REPORT OF PROJECT COMMITTEE ON TRACTIVE RESISTANCE AND ALLIED PROBLEMS

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FURTHER TRACTIVE RESISTANCE TESTS WITH A GAS ELECTRIC DRIVE AUTOMOBILE

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[In Abstract[1]]

Further tests on the gas-electric drive automobile described at the Twelfth Annual Meeting of the Highway Research Board are given in this report The equipment and methods used are described in the Twelfth Proceedings of the Highway Research Board [2] For these tests the Model 314 Cadillac Coach with General Electric gas-electric drive was used with an average weight, including driver and two observers, of 6300 pounds The tires were 33 by 6 75 inch heavy duty balloons, normal inflation 45 lb per sq in , load per tire 1575 pounds.

Several methods[3] of measuring tractive resistance have been described To them should be added the method by direct measurement used in this investigation In this method the magnitudes of the forces resisting movement of the vehicle are determined by measuring the electrical energy consumed in propelling the car

A series of runs was first made on a level concrete road surface at a uniform temperature of 70°F to determine the amount of power required to drive the test car at various speeds From these tests it was found that the total tractive resistance (rolling + air resistance) could be expressed by the formula

$$R = 45.0 + 1\ 6125S + 0\ 025875S^2$$

where R = Total tractive resistance
S = Speed in miles per hour

The correctness of this formula was verified by a series of determinations of the tractive resistance of the test car by means of the "Coasting Method"[3] using one, two and three per cent grades The

[1] A detailed report of this investigation may be found in a forthcoming Bulletin of the Engineering Experiment Station, Iowa State College

[2] Tractive Resistance Determinations with a Gas Electric Drive Automobile, R G Paustian, Proc Highway Research Board, Vol 12, page 75

[3] Air Resistance of Motor Vehicles, W E Lay, Proc Highway Research Board, Vol 12, pp 66–75

results of these tests were corrected for the effects of weight variation, temperature and wind in so far as is possible at present The values for various speeds are shown in Figure 1

Having thus established the accuracy of the determinations the total resistance was then separated into its component parts, rolling and air resistance, by chassis dynamometer tests of rolling resistance Efficiency curves plotted from the results of the dynamometer tests indicated what percentage of total power at the drive shaft is used in overcoming rolling resistance and what amount is available for use in

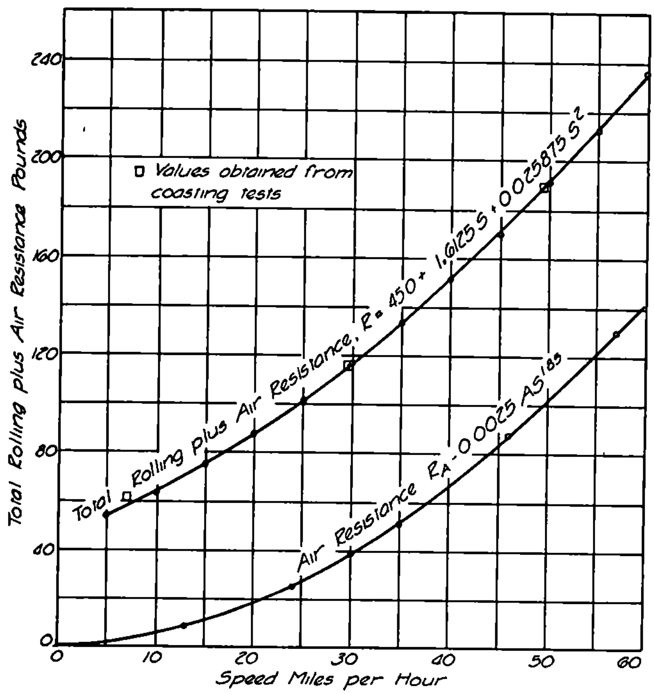

Figure 1 Analysis of tractive resistance on a level road surface. Smooth concrete surface. Temperature 70°F.

overcoming air resistance on the road The following formulas applicable to the particular car in use were deduced from these tests:

$$\text{Rolling Resistance} = R_r = 45 + 3\ 189S^{0\ 676}$$
$$\text{Air Resistance} = R_a = 0\ 0025AS^{1\ 85} \text{ (Fig 1)}$$

where A = projected area of car (28 72 sq ft in this case)

Having these fundamental characteristics established, investigations were made of power and gasoline consumption on grades, energy consumption on rolling grades, temperature effects, wind effects, and tire behavior.

