + e^{(.066\ G(1+1.15\ L))})^{.05\ V}$$

S = 1.01

Ford-400 Paved

$$F = .8 + (.65 + .24\ L + e^{(.11\ G(1+1.27\ L))})^{.0344\ V}$$

S = .82

MB-1113 Unpaved

$$F = (\ .95 + .45\ L + e^{(.21\ G(1+1.96\ L))})^{.0343\ V}$$

S = .09

MB-1113 Paved

$$F = (1.52 + .627\ L + e^{(.32\ G(1+1.32\ L))})^{.0236\ V}$$

S = .16

MB-Bus Unpaved

$$F = (1.36 + .167\ L + e^{(.3\ G(1+.44\ L))})^{.0245\ V}$$

S = .32

MB-Bus Paved

$$F = (2.3 + .24\ L + e^{(.5\ G(1+.31\ L))})^{.015\ V}$$

S = .30

Scania Unpaved

$$F = 1.02 - .3\ L + .072(L+1)\ V + .03(L+1)^{1.45}\ G\ V$$

S = .30

Scania Paved

$$F = 1.35 - .403\ L + .054(L+1)^{1.32}\ V + .026(L+1)^{1.32}\ G\ V$$

S = .54

where C = Class, 1=Volkswagen, 2=Kombi
G = Grade in Percent
V = Velocity in Km per hour
L = Load factor, 0=Empty 1=Full
F = Fuel in ml per second
S = Standard error of the equation

$$\text{Fuel/sec} = A_0 + A_1 L + A_2 I \qquad (3)$$

where $A_0 - A_2$ = coefficients

L = dummy load value (0=EMPTY, 1=FULL)

I = interaction of load, speed, and grade factors

The equations for the paved and unpaved test sections are given in Table 4 .

The fuel-consumption regression equations for positive grades are presented in Figures 8 through 19.

For the Volkswagen and Kombis, the same main effects and interactions that were significant for the positive paved sections were also significant for the negative paved sections. The influences, however, are different in some cases. The most obvious difference is related to the effect of the load. For negative grades less than 2%, the empty vehicle consumes less than the laden vehicle, assuming all other effects are held constant. However, for both the Volkswagen and the Kombis, the influence of the load changes as the negative grade increases from 2 to 4%. For negative grades of more than 4%, the laden vehicle consumes less than the empty vehicle.

For negative unpaved sections, all load effects proved to be non-significant. For this reason, different models were used for the paved and unpaved equations for the Volkswagen and Kombis. The function for the paved case is much more complicated since it has to account for the load effects. Since there are many unique functions for the negative grades, the general forms are not presented for each case. Table 5 presents all equations in their final forms.

The load effect for the truck on negative grades was similar to that for the lighter vehicles. For flat sections, the laden vehicle consumed more than the empty vehicle. As the grade becomes steeper the load effect reverses.

A major difference in the effect of speed occurred for the

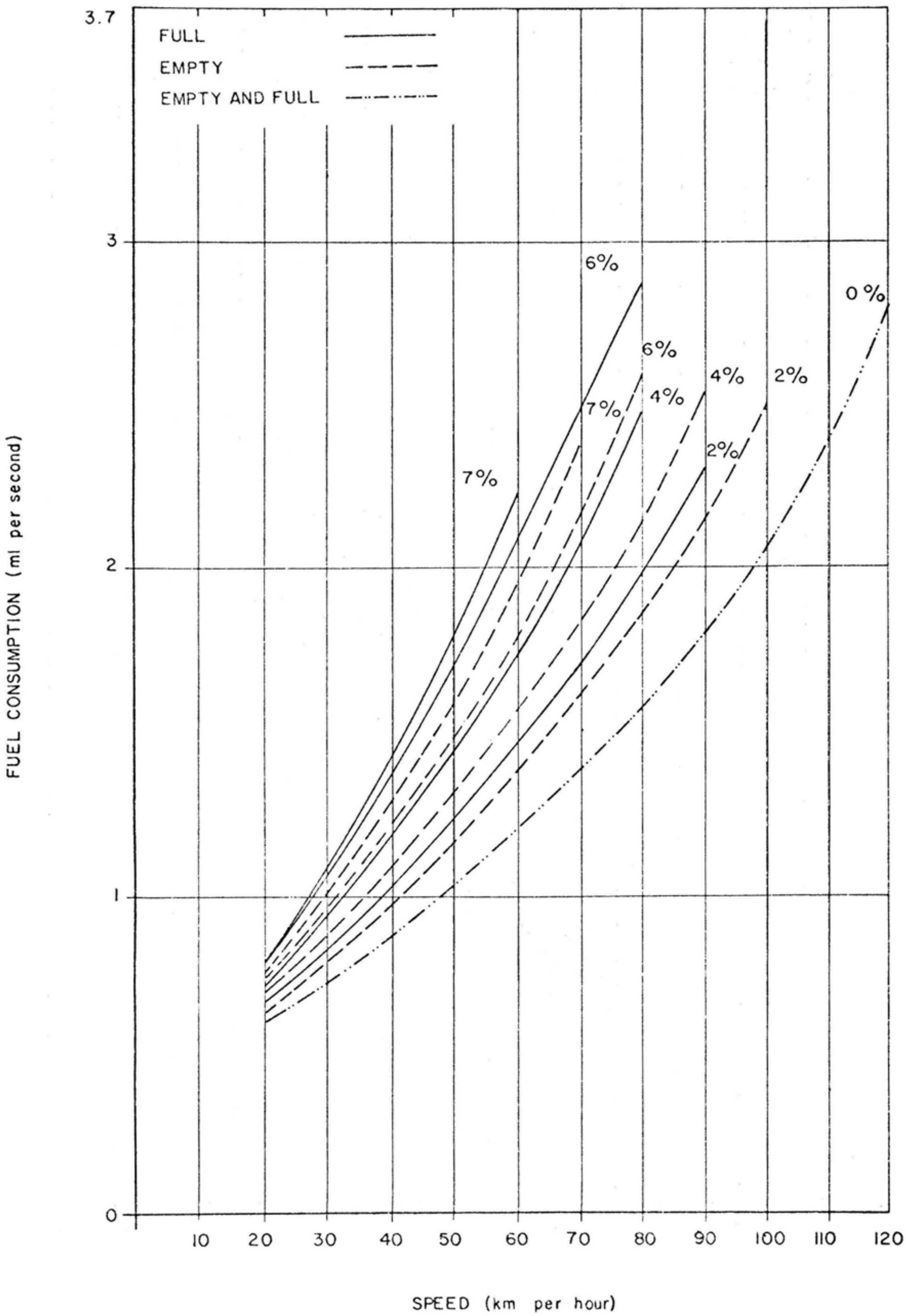

Figure 8 - Fuel Related to Speed for a Full and Empty Volkswagen 1300 Operating on Positive Paved Grades Between Zero and Seven Percent