Technical Support Report for Regulatory Action

Light Duty Truck Road Load Determination

by

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Abstract

When vehicle exhaust emission tests or vehicle fuel consumption measurements are performed on a chassis dynamometer, the dynamometer is usually adjusted to simulate the road experience of the vehicle. Specifically, if the dynamometer measurements are to accurately reflect on-road operation of the vehicle, the dynamometer must supply the appropriate load; that is, the force required to drive the vehicle on a level surface as a function of the vehicle speed. In this study, road load versus speed data were obtained from 15 light duty trucks. The road load of each truck was determined for different payloads, resulting in a total of approximately 50 road load measurements. The coast down technique, in which the forces acting on a freely decelerating vehicle are deduced from the speed-time history of the deceleration, was used for all track measurements.

When a vehicle is operated on a chassis dynamometer, the vehicle must overcome the dissipative losses of the drive train and tires before power is transmitted to the dynamometer. Therefore, to derive a dynamometer setting appropriate to simulate the road experience of a vehicle, these losses must be subtracted from the total system losses measured on the track. Measurements of the dissipative forces of the driving tires, the drive train, the non-driving tires, and the non-driving wheel bearings were performed on a 48 inch diameter single roll electric dynamometer.

The dynamometer load settings, resulting from the subtraction of the dissipative losses of the drive train and the driving tires from the total system measurements, are presented. These data are regressed first against vehicle frontal area and then against vehicle inertia weight category to develop equations to predict the dynamometer load settings.

It is concluded that the dynamometer load settings predicted on the basis of vehicle frontal area are the most accurate. In addition to greater accuracy, the frontal area based prediction system is more flexible in allowing possible refinements and improvements within the framework of the system. While it is recognized that a prediction system based on vehicle frontal areas is more complex to implement, this approach is recommended.

I. Purpose

The purpose of this study is to develop equations to predict the dynamometer adjustment forces appropriate to simulate the on road experiences of light duty trucks. To accomplish this, equations of road load versus speed were obtained from a diverse class of light duty trucks. These data were then converted to dynamometer adjustment forces appropriate to simulate the on road experience of a vehicle.

II. Introduction

When vehicle exhaust emission tests or vehicle fuel consumption measurements are performed on a chassis dynamometer, the dynamometer is usually adjusted to simulate the road experience of the vehicle. Specifically the dynamometer must simulate the road load of the vehicle. In this report the vehicle road load is defined as the component of force in the direction of vehicle motion which is exerted by the road on the vehicle driving wheels. As defined, the road load force is the force which propells the vehicle. In the standard case, when a vehicle is moving with a constant velocity vector on a level surface, this force is equal in magnitude to the sum of the rolling resistance and the aerodynamic drag of the vehicle. Unfortunately, neither this road-tire force, nor the equal magnitude tire-road force can be directly measured because of the virtual impossibility of instrumenting the tire-road interface. Consequently, all experimental methods involve indirect measurements and some corrective process.

Commonly used methods for road-load determination are: the deceleration or coast down technique, drive line force or torque measurements, and manifold pressure measurements. The coast down method was selected as the approach best suited for this study since a method easily adaptable to a diverse class of vehicles was required. The concept of the coast down technqiue is to determine the rate of deceleration of a freely coasting vehicle; then, knowing the mass of the vehicle, the road-load force may be calculated by Newton's second law, $f = ma$. Previous experi-- mental work at the EPA has demonstrated similar results are obtained with the coast down technique and with drive shaft torque meters.

Fifteen diverse light duty trucks were chosen as the experimental sample. These trucks were chosen to approximately represent the sales weighting of light duty trucks. Each of the 15 trucks was tested with varying payloads, such that the vehicle test weights ranged from the empty vehicle weight to the GVW. This resulted in a total of approximately 50 track tests.

The track measurements include the dissipative losses of the vehicle tires, wheel bearings and drive train. To determine a road value appropriate for adjusting a chassis dynamometer, the dissipative losses from the drive train and driving tires must be subtracted from the total system measurements. These dissipative losses were measured using a 48" diameter roll electric dynamometer.

III. Discussion

This section discusses the specific physical measurements which must be performed to yield the dynamometer adjustment information. This section is included since some of the desired parameters must be determined indirectly; consequently the reason for some of the measurements may not be apparent.

The discussion is presented in three subsections. The system energy section discusses the general aspects of the problem and introduces the concept of equivalent effective mass. The track measurements determine the acceleration of the vehicle. The mass measurements provide the remaining information necessary to calculate the total road load of the vehicle system.

A. System Energy

The introduction states that the vehicle mass and the vehicle deceleration under freely rolling conditions are the general parameters which must be obtained to determine road-load with the coast down technique. This section will discuss in detail what measurements must be performed to obtain these data.

The total energy of the decelerating vehicle system is the sum of the translational kinetic energy of the vehicle and the rotational kinetic energy of any vehicle components in rotational motion. For all mechanical components of the wheels and drive train, the rotational velocity is proportional to the vehicle velocity; therefore, the energy of the system may be written as:

$$E = 1/2\ mv^2 + 1/2\ (\sum_i I_i \alpha_i^2) v^2 \qquad (1)$$

Where:

E = the total system energy
m = the vehicle mass
v = the vehicle speed
I_i = rotational inertia of the i^{th} rotating component
α_i = the proportionality constant between the rotational velocity of the i^{th} rotating component and the vehicle speed

Differentiating equation (1) with respect to time, and comparing the resulting expression for power with the similar time derivative of a purely translational system, the generalized force on the system may be expressed as:

$$F = (m + \sum_i I_i \alpha_i^2) A \tag{2}$$

Where:

F = the generalized system force
A = the translational acceleration of the system

Defining M as the "total effective mass of the system", where:

$$M = m + \sum_i I_i \alpha_i^2 \tag{3}$$

Equation (2) now has the familiar form

$$F = MA \tag{4}$$

The $\sum I_i \alpha_i^2$ term is identified as the "equivalent effective mass" of the rotating components and may be designated by:

$$m_{eq} = \sum I_i \alpha_i^2 \tag{5}$$

The equivalent effective mass, defined by equations (3) and (5), is simply one approach to include the effect of the rotational kinetic energy of the system. Equations (2) through (4) indicate that the acceleration of the system, the vehicle mass and the equivalent mass of the rotating components are the parameters which must be measured to determine the road load force.

B. Acceleration

Experimentally, it is not practical to measure the vehicle acceleration directly; however, the acceleration may be determined from the vehicle speed. The vehicle acceleration can be calculated by numerically differentiating the velocity versus time data. This is theoretically undesirable for two reasons. The non-analytical differentiation process is inherently noise sensitive and this can be a problem when attempting a least squares fit to the differentiated data. Also, since the acceleration must be derived from the velocity, the initially random errors in the velocity versus time data may not yield normally distributed errors in the acceleration versus velocity. A better approach is to assume a model for the acceleration versus speed equation and then perform analytical operations on this equation to convert it to the form of a speed versus time function. This expression may then be directly fitted to the velocity versus time data to obtain dv/dt as a function of vehicle velocity. The latter approach was chosen. The exact method used is an extension of the approach used by Korst and White[1] and is discussed in detail in reference[2].

C. Mass

The required masses are the gravitational mass and the equivalent effective mass of the rotating components. Equation (5) indicates that the rotational inertia is the primary measurement necessary to determine the equivalent effective msss of the rotating components.

1) Gravitational Mass

The gravitational mass of the system may be easily measured by a vehicle scale.

2) Effective Equivalent Mass of the Drive Wheels and Drive Train

The effective equivalent mass of the drive wheels and drive train was calculated using a coast down method to determine the drive wheel and drive train inertia. This technique was chosen because it gives a measure of rotational inertia of all drive train components. The rotational inertia of the system is given by the familiar equation:

$$\tau = I \frac{d\omega}{dt} \qquad (6)$$

where:

I = the rotational inertia
τ = the torque necessary to motor the system
ω = the angular velocity of the system

Assuming that the torque is a function of velocity, the variables of equation (6) may be separated and the integrals formed:

$$\int_{t_2}^{t_1} dt = I \int_{\omega_2}^{\omega_1} \frac{d\omega}{\tau} \qquad (7)$$

where:

ω_1 = the initial angular velocity
ω_2 = the final angular velocity
t_1 = the initial time
t_2 = the final time

Integrating the left hand side and solving for I yields:

$$I = \frac{(t_1 - t_2)}{\int_{\omega_2}^{\omega_1} \frac{d\omega}{\tau}} \qquad (8)$$

Equation (8) gives the inertia as a function of the torque required to motor the tire and wheel. However the effective equivalent mass is actually the desired quantity. Substituting the definition of effective equivalent mass and

$$\tau = FR$$
$$\omega = v/R \qquad (9)$$

where

R = the rolling radius of the tire
F = the force at the tire roll interface
v = the simulated translational velocity of the vehicle

into equation (8) yields:

$$m_{Req}R^2 = \frac{(t_1 - t_2)}{\int_{v_2}^{v_1} \frac{d(V/R)}{FR}}$$

(10)

$$m_{Req} = \frac{\Delta t}{\int_{v_2}^{v_1} \frac{dv}{F}}$$

where

m_{Req} = the effective equivalent mass of the drive train and driving tires
Δt is the time interval
R = the tire rolling radius
F = the force at the tire roll interface
v_1 = the initial simulated vehicle speed
v_2 = the final simulated vehicle speed

It should be noted that both F and Δt of equations (10) are negative since the drive train is decelerating. Equations (10) indicate that the dissipative forces of the drive train and the time required for the drive train to coast over a known speed range are the parameters necessary to calculate the drive wheel and drive train effective equivalent mass.

3) Equivalent Effective Mass of the Vehicle Non Driving Wheels

The technique of motoring, followed by coast down, was not used for the non-driving wheel effective mass determination because of the very low forces required to motor the front wheels. The equivalent effective masses of the front wheels were determined by the three wire torsional pendulum technique. With this method, the object is suspended by three wires, or placed on a platform suspended by three wires. The platform is rotated through a small angle, released and the period of oscillations timed. The tension in the supporting cables, induced by the mass of the object, causes a restoring torque on the oscillating system, the inertia of the object controls the acceleration of the system and, hence, the period of the oscillation. The rotational inertia of the pendulum system is to a good approximation, given by:[3]

$$I = \frac{g\ell^2}{4\pi^2 L} m_p t_p^2 \qquad (11)$$

where

g = the graviational constant, 9.80 m/sec^2

ℓ = the length from the center of the pendulum to the point of attachment of the supporting wires

L = the length of the supporting wires

m_p = the total mass of the pendulum and any object on the pendulum

t_p = the time period of one oscillation of the system

Equation (11) indicates that the mass of the pendulum plus tire and the period of oscillation of the system are the parameters required to determine the rotational inertia of the front wheels by this method. The effective equivalent mass can then be easily obtained from equation (5) and the rolling radius of the tire.

IV. Data Collection

This section discusses the test vehicles, the instrumentation used to collect the data and the test facilities.

The test vehicles were 15 light duty trucks, 10 pick-up style trucks and 5 vans. These vehicles were selected on a sales weighted basis, and ranged in size from approximately 4000 lbs GVW to 8000 lbs GVW. The vehicles were procured either by renting or by requesting participation from the automotive manufacturers; 87% were obtained from manufacturers and the remaining 13% were rented. Each vehicle was tested with various payloads so that the test weights ranged from the empty vehicle weight to approximately the GVW. Table 1 of Appendix A identifies each vehicle; gives the estimated EPA inertial weight category and the vehicle frontal area. The EPA inertia weight categories were estimated since many of these vehicles are not currently certified in a light duty class. The inertia weight category was estimated by adding 100 to 150 pounds to the test weight of the empty vehicle plus driver. Since the test driver weighed from 150 to 200 pounds this is equivalent to adding 300 pounds to the empty vehicle weight. The resulting weights were factored into inertia weight categories in increments of 500 pounds in the usual EPA manner. That is for example, all vehicles with weights between 3,250 and 3,750 pounds were assigned the inertia weight category of 3500 pounds.

The vehicle frontal areas were obtained from the manufacturers whenever this information was available. For those vehicles where the frontal area was not available from the manufacturer, the frontal area was determined by polar planimeter measurements of photographs.

A. The Track Measurements

The speed versus time data are the only measurements that are required on the test rack. Ambient conditions were, however also monitored to allow correction to a set of standard ambient conditions.

1) Test Facility and Test Procedure

All vehicle speed versus time data were collected on the skid pad of the Transportation Research Center of Ohio, in East Liberty, Ohio. This facility is a multilane, concrete, straight track with large turn around loops at each end. Approximately 1 kilometer of this straight track has a constant grade of 0.5% and this section was used for all measurements.

Prior to the coast down measurements, the vehicle tires were adjusted, when cold, to the manufacturers recommended pressures. The cold tire pressures were recorded, as were the tire pressures immediately after the coast down tests. After adjustment of the tire pressures, the vehicles were warmed up for approximately 30 minutes at about 50 mph.

Twenty coast downs were recorded for each vehicle at each test weight; ten in each direction of travel on the test track. Ten coast downs were conducted by accelerating the vehicle to approximately 65 mph, then shifting into neutral and recording speed versus time as the vehicle freely decelerated. The remaining ten coast downs were conducted in the same manner; however, the initial speed was approximately 40 mph. The two series of coast downs were necessary because the 1 km of section of track with constant grade was insufficient to coast most vehicles from 60 mph to a terminal speed near ten mph.

2) Velocity Instrumentation

The vehicle speed was measured by a police type Doppler radar. The instrumentation contained a noise discriminator system which rejected the Doppler pulse count any time the period between pulses differed significantly from the previous pulse separation.

Modifications were made to the standard configuration to increase the range. The length of the antenna horn was increased and aluminum corner reflectors, or strips of aluminum foil, were placed inside the target vehicle windows. These modifications increased the range from about 0.5 km to approximately 1.0 km. The Doppler frequency counter gate time was also increased from approximately 30 msec to 300 msec in an attempt to improve the system precision. This modification did increase the speed resolution; however, it also increased the total period the discriminator evaluated the Doppler signal for extraneous noise. The system noise is basically random; therefore, the probability the discriminator will reject a measurement of the Doppler frequency is linear with the counter gate time. The increase in the precision of each measurement was accompanied by a decrease in the number of speed versus time points measured during the coast down. Also, the range was greatly reduced since the probability of radar signal noise increased as the distance from the transmitter to the target increased. This modification was subsequently rejected and the final configuration of the system provided a range of about 1 km with a resolution of ± 1 mph.

A count of the Doppler frequency was recorded each second during the coast downs on a seven track magnetic digital tape recorder. This recorder and the support electronics were placed in a small van, parked on the track berm. Electric power was provided by an alternator, battery bank, and inverter on this van. An example of the speed versus time record of a light duty truck coast down is given in Figure 1.

