the cooling system boiled A door was then arranged in both front and rear to allow circulation right up to the time the car moves on to the test mile when both doors are closed and cold water is automatically pumped into the cooling system from an extra supply tank carried on the car

The envelope is quite light so was pushed and pulled by the turbulent eddies at the rear so violently that the scale could not be read until the great dash pots shown in Figure 6, were installed

A very slight wind, in fact any wind that would run the Frieze anemometer would cause the points to fall away off the curve So a call is put in to the weather bureau every day to ask whether the wind will be low the following night and then only the period from 3 A M to 7 A M is usually available for accurate test results

In calibrating the dynamometer it was found that the rear axle torque reaction and the wind pressure both tilted the car backward changing the level of the rollers The car springs had so much friction in them that they would not return to a normal position after being compressed Finally all calibration was made with the engine driving the rear wheels on the drums of the chassis dynamometer taking great pains to keep the weight distribution in the vehicle exactly the same

Thus we find plenty of difficulty in working out this new method, but we are going to complete the work on at least two models, the rectangular box and a practical streamlined body like that shown here in 1931 Wind tunnel tests of exact replicas made to one-eighth scale will be made so that we will have correlated test data for a body of the truck or bus type and of an automobile of very low air resistance

TRACTIVE RESISTANCE DETERMINATIONS WITH A GAS-ELECTRIC DRIVE AUTOMOBILE

By Raymond G Paustian

Junior Highway Engineer, Iowa Engineering Experiment Station

SYNOPSIS

Calibration tests and road tests made with a car with a gas-electric drive are described in this paper Runs have been made on concrete, treated gravel, untreated gravel, and wet muddy roads Curves have been plotted to show gas consumption, power requirements and attractive resistance on these surfaces at speeds up to sixty miles per hour During the course of these researches, several interesting discoveries have been made as to the effect of speed on tire diameters and the effect of tire inflation on power requirements

This is a progress report on a project started by the Iowa Engineering Experiment Station several years ago and described by the author at the 1931 meeting of the Highway Research Board An opinion that the set-up would provide an accurate and dependable method of determining the tractive resistance of various roadway surfaces at both high and low speeds was expressed at that time. The performance of the equipment has more than exceeded those expectations and much valuable and interesting information has been collected during the past year.

LABORATORY CALIBRATION

The car being used is a Model 134 Cadillac coach in which the transmission has been replaced with an electric generator and motor. The generator is connected to the gasoline engine and furnishes electrical

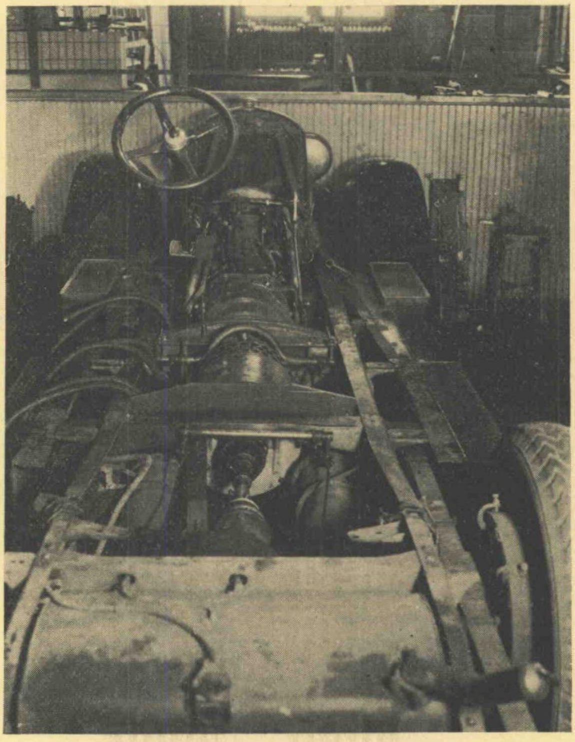

Figure 1. Chassis Assembly

energy to the driving motor attached to the rear wheels in accordance with the speed of the engine and the power required to move the car. The electrical energy developed is metered and an accurate measurement of the power requirements may thus be had. In addition to the electrical equipment, the car is equipped to give accurate measurements of gasoline consumption and to record both front and rear wheel revolutions. A view of the chassis assembly showing the generator and motor in place is shown in Figure 1; Figures 2 and 3 show, respectively, a general view of the car and a view of the instrument panel and meters.

An improvised laboratory set-up of a temporary nature was used in the calibration of the car; a general view of which is shown in Figure 4. The dynamometer drums and shaft are connected directly to a 100 H.P. Sprague dynamometer that may be used either as an absorption dynamometer or as a motor. The drums have laminated wooden rims and roll on roller bearings. A prony brake assembly is attached to the left end of the shaft for power absorption purposes. A steel pulling stand with a bell crank and platform scales to measure draw bar pull is also evident in the photograph. A wooden platform was built around the drums and the car pulled up on a ramp. A view of the equipment with the car in position for a test is shown in Figures 4 and 5.

