to permit of satisfactory penetration of the crack will be rich in bitumen, it is difficult to suggest a type of asphalt filler which will not have a low coefficient of friction after extrusion We may, however, expect the highly filled asphalts to give higher coefficients than those consisting of pure bitumen Although the sanding treatment given in the case of road BA-40 was not particularly successful, repeated sanding at maximum temperature should so fill the extruded filler as to increase the coefficient of friction substantially

MOTOR VEHICLE POWER REQUIREMENTS ON HIGHWAY GRADES

By R A Moyer

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SYNOPSIS

In order to get up to date information bearing upon the effects of highway grades on motor vehicle operating costs, six passenger cars and two trucks were used in a series of laboratory and road tests

In the laboratory, dynamometer tests were made on the rolling resistance, power, and fuel consumption characteristics of the vehicles

The road tests comprised gasoline consumption on various surfaces, gasoline consumption on grades, free wheeling tests; rolling, air and engine resistance, and acceleration and tractive effort

Some of the important points revealed by these tests are as follows In conventional gear the average gasoline consumption, ascending and descending grades at constant speed, increased uniformly with each per cent increase in grade above zero percent In free wheeling, fuel was saved when ascending and descending grades between 1 and 5 per cent, at speeds less than 48 miles per hour as compared to operation on level grades No advantage in gasoline mileage when operating in freewheeling as compared to conventional gear was obtained on a 10-mile hilly course at speeds greater than 52 miles per hour Savings in fuel costs, resulting from grade reduction, were greater for trucks than for passenger cars, on the same tonnage basis

Application of the test data to four typical grade reduction problems brought out these interesting relationships For passenger cars, operating in high gear at constant speed, the savings in fuel costs resulting from reducing a 9-per cent grade to a 6-per cent were ten times greater than in reducing from 6 to 3 per cent when the rise and fall were not affected and were four times greater when the rise and fall were changed Gently rolling grades of 3 per cent or less should cause only slight increases in fuel cost

For grades lower than 9 per cent, the time saving obtained from grade reduction is negligible for automobiles but is an important factor in truck operation on grades steeper than 3 per cent

INTRODUCTION

During the past fifteen years, great advances have been made in reducing highway transportation costs. Travel time has likewise been reduced In view of the billions of miles of highway travel in each state annually, it is important that the highway engineer evaluate the savings in time and in transportation costs based on improvements in road and vehicle design, that he determine the extent to which the cost of these improvements are justifiable, and in so doing, possibly devise means whereby further savings may be realized

An important phase of motor vehicle operation is the effect of highway grades on costs In 1919, Dean Agg as a result of an investigation along this line, advanced a theory of economic grades[1] This theory replaced to a certain extent the empirical rules which were then, and in many cases still are being followed in establishing highway grades At the annual meeting of the Highway Research Board in 1932, Professor Shaw presented a paper on "Highway Grades and Motor Vehicle Costs" This discussion and Dean Agg's theory of grades consisted very largely of theoretical analyses supported by a limited number of road tests Dean Agg's studies revealed that up to a certain percent grade, the fuel costs for passenger cars on grades were no greater than on a level grade, providing the engine was declutched or in freewheeling when descending the grade During the past two years, freewheeling has been given a fair trial by the driving public and has been rejected for the most part for reasons that will be brought out later in the discussion on the freewheeling tests The normal operation of motor vehicles in the future may reasonably be assumed to be in conventional gear on both ascending and descending grades Engine resistance is a relatively large retarding force which supplements air and rolling resistance on descending grades It is therefore an important consideration in determining economical operation

The results of tests in conventional gear as reported by Dean Agg, indicated that the average fuel consumption was greater ascending and descending grades than on a level course of the same length However, the effects of variations in speed and in grade were not definitely established by his tests. Furthermore, since that time, many changes in motor vehicle and road design have been introduced Accordingly, this investigation was started in 1932 by the Iowa Engineering Experiment Station for the purpose of extending Dean Agg's investigation and of bringing up to date the studies on the economics of highway grades

Factors which determine the economy of operation on highway grades are, the effect of speed variations on the fuel consumption for each particular grade in each of the various gears, the effect of variation in the resistance to translation on different road surfaces, that is, in the air, rolling, and engine resistances, the tractive effort, safe coasting speeds, and overall efficiency of motor vehicles in the various gears, and the length of the grade

[1] "The Economics of Highway Grades" Bulletin 65, Iowa Engineering Experiment Station, 1923

Fuel economy is an important consideration in establishing economic highway grades, especially since a fairly definite measure of this phase of operation can be obtained The time factor, safety factor, and energy losses and maintenance expense due to braking are likewise of considerable importance, but unfortunately, cannot be so readily evaluated These factors, however, are not conflicting, since under normal operation, that is, in conventional gear, grades established on the basis of fuel economy will likewise show economy in time, improved safety, and a reduction in the losses due to braking

Although no definite tests are available to determine the effects of grades on lubrication costs, tire wear, and maintenance and depreciation costs, indications from related tests are that these items are so small that they are difficult to evaluate In general, however, it appears that savings in fuel consumption due to the reduction of grades are accompanied by small savings in these items

TEST METHODS AND EQUIPMENT

During the summers of 1932 and 1933 laboratory and road tests were conducted with a 1932 Studebaker Six Coupe The car carried standard equipment throughout, including optional freewheeling The general data for this car are given in Table I

In the summer of 1933, additional road tests were conducted with five other passenger cars and two trucks A general description of these vehicles is given in Table II The projected cross-sectional areas of the cars and trucks were determined in the laboratory by direct offset measurements as the car passed through a square frame on a level floor. These measurements were plotted and the area found by means of a planimeter.

Instruments

The instruments used in measuring gasoline consumption, speed, and time were a gasoline meter, a tachometer, and a space-time recorder

The *gasoline meter* consisted of two glass tubes, graduated to thousands of a gallon, each having a capacity of one-tenth of a gallon The tubes were supplied from the main tank by two electric auto-pulse fuel pumps, which pumped the gasoline into a float bowl, from which it flowed by gravity into the tubes One tube could be filled while the other one was being used The flow into and from each tube was controlled by valves, conveniently located so that accurate measurements could be made and a normal and steady flow to the motor assured On a moderately smooth road, over a one mile course, an accuracy within 0 0005 gallons could be obtained

The *tachometer* used on the Studebaker was attached to the right front wheel and consisted of a magneto-generator and two commutators The magneto-generator was connected with a voltmeter from which the actual speed of the car could be read directly by the observer The commutators were geared to the front wheel and provided contacts for every revolution and also for every third revolution of the front wheel The commutators were connected with an electric revolution counter, located on the instrument board, and with the space-time recorder

A fifth wheel tachometer, which could be easily transferred from car to car, was used during the summer of 1933 It was mounted on a bicycle