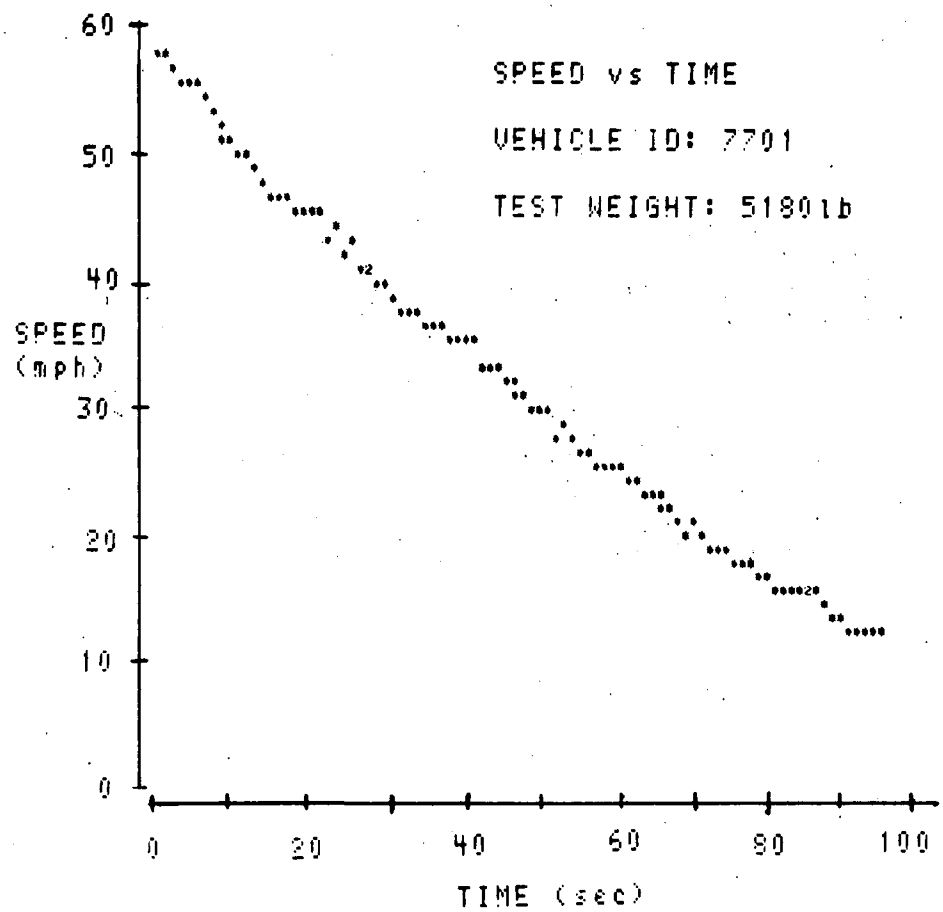

Figure 1

3) Ambient Conditions

Coastdowns were conducted only when steady winds were less than 15 km/hr (9.3 mph) with peak wind speeds less than 20 km/hr (12.4 mph). Wind speed during the test period was measured with a photochopper type six-cup anemometer. The anemometer was located near one side of the test track, at one end of the 1 km test section. These data were recorded at one second intervals on the same magnetic tape as was used to record the vehicle speed. During test periods the ambient temperature was in the range of 5°C (41°F) to 35°C (95°F). The barometric pressure was between 102 kPa (30.2 in Hg) and 94 kPa (27.9 in Hg). The air moisture content ranged from 0.29 to 0.73 gm H_2O/gm dry air. These slowly varying ambient parameters were recorded, by an observer, on a data sheet associated with each vehicle.

B. The Dynamometer Measurements

The dynamometer measurements are conceptually simple since the desired information is force data, and the dynamometer could be used to measure forces directly. The dynamometer used was one of the EPA light duty vehicle electric dynamometers. This dynamometer is a G.E. motor-generator type with a 48" diameter single roll. During these experiments the normal 0-1000 lb. load cell of the dynamometer was replaced with a more sensitive 0-300 lb load cell.

Prior to all measurements the cold tire pressures were adjusted to the manufacturers recommended pressures. Again, the cold pre-test pressures and the hot post-test pressures were recorded. The vehicle weight was adjusted to approximate the vehicle weight during the corresponding track measurement. The dynamometer force measurements were conducted on both the front and rear axles of the vehicle. During the rear axle measurements the transmission was shifted into neutral, as it was during the track coastdowns.

The vehicle was placed on the dynamometer, and then the vehicle and dynamometer were warmed up for 30 minutes at approximately 50 mph. After warm up, the torque necessary to motor the dynamometer and vehicle was measured at speeds from 60 to 10 mph in 5 mph decreasing speed intervals. For each measurement steady state dynamometer speed and torque signals were recorded on a strip chart for a period of approximately 100 seconds. The stabilized values were then read from the strip chart by the dynamometer operator.

After the measurements were completed with the full vehicle weight resting on the dynamometer rolls, the vehicle was then lifted until the vehicle tires were just contacting the dynamometer roll. The vehicle tires were considered to be just touching the dynamometer roll if a person could, with difficulty, manually cause the tire to slip on the roll when the roll was locked. With this test configuration the torque versus speed measurements were repeated as before. Finally, the torque required to motor only the dynamometer was recorded in the same manner.

The dynamometer speed data were converted to the units of m/sec. All torque data were converted to force in newtons at the roll tire interface. A scatter plot of the data from one truck, after conversion to force at the tire-roll interface and subtraction of the force necessary to motor the dynamometer, is given as an example in Figure 2. In addition, the difference between the force measurement when the full weight of the vehicle was on the dynamometer and the force measurement when the tire was just contacting the dyno roll, is also given in Figure 2.

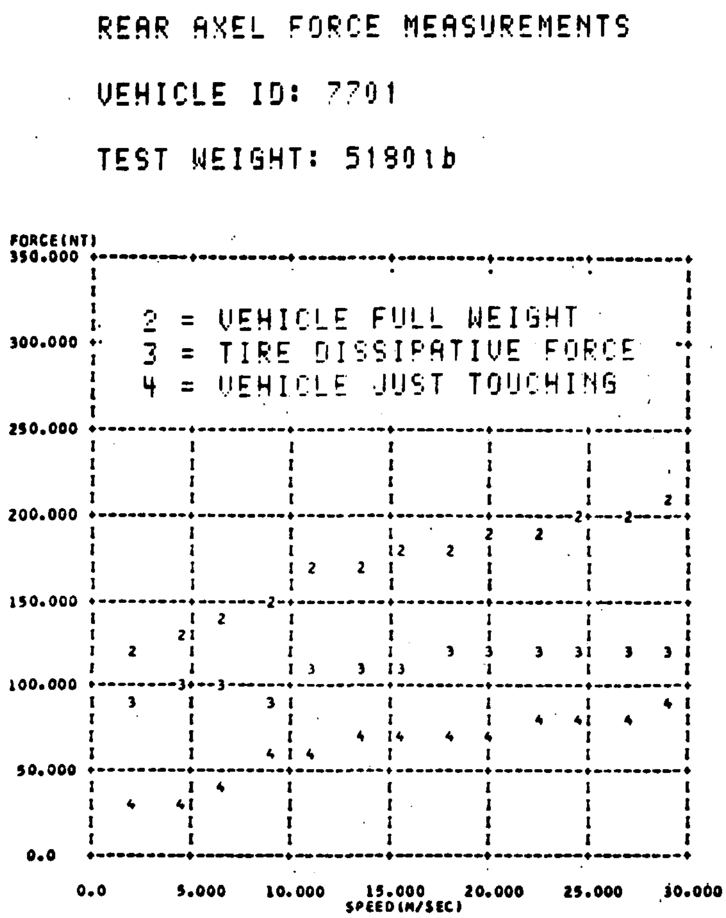

Figure 2 (a)

FRONT AXEL FORCE MEASUREMENTS

VEHICLE ID: 7701

TEST WEIGHT: 5180lb

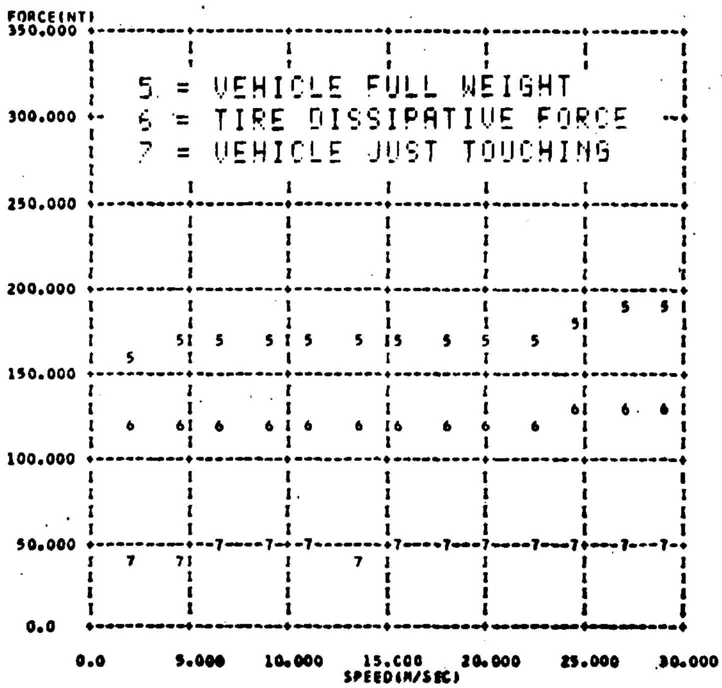

Figure 2(b)

C. Masses

1) The Gravitational Masses

The gravitational mass was measured by weighing each vehicle, with the driver, immediately after the coast downs. The vehicle scale of the TRC was used for all vehicle mass determinations. TRC personnel indicated calibration checks on this scale have repeatedly been within ± 10 pounds in the 0 to 10,000 pound range.

2) Equivalent Effective Mass of the Drive Wheels and Drive Train

In order to calculate the equivalent effective mass of the drive wheels, differential gears, drive shaft and transmission output shaft gears, the dissipative forces of the drive train and the time required for the drive train to coast through a speed interval must be known. The drive train dissipative forces are obtained in the dynamometer measurements, therefore only the method of measuring the coast down time intervals is discussed.

Immediately after the dynamometer force measurements of the rear axle, several white stripes were chalked on each vehicle driving tire. The vehicle tire speed could then be monitored by observing these chalk stripes with a stroboscopic tachometer. The appropriate frequencies corresponding to 60 mph and 10 mph were determined by observing the tachometer when motoring each vehicle with the dynamometer at these speeds. The vehicle, drive train with the transmission in neutral, was motored to approximately 65 mph by the dynamometer. The vehicle was lifted from the dynamometer and the time interval required for the vehicle to decelerate from 60 mph to 10 mph was timed using a stop watch. The initial and final speed points were determined by observing the frequency output of the strobocopic tachometer. Five time intervals were recorded for each drive wheel.

3) Front Wheel Effective Mass

The vehicle front wheels the rotational inertia was measured using a three wire torsional pendulum. This pendulum was constructed from a triangular shaped plywood platform suspended from three 1/8 inch stranded steel cables. The physical parameters of the platform were:

the distance from the axes of rotation to the suspension point = 0.532 m

the length of the suspension wires = 4.79 m

the mass of the platform, including hardware was 2.74 kg.

For the determination of the rotational inertia a vehicle tire and wheel, usually the spare, was placed on the platform. The platform was rotated approximately 0.5 radians and released. The time required for 10 oscillations was then timed with a stop watch. This measurement was repeated 4 times and then averaged.

The mass of each tire was then measured by weighting on a platform scale. This scale was a "shipping clerks" scale with a maximum capacity of 1000 lb, and a resolution of $\pm$ 0.5 lb.

V. Data Analysis

A. Track Data

The usual form of a vehicle deceleration curve is assumed to be a constant plus a term proportional to the velocity squared. However the effect of a steady head-tail wind will appear as a linear-term. Also, the drive train losses were expected to be approximately linear in velocity and some published tire data[4] have indicated the inclusion of a linear term may be theoretically desirable. For these reasons, a model equation was chosen of the form:

$$dv/dt = a_0 + a_1 v + a_2 v^2 \tag{12}$$

Terms were added to equation (12) to account for any effects of wind and track grade. The variables of the resulting equation can be separated and integrated to yield an expression for time as a function of velocity. Since these functions are inverse trigonometric or hyperbolic functions, their inverse may be taken to yield velocity as a function of time. These functions were fitted to the coast down data by the method of least squares to determine the a_0, a_1, and a_2 of equation (9). The mathematics of this technique is discussed in detail in Reference 2 and in the EPA Recommended Practice for Road Load Determination.

Since the a_2 coefficient multiplies the v^2 it was assumed to represent the aerodynamic drag of the vehicle. The aerodynamic drag is proportional to the air density; therefore all a_2 coefficients were corrected for differences between the ambient conditions during the test, and a set of standard ambient conditions chosen to be:

temperature	20°C (68°F)
barometric pressure	98 kPa (29.02 in Hg)
humidity	10 gm H_2O/kg dry air (70 gr H_2O dry air)

The corrected acceleration coefficients for all vehicle tests are presented in table 1 of Appendix B. The vehicle tire pressures for the track measurements are give in table 2 of Appendix B.

B. Dynamometer Data

The dynamometer measurements determine the dissipative losses of the driving tires and the drive train, and supply the necessary data to determine the rotational inertia of the rear wheels and drive train. The dynamometer measurements are conceptually simple since the dynamometer used, a 48" roll GE electric chassis dynamometer, measures the forces directly. The only arithmetic necessary is to convert from the force values at the dynamometer load cell to the force at the tire-roll interface. This conversion is simply the ratio of the length of the moment arms. In addition a conversion to MKS units of force was made at this time.

The data for the tire dissipative losses, the wheel bearing losses, and the drive train dissipative losses were all scatterplotted versus speed. These plots indicate the wheel bearing and drive train losses are linear with speed, while the tire losses are approximately constant with speed. Consequently a linear least squares regression was fitted to each data set of the drive train and rear tire losses, the rear tire losses, the drive train losses and the front tire losses. The coefficients from these regression analyses are given in Tables 1 through 4 respectively of Appendix C.

The vehicle tire pressures for the dynamometer measurements are given in Table 5 of Appendix C.

C. The total Effective Equivalent Mass of the Vehicle

The total effective equivalent mass of the vehicle is the sum of the gravitational mass of the vehicle and the effective equivalent mass of the drive tires, drive train and the non driving wheels.

1) The Gravitational Mass

The gravitational mass was determined by the vehicle scale at the TRC. These data are presented in Table 1 of Appendix D.

2) The Drive Train Effective Equivalent Mass

The equivalent effective mass of the vehicle drive train and drive tire was determined from the drive train coast down measurements. Equation (11):

$$m_{Req} = \frac{\Delta\tau}{\int_{v_2}^{v_1} \frac{dv}{F}} \qquad (13)$$

was directly evaluated by numerical integration. Since F was measured at equally spaced speeds, and known to be quite nearly linear, the simple equally spaced trapezoidal integration algorithm was used. The results of this integration, the effective equivalent mass of the drive train is given in Table 1 of Appendix D.