Determination of Losses. The laboratory calibration was undertaken for the purpose of determining (1) the individual losses in the moving

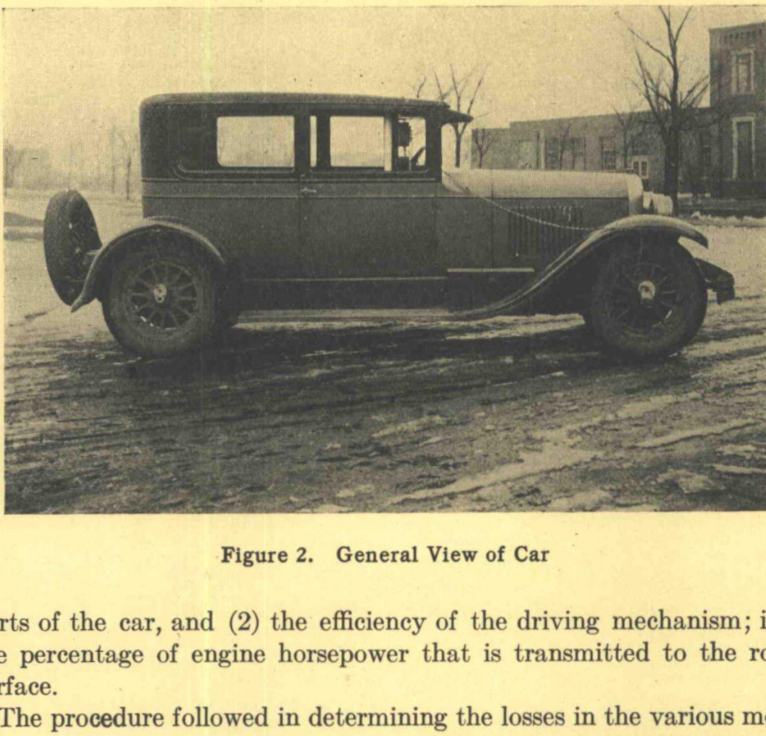

Figure 2. General View of Car

parts of the car, and (2) the efficiency of the driving mechanism; i.e., the percentage of engine horsepower that is transmitted to the road surface.

The procedure followed in determining the losses in the various moving parts of the car was to use the dynamometer as a motor to drive the drums and the wheels of the car. Runs were made in the following sequence, noting, of course, the power requirements in each case; (1) dynamometer drums and shaft alone; (2) rear wheels of car on drums with car drive shaft disconnected; (3) same as (2) except with tires at inflations varying from 25 pounds to 60 pounds; (4) rear wheels of car on drums with car drive shaft connected; and (5) front wheels on drums. In each case, the car was centered on the drums and, at various speeds, records were taken for wheel revolutions, drum revolutions, time, dynamometer reaction, tire inflation, etc. The results of these tests are clearly shown in Figure 6, wherein the losses in the various parts are clearly indicated.

Under (2) above a rather interesting series of tests was made. With the rear wheels of the car centered on the drums and the drive shaft of

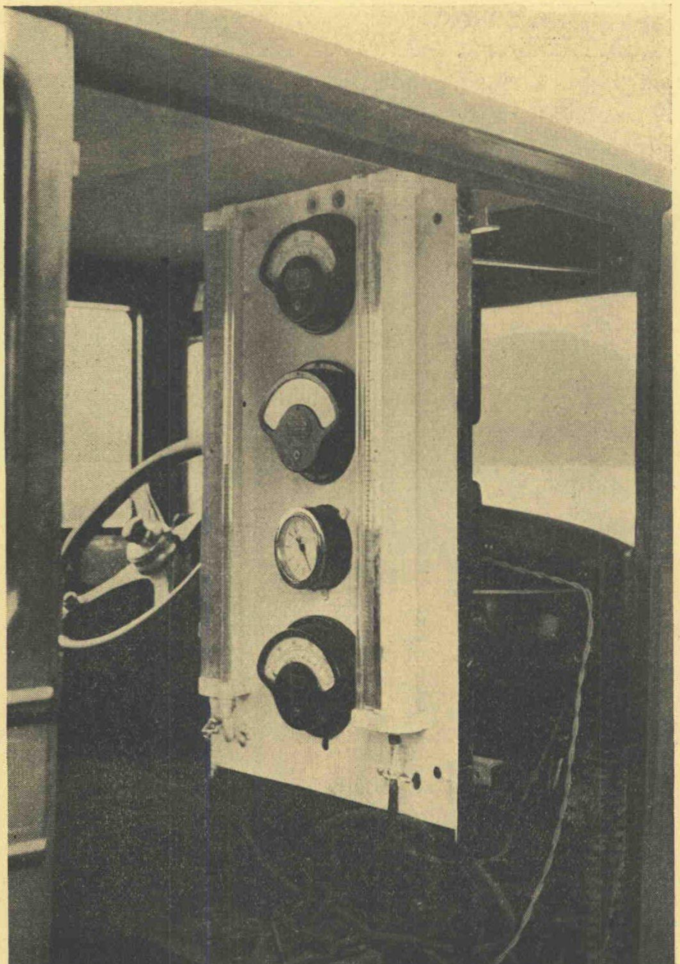

Figure 3. Instrument Panel

the car disconnected, runs were made with tire inflations varying from 60 pounds to 25 pounds. Normal inflation is 45 pounds. The values thus obtained are plotted in Figure 7; it is noted that a decided power loss takes place as the tire inflation is decreased.

One apparent discrepancy in the ratio between wheel diameter and drum diameter was investigated until it was discovered that the diameter of the tires underwent a considerable increase as the speed increased. An average change of about $1\frac{1}{2}$ inches was noted when the speed was