POWER AND GASOLINE CONSUMPTION ON GRADES

On ascending grades, to the rolling and air resistance must be added the grade resistance due to the component of the weight of the vehicle down the grade. It is equal to 20 lbs per ton of vehicle weight times

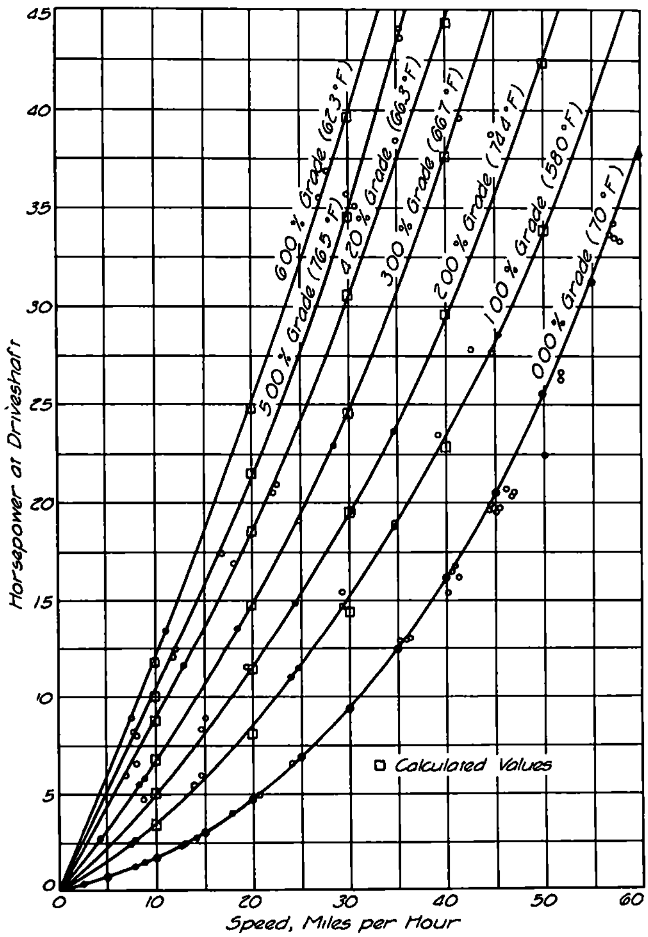

Figure 2. Power requirements on grades Concrete pavement

the per cent of grade The amount of power required to overcome the grade resistance can be calculated from the formula

$$H P = \frac{R \ S}{375}$$

where R = total resistance and S = speed in miles per hour The results of tests on individual grades from one to six per cent (Fig 2) show exceedingly close agreement between the measured and calculated values of rollıng plus aır plus grade resıstance An ınterestıng feature of these tests ıs the ındıcatıon that there ıs a definıte relatıon between rate of grade and the speed at whıch the greatest mıleage per gallon of gasolıne ıs secured (Fıg 3)

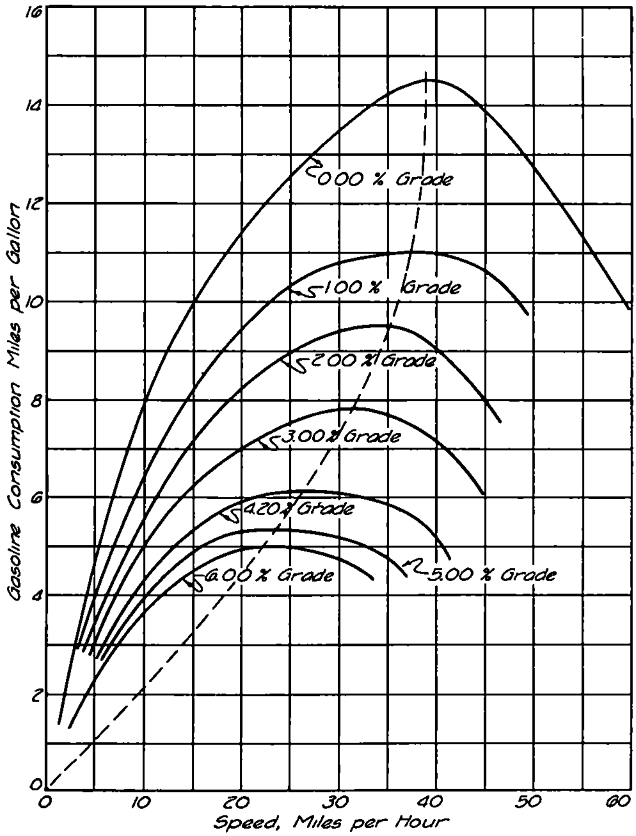

Figure 3. Gasoline consumption on grades Concrete pavement

Energy Consumptıon on Rollıng Grades

In order to secure data related to ordınary drıvıng condıtıons, tests were made over roads havıng serıes of ascendıng and descendıng grades, thus brıngıng ın the effects due to momentum The record was secured by takıng photographs of the ınstrument panel