3) The Front Wheel Effective Equivalent Mass

The inertia of the pendulum with the front tire-wheel combination was calculated from equation (12) using the measured period of oscillation and the tire plus pendulum masses. The inertia of the tire wheel combination was then determined by subtracting the inertia of the pendulum from the total system inertia. The pendulum inertia was determined both theoretically and experimentally and these results were in agreement with 3%.

The effective equivalent mass of the front wheels was then calculated by equation (5), that is:

$$m_{feq} = 2I/R^2 \qquad (14)$$

where

m_{feq} = the effective equivalent mass of both front wheels

I = the rotational inertia of a single wheel-tire

The rolling radii of the tires were determined by measuring the height of the loaded tire, from the contact patch to the top of the tread and dividing by two. Previous experiments at the EPA have shown this technique is a very good simple static measurement of the dynamic rolling radius. Five to ten tires of each tire size were measured and the average rolling radius used for all tires of that size. These average rolling radii are given in Figure 3.

Rolling Radii versus Tire Size

Nominal Tire Size	Average Rolling Radii
14 inches	0.31 m
15 inches	0.34 m
16 inches	0.37 m
16.5 inches	0.35 m

Figure 3

The use of a standard rolling radius for each nominal tire size introduces some error, but this is slight compared to the total vehicle mass and it simplifies the calculation by reducing the number of measured parameters which need to be maintained. The use of the spare tire on the torsional pendulum also neglects the rotational inertia of the brake disk or drum. Several preliminary measurements which included brake disks and drums indicated the effective equivalent mass of the brake is only 10% of the effective equivalent mass of the wheel-tire combination. Since a single wheel-tire combination has typical equivalent mass of 15 kg, neglecting the 10% effect of the brake introduces a probable error of only 3kg in the total vehicle mass. This is less than the probable error in the measurement of the vehicle gravitational mass or the probable error in the determination of the equivalent effective mass of the drive train and rear tire.

The equivalent effective masses of the vehicle non-driving wheels are presented in Table 1 of Appendix D with the other mass terms. Also included in Table 1 is total equivalent effective mass of the vehicle system, the sum of the gravitational mass and the effective equivalent masses of the driving and nondriving wheels.

VI. Results

The total vehicle road load is given by equation (4) as the product of the acceleration and the total system effective mass. The coefficients of this force were calculated and are presented in Table 1 of Appendix E. Also presented in Table 1 of Appendix E is the total road load force and power at 50 mph.

The total vehicle road load force is the sum of the tire rolling resistances; the dissipative losses of the drive train, wheel bearings, and brake drag; and the aerodynamic drag of the vehicle.

$$F_{TOT} = f_{tire} + f_{mech} + f_{aero} \tag{15}$$

where

F_{TOT} = the total vehicle road load force

f_{tire} = the sum of the tire rolling resistances

f_{mech} = the mechanical dissipative losses

f_{aero} = the aerodynamic drag

The total vehicle road load force includes the dissipation in the drive train from the rear wheel up to the point where the drive train is decoupled from the engine. When the vehicle is being tested on a dynamometer, the vehicle engine is required to overcome the drive train and driving tire losses prior to supplying power to the dynamometer. Consequently these losses should not be included in the dynamometer adjustment force. The drive train losses are independent of the choice of a dynamometer, however, the tire rolling resistance will depend on the type of dynamometer. Therefore, to develop the appropriate dynamometer adjustment force, tire losses for that particular dynamometer must be subtracted from the total road measurements, in addition to the drive train losses.

A. Force Coefficients for Road Simulation on a Small Twin Roll Dynamometer

In order to calculate a force appropriate for adjusting a small twin roll dynamometer two assumptions must be made about tire power dissipation on a small twin roll dynamometer.

Assumption 1: Two on the rolls equals four on the road"

It is commonly stated that two tires dissipate as much energy on a small twin roll dynamometer as four tires dissipate on a flat surface. However, measurements on sufficiently large tire sample to prove or disprove this concept have not yet been reported in the literature.

There is some theoretical basis for this statement[5], and one study[6] has reported the power consumption of a bias ply tire on a small twin roll dynamometer to be very nearly twice the power consumption of the same tire, at the same inflation pressure, on a flat road. This same study, however, reported the power consumption of a radial tire on a small twin roll dynamometer to be significantly greater than the power consumption of the same tire or a flat road surface. The problem is further complicated since most discussions have been directed toward light duty vehicle tires. The truck tire is frequently constructed with a greater number of carcase plies and it is typically operated at higher inflation pressures. Truck tires, at the present time, are predominantly bias ply construction.

Assumption 2: Power dissipation on a large single roll is proportional to road power dissipation.

The assumption that tire power dissipation on a large single roll dynamometer is greater than, but proportional to, the power dissipation a flat surface is much better documented. The relationship between tire losses on a large single roll and a flat surface, when determined by torque or power consumption measurements, has been shown theoretically[7] to be given by:

$$F_R = F_D / \sqrt{1 + \frac{r}{R}} \qquad (16)$$

where

F_R = the rolling resistance of the tire on a flat road surface
F_D = the rolling resistance of the tire on a cylindrical dynamometer surface
r = the rolling radius of the tire
R = the radius of the dynamometer roll

The theoretical treatise used to develop equation (16) has also been used to predict the relationship between tire rolling resistances on a large single roll and on a flat surface when the measurements are obtained directly from spindle force transducers. This relationship has been experimentally tested[8] and appears reasonably valid.

To calculate a dynamometer power absorber setting for a twin roll dynamometer, the above two assumptions were used. The rolling radii given in Figure 3 were inserted into equation (16). The correction factor, $\sqrt{1+r/R}$ ranged from .814 to .789. Since this value was very nearly constant the value 0.8 was used to convert the rolling resistance measurements for all front and rear tires to estimates of the tire rolling resistance on a flat road.

To obtain the force coefficients appropriate for adjusting a small twin roll dynamometer the estimate of the flat surface tire rolling resistances for both front and rear tires were subtracted from the total road forces as required by assumption 1. In addition, the drive train losses were also subtracted. The resulting coefficients are given in Table 2 of Appendix E as are the force and horsepower at 50 mph.

A significant purpose of this study is to develop equations to predict the appropriate dynamometer power absorber setting as a function of some easily measured vehicle parameter. The ability to predict the small twin roll dynamometer power absorber setting as a function of vehicle frontal area, test mass and the EPA inertia weight category will be discussed in the following sections.

1) Frontal Area as a predictor of dynamometer power absorber setting.

The assumptions regarding tire rolling resistance on a small twin roll dynamometer, and the resulting corrections to the total road load force, remove all tire dissipation from the small twin roll dynamometer adjustment force. In addition, the drive train losses are subtracted, therefore equation (15) shows only a portion of the mechanical losses; the non-driving wheel bearing losses, and the non-driving wheel brake drag remain in addition to the aerodynamic drag. These remaining mechanical losses are probably weakly dependent on the vehicle mass since the vehicle bearing and brake size depend on vehicle mass. However, the random nature of these forces, especially the brake drag, will predominate over any systematic effects for a sample size of 15 vehicles. Consequently the remaining mechanical losses can be expected to appear as random "noise" superimposed on the primary force of the aerodynamic drag.

Since the aerodynamic forces predominate in the small twin roll dynamometer adjustment, an aerodynamic model is the logical choice for predicting this dynamometer adjustment force. The aerodynamic drag of the vehicle is theoretically given by:

$$F_{aero} = \frac{1}{2} \rho C_D A v^2 \qquad (17)$$

where

F_{aero} = the aerodynamic drag force
ρ = the air density
C_D = the drag coefficient of the vehicle
v = the vehicle velocity

If the drag coefficients of the vehicles are approximately constant, then the drag force, and hence the power should be linear in frontal area. In Figure 4, the plot of twin roll dynamometer adjustment power versus frontal area, the vehicles with frontal areas below

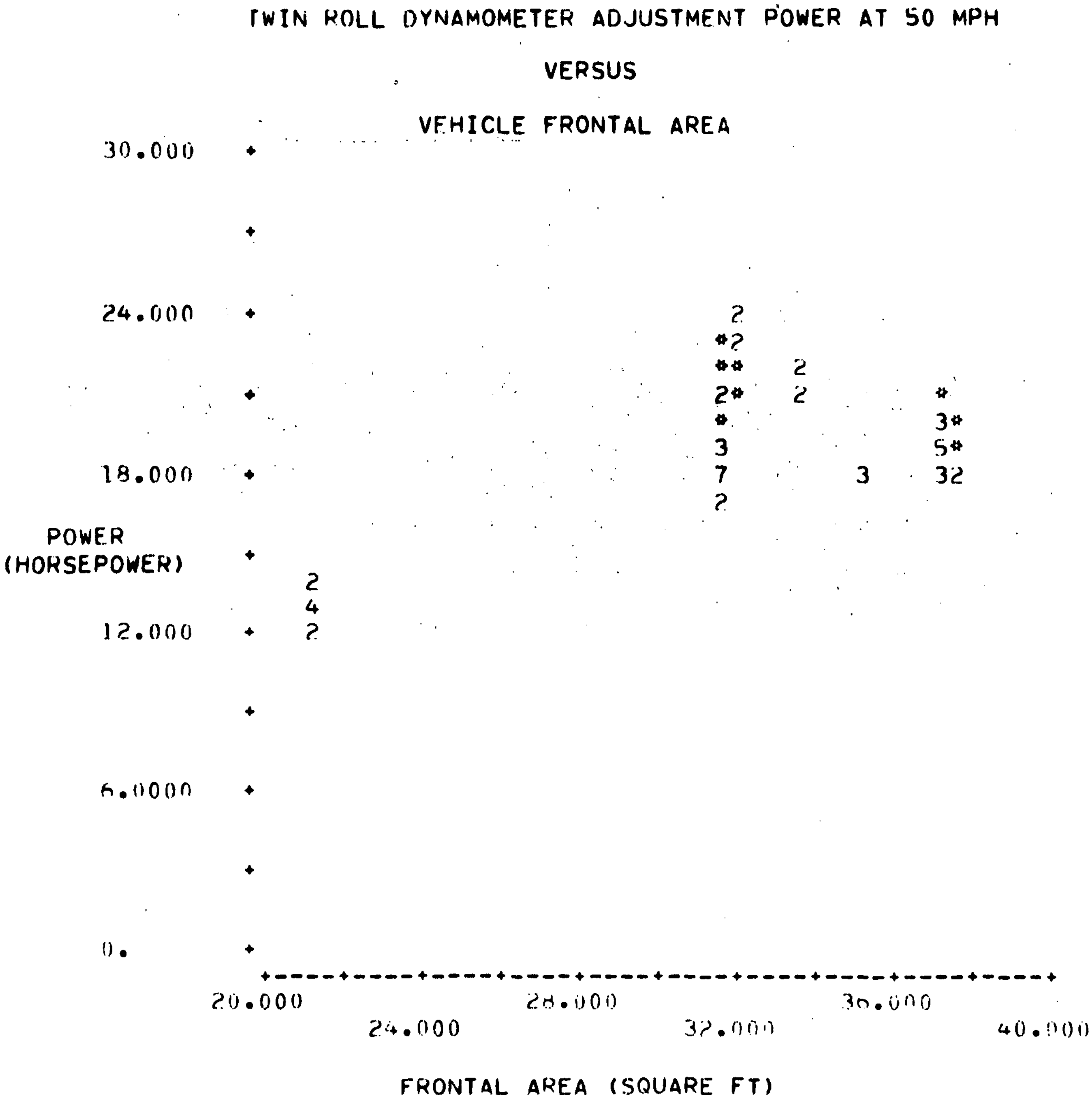
TWIN ROLL DYNAMOMETER ADJUSTMENT POWER AT 50 MPH
VERSUS
VEHICLE FRONTAL AREA
30.000
24.000
18.000
12.000
6.0000
0.
POWER
(HORSEPOWER)
20.000
24.000
28.000
32.000
36.000
40.000
FRONTAL AREA (SQUARE FT)

Figure 4

34 ft^2 are pick up trucks while the remaining vehicles are vans. For the pick up trucks the dynamometer power absorber setting at 50 mph does appear to be linear with frontal area, however the data occur in two major groups with no intermediate points. The power absorber setting for vans may also be linear with frontal area, however since no vans with small frontal areas were included in the test fleet this cannot be empirically determined. These vans were not included since few, if any, such vehicles are currently being sold.

A simple regression line could be fitted to the dynamometer power absorber setting versus frontal area, however if a linear model were chosen this would under estimate the power absorber setting for the large pick up trucks and overestimate the setting for vans. If a non-linear model were chosen this could adapt to the reduced road load of the large frontal area vans, but would be inappropriate for any possible pick up trucks with large frontal areas. To avoid this dilemma the frontal area variable was "factored" into two variables one giving the frontal areas of the pick up trucks only, and a second variable having the values of the frontal areas of the vans only. This is approximately equivalent to separating the data into two groups, vans and pick ups. A general linear regression of these independent variables was first performed. As theoretically predicted, the intercept was nearly zero and there was relatively little statistical confidence that the intercept was not zero. Consequently a linear regression was performed forcing the regression line through zero. The results of this regression are:

Regression of Twin Roll Dynamometer Adjustment Power
at 50 mph versus Vehicle Frontal Area

Regression model: $H_p = a\,A_{pu} + b\,A_{van}$

H_p = the dynamometer power absorber setting (Horsepower)

A_{pu} = the frontal area of the pick up trucks (ft^2)

A_{van} = the frontal area of the vans (ft^2)

a = .633 hp/ft^2

b = .511 hp/ft^2

sample size 54

multiple correlation coefficient .856 $R^2 = .733$

standard error of the regression 1.59

The two prediction equations are:

$$H_p = .633\ A \quad \text{for pick up trucks}$$
$$H_p = .511\ A \quad \text{for vans} \qquad (18)$$

where

A = the vehicle frontal area (ft^2)

The square of the correlation coefficient indicates the proportion of the variation of the data which is explained by the proposed model. In this case 73% of the variation of the data is explained by the model. The standard error of the regression is similar to a standard deviation; approximately 68% of the data may be expected to lie within plus or minus one standard error of the regression line. In this case approximately 68% of the measured data points are within 1.6 hp of the regression line.

It must be remembered that equations (18) include the non-aerodynamic losses associated with the front wheel. Consequently these forces are greater than wind tunnel measurements of vehicle aerodynamic drag. Measurements of wheel bearing, brake drag, and tire aerodynamic drag of light duty trucks indicate these losses are approximately 1.8 horsepower at 50 mph. Consequently the powers of equations (18) are approximately 9% greater than the aerodynamic drag of the vehicle.

2) Vehicle Test mass as a Predictor of the Dynamometer Power Absorber Setting.

The vehicle test mass was defined as the total mass of the vehicle including the driver and any payload. Figure 5, the plot of dynamometer power absorber setting at 50 mph versus vehicle test mass, indicates the power absorber setting increases with increasing test mass until about 2000 kg. Above 2000 kg the power absorber setting is approximately constant. This occurs because the measurements at the higher test masses resulted from increasing the vehicle payload with sandbags. Since sand is relatively dense, the height of the sandbags never exceeded the height of the sides of the pick up truck bed. Consequently the payload does not directly affect the aerodynamic drag significantly in the case of pick-up trucks and has no direct effect on the aerodynamic drag of a van. Any aerodynamic effect which might occur from increasing the vehicle payload would be an indirect result from changes in the vehicle ground clearance or the aerodynamic angle of attack.