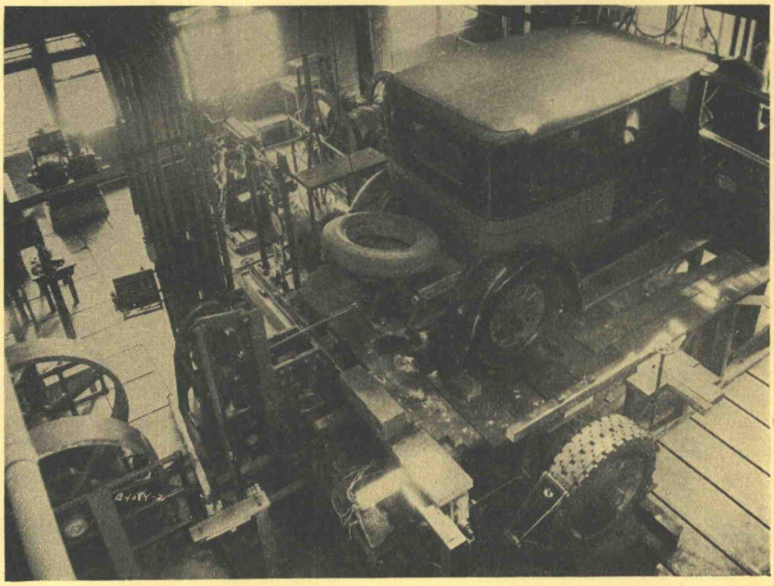

Figure 4. General View of Dynamometer Set-up

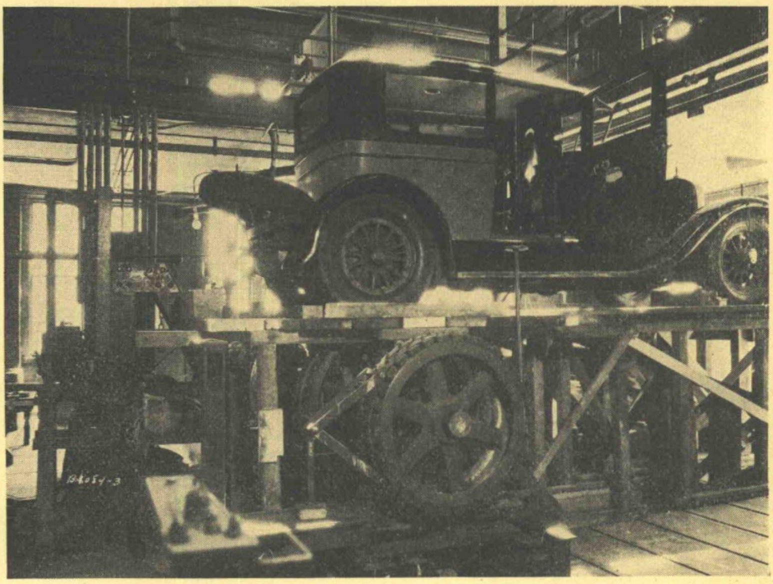

Figure 5. Car in Position for Calibration Test

increased from 5 to 65 miles per hour. This factor has been carefully checked in road tests and will be discussed later.

Mechanical Efficiency In determining the mechanical efficiency, or ratio of output horse power to input horse power, the rear wheels of the car were accurately centered on the drums by means of an engineer's transit set on line with the center of the drum shaft The front wheels of the car did not rest on the platform, the front wheel friction was eliminated by supporting the front axle on knife-edges The power developed by the car was absorbed by the prony brake attached to the end of the shaft By adding the shaft loss to the brake horse power, it

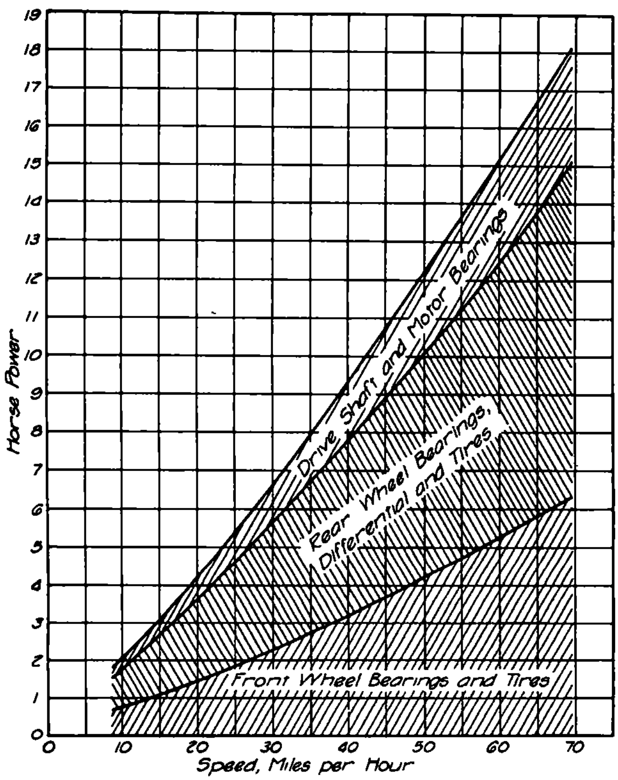

Figure 6. Horse Power Losses in Moving Parts of Cadillac Gas-Electric Car

was possible to determine draw-bar horse power; this, in turn, was checked by the reading of the platform scale attached to the bell crank of the pulling stand A consistent check between calculated and observed draw-bar horse power was noted

In making the runs for this determination it was necessary to record, for the car, speedometer readings, amperes, volts, gasoline consumption, and wheel revolutions, and for the brake assembly, shaft revolutions, prony brake scale readings, and pulling stand readings The results of runs taken on four consecutive days are shown in the efficiency curves of Figure 8 These may be said to be total mechanical efficiency curves, as they include front wheel losses.