Most of these runs were made at constant throttle openıng although data were also secured for constant speed operatıon and by allowıng the car to coast down and then ascend at a constant speed (called mınımum speed) The operatıon wıth constant throttle openıngs showed a definıte ıncrease ın speed over that whıch the same throttle openıngs gave on the level surface Constant throttle openıng was accompanıed by constant power consumptıon ırrespectıve of the road profile

A surprising result of the constant throttle opening was that the average amount of power used in traveling over a rolling grade at a certain average speed was less than that required to propel the car over a level surface at the same speed (Fig 4)

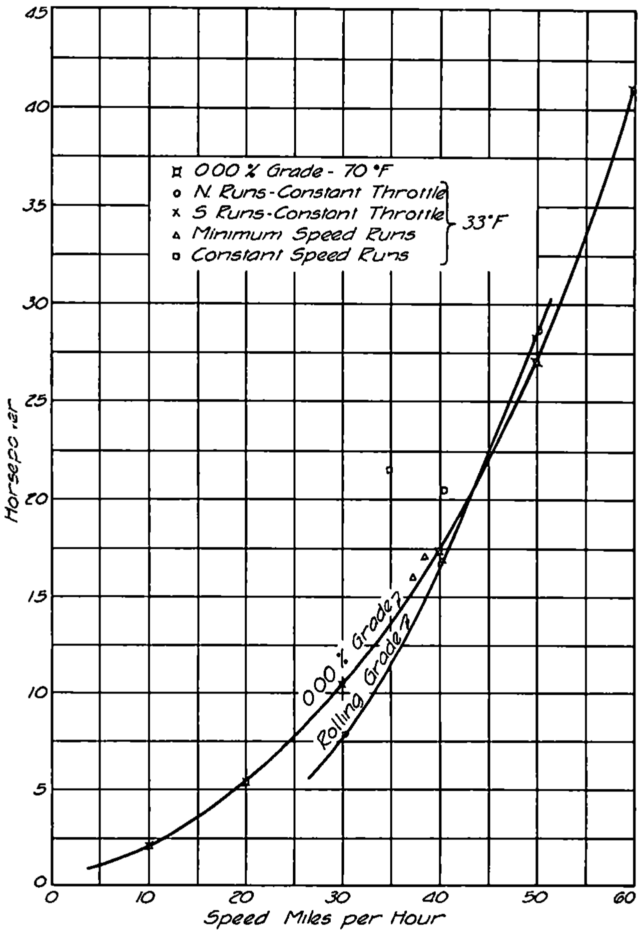

Figure 4. Comparison of power requirements on rolling and level grades

The "constant speed" and "minimum speed" runs showed increases in power consumption over those used on the zero per cent grade The increase in the average power used at constant speed may be accounted for by the fact that the brakes are used while descending and excessive power was needed in ascending The average amount of power used in the minimum speed runs was less than that used at constant speed and more than that needed for constant throttle

TEMPERATURE EFFECTS

The results of the tests indicate definitely that power consumption increases with decrease in temperature and that the effect increases with speed At 45 miles per hour the increase in power caused by a temperature drop of from 57°F to 21°F was 3 75 H P

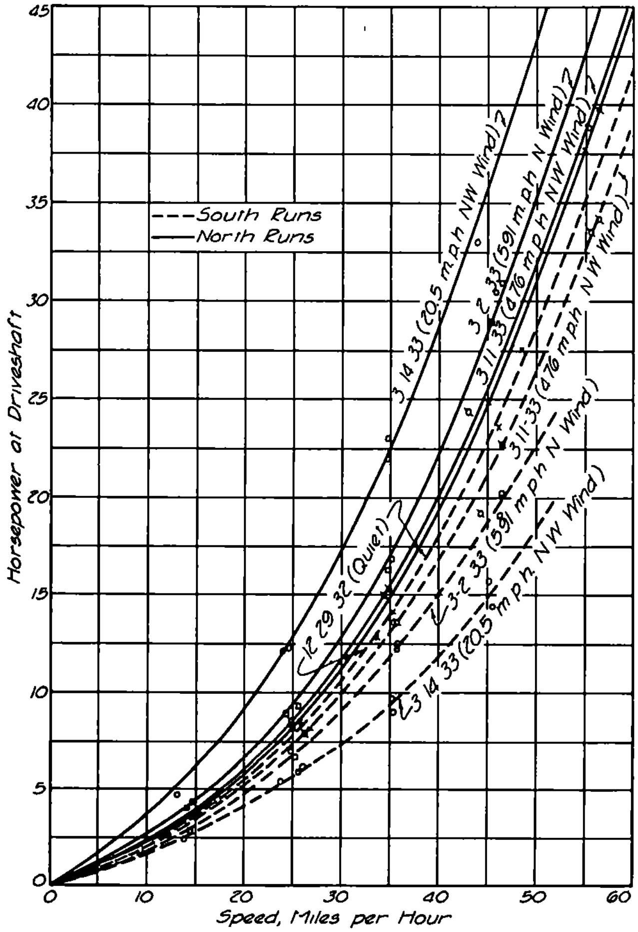

Figure 5 Effects of wind on power consumption

EFFECTS OF WIND

A number of interesting runs were made showing the effects of head winds and tail winds of various velocities upon power consumption Wind velocities were measured by a pitot-static tube mounted on the front of the car and connected with a manometer tube on the instrument panel Typical relations are shown on Figure 5 The differences between the curves for runs in opposite directions was due to the fact that the course used was not exactly level

BEHAVIOR OF TIRES

Observations of the relations between speed, grades, tire size and tire temperatures under test conditions yielded some interesting facts.