Increasing the vehicle payload does increase the tire rolling resistance. However, the assumptions about the rolling resistance of tires on a twin roll dynamometer, and the resulting corrections to the total road load force attempt to remove the tire rolling resistance from the

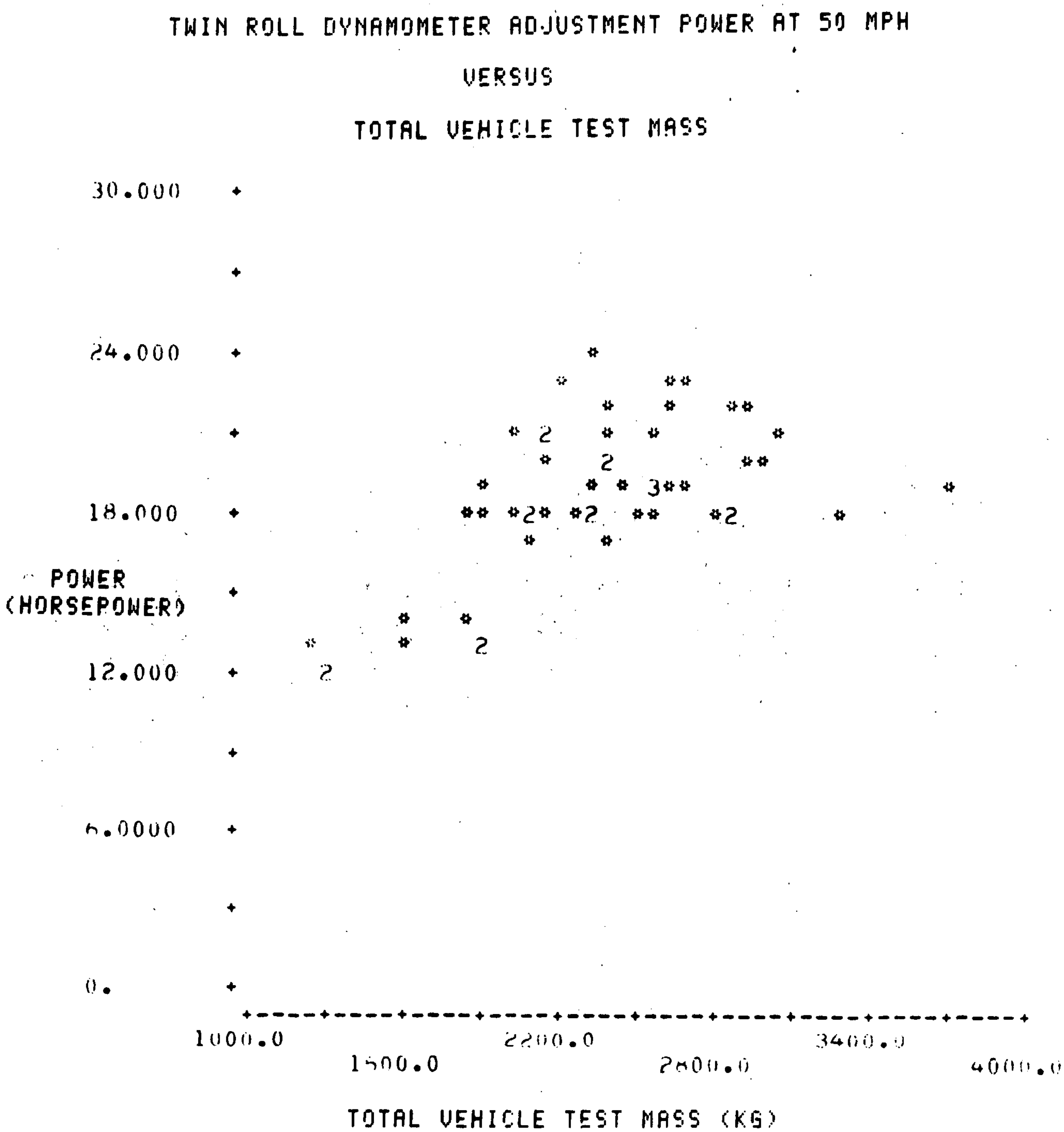
TWIN ROLL DYNAMOMETER ADJUSTMENT POWER AT 50 MPH
VERSUS
TOTAL VEHICLE TEST MASS
30.000
24.000
18.000
12.000
6.0000
0.
POWER
(HORSEPOWER)
1000.0
1600.0
2200.0
2800.0
3400.0
4000.0
TOTAL VEHICLE TEST MASS (KG)

Figure 5

dynamometer adjustment. Investigating the calculated twin roll dynamometer power absorber settings, given in Appendix E, demonstrate the calculated dynamometer power absorber settings for different test masses of each vehicle were generally within $\pm$ 1 horsepower of the mean power absorber setting for that vehicle. Furthermore, the value of the power absorber settings do not systematically increase or decrease with changes in the vehicle test mass. This demonstrates that the data analysis has quite successfully removed the tire rolling resistance.

Since the test mass of any vehicle can vary significantly without systematic effect on the dynamometer power absorber setting, the test mass is not a logical parameter to use to predict the dynamometer power absorber setting. In addition the data analysis indicates increasing the payload of a vehicle does not adequately simulate vehicles of larger mass. The simulation is inadequate because an increase in payload does not affect the aerodynamic drag, while vehicles which are heavier when empty tend to be physically larger and hence have larger aerodynamic drag forces.

3) Inertia Weight Category as a Predictor of the Dynamometer Power Absorber Setting.

The scatter plot of the dynamometer power absorber setting at 50 mph versus the EPA inertia weight category of the vehicle, Figure 6, places all calculated power absorber settings for each vehicle at a single abscissa position. This position is approximately the curb weight of the vehicle plus 300 pounds. This approach is consistent with the previously demonstrated test mass independence of the calculated twin roll dynamometer power absorber setting.

The data plotted in Figure 6 appear approximately linear in EPA inertia category, except for the notable exception of the heaviest inertia category vehicle. This vehicle is a GM van. Because of this exception, a linear regression would under estimate the dynamometer power absorber settings for the majority of vehicles which are in the 4000 to 5000 pound categories, while still over estimating the dynamometer power absorber setting for the heaviest vehicle. Furthermore, a linear model is not theoretically logical since the twin roll dynamometer power absorber setting represents the aerodynamic drag of the vehicle, and there is no theoretical reason to anticipate the aerodynamic drag increases linearly with inertia weight.

A theoretically based model can be developed based on several logical assumptions. The first assumption is that, because of similarities in manufacturing technology, the density of light duty trucks is approximately constant. Stated as an equation, the assumption is:

$$W \sim V \qquad (19)$$

TWIN ROLL DYNAMOMETER ADJUSTMENT POWER AT 50 MPH

VERSUS

INERTIA WEIGHT CATEGORY

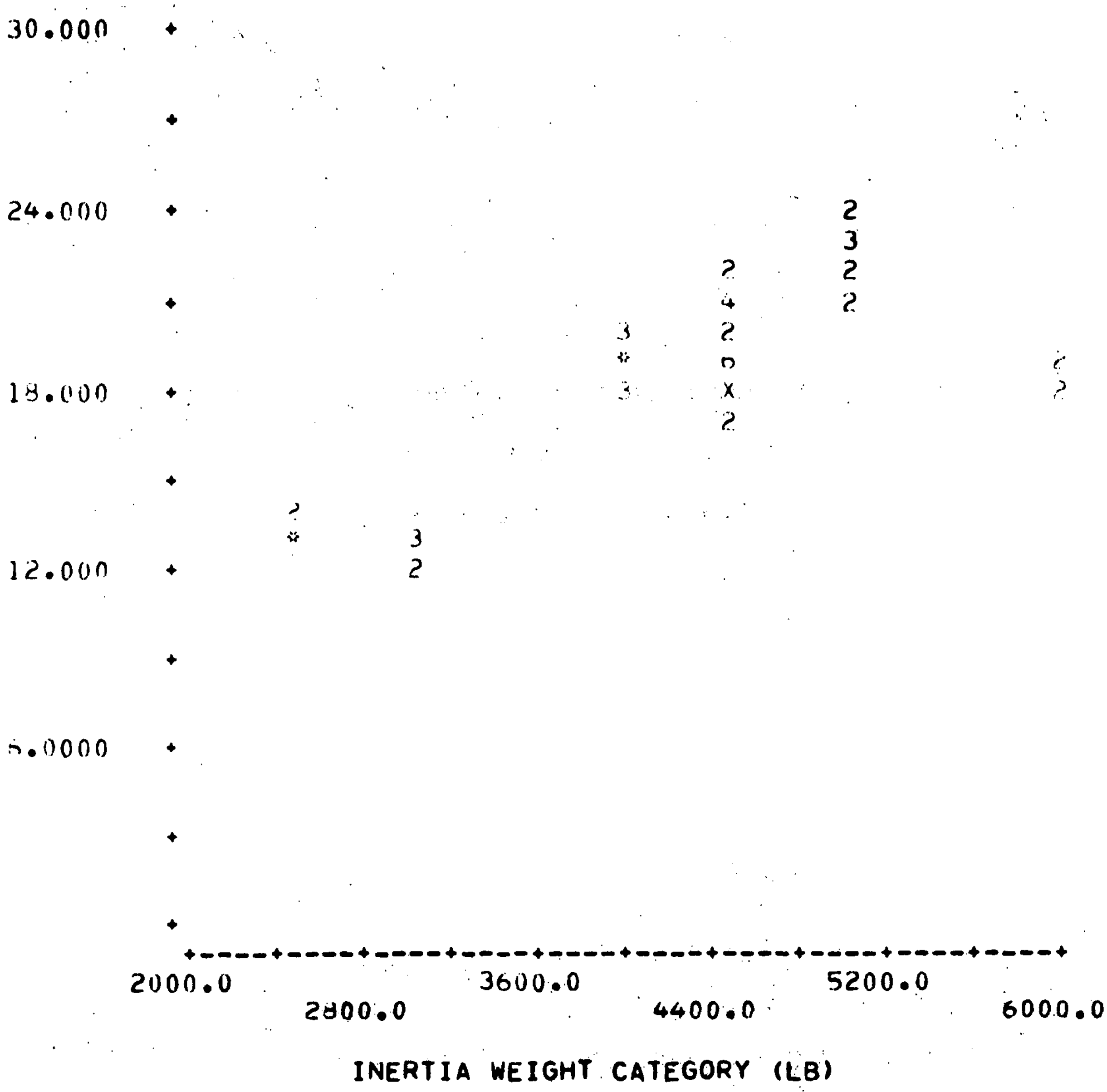

Figure 6

where

W = the inertia weight category of the vehicle (ie: the empty weight plus a standard small payload)

V = the volume of the vehicle

The vehicle volume is approximately equal to the product of the three major dimensions. The second assumption is that each of the major vehicle dimensions may be expected to increase approximately equally with an increase in weight. Consequently each major dimension is proportional to the cube root of the vehicle weight. That is:

$$L \sim W^{1/3} \tag{20}$$

where

L = any of the major vehicle dimensions of height width and length.

The twin roll dynamometer power absorber setting is primarily the aerodynamic drag of the vehicle. The aerodynamic drag is proportional to the frontal area which is approximately equal to the product of the vehicle height and width. Consequently the twin roll dynamometer power absorber setting should be proportional weight of the vehicle to the two-thirds power.

$$H_p \sim W^{2/3} \tag{21}$$

The previous arguments are hardly rigorous, therefore a model of the form:

$$H_p = aW^x \tag{22}$$

was chosen which allowed the exponent to vary. This model will predict a dynamometer power absorber setting of zero horsepower for a vehicle of zero mass, which is theoretically appropriate. Also, if x is less than 1, the model predicts the slope of the horsepower versus weight curve will decrease as the weight increases. This is also theoretically logical; and consistent with the observed data.

The model, equation (21), unfortunately cannot be conveniently fitted to the data by least squares process. The fitting process is difficult since the normal equations resulting from the least squares criterion are non-linear. These equations can be solved simultaneously by numerical methods however a simplier approach is to "linearize" equation (22) by the following logarithimic transformation.

$$\begin{aligned} \ln H_p &= \ln a W^x \\ &= \ln a + \ln W^x \\ &= \ln a + x \ln W \end{aligned} \tag{23}$$

Identifying $\ln H_p$ as the dependent variable and $\ln W$ as the independent variable, equation (23) can now be fitted by a simple linear regression. The results of this regression are:

Regression of Twin Roll Dynamometer Power at 50 mph
versus
Vehicle Inertia Weight Category

Regression model $\ln H_p = \ln a + x \ln W$

$\ln H_p$ = the natural logarithm of the dynamometer power absorber setting (horsepower)

$\ln W$ = the natural logarithm of the vehicle inertia weight category.

$\ln a$ = -2.531

x = 0.6509

Sample size 54

Multiple correlation coefficient .767 $R^2 = .589$

Standard error of the regression .1137

Converting to the form of the original model, the prediction equation is:

$$H_p = .0796\ W^{0.651} \qquad (24)$$

The correlation coefficient of the regression may indicate this regression does not fit the data as well as the previous area based regression model, however the statistics of this regression cannot be readily interpreted since they are the statistics of the regression performed on the transformed parameters.

In order to evaluate the inertia weight prediction model versus the model using frontal area as the predictor of the dynamometer power absorber setting, the prediction equations are plotted in figures 7, and 8. Also plotted in these figures are mean values of the calculated power absorber settings for each vehicle versus the predictor variable. Plotting only the mean values reduces the number of points plotted so that the vehicle types may be identified. These mean values are given in Table 3 of Appendix E.