A curve showing the horse power developed by the gasoline engine for a definite quantity of gasoline comprises Figure 9 Assuming that each pound of gasoline used contains 19,200 B T U , it is quite evident that the over all efficiency may be calculated from Figures 8 and 9 Such efficiency curves have been plotted and are shown in Figure 10,

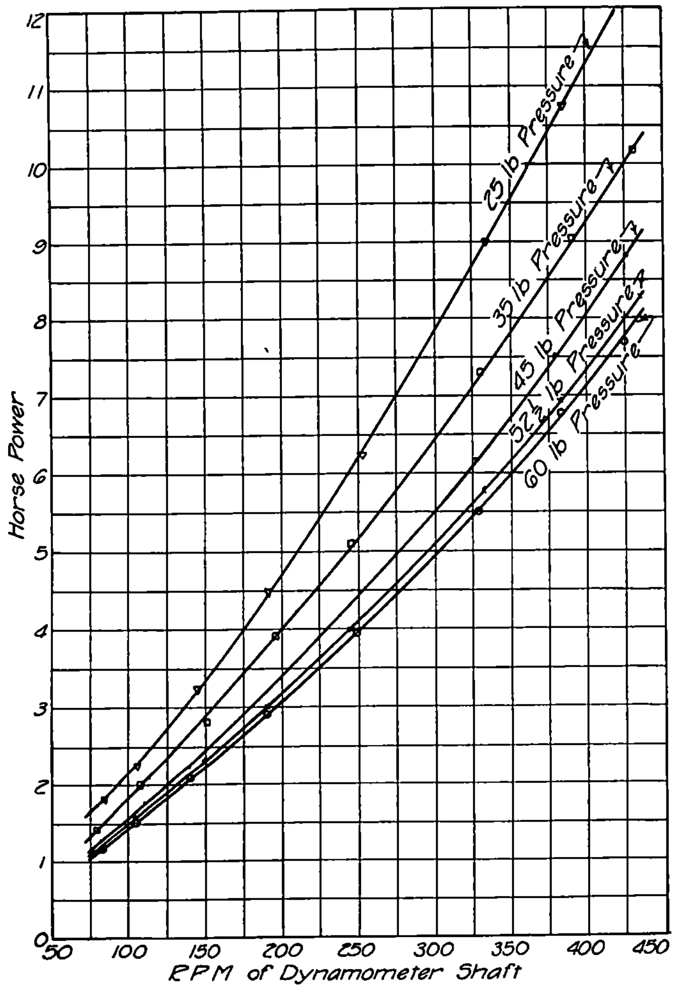

Figure 7. Effect of Tire Inflation on Power Requirements

evidently, only a very small part of the power contained in a gallon of gasoline can be utilized in overcoming the forces which tend to impede the progress of the vehicle on the road

ROAD TESTS

Road tests conducted during the past season consisted primarily of tests made to determine the power requirements of the car while

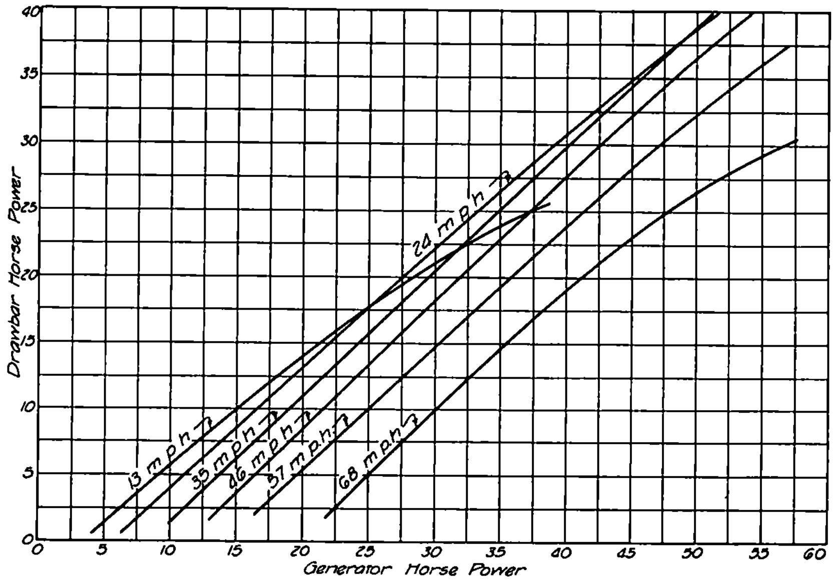

Figure 8 Efficiency Curves Showing the Relation between Output and Input Horse Power

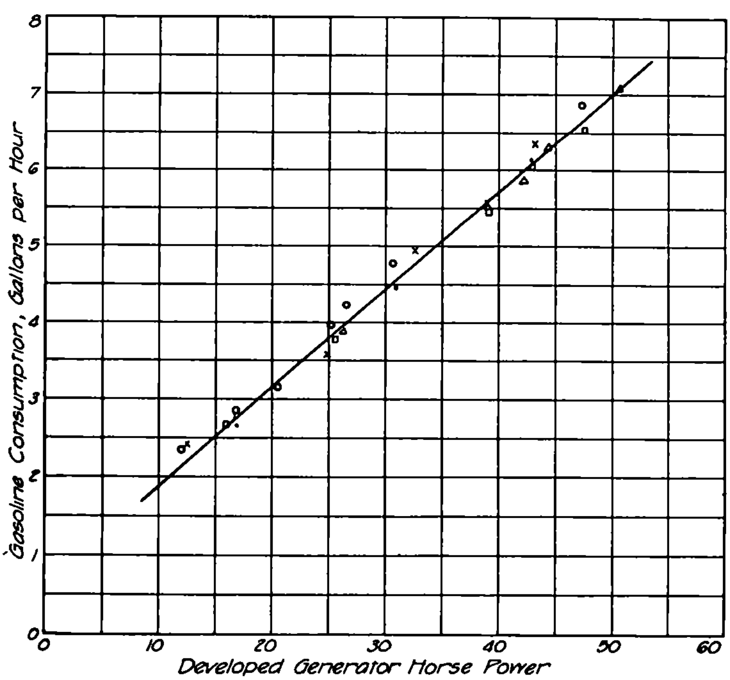

Figure 9 Curve Showing Gasoline Consumption

traveling over different road surfaces under different temperature and climatic conditions In other words, a careful determination of tractive resistance, or rolling plus air resistance, was made