TABLE I

General Car Data for Studebaker Test Car, Model 55, Standard Coupe

No of cylinders 6	Bore and stroke $3\frac{1}{4}'' \times 5\frac{1}{8}''$
Displacement 230 2 cu in	S A E rating 25 4 H P
Carburetor Stromberg	Oil capacity 6 qts
Tire size 18 x 5 50 inches	Wheels 18-inch Kelsey wire
Tire pressure 35 lb	Wheel base 117 in
Rear axle gear ratio 4 27	Engine r p m for 10 m p h 499
Transmission ratios high 1, intermediate 1 64, low 2 87, reverse 3 45	Maximum speed 71 5 m p h

TABLE II

Description of Test Cars and Trucks

Car	Year	Model	Weight (Loaded for Tests)	Projected Area	Air Resistance Drag Coefficient K
			pounds	*sq ft*	
Studebaker	1932	Std Coupe	3,490	27 77	0 00186
Chevrolet	1933	Std Coach	3,360	24 18	0 00176
Ford V-8	1933	Deluxe Tudor	3,520	26 30	0 00176
Ford A	1931	Coach	3,180	26 20	0 00223
Essex	1929	Coach	3,580	24 59	0 00233
Buick 8	1931	Sedan	5,110	29 01	0 00199
Graham	1928	2-Ton Truck No Load	6,490	33 02	0 00257
		2-Ton Load	10,510	32 10	
Reo	1927	Moving Van No Load	9,150	71 04	0 00146
		2-Ton Load	13,150	69 30	

wheel and fitted to a frame which could be securely clamped to the running board of the car or truck This arrangement was used only when space-time records were desired In the gas consumption runs, the speed was obtained from the calibrated speedometer readings of the car or truck and from stop watch computations

The *space-time recorder* on the Studebaker car was of the usual paper ribbon type driven by gears connected with the driveshaft at the point where the speedometer cable was attached. The recorder had three

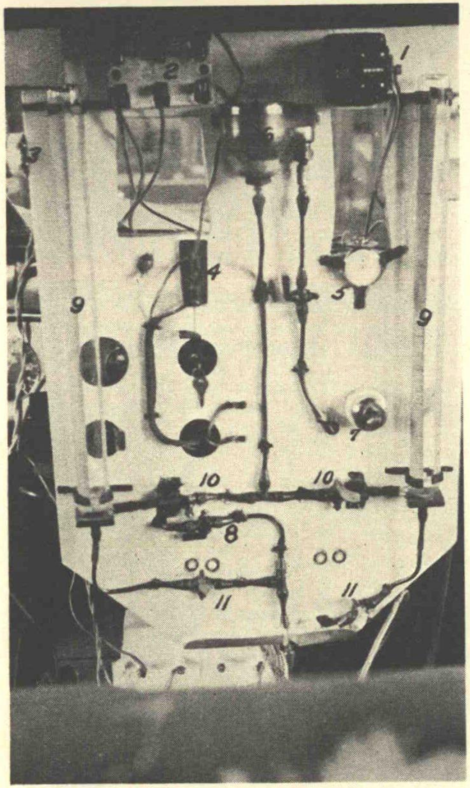

Figure 1a

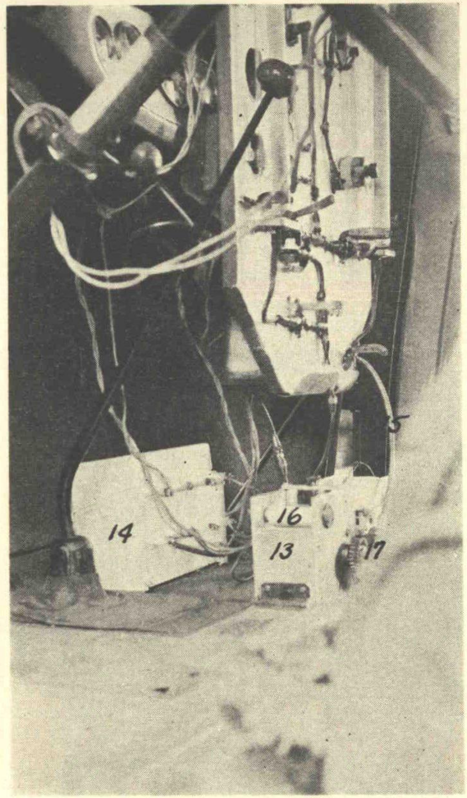

Figure 1b

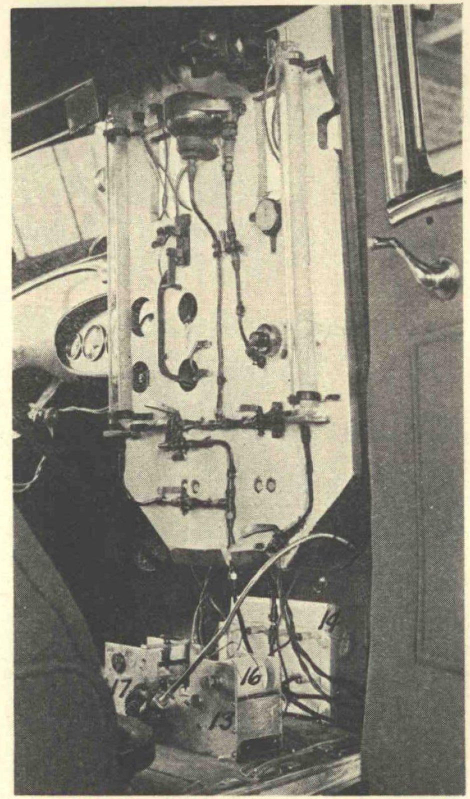

Figure 1c

Figure 1. General View of Instrument Board and Space-time Recorder, Studebaker Test Car.

Gasoline Meter: 1, revolution counter; 2, space-time recorder switch; 3, switch for "start and stop" signal on space-time recorder; 4, switch for fuel pumps; 5, stop watch; 6, float bowl; 7, two-way switch to revolution counter; 8, by-pass valve; 9, gasoline tubes (1/10th gal. cap.); 10, valves to control gasoline intake; 11, valves to control gasoline outflow; 12, voltmeter terminals.

Space-time Recorder: 13, space-time recorder; 14, coil box for high tension sparks; 15, speedometer cable; 16, paper rolls; 17, paper drive, geared with speedmeter cable.

points, each connected to an induction coil which furnished a record by burning holes through the moving paper ribbon. One point was connected to the commutator on the front wheel, another to a one-tenth second electric contact clock, and a third to a push button used to mark the beginning and end of the test run.

In the 1933 tests, a portable space-time recorder was necessary to make the unit easily transferable from one car or truck to another. A 6-volt motor drive was substituted for the transmission drive and all of the apparatus was mounted on one board. A stop watch was also used as a check on the timing measurements.