Figure 7, the plot of the power absorber setting versus inertia weight category shows the fitted model to be a very reasonable appearing choice for these data. However the worst case error of the fitted line

Mean Twin Roll Dynamometer Power Absorber Setting at 50 mph
versus
Vehicle Inertia Weight

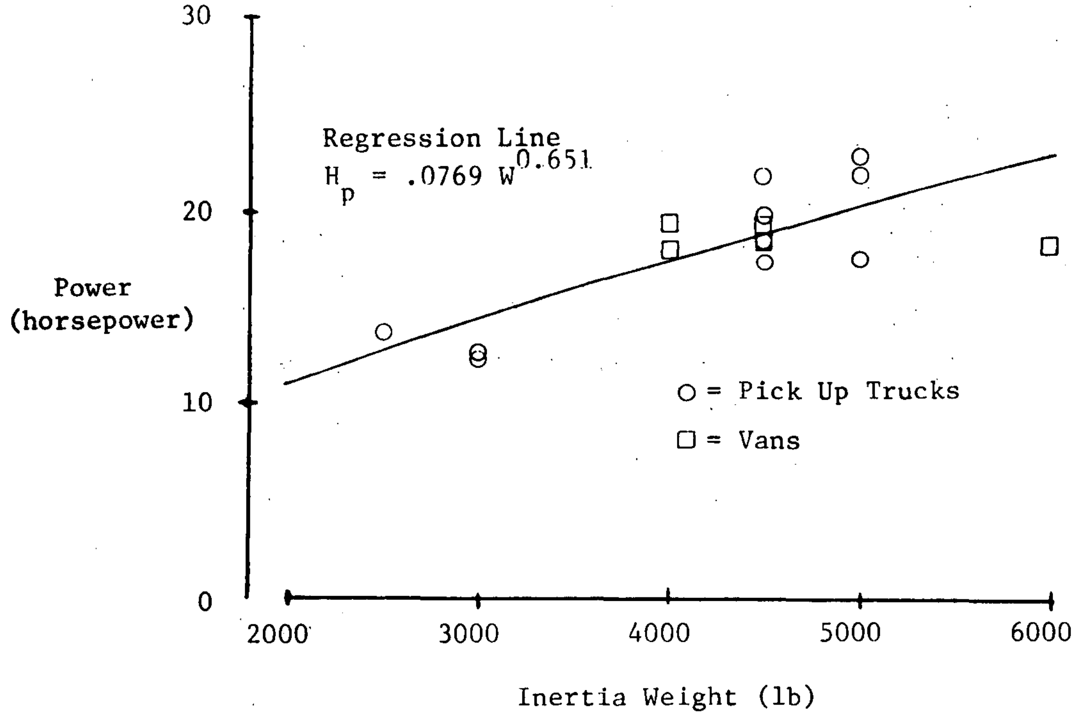

Figure 7

from the data is about 4.5 horsepower. There are two additional cases of errors of about three horsepower and 4 errors of approximately two horsepower. The average dynamometer setting is about 18 horsepower, therefore a two horsepower error is an error slightly greater than 10%.

Figure 8, the plot of power absorber setting versus frontal area, with the vehicles divided into two categories, shows the worst case error in this approach is only approximately 2.5 horsepower. In addition there is only one other data point which is farther than two horsepower from the regression lines.

An additional problem in the treatment of vans when using inertia weight as the predictor of the dynamometer power absorber setting is also apparent from Figures 7 and 8. The inertia weights of the vans tested varied by 2000 pounds or about 40% of the mean inertia weight of the vans. The dynamometer power absorber setting only varied about 1.5 horsepower or less than 8%. Consequently the inertia weight regression equation predicts significantly different dynamometer power absorber settings for different inertia weight vans, while no significant difference was observed. Figure 8 indicates no differences should be expected in the power absorber setting for the vans since the frontal areas, and hence the aerodynamic drag of the vehicles were approximately equal. The prediction model based on vehicle frontal area correctly predicts nearly equal dynamometer power absorber settings for all of the vans in the test fleet.

It is concluded that the prediction system based on the vehicle frontal area, when the vehicles are divided into the categories of vans and pick ups, is significantly better than a prediction system based on the vehicle inertia weight categories. Both models had two parameters which were fitted to the data, therefore the advantage of frontal area as a predictor of the dynamometer power absorber setting is not merely the result of a more flexible model.

The dynamometer adjustment powers could be regressed against both frontal area and weight. Since this would introduce an additional degree of freedom in the model, the prediction precision might appear better. There is, however, no physically logical reason to expect significant mass and frontal area dependence. The mass is a reasonably successful predictor of the dynamometer adjustment primarily because of a high intercorrelation between mass and frontal area. This intercorrelation would make the relative magnitudes of the effects attributed to weight and frontal area characteristic of the specific sample investigated. This approach was not seriously considered because of this problem of relative coefficient instability. If frontal area and mass are to be included in the same regression, the mass contribution should be constrained so that it cannot exceed the effect anticipated for the mechanical losses of the front wheel. With this constraint, the addition of mass to the prediction system cannot be expected to significantly improve the prediction accuracy for the reasons discussed earlier. It

Mean Twin Roll Dynamometer Power Absorber Setting at 50 mph

versus

Frontal Area

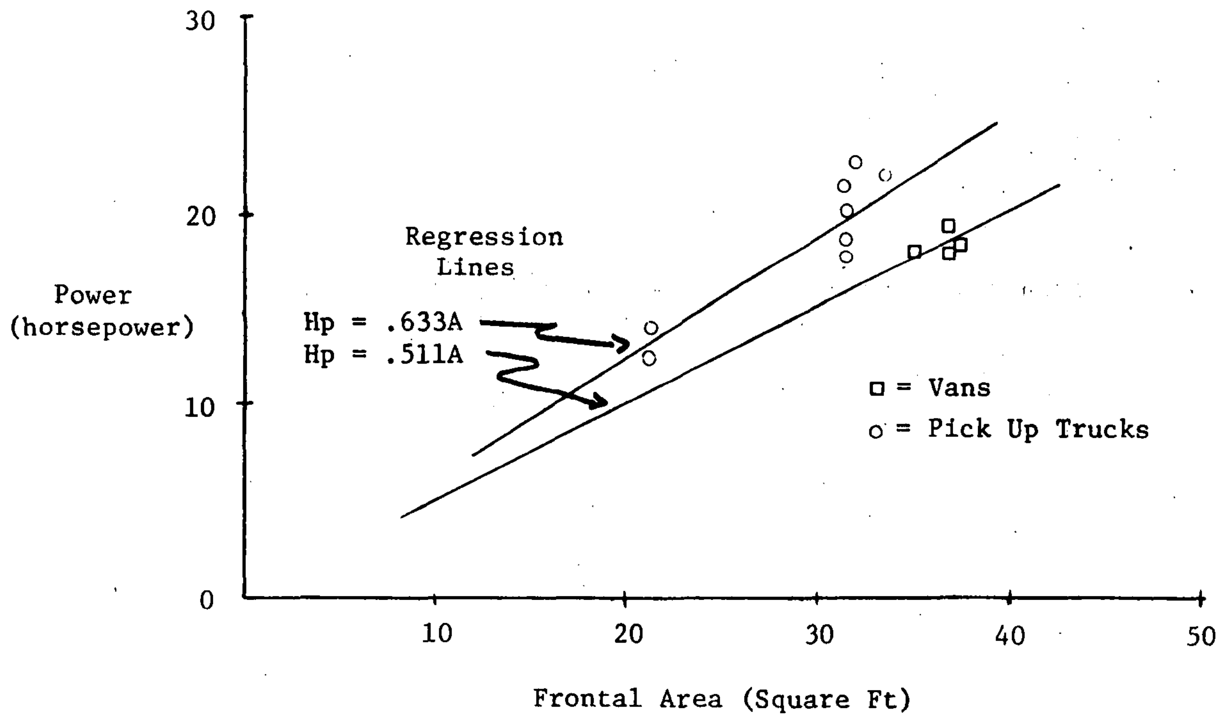

Figure 8

would complicate the prediction system and was therefore not considered.

It may be desirable to consider the approach of constrained mass plus frontal area prediction system in the future if a single prediction equation is to be applied to very diverse vehicles, or if it is desirable to isolate the pure aerodynamic drag. An example of the first case would be if a single equation were to describe all road vehicles. A possible reason for the second argument would be to allow into tunnel measurements of aerodynamic drag to be directly introduced with the dynamometer adjustment equation. Wind tunnel measurements can be incorporated in the current prediction system, but would require corrections for the mechanical losses of the non-driving wheels.

B. Large Roll Dynamometer Adjustment Force

Equations to predict the power absorber settings for large single roll dynamometer are developed since these equations may be useful at the present, or in future work. Since the majority of EPA testing is conducted on small twin roll dynamometers it is assumed that whatever prediction system is chosen for the twin roll dynamometer will also be used for large single roll dynamometers. Therefore only the necessary modifications to the small twin roll dynamometer prediction equations, will be developed.

The appropriate adjustment force for a large roll dynamometer can be obtained directly since the tire and drive train dissipative losses were measured on this dynamometer. To obtain the force coefficients appropriate for adjusting a 48" roll dynaometer, the coefficients of the tire and drive train losses, given in Table 1 of Appendix C, were subtracted from the total force coefficients, given in Table 1 of Appendix E. The resulting net force coefficients, representing the sum of the non-driving tire and wheel bearing losses plus the vehicle aerodynamic drag, are presented in Table 3 of Appendix E. The forces at 50 mph and the appropriate power setting for a large single roll dynamometer to simulate the vehicle road load at 50 mph are also presented in Table 3.

The differences between the small twin roll dynamometer power absorber loads and the power absorber adjustment for a large single roll is primarily the front tire rolling resistances. Since tire rolling resistances are approximately proportional to the vertical load on the tire, the differences in the power absorber loads should be linear in the vehicle test mass. The power absorber setting for a small twin roll dynamometer, given in Table 2 of Appendix E was subtracted from the power absorber setting appropriate for a large single roll dynamometer, given in Table 3 of Appendix E. The difference is scatter plotted in figure 9 versus the vehicle test mass.

The scatter plot of the differences in the dynamometer power absorber settings indicate these data are approximately linear in the vehicle test mass, although a significant amount of data scatter is present. A regression, using the model that the tire rolling resistance is proportional to the vehicle test mass was performed. The results of

DIFFERENCES BETWEEN LARGE SINGLE ROLL DYNAMOMETER ADJUSTMENT

AND SMALL TWIN ROLL DYNAMOMETER ADJUSTMENT AT 50 MPH

VERSES

VEHICLE TEST MASS

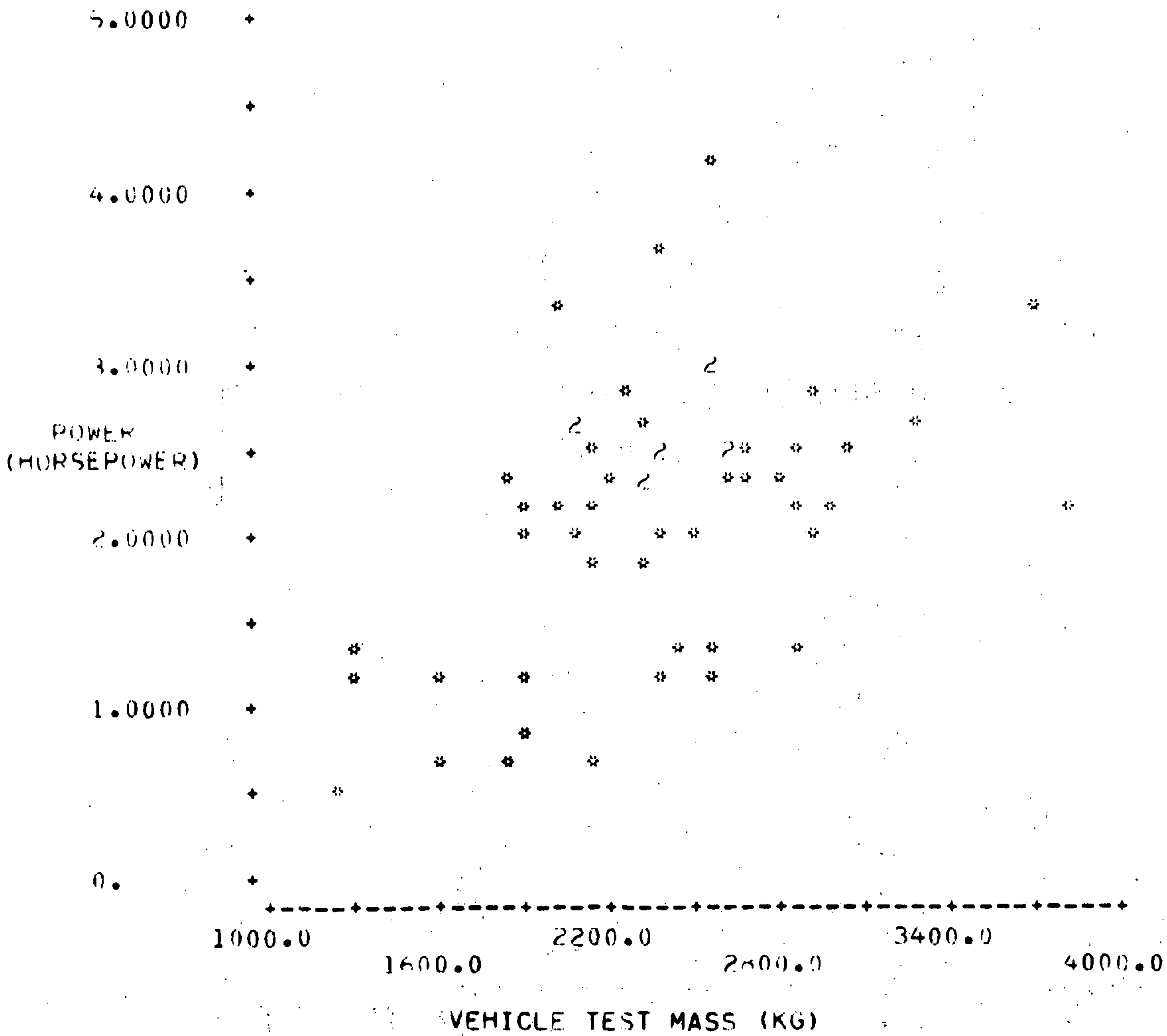

Figure 9

this regression are:

Regression of the Differences in Dynamometer Power Absorber Settings
versus
Vehicle Test Mass

Regression model: $H_p = aM$

H_p = the difference in dynamometer power absorber settings (horsepower)

M = the vehicle test mass (kg)

a = 0.000887

Sample size 54

Correlation coefficient 0.46 $R^2 = 0.215$

Standard error of the regression 0.702

The results of this regression are appended to the prediction equations (17) and (23). The dynamometer power absorber setting, predicted by the vehicle frontal area and weight is given by:

$$H_p = .633\ A + .0004W \quad \text{for pick up trucks}$$
$$H_p = .511\ A + .0004W \quad \text{for vans} \qquad (25)$$

where

A = the vehicle frontal area (ft^2)

W = the vehicle weight (lb)

A factor of 1/2.2 has been introduced since the independent variable vehicle mass in kg, while equations (25) use the vehicle weight in pounds.

Similarly equation (24) is augmentical to:

$$H_p = .0796W^{0.651} + .0004W \qquad (26)$$

Since equation (25) and (26) depend strongly on equations (18) and (24) it is concluded that the prediction system based on vehicle frontal areas, equation (25) is the most accurate.

VII. Conclusions

If light duty trucks are divided into two classes, pick-up trucks and vans, then vehicle frontal area is a significantly better predictor of the appropriate dynamometer power absorber setting than is the vehicle weight. Since the power absorber adjustment of a twin roll dynamometer primarily represents the aerodynamic drag of the vehicle, frontal area is also the physically logical predictor. Therefore, it is concluded that frontal area is the preferred predictor.

There are, however, disadvantages in predicting the dynamometer power absorber setting from the vehicle frontal area. The major disadvantage is that a second parameter must be associated with each vehicle, since the vehicle weight must be retained to adjust the flywheel inertia simulation. In addition frontal areas are more difficult to measure than vehicle weight. Several common methods exist for frontal area measurement; such as polar planimetery of photographs or cutting and weighing photographic images. Automated methods, such as computer scanning of photographs are also in use by the automotive industry. However, all photographic methods require the time necessary to develop the photographic print. The final print size should be at least 8 x 10 inches to minimize errors in the area measurements which precludes the use of currently available instant print processes. Fully automated techniques, such as computer scanning of a television image or photocell scanning of the vehicle shadow are feasible, but may involve expensive equipment.