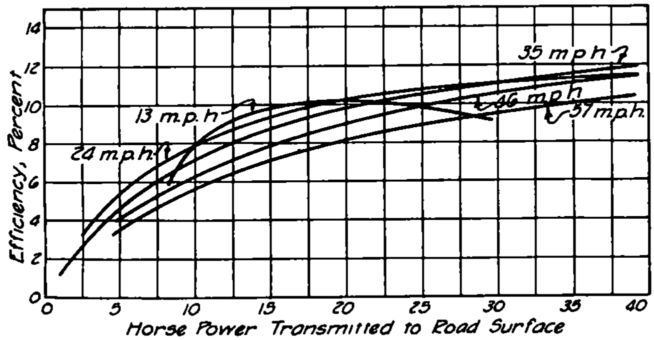

Figure 10 Overall Efficiency Curves

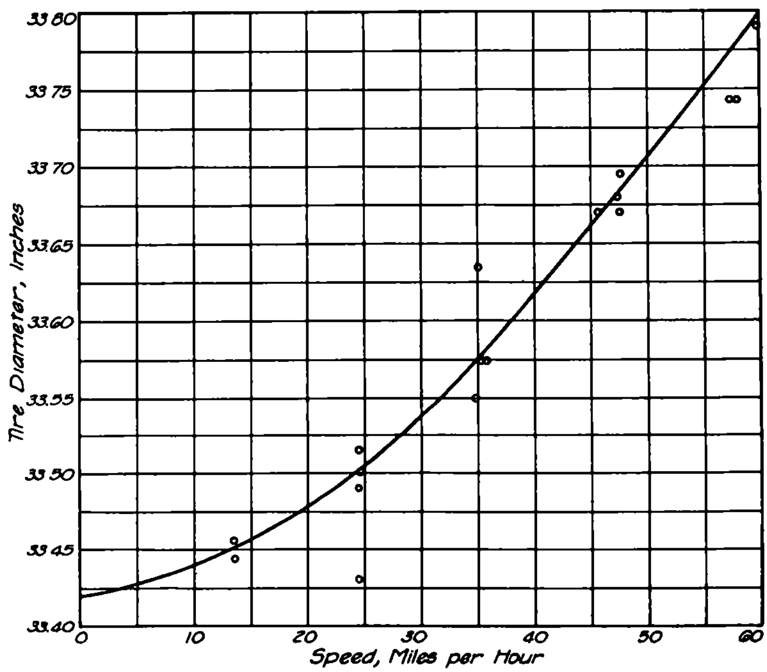

Figure 11. Curve Showing Effect of Speed on Tire Diameter

Equipment and Method of Procedure The instruments shown in Figure 3 consist of two gasoline gauges (burrettes calibrated to 0 005 gal), an ammeter and voltmeter to record generator output, a photographic timer used as a half-second timing device, and a voltmeter attached to a tachometer on the front wheel to give an accurate indication of the speed These are supplemented by a space-time recorder of the usual paper roll type, driven by a controlled variable speed motor The recorder has four contact points connected to as many induction coils, which furnish a record by burning holes through the moving paper ribbon One contact point is attached to a contact on the front wheel, another to a contact on the rear wheel, another to the timing device, and the last to two push-buttons, one of which is used to mark the begin-

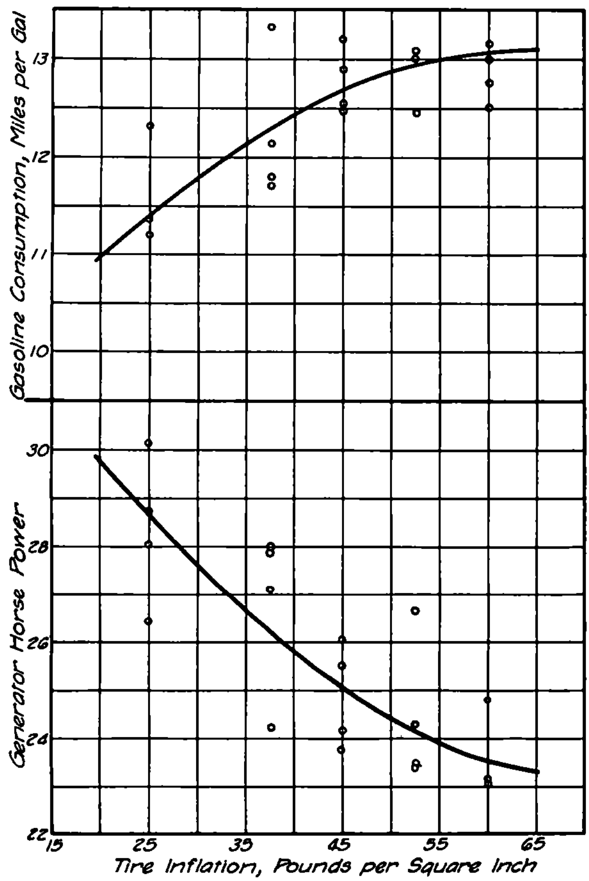

Figure 12. Effect of Tire Inflation on Gasoline Consumption and Power Requirements at 40 Miles per Hour

ning and end of run and the other to record gasoline consumption From the paper ribbons, it is possible to obtain records of front and rear wheel revolutions, of actual speed, and of gasoline consumption These, tied in which the power readings furnished by the instruments on the panel, give an accurate and unfailing record of the performance of the car