General views of the instrument board and the space-time recorder as used on the Studebaker test car are shown in Figure 1.

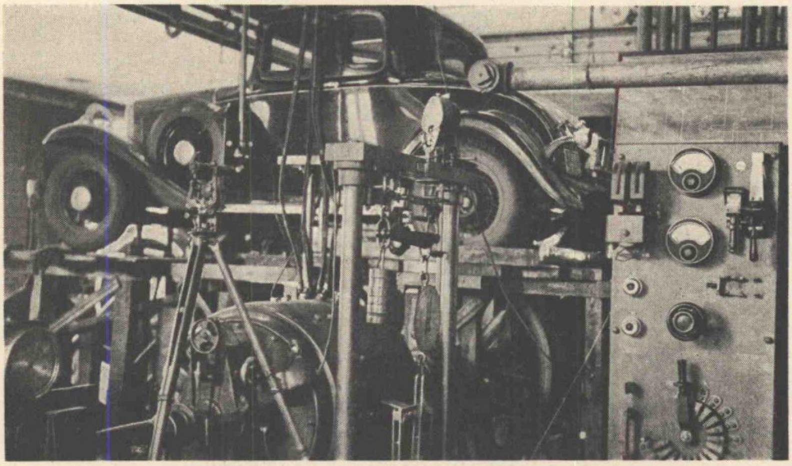

Figure 2. Arrangement for Laboratory Tests on Studebaker Test Car

Calibration

Laboratory Tests. Laboratory tests on a chassis dynamometer were made with the Studebaker test car to measure the operating characteristics which could not be measured in road tests, and also as a check on operating characteristics obtained in the road tests. The dynamometer drums and shaft were connected directly to a 100-horsepower Sprague dynamometer that could be used either as a motor or as an absorption dynamometer. A prony brake was attached to one end of the shaft for the purpose of additional power absorption. Draw-bar pull was measured on a steel pulling stand with a bell crank and platform scales. The rear and then the front wheels of the car were centered on the traction drives (Fig. 2) and anchored on the center of the drums by means of an adjustable rod. A transit was set on line with the axis of the dynamometer shaft for the purpose of centering the tires on the drums Friction at the end of the car, not supported on the drums, was eliminated by supporting this end on a vertical framework that rested on knife edges In this way only a vertical force could be transmitted at these supports The drums were run at constant speeds with increments of ten miles per hour up to 60 miles per hour As soon as the dynamometer reaction readings remained constant, the following general data were obtained at each speed: (1) dynamometer r p m , (2) car-wheel r p m , (3) dynamometer reaction, (4) draw-bar pull, (5) indicated speed from car speedometer, (6) air temperatures, wet and dry bulb, (7) tire temperatures and pressures

In order to make the laboratory tests and road tests comparable, the tire pressures were kept constant at 35 pounds in all the standard tests The axle loads were also kept constant, the weight of the testing equipment and the equivalent of two passengers being included in all tests

The electrical dynamometer was used to obtain resistances under the following conditions:

At the rear wheels
1 In conventional gear-declutched
2 In conventional gear-neutral
3 In freewheeling-high gear
4 In freewheeling-neutral

At the front wheels
1 With the tires in full contact on the drums
2 With the tires just touching the drum
3 Under varying tire pressures

Tests were conducted in the laboratory using the car motor as the driving force when the rear wheels were on the drums The maximum torque and horsepower were determined at speed increments of 10 miles per hour up to 60 miles per hour Simultaneously gasoline consumption data were taken The electrical dynamometer was disconnected in part of these tests and the prony brake was used as the absorption dynamometer

Space-Time Recorder, Tachometer and Speedometer At various stages during the testing program, calibrations of the space-time recorder, the tachometer, and the speedometer were necessary These calibrations were made on a straight stretch of smooth concrete pavement, 5 miles in length, the grades on which ranged from 0 0 to 0 3 per cent with the maximum difference in elevation not exceeding 10 feet per mile

Road Tests on Level Grades The tests on level grades to determine the various operating characteristics of each car included gasoline consumption in various gears, at speeds ranging from 10 to 60 miles per hour and acceleration and deceleration tests on a zero percent grade in the various gears Practically all of these tests were made with an average wind velocity of 8 miles per hour or less Runs were made in both directions to reduce the wind effects to a negligible quantity Average wind velocities were measured with a Robinson three-cup anemometer

Tests to determine gasoline consumption were made at each speed over a 2-mile course and for a portion of the tests, over the 5-mile course Not less than two and as many as five runs in each direction were made to obtain reasonably constant readings at the given speed

To determine the effects of various types of road surfaces on gasoline consumption, tests were run on various typical surfaces with the Studebaker test car Test courses were selected in the vicinity of Ames, in various sections of Iowa and in southwestern Minnesota These test courses were straight, level, and uniform in surface condition Since the results of tests on concrete were remarkably uniform, test courses on concrete were established in the vicinity of the test courses on other surfaces These concrete courses served as calibration courses when running tests on other types of surfaces In this way, corrections for climatic conditions, such as temperature, humidity, and atmospheric pressure, and slight changes in fuel characteristics and motor operation could be made

The acceleration tests in the various gears were made to determine the accelerating characteristics of the various cars and also to provide the data used in computing the maximum tractive effort in the various gears

The deceleration or coasting tests on the zero percent grade were made to determine the air and rolling resistance of each vehicle, and served as a check on similar values obtained by coasting on various grades at uniform speeds in freewheeling or with the motor declutched

Road Tests on Various Grades Tests were run on grades ranging from 0 0 to 9 0 percent and varying in length from 900 to 2,000 feet All of the tests on grades were run on smooth concrete In the tests on grades, gasoline consumption was measured ascending and descending in the various gears (also descending in freewheeling for the Studebaker test car) at speeds ranging from 10 miles per hour to the maximum speed for that grade Uniform coasting speeds were determined for the various cars and trucks in freewheeling or with the motor declutched and in the various gears when descending grades These determinations furnished accurate information concerning the air, rolling, and engine resistances of each vehicle Valuable checks on the air and rolling resistance were obtained in the coasting tests on the various grades as compared with those obtained in the deceleration tests on the zero percent grade

RESULTS OF TESTS

Laboratory Tests

The dynamometer tests furnished information concerning the resistance of the wheel bearings, tires, and that part of the transmission system behind the clutch or freewheeling unit of the Studebaker test car The horsepower output, maximum tractive effort, and gasoline consumption at no load and at full throttle were also determined

The horsepower required to drive the front and rear wheels for various test conditions at different speeds was determined Low losses in the transmission system are indicated by the fact that the power required to drive the rear wheels was 55 to 60 per cent of the total power required to drive all four wheels