It must be noted that the vehicle frontal area is significantly better than weight in predicting the dynamometer power absorber setting only when light duty trucks are divided into subclasses of vans and pick-up trucks. While this is relatively simple, it introduces the vehicle shape as a predictor of the dynamometer power absorber setting. Implicitly, the division of vehicles is a very simple means of estimating the relative drag coefficients. This is of no major technical significance, and conceptionally parallels the separation of light duty truck dynamometer settings from those of light duty vehicles. It is, however, a distinct philosophical variation from past methods.

A potential advantage of a prediction system which considers vehicle shape factors is that it enables introduction of possible refinements. It is possible to design either vans or pick-up trucks with better aerodynamic characteristics than current designs. Within a system based on vehicle shape, these designs can be encouraged. The current test sample of 15 vehicles is not sufficiently large or diversified to allow extensive empirical treatment of light duty truck shapes; however, sufficient information may be available from vehicle manufacturers. Also, theoretical treatment from the literature of road vehicle aerodynamics is also possible. Reference 9 is given as one of the more extensive recent publications on road vehicle aerodynamics.

VIII. Recommendations

A dynamometer power absorber setting based on light duty truck frontal area is recommended. The possible improvements in accuracy of this approach are considered sufficient to warrant the increase in complexity. Since EPA receives criticism about the accuracy of our dynamometer measurements, such a relatively simple improvement should not be ignored.

It is further recommended that the distinction between pick-up trucks and vans be made on the basis of those characteristics of the vehicles which are responsible for aerodynamic differences. If the vehicle dynamometer power absorber adjustment is specified in terms of vehicle "shape factor" this will allow convenient expansion and refinements as more information becomes available.

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9. A. J. Scibor-Rylski, "Road Vehicle Aerodynamics," John Wiley and Sons, New York, 1975.

APPENDIX A

VEHICLE TEST FLEET IDENTIFICATION

TABLE 1

ID	VEHICLE TYPE	EPA INERTIA WT. CLASS (LB)	FRONTAL AREA (FT**2)
5902	FORD F-100	4500	31.4(F)
7001	CHEV CHEYENNE 20	5000	32.0(GM)
7101	CHEV SCOTTSDALE 10	4500	31.6(GM)
7201	CHEV CHEYENNE 10	4500	31.6(GM)
7301	CHEV G-20 VAN	4000	37.0(GM)
7402	FORD F-100 4X4	5000	31.4(F)
7502	FORD F-250	4500	33.6(F)
7602	FORD F-100 R XLT	4500	31.4(F)
7701	CHEV G-10 VAN	4500	37.0(GM)
7901	CHEV G-30 VAN	6000	37.0(GM)
8002	FORD E-150 VAN	4500	37.7(F)
8206	TOYOTA HILUX SR-5	3000	21.2(EPA)
8306	TOYOTA HILUX 2	3000	21.2(EPA)
8507	DATSUN	2500	21.2(EPA)
9003	DODGE TRADESMAN 100 VAN	4000	35.1(EPA)

APPENDIX B

TRACK MEASUREMENTS

TABLE 1

AMBIENT CORRECTED ACCELERATION COEFFICIENTS

ID	WT (LB)	A0 (M/SEC**2)	A1 (1/SEC)	A2 (1/M)
7101	4110	0.1364E+00	0.3978E-02	0.4116E-03
7001	6050	0.1199E+00	0.8064E-02	0.1288E-03
7701	4500	0.1117E+00	-0.5550E-02	0.9136E-03
5902	4270	0.1464E+00	0.7684E-02	0.2577E-03
8206	2750	0.1210E+00	0.6234E-02	0.3516E-03
5902	4330	0.7434E-01	0.1432E-01	0.1712E-03
7001	4930	0.1879E+00	0.3511E-02	0.3653E-03
7502	4540	0.1444E+00	0.2891E-02	0.4456E-03
7402	5540	0.1803E+00	0.1476E-02	0.3774E-03
7001	5530	0.2035E+00	-0.3568E-03	0.4210E-03
7001	4620	0.1919E+00	0.7623E-02	0.2025E-03
7901	5690	0.1109E+00	0.1009E-02	0.4044E-03
7001	5500	0.1833E+00	0.2383E-02	0.3268E-03
7301	4560	0.1225E+00	0.2950E-02	0.4364E-03
7402	5760	0.1425E+00	0.6534E-02	0.2282E-03
7201	5110	0.7001E-01	0.7501E-02	0.2279E-03
7701	4990	0.1015E+00	0.4450E-02	0.3541E-03
5902	5020	0.1575E+00	0.1879E-02	0.4400E-03
8002	4370	0.6343E-01	0.8668E-02	0.3015E-03
7201	5480	0.1091E+00	0.1483E-02	0.3843E-03
7301	5050	0.8896E-01	0.7113E-02	0.2559E-03
8002	5530	0.1101E+00	0.2612E-02	0.3664E-03
8206	4050	0.1339E+00	0.3006E-02	0.2814E-03
8507	3900	0.1540E+00	0.5791E-02	0.1975E-03
8002	6320	0.8744E-01	0.5471E-02	0.2508E-03
7301	6420	0.1276E+00	0.2068E-02	0.3076E-03
7502	5500	0.1580E+00	0.4098E-02	0.2756E-03
7901	7900	0.8297E-01	0.4818E-02	0.1645E-03
7502	6240	0.1114E+00	0.8449E-02	0.1471E-03
7001	8190	0.1188E+00	0.5222E-02	0.1503E-03
8306	3490	0.1408E+00	0.5705E-02	0.2666E-03
8507	3370	0.1574E+00	0.6569E-02	0.2244E-03
9003	3970	0.1493E+00	0.3367E-02	0.4221E-03
9003	4380	0.8530E-01	0.1036E-01	0.1798E-03
9003	4810	0.1482E+00	-0.5306E-03	0.5140E-03
7701	5620	0.8704E-01	0.4485E-02	0.3136E-03
7201	6060	0.6875E-01	0.6287E-02	0.1920E-03
7101	5020	0.9678E-01	0.7696E-02	0.2047E-03
7901	7040	0.1083E+00	0.2564E-02	0.2221E-03
8002	5010	0.1228E+00	0.5966E-04	0.4946E-03
7701	5980	0.9093E-01	0.3926E-02	0.2649E-03
7502	5020	0.1120E+00	0.8399E-02	0.2351E-03
8206	3550	0.1387E+00	0.3739E-02	0.3136E-03
7201	4540	0.6536E-01	0.8017E-02	0.2499E-03
7301	4060	0.8686E-01	0.6857E-02	0.3856E-03
7101	4500	0.7461E-01	0.9948E-02	0.2024E-03
7402	5110	0.1519E+00	0.3603E-02	0.3729E-03
7602	5030	0.6956E-01	0.9136E-02	0.1548E-03
7101	5330	0.1080E+00	0.4081E-02	0.3279E-03
7901	6060	0.6192E-01	0.6517E-02	0.1909E-03
7001	6490	0.1244E+00	0.6162E-02	0.1420E-03
8306	4140	0.1251E+00	0.4669E-02	0.2295E-03
8306	2700	0.9182E-01	0.1190E-01	0.1881E-03
8507	2560	0.1643E+00	0.85653-02	0.2637E-03

TABLE 2
TIRE PRESSURES

ID	WT (LB)	BEFORE FRONT (PSI)	BEFORE REAR (PSI)	AFTER LEFT FRONT (PSI)	AFTER RIGHT FRONT (PSI)	AFTER LEFT REAR (PSI)	AFTER RIGHT REAR (PSI)
5902	4330	30.0	30.0	34.5	34.4	34.7	34.5
5902	4270	36.0	40.0	36.5	39.0	42.2	42.2
5902	5020	36.0	40.0	40.5	40.5	44.3	45.0
7001	4620	35.0	60.0	38.5	38.8	64.5	65.0
7001	4930	35.0	60.0	38.5	38.0	64.0	65.5
7001	5530	35.0	60.0	39.0	39.0	62.0	65.5
7001	5500	35.0	60.0	39.5	39.6	66.0	66.0
7001	6050	35.0	60.0	38.8	38.7	65.7	65.4
7001	6490	35.0	60.0	39.5	40.0	67.5	66.5
7001	8190	35.0	60.0	40.0	39.5	70.5	69.5
7101	4110	32.0	32.0	34.8	34.0	35.0	34.5
7101	4500	32.0	32.0	35.0	35.0	35.0	35.0
7101	5020	32.0	32.0	35.5	35.5	35.0	35.0
7101	5330	32.0	32.0	34.8	35.0	35.0	35.2
7201	4540	28.0	32.0	30.5	30.0	34.5	34.5
7201	5110	28.0	32.0	31.0	30.5	35.0	34.5
7201	5480	28.0	32.0	30.5	30.5	35.0	34.5
7201	6060	28.0	32.0	29.3	29.0	33.0	33.0
7301	4060	30.0	32.0	32.5	32.5	34.5	34.5
7301	4560	30.0	32.0	32.5	33.0	34.5	35.0
7301	5050	30.0	32.0	32.0	32.0	34.5	34.5
7301	6420	30.0	32.0	32.5	32.5	36.0	36.5
7402	5110	32.0	32.0	37.5	37.5	36.5	36.5
7402	5540	32.0	32.0	37.0	37.0	37.0	37.0
7402	5760	32.0	32.0	37.0	37.0	37.5	36.5
7502	4540	35.0	45.0	39.5	39.5	48.0	47.5
7502	5020	35.0	45.0	38.0	38.5	47.5	48.0
7502	5500	35.0	45.0	38.0	39.2	48.0	49.0
7502	6240	35.0	45.0	39.5	40.0	51.0	50.5
7602	5030	36.0	40.0	40.2	40.0	45.0	44.5
7701	4500	32.0	32.0	35.5	33.0	35.0	35.0
7701	4990	32.0	32.0	35.0	34.5	35.0	35.0
7701	5620	32.0	32.0	33.5	33.2	33.2	33.2
7701	5980	32.0	32.0	36.0	35.0	36.0	35.0
7901	5690	45.0	60.0	49.0	49.4	63.5	64.7
7901	6060	45.0	60.0	49.0	48.8	64.5	65.0
7901	7040	45.0	60.0	51.0	49.0	67.0	65.5
7901	7900	45.0	60.0	49.5	48.0	65.5	65.0
8002	4370	32.0	40.0	35.0	34.5	42.0	43.7
8002	5010	32.0	40.0	35.0	34.5	43.5	41.5
8002	5530	32.0	40.0	36.5	36.0	45.0	44.5
8002	6320	32.0	40.0	37.0	37.0	45.5	45.5
8206	2750	20.0	20.0	22.5	22.0	23.0	22.0
8206	3550	20.0	20.0	22.5	22.0	23.0	21.5
8206	4050	20.0	30.0	23.0	22.3	34.0	33.0
8306	2700	20.0	20.0	23.0	22.5	22.5	22.0
8306	3490	20.0	20.0	22.0	21.5	23.3	22.5
8306	4140	20.0	32.0	24.5	24.0	36.5	36.0
8507	2560	21.0	26.0	24.5	24.0	28.0	27.3
8507	3370	21.0	42.0	24.0	24.0	44.5	43.7
8507	3900	21.0	42.0	25.0	25.5	47.0	47.2
9003	3970	30.0	30.0	32.0	32.5	32.5	33.0
9003	4380	30.0	30.0	33.5	33.5	33.5	33.5
9003	4810	32.0	32.0	35.0	35.0	35.0	35.0

APPENDIX C

DYNAMOMETER MEASUREMENTS

TABLE 1
DRIVE TRAIN + REAR TIRE

REGRESSION COEFFICIENTS

ID	WT (LB)	A (NT)	B (KG/SEC)
7101	4110	125.089	1.907
7101	4500	142.537	2.218
7101	5020	163.138	2.473
7101	5330	176.577	2.081
7201	5480	147.625	1.704
7201	4540	94.002	2.297
7201	5110	120.298	2.601
7201	6060	170.826	2.007
7502	4540	126.448	2.814
7502	5020	149.018	2.951
7502	5500	170.187	3.685
7502	6240	212.167	2.824
7602	5040	132.137	1.656
7602	4430	115.029	1.510
7602	5530	156.920	1.471
8002	4370	79.075	3.480
8002	5010	104.432	3.995
8002	5530	83.967	4.311
8002	6320	121.000	4.973
8206	2750	81.356	2.150
8206	4050	135.113	2.290
8306	2700	85.214	2.253
8306	3490	128.722	2.343
8306	4140	152.310	2.400
8507	2560	100.226	2.213
8507	3370	113.064	2.145
8507	3900	143.116	2.404
9003	3970	96.395	2.009
9003	4380	110.992	1.914
9003	4810	122.549	2.225
5902	4310	105.970	2.939
5902	5020	135.467	2.922
5902	5500	163.721	2.760
7001	4620	127.895	1.958
7001	4930	139.843	1.841
7001	5530	160.010	1.823
7001	6050	146.015	2.995
7001	6490	172.954	3.111
7001	8190	251.360	3.301
7301	4060	83.631	1.685
7301	4560	95.228	1.584
7301	5050	114.625	1.665
7301	6420	195.448	2.476
7402	5110	157.907	3.445
7402	5540	163.957	3.215
7402	5760	172.719	3.372
7701	4500	109.004	1.846
7701	4990	106.903	2.312
7701	5620	116.962	2.690
7701	5980	130.141	2.818
7901	5690	121.809	2.681
7901	6060	133.591	2.955
7901	7040	160.318	2.992
7901	7900	200.388	2.728

TABLE 2
REAR TIRE

REGRESSION COEFFICIENTS

ID	WT (LB)	A (NT)	B (KG/SEC)
7101	4110	84.692	.239
7101	4500	102.140	.549
7101	5020	122.740	.804
7101	5330	136.180	.412
7201	5480	116.237	-.236
7201	4540	62.614	.357
7201	5110	88.909	.661
7201	6060	139.438	.067
7502	4540	88.802	.229
7502	5020	111.373	.366
7502	5500	132.542	1.099
7502	6240	174.522	.239
7602	5040	101.569	.100
7602	4430	84.462	-.045
7602	5530	126.352	-.084
8002	4370	70.134	.349
8002	5010	95.492	.864
8002	5530	75.027	1.180
8002	6320	112.060	1.842
8206	2750	56.494	.200
8206	4050	110.251	.340
8306	2700	61.014	-.020
8306	3490	104.522	.070
8306	4140	128.109	.127
8507	2560	77.627	-.324
8507	3370	90.466	-.392
8507	3900	120.517	-.133
9003	3970	83.001	.325
9003	4380	97.598	.230
9003	4810	109.156	.542
5902	4310	65.601	-.633
5902	5020	95.098	-.650
5902	5500	123.353	-.812
7001	4620	76.228	-.480
7001	4930	88.175	-.597
7001	5530	108.342	-.614
7001	6050	94.346	.558
7001	6490	121.286	.673
7001	8190	199.693	.863
7301	4060	64.873	-.087
7301	4560	76.469	-.187
7301	5050	95.867	-.107
7301	6420	176.690	.705
7402	5110	135.962	2.803
7402	5540	142.012	2.573
7402	5760	150.774	2.730
7701	4500	68.629	.214
7701	4990	66.529	.680
7701	5620	76.588	1.058
7701	5980	89.767	1.186
7901	5690	88.516	.353
7901	6060	100.298	.627
7901	7040	127.025	.663
7901	7900	167.096	.400