The method of procedure used in making road tests was to run the car over a measured course not less than one-half mile in length, and record the necessary data In most cases, four runs (two in each direction) at speedometer readings of 10, 20, 30, 40, and 50 miles per hour comprised one series These correspond to actual speeds of 13, 24, 35, 46, and 57 miles per hour The crew of the car consists of a driver and two observers, making the average road weight of the car about 6000 pounds

Tire Diameter Changes The increase in tire diameter noted in the calibration of the car on the dynamometer was carefully checked by a series of road tests The results of these tests are shown in Figure 11, an increase of approximately 0 4 inch in diameter is apparent with an increase of speed from 0 to 60 miles per hour Aside from the necessity of knowing this variation for purposes of the present investigation, it is

TABLE I

REAR WHEEL SLIPPAGE ON VARIOUS TYPES OF ROADWAY SURFACES

Run No	Type of surface	Condition	Slip at various speeds—per cent			
			24 M P H	35 M P H	46 M P H	57 M P H
8-10	Gravel	Dry	0 12	0 20	0 36	
8-11	Gravel	Wet	0 29	0 39	0 48	
8-13	Rough Gravel	Wet	0 51	0 53		
8-13	Corr Gravel	Wet	0 53	0 73		
8-13	Gravel and Mud	Soft	8 65			
8-18	Bit Tr Gravel	Dry	0 09	0 10	0 26	0 46
8-22	Rough Concrete	Dry	0 10	0 15	0 21	0 53

evident that the reading of the speedometer on the average car is affected to a more or less extent by this change

The Effect of Tire Inflation on Power Requirements As a result of the dynamometer tests, it was thought that the effect of tire inflation on power requirements might well be investigated by a series of road tests Inasmuch as the loss in the tires due to a difference in inflation is quite small compared to the total engine horsepower, it was evident that extreme care would have to be exercised in the power measurements With this thought in mind, road tests were made at a speed of about 45 miles per hour for tire inflations varying from 60 to 25 pounds per square inch The resulting gasoline mileage curve and horse power curve is shown in Figure 12 The fallacy of allowing tire pressures to drop below normal is quite apparent

Rear Wheel Slippage When a car travels along a road, there is a certain amount of slippage between the rear wheels and the road surface A measurement of this factor may be had by comparing the number of revolutions of front and rear wheels and expressing the difference, or "slip," as a percentage of front wheel revolutions Such percentages have been calculated and are included as a part of Table I It will be noted that the slippage rarely exceeds one per cent

Power Requirements on Various Types of Surfaces The tests that have thus far been described, with the exception of slippage, were run on smooth concrete pavement Tests have been made on many different types of surfaces, however, and the power requirements determined in each case The surfaces on which runs were made include smooth concrete, both wet and dry, rough concrete, bituminous treated gravel,

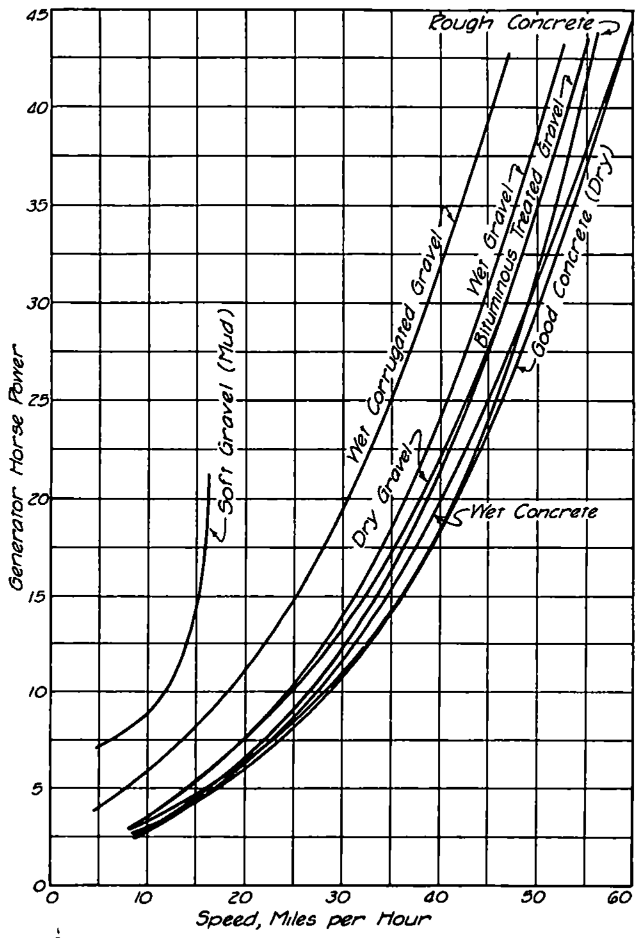

Figure 13. Effect of Road Surface on Horse Power Requirements

dry light gravel, loose gravel, wet gravel, wet corrugated gravel, and soft, muddy gravel All tests were made early in the morning, in the absence of any wind, with all windows in the car closed

The results of these tests have been shown in Figures 13 and 14 The horsepower values from which the curves of Figure 13 are plotted were calculated on the basis of the ammeter and voltmeter readings The effect of the type of road surface and the power required is clearly indicated Gasoline consumption is also affected by the type of road surface in accordance with the curves shown in Figure 14

ANALYSIS OF TRACTIVE RESISTANCE

The term "tractive resistance" is usually interpreted to mean a hypothetical force whose line of action is parallel to the road surface and the longitudinal axis of the vehicle and whose magnitude is equal to the summation of the components in that line of all forces acting upon the vehicle when it is traveling on a level surface In other words, tractive resistance may be considered as the sum of rolling resistance and air resistance The magnitude of this force may be expressed in pounds, or, as it is more commonly denoted, in pounds per ton