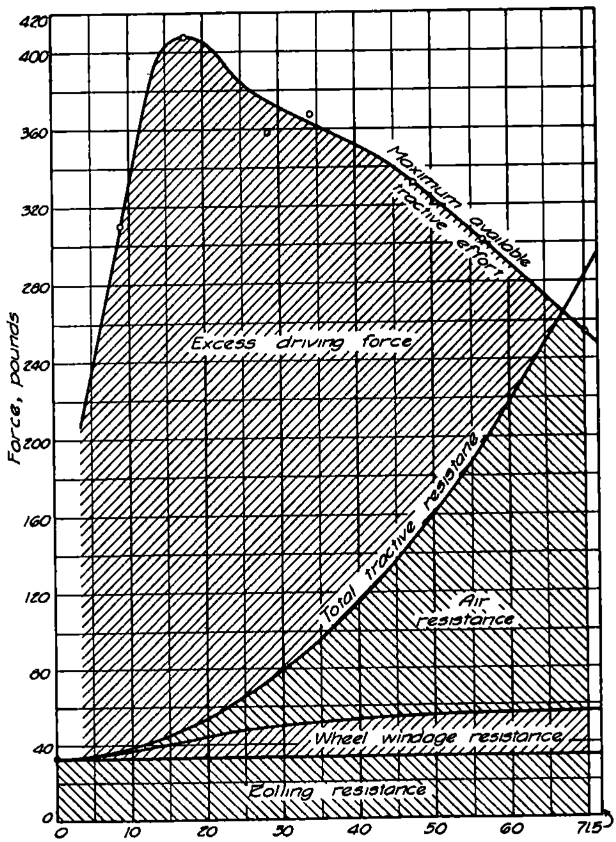

Figure 3 Maximum Available Tractive Effort on Dynamometer

The effect of wheel windage and bearing friction was obtained by comparing the horsepower required to drive the front wheels when in full contact and when just touching the dynamometer drums The difference between these two values may be reasonably assumed to represent the power requirements of tire resistance The total resistance of the front wheels, including wheel windage, ranged from 18 lb per ton at starting speed to 29 lb per ton at 70 miles per hour. However, by assuming that the differences in the two test conditions represented tire resistance, values of 18 lb per ton at starting speed to 14 lb per ton at 70 miles per hour were obtained for tire resistances Although these tests indicate that tire resistance decreases slightly with increase in speed on rigid smooth surfaces, the differences are so small that they are difficult to measure in the road tests It is for this reason that rolling resistance is generally assumed to be constant with increase in speed

In tests where the Studebaker car was used as the prime mover, the maximum available horsepower, the maximum tractive effort, and the gasoline consumption in gallons per hour and miles per gallon were

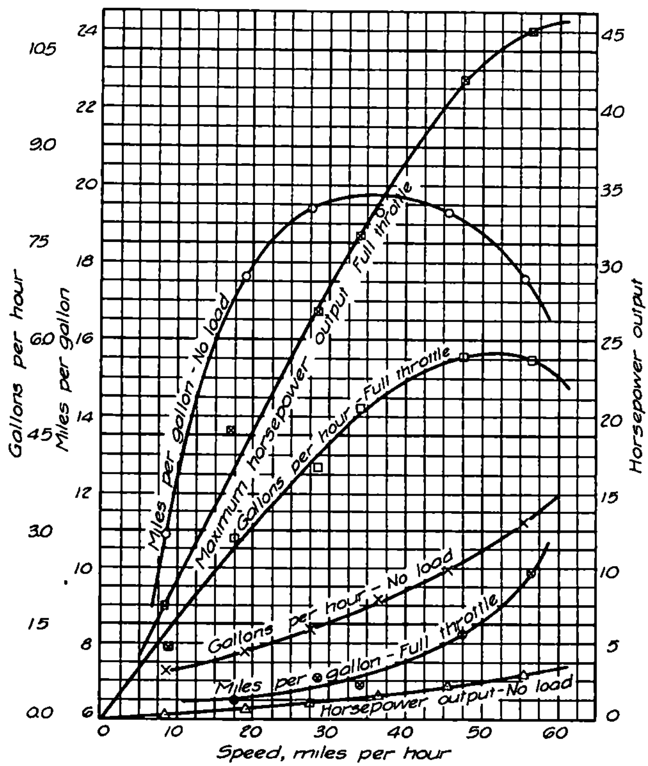

Figure 4. Gasoline Consumption Obtained on Dynamometer under No Load Conditions.

measured Results of these tests are shown in Figures 3 and 4 The rolling resistance and wheel windage as measured in the dynamometer tests are shown combined with the air resistance as determined in the road tests, the sum total of these forces being the total tractive resistance These curves clearly point out the way in which air resistance determines the power required and the extent of excess power on driving force available, especially at the lower speeds Thus, at 20 miles per hour only about one-tenth of the maximum available tractive effort was required to overcome both rolling and air resistance, whereas, at 68 miles per hour, the dynamometer tests showed that no excess power was available and, therefore, the maximum speed of the car was reached At that speed, 86 percent of the total tractive effort was required to overcome air resistance and only 14 percent to overcome rolling resistance The maximum speed obtained on a level grade in the road tests was 71 5 miles per hour, requiring a maximum tractive effort of 290 lb as compared with 250 lb measured in the dynamometer tests In the laboratory tests, operating conditions were not so favorable, especially in regard to the traction on the wooden drums and the high temperature of the exhaust manifold and the exhaust line under full throttle at high speeds This appeared to affect the carburation by overheating the intake manifold The maximum tractive effort as determined from road tests did not drop off so sharply at the high speeds as that determined in the laboratory Although a satisfactory check was obtained in these tests, the data clearly demonstrate that road tests are more satisfactory than dynamometer tests in determining maximum tractive effort characteristics

The results of the gasoline consumption tests (Fig 4) are significant since they show that the maximum gasoline mileage obtained on the dynamometer under no load conditions (rolling and bearing resistances only) amounted to 19 4 miles per gallon and that this amount remained fairly constant between speeds of 25 and 50 miles per hour Beyond 50 miles per hour, a sharp drop was observed In the road tests, the maximum fuel economy of 18 miles per gallon was obtained at 28 miles per hour This decreased to 14 miles per gallon at 50 miles per hour Therefore, these tests indicate that with perfect streamlining on this car, the gasoline mileage would not be increased by more than 1 to 5 miles per gallon in this speed range The sharp drop beyond 50 miles per hour in the dynamometer tests may be attributed to a number of causes, the more important being: (1) The increase at the higher speeds in engine resistance, part of which was caused by the extra force required to exhaust the large volume of gases through the small ports of the cylinders, (2) the increase in wheel windage resistance, both for the car wheels and for the dynamometer drums, and (3) the rate at which the fuel could be charged into the cylinders decreased slightly at higher speeds