TABLE 3
DRIVE TRAIN

REGRESSION COEFFICIENTS

ID	WT (LB)	A (NT)	B (KG/SEC)
7101	4110	40.398	1.668
7101	4500	40.398	1.668
7101	5020	40.398	1.668
7101	5330	40.398	1.668
7201	5480	31.388	1.940
7201	4540	31.388	1.940
7201	5110	31.388	1.940
7201	6060	31.388	1.940
7502	4540	37.645	2.586
7502	5020	37.645	2.586
7502	5500	37.645	2.586
7502	6240	37.645	2.586
7602	5040	30.568	1.555
7602	4430	30.568	1.555
7602	5530	30.568	1.555
8002	4370	8.940	3.131
8002	5010	8.940	3.131
8002	5530	8.940	3.131
8002	6320	8.940	3.131
8206	2750	24.862	1.950
8206	4050	24.862	1.950
8306	2700	24.200	2.273
8306	3490	24.200	2.273
8306	4140	24.200	2.273
8507	2560	22.598	2.537
8507	3370	22.598	2.537
8507	3900	22.598	2.537
9003	3970	13.394	1.684
9003	4380	13.394	1.684
9003	4810	13.394	1.684
5902	4310	40.369	3.572
5902	5020	40.369	3.572
5902	5500	40.369	3.572
7001	4620	51.668	2.437
7001	4930	51.668	2.437
7001	5530	51.668	2.437
7001	6050	51.668	2.437
7001	6490	51.668	2.437
7001	8190	51.668	2.437
7301	4060	18.758	1.772
7301	4560	18.758	1.772
7301	5050	18.758	1.772
7301	6420	18.758	1.772
7402	5110	21.946	.642
7402	5540	21.946	.642
7402	5760	21.946	.642
7701	4500	40.374	1.632
7701	4990	40.374	1.632
7701	5620	40.374	1.632
7701	5980	40.374	1.632
7901	5690	33.293	2.328
7901	6060	33.293	2.328
7901	7040	33.293	2.328
7901	7900	33.293	2.328

TABLE 4
FRONT TIRE

REGRESSION COEFFICIENTS

ID	WT (LB)	A (NT)	B (KG/SEC)
7101	4110	100.119	.147
7101	4500	101.676	.376
7101	5020	98.805	.544
7101	5330	102.698	.705
7201	5480	73.717	.284
7201	4540	74.043	.941
7201	5110	71.504	.587
7201	6060	75.010	.592
7502	4540	53.455	-.047
7502	5020	78.666	.021
7502	5500	72.612	.671
7502	6240	138.780	-.413
7602	5040	116.928	.666
7602	4430	111.475	.910
7602	5530	128.301	1.112
8002	4370	125.442	-.570
8002	5010	123.561	.636
8002	5530	133.580	.760
8002	6320	151.844	.204
8206	2750	54.797	.367
8206	4050	61.980	.171
8306	2700	68.994	.107
8306	3490	75.065	.146
8306	4140	75.603	.222
8507	2560	53.466	-.591
8507	3370	56.870	-.294
8507	3900	70.427	-.503
9003	3970	136.528	-.634
9003	4380	148.811	-.418
9003	4810	159.544	-.405
5902	4310	132.806	.737
5902	5020	132.485	1.966
5902	5500	145.088	2.543
7001	4620	110.863	.088
7001	4930	108.425	.391
7001	5530	116.727	.514
7001	6050	118.585	.634
7001	6490	129.009	.416
7001	8190	132.334	.513
7301	4060	94.076	.447
7301	4560	107.055	.543
7301	5050	109.559	.858
7301	6420	117.703	1.015
7402	5110	******	******
7402	5540	******	******
7402	5760	******	******
7701	4500	99.552	.535
7701	4990	109.240	.372
7701	5620	111.976	.563
7701	5980	113.440	.552
7901	5690	132.923	-.204
7901	6060	121.567	-.043
7901	7040	145.946	.103
7901	7900	173.943	.405

TABLE 5
TIRE PRESSURES

		BEFORE		AFTER			
ID	WT	FRONT	REAR	LEFT FRONT	RIGHT FRONT	LEFT REAR	RIGHT REAR
	(LB)	(PSI)	(PSI)	(PSI)	(PSI)	(PSI)	(PSI)
5902	4330	36.0	40.0	42.2	42.0	46.0	47.0
5902	5020		40.0	43.4	43.5	47.3	48.1
5902	5500	36.0	40.0	42.0	42.0	47.3	49.0
7001	4620	35.0	60.0	40.5	40.5	64.5	64.0
7001	4930	35.0	60.0	42.2	42.0	65.0	64.8
7001	5530	35.0	60.0	42.5	42.5	65.5	65.0
7001	6050	35.0	60.0	42.8	42.8	70.0	69.5
7001	6490	35.0	60.0	42.0	41.8	69.0	67.5
7001	8190	35.0	60.0	42.5	43.0	75.0	73.5
7101	4110	32.0	32.0	37.4	37.0	35.0	34.4
7101	4500	32.0	32.0	37.0	37.4	34.5	34.5
7101	5020	32.0	32.0	37.4	37.0	35.0	35.4
7101	5330	32.0	32.0	37.0	37.0	37.0	37.0
7201	4540	28.0	32.0	33.7	34.7		
7201	5110	28.0	32.0	33.8	33.4	34.0	34.4
7201	5480	28.0	32.0	32.6	33.6	36.0	36.0
7201	6060	28.0	32.0	32.0	32.0	36.4	36.4
7301	4060	30.0	32.0			37.0	36.0
7301	4560	30.0	32.0	34.0	34.0	37.5	36.5
7301	5050		32.0			37.0	37.0
7301	6420	30.0	32.0	35.0	35.0	38.0	38.0
7402	5110		32.0			39.0	37.5
7402	5540	32.0	32.0	42.0	41.0		
7402	5760		32.0			41.5	41.0
7502	4540	35.0	45.0	43.0	43.2	48.4	48.4
7502	5020	35.0	45.0	42.0	42.0	49.8	49.4
7502	5500	35.0	45.0	41.6	42.2		
7502	6240	35.0	45.0	41.6	42.2	50.0	50.4
7602	4430	36.0	40.0	41.8	42.0	47.0	46.6
7602	5030	36.0	40.0	42.0	42.0	47.2	47.4
7602	5540	36.0	40.0	43.6	43.7	47.5	47.5
7701	4500	32.0	32.0	38.0	39.0	36.0	35.0
7701	4990	32.0	32.0	38.0	39.0	36.5	35.0
7701	5620	32.0	32.0	39.0	40.0	38.0	36.0
7701	5980	32.0	32.0	39.8	40.5	37.8	35.5
7901	5690	45.0	60.0	52.0	51.0	69.5	67.2
7901	6060	45.0	60.0	52.0	51.0	70.5	70.5
7901	7040	45.0	60.0	54.0	52.5	72.2	71.2
7901	7900	45.0	60.0	52.0	51.0	72.8	72.6
8002	4370	32.0	40.0	33.5	34.0	43.2	44.0
8002	5010	32.0	40.0	36.5	36.5	43.2	43.0
8002	5530	32.0	40.0	37.4	37.5	44.2	44.6
8002	6320	32.0	40.0	36.5	36.5	45.0	45.6
8206	2750	20.0	20.0	21.8	21.8	22.0	22.8
8206	4050	20.0	30.0	24.8	24.8	35.2	34.2
8306	2700	20.0	20.0	24.2	24.6	25.4	25.4
8306	3490	20.0	20.0	24.2	24.4	28.8	28.8
8306	4140	20.0	32.0	24.2	24.4	39.2	38.8
8507	2560	21.0	26.0	26.0	25.8	28.6	28.8
8507	3370	21.0	42.0	28.4	27.0	50.5	48.0
8507	3900	21.0	42.0	28.4	27.4	53.2	50.8
9003	3970	30.0	30.0	35.5	36.0	36.0	35.0
9003	4380	30.0	30.0	36.0	36.0	35.0	34.5
9003	4810	32.0	32.0	37.5	38.0	38.5	37.5

APPENDIX D

MASSES

TABLE 1
VEHICLE MASSES

ID	GRAV MASS (KG)	DTT EFF MASS (KG)	FT EFF MASS (KG)	TOTAL VEH MASS (KG)
7101	1868.2	33.811	26.04	1928.0
7101	2045.5	33.811	26.04	2105.3
7101	2281.8	33.811	26.04	2341.7
7101	2422.7	33.811	26.04	2482.6
7201	2490.9	64.657	31.75	2587.3
7201	2063.6	64.657	31.75	2160.0
7201	2322.7	64.657	31.75	2419.1
7201	2754.5	64.657	31.75	2851.0
7502	2063.6	42.007	44.30	2149.9
7502	2281.8	42.007	44.30	2368.1
7502	2500.0	42.007	44.30	2586.3
7502	2836.4	42.007	44.30	2922.7
7602	2286.4	43.537	27.34	2357.2
7602	2013.6	43.537	27.34	2084.5
7602	2518.2	43.537	27.34	2589.1
8002	1986.4	30.971	31.92	2049.3
8002	2277.3	30.971	31.92	2340.2
8002	2513.6	30.971	31.92	2576.5
8002	2872.7	30.971	31.92	2935.6
8206	1250.0	31.074	20.75	1301.8
8206	1840.9	31.074	20.75	1892.7
8306	1227.3	20.605	22.91	1270.8
8306	1586.4	20.605	22.91	1629.9
8306	1881.8	20.605	22.91	1925.3
8507	1163.6	30.183	22.80	1216.6
8507	1531.8	30.183	22.80	1584.8
8507	1772.7	30.183	22.80	1825.7
9003	1804.5	42.142	19.64	1866.3
9003	1990.9	42.142	19.64	2052.7
9003	2186.4	42.142	19.64	2248.1
5902	1940.9	46.852	26.90	2014.7
5902	1968.2	46.852	26.90	2041.9
5902	2281.8	46.852	26.90	2355.6
5902	2500.0	46.852	26.90	2573.8
7001	2100.0	55.724	46.67	2202.4
7001	2240.9	55.724	46.67	2343.3
7001	2500.0	55.724	46.67	2602.4
7001	2513.6	55.724	46.67	2616.0
7001	2750.0	55.724	46.67	2852.4
7001	2950.0	55.724	46.67	3052.4
7001	3722.7	55.724	46.67	3825.1
7301	1845.5	50.140	28.90	1924.5

(TABLE 1 CONTINUED)

7301	2072.7	50.140	28.90	2151.8
7301	2295.5	50.140	28.90	2374.5
7301	2918.2	50.140	28.90	2997.2
7402	2322.7	43.537	28.81	2395.0
7402	2518.2	43.537	28.81	2590.5
7402	2618.2	43.537	28.81	2690.5
7701	2045.5	41.779	27.16	2114.4
7701	2268.2	41.779	27.16	2337.1
7701	2554.5	41.779	27.16	2623.5
7701	2718.2	41.779	27.16	2787.1
7901	2586.4	56.206	38.04	2680.6
7901	2754.5	56.206	38.04	2848.8
7901	2977.3	56.206	38.04	3071.5
7901	3200.0	56.206	38.04	3294.2
7901	3590.9	56.206	38.04	3685.2

APPENDIX E

VEHICLE ROAD LOAD

AND

DYNAMOMETER ADJUSTMENT TO SIMULATE VEHICLE ROAD LOAD

TABLE 1
TOTAL VEHICLE ROAD LOAD

ID	WT (LB)	F0 (NT)	F1	F2	F50 (NT)	HP50 (HP)
5902	4330	0.1518E+03	0.2924E+02	0.349[illegible]E+00	0.9799E+03	29.369
5902	5020	0.3710E+03	0.4426E+01	0.1036E+01	0.9877E+03	29.603
5902	5500	0.2811E+03	0.1957E+02	0.5878E+00	0.1012E+04	30.331
7001	4620	0.4226E+03	0.1679E+02	0.4459E+00	0.1021E+04	30.601
7001	4930	0.4404E+03	0.8227E+01	0.8560E+00	0.1052E+04	31.530
7001	5530	0.5325E+03	-0.9334E+00	0.1101E+01	0.1062E+04	31.830
7001	6050	0.3419E+03	0.2300E+02	0.3673E+00	0.1039E+04	31.141
7001	6490	0.3796E+03	0.1881E+02	0.4333E+00	0.1016E+04	30.451
7001	8190	0.4543E+03	0.1997E+02	0.5747E+00	0.1188E+04	35.607
7101	4110	0.2630E+03	0.7670E+01	0.7936E+00	0.8309E+03	24.904
7101	4500	0.1571E+03	0.2094E+02	0.4260E+00	0.8380E+03	25.116
7101	5020	0.2266E+03	0.1802E+02	0.4793E+00	0.8688E+03	26.040
7101	5330	0.2682E+03	0.1013E+02	0.8141E+00	0.9014E+03	27.017
7201	4540	0.1412E+03	0.1732E+02	0.5397E+00	0.7978E+03	23.912
7201	5110	0.1694E+03	0.1815E+02	0.5514E+00	0.8504E+03	25.488
7201	5480	0.2823E+03	0.3837E+01	0.9955E+00	0.8653E+03	25.935
7201	6060	0.1960E+03	0.1792E+02	0.5473E+00	0.8700E+03	26.075
7301	4060	0.1672E+03	0.1320E+02	0.7422E+00	0.8328E+03	24.961
7301	4560	0.2636E+03	0.6348E+01	0.9434E+00	0.8767E+03	26.276
7301	5050	0.2112E+03	0.1689E+02	0.6076E+00	0.8923E+03	26.744
7301	6420	0.3825E+03	0.6198E+01	0.9219E+00	0.9816E+03	29.420
7402	5110	0.3637E+03	0.8629E+01	0.8931E+00	0.1003E+04	30.062
7402	5540	0.4672E+03	0.3824E+01	0.9776E+00	0.1041E+04	31.201
7402	5760	0.3834E+03	0.1758E+02	0.6139E+00	0.1083E+04	32.459
7502	4540	0.3105E+03	0.6215E+01	0.9580E+00	0.9280E+03	27.814
7502	5020	0.2653E+03	0.1989E+02	0.5567E+00	0.9879E+03	29.609
7502	5500	0.4087E+03	0.1060E+02	0.7128E+00	0.1002E+04	30.032
7502	6240	0.3256E+03	0.2469E+02	0.4298E+00	0.1092E+04	32.729
7602	4430	0.9496E+02	0.2743E+02	0.2393E+00	0.8276E+03	24.805
7602	5030	0.1640E+03	0.2154E+02	0.3649E+00	0.8275E+03	24.802
7602	5540	0.2093E+03	0.2173E+02	0.3916E+00	0.8905E+03	26.690
7701	4500	0.2361E+03	-0.1173E+02	0.1932E+01	0.9387E+03	28.135
7701	4990	0.2373E+03	0.1040E+02	0.8276E+00	0.8831E+03	26.468
7701	5620	0.2283E+03	0.1177E+02	0.8228E+00	0.9023E+03	27.044
7701	5980	0.2534E+03	0.1094E+02	0.7382E+00	0.8667E+03	25.977
7901	5690	0.2973E+03	0.2705E+01	0.1084E+01	0.8993E+03	26.954
7901	6060	0.1764E+03	0.1857E+02	0.5439E+00	0.8630E+03	25.866
7901	7040	0.3567E+03	0.8446E+01	0.7315E+00	0.9109E+03	27.301
7901	7900	0.3058E+03	0.1776E+02	0.6061E+00	0.1005E+04	30.122
8002	4370	0.1300E+03	0.1776E+02	0.6179E+00	0.8357E+03	25.047
8002	5010	0.2874E+03	0.1396E+00	0.1157E+01	0.8687E+03	26.037
8002	5530	0.2837E+03	0.6730E+01	0.9441E+00	0.9057E+03	27.145
8002	6320	0.2567E+03	0.1606E+02	0.7361E+00	0.9834E+03	29.474
8206	2750	0.1575E+03	0.8115E+01	0.4578E+00	0.5675E+03	17.009
8206	4050	0.2535E+03	0.5689E+01	0.5326E+00	0.6467E+03	19.383
8306	2700	0.1167E+03	0.1512E+02	0.2390E+00	0.5741E+03	17.207
8306	3490	0.2295E+03	0.9299E+01	0.4346E+00	0.6544E+03	19.614
8306	4140	0.2408E+03	0.8989E+01	0.4419E+00	0.6625E+03	19.856
8507	2560	0.1999E+03	0.1042E+02	0.3209E+00	0.5931E+03	17.776
8507	3370	0.2495E+03	0.1041E+02	0.3556E+00	0.6597E+03	19.772
8507	3900	0.2812E+03	0.1057E+02	0.3606E+00	0.6976E+03	20.908
9003	3970	0.2787E+03	0.6284E+01	0.7878E+00	0.8126E+03	24.355
9003	4380	0.1751E+03	0.2127E+02	0.3691E+00	0.8348E+03	25.020
9003	4810	0.3332E+03	-0.1193E+01	0.1156E+01	0.8838E+03	26.489