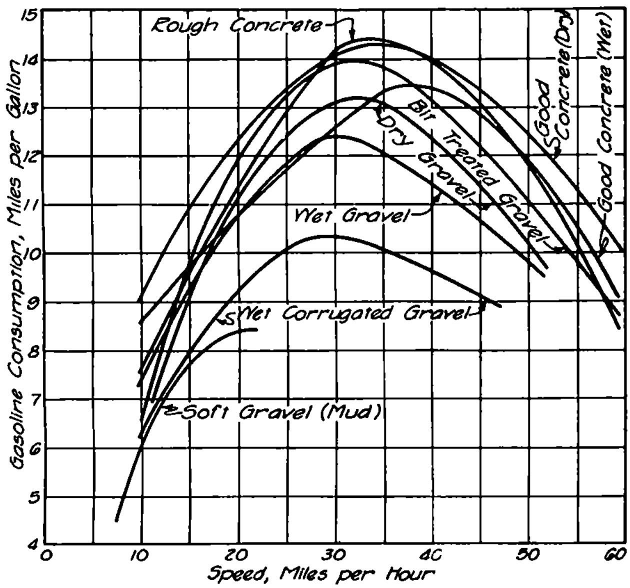

Figure 14. Effect of Road Surface on Gasoline Consumption

From the road tests and laboratory calibrations that have been described, it is possible to determine the components of tractive resistance when the car travels over any type of road surface Such an analysis will now be made for a smooth concrete pavement

Determination of Wind Resistance In Figure 15, the curve labeled "engine horsepower" represents the power required to move the vehicle over a smooth concrete pavement at the speeds indicated This curve has been plotted from data taken during a test run A certain amount of this power is used up in overcoming rolling resistance (due to friction in the moving parts of the vehicle), while the balance is transmitted to the road surface to overcome air resistance The smoothness of the road surface obviates any need for the consideration of impact resistance: grade resistance is likewise eliminated because of the flatness of the test course and the manner in which runs are made The efficiency curves of Figure 8 show that a definite part of the engine horse power is used to overcome friction in the moving parts, tire resistance, etc Assuming that these values, determined for definite values of engine horse power at definite speeds, apply to road conditions, it is at once evident that the power required to overcome air resistance can be deter-

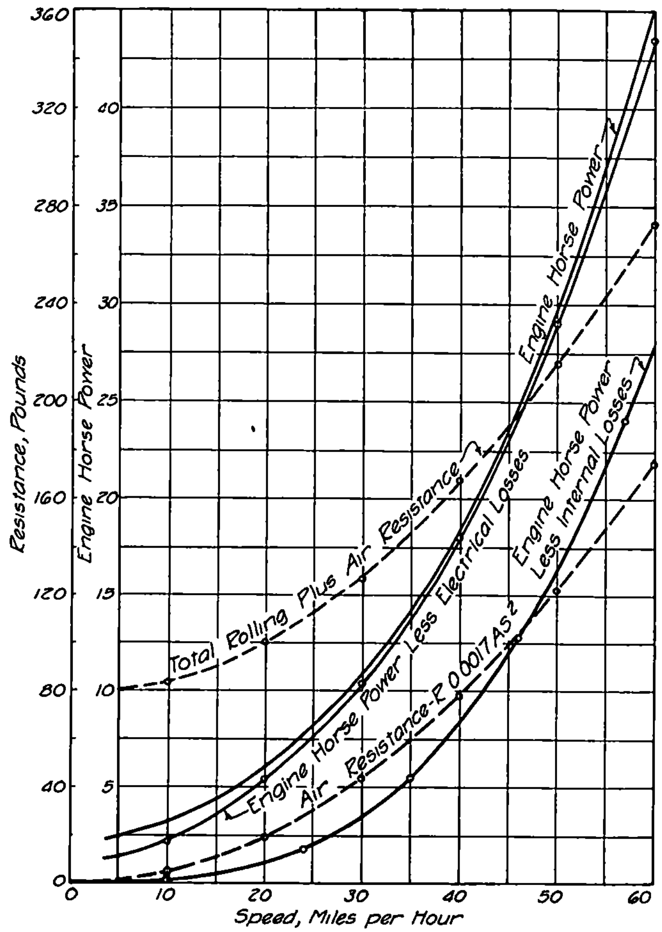

Figure 15. Analysis of Tractive Resistance—Smooth Concrete Pavement

mined These values have been computed and plotted in Figure 15 as points on the curve labeled "Engine Horsepower less internal losses"

If the horse power, the wheel radius, and the number of wheel revolutions per minute are known, it is possible to calculate the resisting force by the formula

$$H P = \frac{2\pi r\, NW}{33000},$$

where r = the radius of the wheel
N = R P M of the wheel
W = the resisting force in pounds

Taking values from the horsepower windage curve (engine horsepower less internal losses) and substituting them in this formula, it becomes possible to express the resistance force of the air in pounds The forces thus determined have been plotted to form an "Air Resistance" curve

The shape of the usual air resistance curve ordinarily conforms to the expression

$$R = KAS^2,$$

wherein: R = the total resistance in pounds
K = a constant
A = the projected area of the car in square feet = 28 72 sq ft
S = the speed in miles per hour

If values are taken from the air resistance curve of Figure 15 and substituted in the above formula, it is found that $K = 0\,0017$ Furthermore, every point on the air resistance curve, as *calculated* and *plotted*, falls on the curve represented by the equation $R = 0\,0017\ AS^2$ Such a check indicates the probable correctness of the data, and is especially encouraging since the value of $K = 0\,0017$ is identical with that given by Prof E H Lockwood[1] for closed cars