The diameters of the tires increased with speed, both on level and ascending grades.

At a given speed the diameters of the rear tires were less than those of the front tires. On a level road the rear tire diameters increased 0.35 in. and front tire diameters increased 0.41 in. while accelerating from 0 to 50 miles per hour.

Tire temperatures were measured with a special thermometer set in a protective case within the inner tube.

The temperature within the tire rises rapidly after the car has run a short distance and continues to rise until a maximum for the speed is reached. Rear tire temperatures are considerably greater than those of front tires. A close relation between tire and air temperatures was also noted.

For the particular tires used in these tests the following relations prevailed:

Front Tire Temperature = Air temperature (Deg. F.) + 8 + 0.22 times speed (m.p.h.)

Rear Tire Temperature = Air temperature (Deg. F.) + 18 + 0.33 times speed (m.p.h.)

It was also noted that the tire temperatures were sensitive to the difference between sunlight and shade.

DISCUSSION
ON
TESTS WITH A GAS-ELECTRIC DRIVE AUTOMOBILE

MR. F. LAVIS, *Consulting Engineer, New York.* The observations of these tests confirm those made and reported by the late A. M. Wellington in his "Economic Theory of Railway Location" a good many years ago to the effect that, within certain limits, rolling grades had practically no effect on the costs of train operation.

It is evident that rolling grades on highways which do not affect costs of operation may be much more pronounced both as to length and steepness of gradients than those of railways. The limits on railways are, of course, those descending gradients which require the use of brakes, or where the additional effort required on ascending gradients is not balanced or nearly so by power saved on descending gradients.

In the studies[1] made in connection with the design of Route 1 Extension, now Route 25, of the New Jersey State Highways, the assump-

[1] Highways as Elements of Transportation, Transactions Am. Soc. C. E. Vol. 95, p. 1020 (1930).

tion was made that within certain limits rolling gradients had no effect on costs of operation of the vehicles using the highway We had then no facts or experiments on which to rely so we were obliged to make an arbitrary ruling Mr Paustian's tests now carry our knowledge a little further

Mr T C Smith I noticed that wind resistance was made a function of cross-sectional area, but that there was no factor with regard to stream-lining What does that area mean?

Mr Paustian The area referred to is the projected or cross-sectional area of the car The effect of stream-lining will show up in the value of the constant, K, used in the equation for air resistance For our test car, this value is 0 0025, for a car that is more stream-lined, there will be a corresponding lower value of the constant

SKIDDING CHARACTERISTICS OF ROAD SURFACES

By R A Moyer[1]

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SYNOPSIS

The coefficients of friction of rubber tires on various road surfaces both wet and dry were measured for both straight ahead and sideways skidding at speeds of from three to forty miles per hour An ingenious special integrating dynamometer was designed for measuring the skidding forces

Tests were run upon 25 different types of surfaces, including asphalt, tar, road oil, portland cement, brick, gravel, cinders, asphalt plank, steel plates, wood plank, and mud on concrete In general a marked decrease in coefficient of friction was noted with increase in speed although the reverse was true in the case of the gravel and cinder surfaces It was found that the coefficients at three to five mile speeds are not indicative of the values at the higher rates of speed

Typical of the data observed in these tests are the following coefficients of friction on various wet pavement surfaces for skidding straight ahead at thirty miles per hour sandstone rock asphalt 0 59 to 0.77, sheet asphalt 0 47 to 0 63, bitulithic 0 50 to 0 63, asphaltic concrete 0 65 to 0 60, asphaltic retread 0 40 to 0 51, road oil mix 0 35 to 0 50, penetration macadam 0 20 to 0 28, repressed brick with grout

[1] The project covered by this report is a continuation of the program of highway research initiated 14 years ago by Dean T R Agg at Iowa State College By tests made in 1923 and 1927 fundamental facts concerning the coefficients of friction of tires on road surfaces were established However in view of the changes in tires, road surfaces and traffic conditions further studies were begun by Professor Moyer two years ago Mr Earl Allgaier and Mr Donald Berry, to whom much of the credit for the success of this project should be given, assisted the author throughout most of the work