Road Tests

Gasoline consumption was measured on various types of road surfaces on level grades using the Studebaker test car Gasoline consumption for six passenger cars and two trucks was also measured on uniform grades ranging from 0 to 9 percent, ascending and descending in various gears (and in freewheeling with the Studebaker test car) at speed increments of 10 to 60 miles per hour Similar tests with the Studebaker test car were run on a 10-mile hilly course in conventional gear and in free-wheeling Rolling, air, and engine resistances were determined by coasting at constant speeds on various uniform grades Rolling and air resistance was also determined in deceleration tests on level grades Acceleration tests were run in the various gears on a level grade to determine the accelerating characteristics of the car and the maximum tractive effort in each gear

This program of road tests provided typical information which should be useful in solving a large variety of problems in connection with the operation of cars and trucks on grades

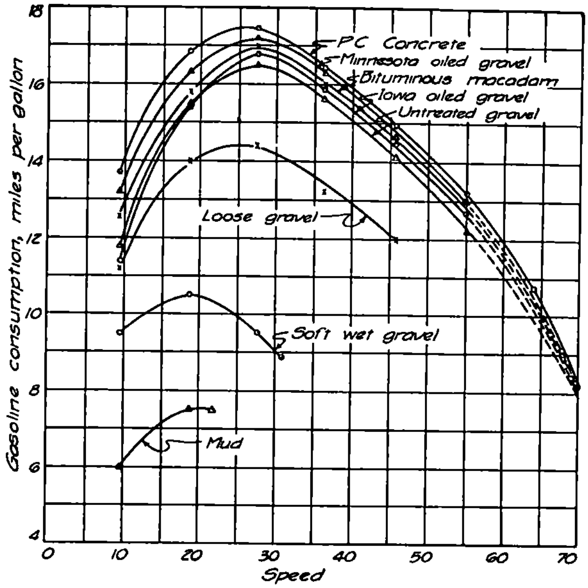

Figure 5. Gasoline Consumption Curves for the Studebaker Test Car on Various Surfaces Obtained by Driving at Constant Speed on Level Grades

Gasoline Consumption On Various Road Surfaces Test runs were made with the Studebaker test car on eight different surfaces on level grades to determine typical road surface characteristics for at least one test car The surfaces ranged from a smooth hard surface with a low tractive resistance to a soft muddy surface with high tractive resistance, and included smooth portland cement concrete, Minnesota oiled gravel, bituminous macadam (open grained "nonskid" texture) Iowa oiled gravel, untreated gravel (dry and firm), loose gravel, soft wet gravel, and Iowa mud

The tests on these surfaces were run in August and September, 1932 The average air temperature for the majority of the tests was close to 70°F and the results for all the surfaces were reported on that basis (Fig 5). In running these tests the car was calibrated on a smooth dry portland cement concrete test course in the vicinity of the surface to be tested In this way, corrections for variations in temperature, humidity, atmospheric pressure, fuel and motor characteristics could be made

Increase in tractive resistance was reflected in a decrease in gasoline mileage. This decrease was found to be very similar to that obtained for increased grade resistance The smooth, hard, unyielding portland cement concrete surfaces were found to provide the highest gasoline mileage The Minnesota oiled gravel surface was smooth and hard and it is for this reason that a higher gasoline mileage was obtained on it than on the Iowa oiled gravel which had not been so well compacted and was somewhat softer and more uneven

It is of interest to note the effect of Iowa mud on gasoline mileage at 20 miles per hour, as only 7½ miles per gallon were obtained in the mud as compared to 17 miles per gallon on portland cement concrete at the same speed A feature of the tests on the mud road was the increase of 450 lb in the weight of the car after two hours testing, due to the accumulation of mud In the tests in mud, the throttle was practically wide open and the maximum tractive effort of the motor had to be exerted to pull the car through The tractive effort at full throttle, therefore, was a measure of the tractive resistance of this surface and it averaged about 200 to 220 lb per ton

A significant observation in the tests was the closer grouping of the curves at the higher speeds on surfaces which were firm and smooth This result is logical since the effect of differences of 2 to 10 lb per ton in rolling resistance should be proportionally greater at low speeds with low tractive resistance than at the high speeds where increased air resistance forms a very large proportion of the total resistance

Gasoline Consumption on Grades The results of tests on grades to determine gasoline consumption when ascending and descending in the various gears are shown in Figures 6 to 10

The gasoline consumption characteristics of the various test cars and trucks operating on level grades are shown in Figure 6 on a miles per gallon basis The results indicate wide divergence in gasoline mileage at the lower speeds for the different cars and trucks and closer agreement at the higher speeds For speeds greater than 30 miles an hour, variations were almost the same for all cars tested with an average of about 14 miles per gallon at 60 miles per hour as compared to 20 miles per gallon at 30 miles per hour The increased load on the trucks caused an increase in the motor efficiency of the trucks as compared to that of the cars On a ton-miles per gallon basis the gasoline consumption values secured in the tests for the trucks were practically double those for the cars for speeds of 20 to 40 miles per hour

In the tests to determine gasoline consumption when ascending grades, the effect of the 20 lb per ton increase in grade resistance for each percent increase in grade was reflected in a proportional decrease in gasoline mileage The grouping of the gasoline mileage curves was closer on the steep than on the flat grades, and in second and low gears than in high gear Since the tractive resistance force introduced by grade is definitely equal to 20 lb per ton for each percent of grade on grades less than 10 percent, the gasoline consumption values obtained on ascending grades provide a definite measure of the variations in tractive

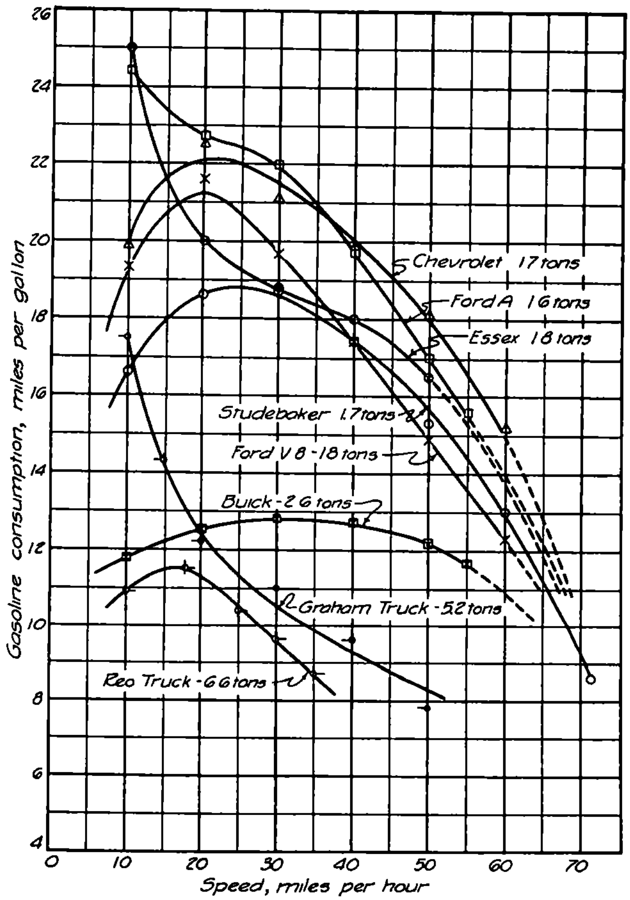

Figure 6 Gasoline Consumption for Test Cars and Trucks on Level Grades in 1933.