TABLF 2

TWIN SMALL POLL DYNAMOMETER

ID	WT (LB)	F0 (NT)	F1	F2	F50 (NT)	HP50 (HP)
5902	4330	-0.4729E+02	0.2558E+02	0.3496E+00	0.6991E+03	20.954
5902	5020	0.1486E+03	-0.1990E+00	0.1036E+01	0.6616E+03	19.830
5902	5500	0.2598E+02	0.1461E+02	0.5878E+00	0.6462E+03	19.368
7001	4620	0.2213E+03	0.1467E+02	0.4459E+00	0.7718E+03	23.132
7001	4930	0.2315E+03	0.5955E+01	0.8560E+00	0.7921E+03	23.742
7001	5530	0.3008E+03	-0.3290E+01	0.1101E+01	0.7772E+03	23.294
7001	6050	0.1199E+03	0.1961E+02	0.3673E+00	0.7416E+03	22.228
7001	6490	0.1277E+03	0.1550E+02	0.4333E+00	0.6906E+03	20.699
7001	8190	0.1370E+03	0.1643E+02	0.5747E+00	0.7914E+03	23.719
7101	4110	0.7475E+02	0.5693E+01	0.7936E+00	0.5984E+03	17.935
7101	4500	-0.4635E+02	0.1853E+02	0.4260E+00	0.5806E+03	17.403
7101	5020	0.8966E+01	0.1527E+02	0.4793E+00	0.5898E+03	17.676
7101	5330	0.3670E+02	0.7568E+01	0.8141E+00	0.6125E+03	18.358
7201	4540	0.4870E+00	0.1434E+02	0.5397E+00	0.5906E+03	17.701
7201	5110	0.9682E+01	0.1521E+02	0.5514E+00	0.6251E+03	18.735
7201	5480	0.9895E+02	0.1859E+01	0.9955E+00	0.6378E+03	19.115
7201	6060	-0.6946E+01	0.1545E+02	0.5473E+00	0.6118E+03	18.337
7301	4060	0.2128E+02	0.1114E+02	0.7422E+00	0.6410E+03	19.212
7301	4560	0.9802E+02	0.4292E+01	0.9434E+00	0.6652E+03	19.937
7301	5050	0.2810E+02	0.1452E+02	0.6076E+00	0.6561E+03	19.664
7301	6420	0.1282E+03	0.3050E+01	0.9219E+00	0.6569E+03	19.689
7402	5110	0.1394E+03	0.5212E+01	0.8931E+00	0.7021E+03	21.042
7402	5540	0.2290E+03	0.2340E+00	0.9776E+00	0.7226E+03	21.657
7402	5760	0.1382E+03	0.1386E+02	0.6139E+00	0.7547E+03	22.620
7502	4540	0.1590E+03	0.3484E+01	0.9580E+00	0.7155E+03	21.444
7502	5020	0.7562E+02	0.1699E+02	0.5567E+00	0.7335E+03	21.985
7502	5500	0.2069E+03	0.6598E+01	0.7128E+00	0.7105E+03	21.294
7502	6240	0.3731E+02	0.2224E+02	0.4298E+00	0.7491E+03	22.453
7602	4430	-0.9236E+02	0.2518E+02	0.2393E+00	0.5900E+03	17.684
7602	5030	-0.4137E+02	0.1937E+02	0.3649E+00	0.5739E+03	17.200
7602	5540	-0.2499E+02	0.1935E+02	0.3916E+00	0.6031E+03	18.077
7701	4500	0.6118E+02	-0.1396E+02	0.1932E+01	0.7142E+03	21.407
7701	4990	0.5631E+02	0.7926E+01	0.8276E+00	0.6469E+03	19.388
7701	5620	0.3708E+02	0.8842E+01	0.8228E+00	0.6457E+03	19.353
7701	5980	0.5046E+02	0.7917E+01	0.7382E+00	0.5962E+03	17.868
7901	5690	0.8686E+02	0.2580E+00	0.1084E+01	0.6341E+03	19.005
7901	6060	-0.3439E+02	0.1577E+02	0.5439E+00	0.5899E+03	17.679
7901	7040	0.1050E+03	0.5506E+01	0.7315E+00	0.5935E+03	17.788
7901	7900	-0.3242E+00	0.1479E+02	0.6061E+00	0.6329E+03	18.971
8002	4370	-0.3540E+02	0.1481E+02	0.6179E+00	0.6042E+03	18.108
8002	5010	0.1032E+03	-0.4191E+01	0.1157E+01	0.5875E+03	17.608
8002	5530	0.1079E+03	0.2047E+01	0.9441E+00	0.6252E+03	18.739
8002	6320	0.3664E+02	0.1129E+02	0.7361E+00	0.6567E+03	19.683
8206	2750	0.4360E+02	0.5711E+01	0.4578E+00	0.3999E+03	11.987
8206	4050	0.9085E+02	0.3330E+01	0.5326E+00	0.4313E+03	12.928
8306	2700	-0.1151E+02	0.1278E+02	0.2390E+00	0.3934E+03	11.792
8306	3490	0.6163E+02	0.6853E+01	0.4346E+00	0.4319E+03	12.944
8306	4140	0.5363E+02	0.6436E+01	0.4419E+00	0.4182E+03	12.535
8507	2560	0.7243E+02	0.8615E+01	0.3209E+00	0.4253E+03	12.746
8507	3370	0.1090E+03	0.8422E+01	0.3556E+00	0.4749E+03	14.233
8507	3900	0.1058E+03	0.8541E+01	0.3606E+00	0.4769E+03	14.292
9003	3970	0.8968E+02	0.4847E+01	0.7878E+00	0.5915E+03	17.729
9003	4380	-0.3542E+02	0.1974E+02	0.3691E+00	0.5901E+03	17.685
9003	4810	0.1048E+03	-0.2987E+01	0.1156E+01	0.6155E+03	18.449

TABLE 3
SINGLE LARGE ROLL DYNAMOMETER

ID	WT (LB)	F0 (NT)	F1	F2	FS0 (NT)	HP50 (HP)
5902	4330	0.4583E+02	0.2630E+02	0.3496E+00	0.8083E+03	24.226
5902	5020	0.2355E+03	0.1504E+01	0.1036E+01	0.7867E+03	23.577
5902	5500	0.1174E+03	0.1681E+02	0.5878E+00	0.7867E+03	23.579
7001	4620	0.2947E+03	0.1483E+02	0.4459E+00	0.8489E+03	25.444
7001	4930	0.3006E+03	0.6386E+01	0.8560E+00	0.8709E+03	26.102
7001	5530	0.3725E+03	-0.2756E+01	0.1101E+01	0.8609E+03	25.801
7001	6050	0.1959E+03	0.2000E+02	0.3673E+00	0.8265E+03	24.771
7001	6490	0.2066E+03	0.1570E+02	0.4333E+00	0.7740E+03	23.197
7001	8190	0.2029E+03	0.1667E+02	0.5747E+00	0.8626E+03	25.853
7101	4110	0.1379E+03	0.5763E+01	0.7936E+00	0.6631E+03	19.875
7101	4500	0.1456E+02	0.1872E+02	0.4260E+00	0.6458E+03	19.356
7101	5020	0.6346E+02	0.1555E+02	0.4793E+00	0.6504E+03	19.492
7101	5330	0.9162E+02	0.8049E+01	0.8141E+00	0.6782E+03	20.326
7201	4540	0.4720E+02	0.1502E+02	0.5397E+00	0.6526E+03	19.558
7201	5110	0.4910E+02	0.1555E+02	0.5514E+00	0.6721E+03	20.143
7201	5480	0.1347E+03	0.2133E+01	0.9955E+00	0.6796E+03	20.369
7201	6060	0.2517E+02	0.1591E+02	0.5473E+00	0.6542E+03	19.608
7301	4060	0.8357E+02	0.1151E+02	0.7422E+00	0.7117E+03	21.330
7301	4560	0.1684E+03	0.4764E+01	0.9434E+00	0.7461E+03	22.362
7301	5050	0.9657E+02	0.1522E+02	0.6076E+00	0.7404E+03	22.190
7301	6420	0.1871E+03	0.3722E+01	0.9219E+00	0.7307E+03	21.902
7402	5110	0.2058E+03	0.5184E+01	0.8931E+00	0.7678E+03	23.012
7402	5540	0.3032E+03	0.6090E+00	0.9776E+00	0.8052E+03	24.133
7402	5760	0.2107E+03	0.1421E+02	0.6139E+00	0.8349E+03	25.023
7502	4540	0.1841E+03	0.3401E+01	0.9580E+00	0.7386E+03	22.137
7502	5020	0.1163E+03	0.1694E+02	0.5567E+00	0.7730E+03	23.167
7502	5500	0.2385E+03	0.6915E+01	0.7128E+00	0.7491E+03	22.453
7502	6240	0.1134E+03	0.2187E+02	0.4298E+00	0.8168E+03	24.482
7602	4430	-0.2007E+02	0.2592E+02	0.2393E+00	0.6788E+03	20.344
7602	5030	0.3186E+02	0.1988E+02	0.3649E+00	0.6585E+03	19.738
7602	5540	0.5238E+02	0.2026E+02	0.3916E+00	0.7008E+03	21.004
7701	4500	0.1271E+03	-0.1358E+02	0.1932E+01	0.7887E+03	23.640
7701	4990	0.1304E+03	0.8088E+01	0.8276E+00	0.7246E+03	21.717
7701	5620	0.1113E+03	0.9080E+01	0.8228E+00	0.7253E+03	21.738
7701	5980	0.1233E+03	0.8122E+01	0.7382E+00	0.6735E+03	20.187
7901	5690	0.1755E+03	0.2400E-01	0.1084E+01	0.7175E+03	21.505
7901	6060	0.4281E+02	0.1562E+02	0.5439E+00	0.6635E+03	19.886
7901	7040	0.1964E+03	0.5454E+01	0.7315E+00	0.6837E+03	20.491
7901	7900	0.1054E+03	0.1503E+02	0.6061E+00	0.7441E+03	22.303
8002	4370	0.5093E+02	0.1428E+02	0.6179E+00	0.6787E+03	20.343
8002	5010	0.1830E+03	-0.3855E+01	0.1157E+01	0.6747E+03	20.223
8002	5530	0.1997E+03	0.2419E+01	0.9441E+00	0.7254E+03	21.741
8002	6320	0.1357E+03	0.1109E+02	0.7361E+00	0.7512E+03	22.515
8206	2750	0.7614E+02	0.5965E+01	0.4578E+00	0.4381E+03	13.132
8206	4050	0.1184E+03	0.3399E+01	0.5326E+00	0.4604E+03	13.799
8306	2700	0.3149E+02	0.1287E+02	0.2390E+00	0.4384E+03	13.141
8306	3490	0.1008E+03	0.6956E+01	0.4346E+00	0.4733E+03	14.187
8306	4140	0.8849E+02	0.6589E+01	0.4419E+00	0.4565E+03	13.682
8507	2560	0.9967E+02	0.8207E+01	0.3209E+00	0.4434E+03	13.289
8507	3370	0.1364E+03	0.8265E+01	0.3556E+00	0.4988E+03	14.950
8507	3900	0.1381E+03	0.8166E+01	0.3606E+00	0.5007E+03	15.008
9003	3970	0.1823E+03	0.4275E+01	0.7878E+00	0.6714E+03	20.122
9003	4380	0.6411E+02	0.1936E+02	0.3691E+00	0.6811E+03	20.413
9003	4810	0.2107E+03	-0.3418E+01	0.1156E+01	0.7117E+03	21.331

TABLE 4

MEAN VALUES OF THE

SMALL TWIN ROLL DYNAMOMETER

POWER ABSORBER SETTINGS AT 50 MPH

ID	EPA INERTIA WT. CLASS (LB)	FRONTAL AREA (FT**2)	MEAN POWER 50 MPH (HORSEPOWER)
5902	4500	31.4(F)	20.051
7001	5000	32.0(GM)	22.802
7101	4500	31.6(GM)	17.843
7201	4500	31.6(GM)	18.472
7301	4000	37.0(GM)	19.625
7402	5000	31.4(F)	21.773
7502	4500	33.6(F)	21.794
7602	4500	31.4(F)	17.654
7701	4500	37.0(GM)	19.504
7901	6000	37.0(GM)	18.361
8002	4500	37.7(F)	18.534
8206	3000	21.2(EPA)	12.457
8306	3000	21.2(EPA)	12.424
8507	2500	21.2(EPA)	13.757
9003	4000	35.1(EPA)	17.954