Determination of Rolling plus Air Resistance The power losses in the moving parts of the car, the values for which are given in Figure 6, may now be added to the power values given to overcome air resistance It is at once evident that the resulting values indicate the power necessary to overcome both air and rolling resistance, it should be noted that electrical losses through the driving motor are not included A power curve representing "Engine Horsepower Less Electrical Losses" has been shown in Figure 15 On the basis of this curve, calculations have been made to determine "Total Rolling Plus Air Resistance," resulting in the curve thus labeled in the figure

The curves of Figure 15 have a double significance in that the accuracy of the determinations is assured because of the close agreement with the accepted values for air resistance, and that tractive resistance may be separated into its component parts with comparative ease

Determination of Impact Resistance and Surface Resistance In order to further disclose the possibilities of the present investigation, an attempt will be made to separate impact resistance and surface resistance from total tractive resistance In this case, the power curve shown in Figure 13 for a wet, corrugated gravel surfaced road will be used As in the foregoing analysis, the internal losses were separated from the total power consumption through use of the efficiency curves Calcula-

[1] "Air Resistance of Automobiles," E H Lockwood Proceedings, Eighth Annual Meeting of the Highway Research Board, pp 142–153.

tions made to determine the magnitude of the remaining resisting force result in curve A of Figure 16 Evidently, this curve represents the the sum of air resistance, impact resistance, and surface resistance Separation of air resistance is accomplished through rise of the formula $R = 0\ 0017\ AS^2$, curve B, therefore, represents impact resistance plus surface resistance

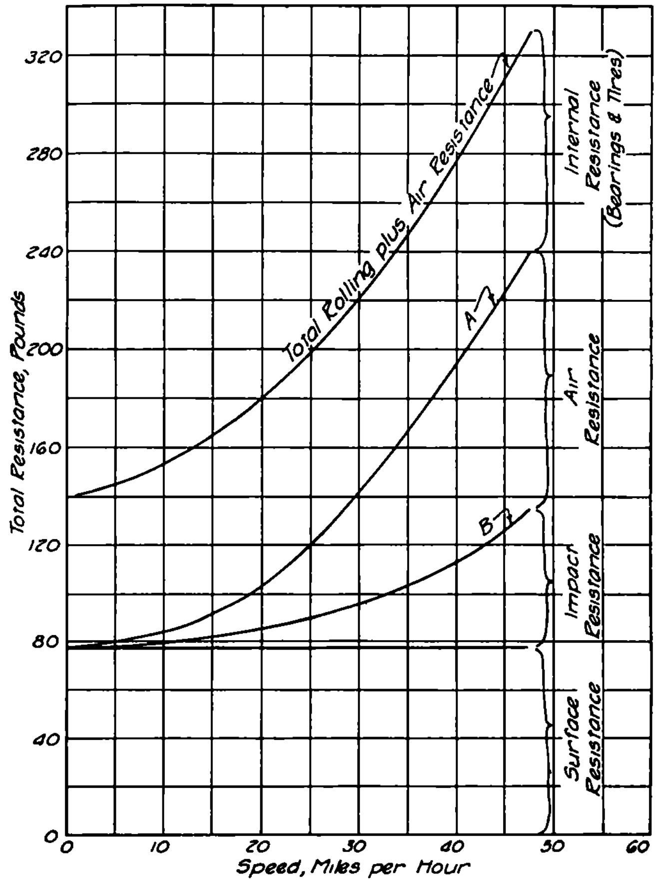

Figure 16 Analysis of Tractive Resistance—Wet Corrugated Gravel Surface

A horizontal line drawn through the value given by curves A and B at a speed of zero miles per hours, represents surface resistance It is quite natural to believe that the resistance due to the condition of the road surface will remain constant, regardless of speed The separation of impact resistance and surface resistance is thus accomplished with comparative ease The total rolling plus air resistance curve has, of course, been obtained by adding the internal losses to curve A The total resistance of 140 pounds at the lower speed for a rough gravel surface should be compared with a total resistance of 80 pounds for smooth concrete at the same speed

SUMMARY

In summarizing the foregoing progress report, it is difficult to arrive at any definite conclusions It is of singular significance that we have, in the present equipment, an accurate and practical way of determining tractive resistance Furthermore, the separation of this item into its component parts has been accomplished with relative ease At the present time, the investigation is being carried on along the lines described in this paper It should result in a determination of values for impact resistance, surface resistance, etc , for different surfaces under different conditions The value of such knowledge to the highway engineering profession can hardly be over-emphasized

HIGHWAY GRADES AND MOTOR VEHICLE COSTS

By Howard Burton Shaw

Professor of Industrial Engineering, North Carolina State College

SYNOPSIS

The presentation of a direct method of computing the relative use of gasoline on grades and on the level at different constant speeds without recourse to the utilization of kinetic energy nor to the method which makes use of the potential energy for a "rise" of one foot Observed ranges of rolling plus air resistance are given

Grades, the descent of which at a specified constant speed require neither positive nor negative power from the engine are designated as "floating grades " Ranges of floating grades for passenger cars are computed

Comparisons of average amounts of gasoline for ascending and descending grades with amounts used on the level are made

No-extra-gasoline-cost grades are determined, although more data on straight-line characteristics of engines (and carburetors) of modern cars are needed for more precise determination

Examples of application and extension of the method to several individual up-to-date trucks are given in brief, and its application to the problem of justification of expenditures for grade reduction is discussed

Very careful consideration of the effects of highway grades upon motor vehicle costs is essential to the economic relocation of highways This article presents a direct method of determining the effects of different highway grades upon one of the main items of motor vehicle cost, that is, the cost of gasoline, when the vehicle is operated at a constant speed, thus omitting the consideration of kinetic energy and "rise and fall" by the potential energy method The general application of this direct method requires more data than are yet available, illustrations of its application are given, however, and some general conclusions are