resistances on the various road surfaces Thus, 7½ miles per gallon was the measure of the gasoline consumption of the Studebaker ascending a 9-percent grade on a concrete surface at 20 miles per hour, while a similar amount was required in the test on Iowa mud Hence, it is reasonable to assume that the additional tractive resistance developed on the level Iowa mud test course amounted to 180 pounds per ton more than on the 9-percent grade on concrete Corrections can, therefore, be made on this basis in gasoline consumption curves to determine the probable gasoline consumption on the various grades for any road surface for which the tractive resistance or gasoline consumption on a level course is known

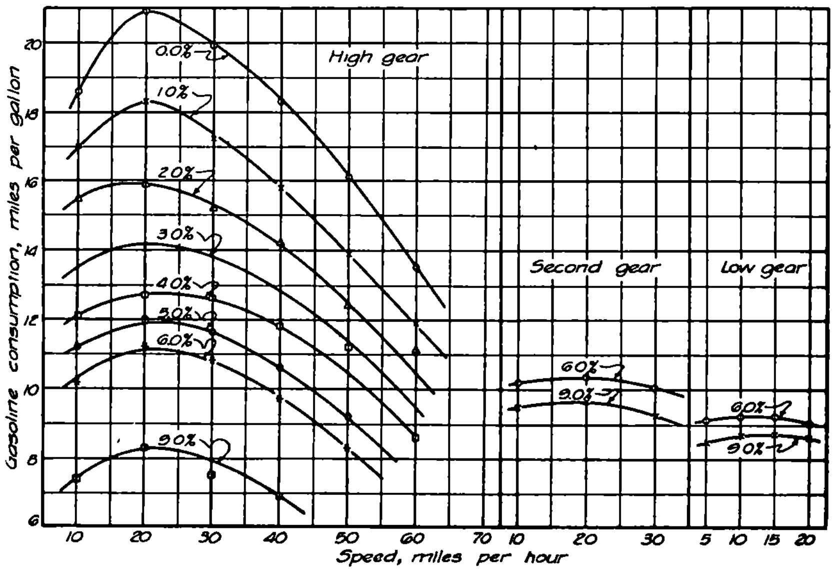

Figure 7. Average Gasoline Consumption of Three Cars, Ascending Grades

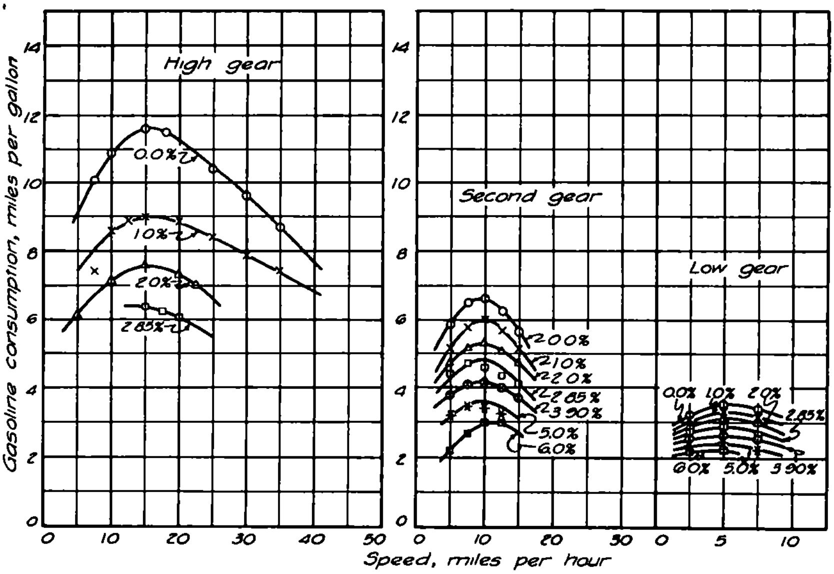

Figure 8. Gasoline Consumption, Reo Moving Van, Ascending Grades

The increase observed in the gasoline mileage on descending grades followed the same trend established in the tests on ascending grades

In all of these tests, the motor was always in gear and at no times were the brakes used At speeds lower than those at which the test car

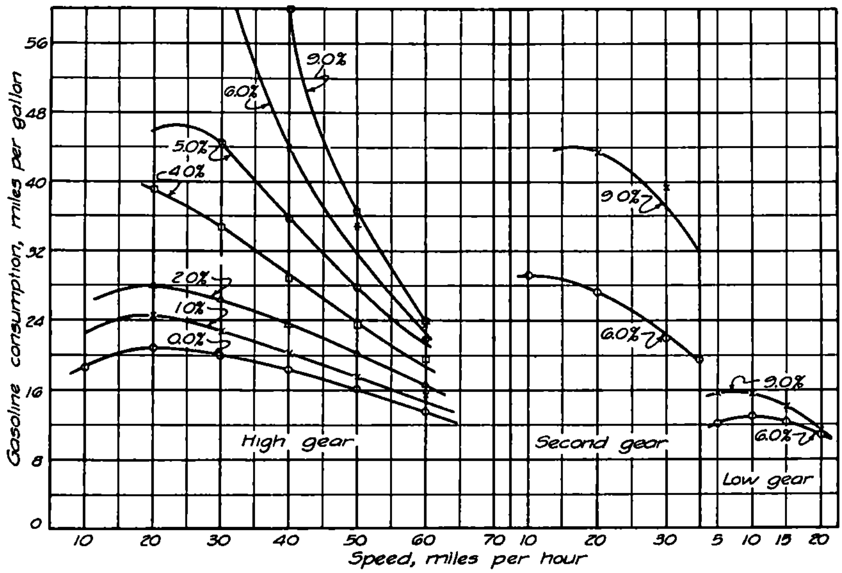

Figure 9. Average Gasoline Consumption of Three Cars, Descending Grades

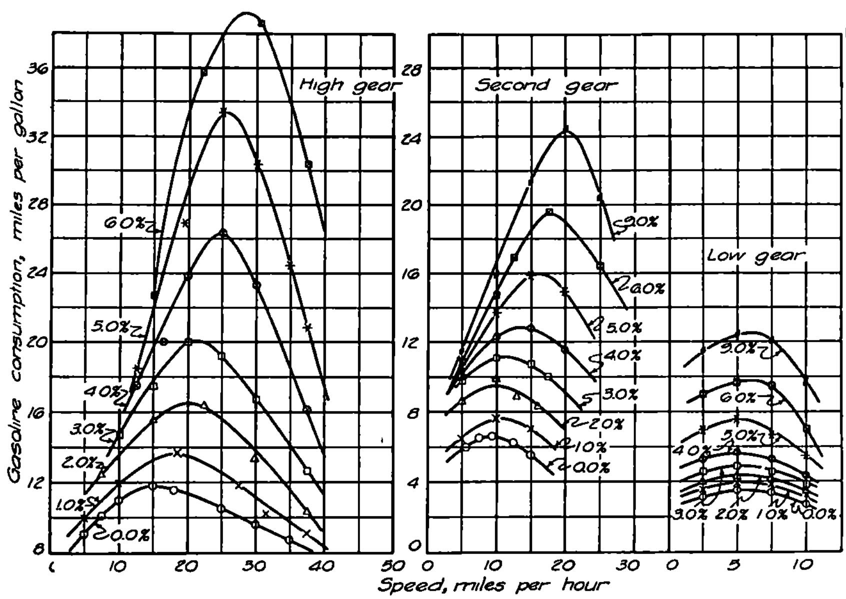

Figure 10. Gasoline Consumption, Reo Moving Van, Descending Grades

would coast down the grade at uniform speed, acceleration was permitted and the gasoline consumption was reported for the average speed over the course This procedure, however, was necessary only for speeds of 30 miles an hour or less for the passenger cars since even on a 6-percent grade, the uniform coasting speed in high gear averaged about 32 miles an hour In other words, it was necessary to increase the throttle opening to maintain uniform speeds above 32 miles an hour when descending grades of 6 percent or less The coasting speeds for the trucks on the 6-percent grade were 10 to 12 miles an hour higher than for the cars because of their greater weight

The most important observation made in connection with operation on grades in conventional gear was that at any given speed, the average gasoline consumption on ascending and descending grades at a given constant speed, increased fairly uniformly with each percent increase above a level grade This characteristic was definitely established in the tests with cars and was fairly well established in the tests with the trucks. It was equally true for tests in all the gears although the effect of grade was proportionally lower in the lower gears where the grade resistance formed a proportionally smaller part of the total resistance An increase in gasoline consumption of about 2 percent for each percent increase in grade was observed in high gear For grades on which shifting to a lower gear was required, the gasoline consumption was greater depending on the speed and the exact nature of the operation

Two important factors which caused operations on the steeper grades to be more costly than on the flatter grades are engine resistance and variation in overall thermal efficiency. Grade resistance acts as a retarding force when ascending and as a driving force when descending On the same grade and at the same speed, its effect should theoretically be neutralized The overall thermal efficiency, however, varies considerably with the load In Figures 11 and 12 the overall thermal efficiencies for the Ford V-8 test car are shown at various speeds in high and second gear, based on the gasoline consumption on grades, ranging from 0 to 9 percent. In computing the overall thermal efficiency a B.T.U value of 19,200 per pound was used for the gasoline Air and rolling resistance values were taken from the curves in Figure 17 On the basis of the computations for overall thermal efficiency, it was found that the efficiency may vary from 3 5 percent at 10 miles per hour to about 16 percent at 60 miles an hour on a level grade in high gear The curves in Figure 12 indicate that the rate of increase in efficiency decreases with an increase in load and it is largely for this reason that more fuel is required when ascending and descending grades on a course of given length than when traveling on a level course of the same length.

Freewheeling Tests Engine resistance may be practically eliminated at some speeds when descending certain grades by operating the car in freewheeling or by declutching the motor By this operation, the motor is reduced to the idling speed and the fuel requirements are likewise reduced Tests were conducted with the Studebaker test car in con-

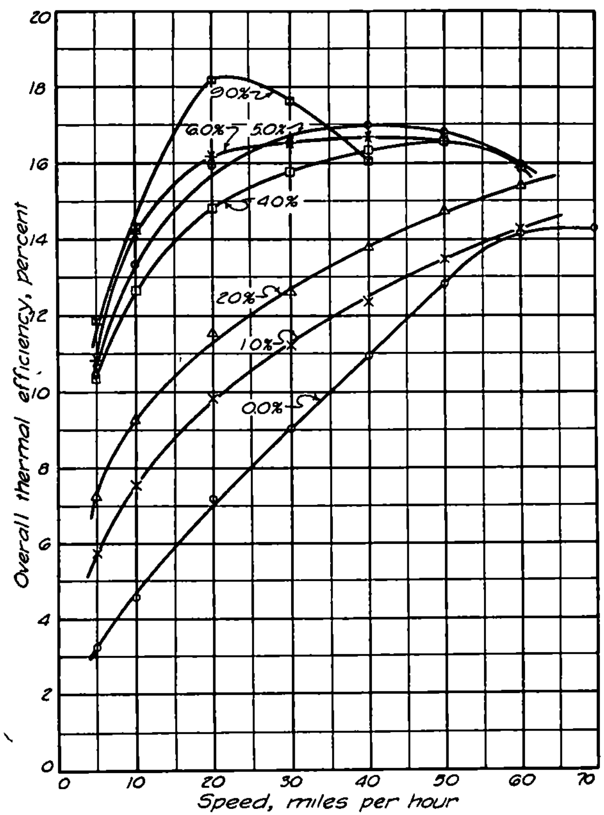

Figure 11 Overall Thermal Efficiency of Ford V-8 Test Car in High Gear

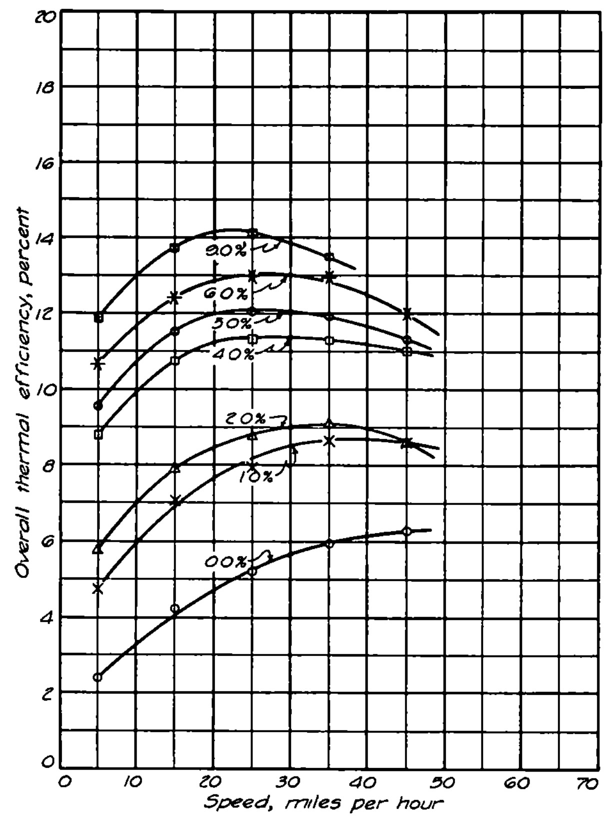

Figure 12 Overall Thermal Efficiency of Ford V-8 in Second Gear

ventional gear and in freewheeling on various uniform grades and on a 10-mile hilly course of smooth portland cement concrete paving

The results of tests descending uniform grades in freewheeling are given in Figure 13 On the one percent grade the gasoline mileage was the same as that in conventional gear, because the car could not be operated in freewheeling, the rolling and air resistance on this grade

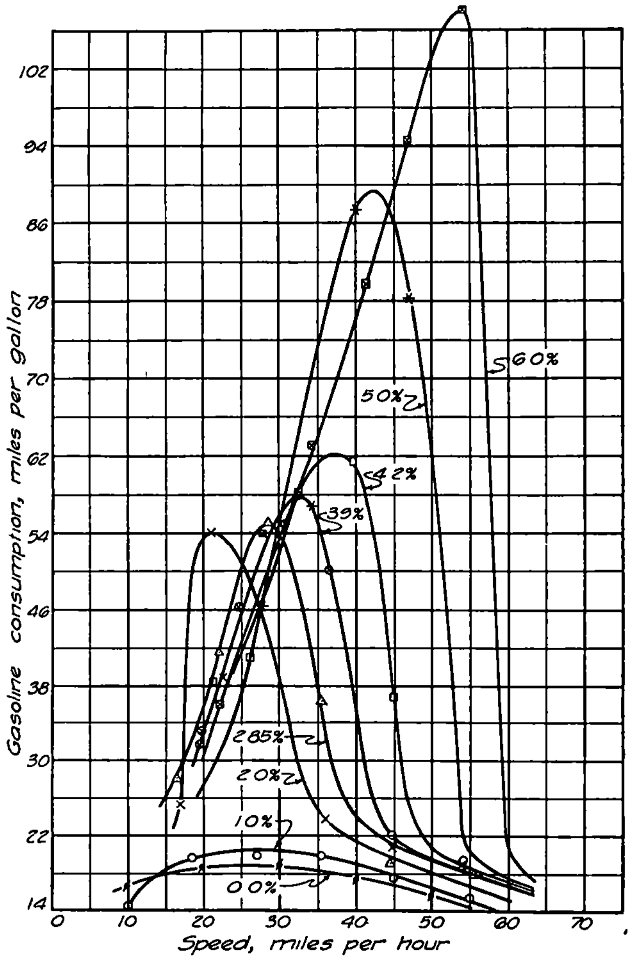

Figure 13. Gasoline Consumption, Studebaker Test Car, Descending Grades in Free-wheeling

being greater than the driving force of 20 lb per ton developed by the car. When descending grades steeper than one percent, there was a marked increase in gasoline mileage for each percent increase in grade The maximum mileage was obtained at the coasting speeds for each grade The values reported for speeds lower than the coasting speed represent the gasoline consumption for the average speed over the course

In Figure 14, the average gasoline consumptions ascending and descending the grade in freewheeling are given These curves show that no saving is possible on a 1-percent grade, that the largest saving is obtained on a 2-percent grade for speeds up to 32 miles per hour, for speeds between 32 and 44 miles per hour, the largest saving is possible on a 4-percent grade, and from 44 to 48 miles per hour a slight saving in gasoline is obtained on a 5-percent grade Beyond 48 miles per hour, freewheeling provided no advantage in gasoline consumption on any

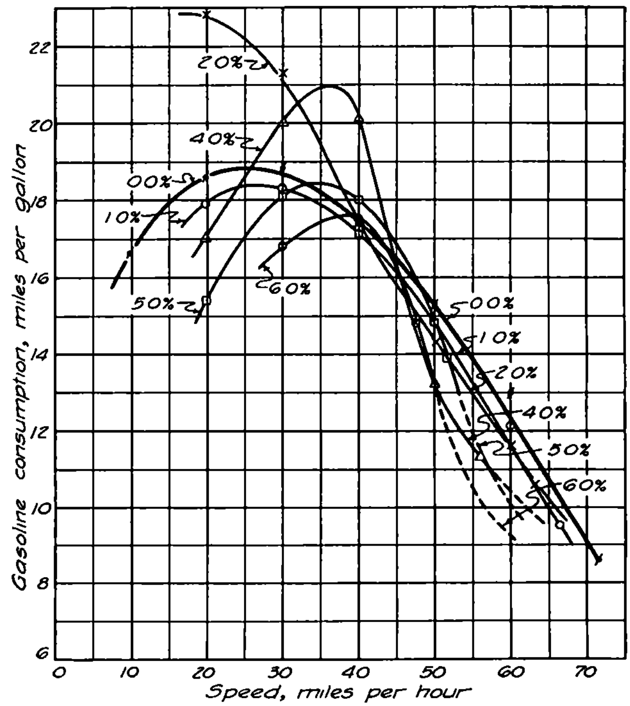

Figure 14. Average Gasoline Consumption, Studebaker Test Car, Ascending and Descending in Free-wheeling.

grade over that obtained when operating in conventional gear on a level grade

The same general gasoline mileage characteristics were obtained over a 10-mile hilly course In these tests (Fig 15) a maximum increase in gasoline mileage of about 20 percent was obtained when operating in freewheeling as compared to conventional gear. This increase was obtained when operating at average speeds of less than 32 miles per hour The gasoline mileage advantage, due to freewheeling, gradually decreased as the speed was increased beyond 32 miles per hour, reducing to zero at about 60 miles per hour. When comparing operation in freewheeling on the hilly course with the operation in conventional gear on a level grade, the advantage in freewheeling reduced to zero at about 52 miles per hour

A decrease of about four percent in gasoline mileage was obtained when operating in conventional gear on the 10-mile hilly course as compared with a level course of the same length The total rise and fall for the hilly course was 820 feet The difference between the true length of the course and the horizontal distance was 18 1 feet which is negligible when considering gasoline measurements over so long a course The grades on the course were not steeper than 6 percent and averaged

Av speed	Total running time min-sec.		Free wheeling time min.-sec.			Max speed m p h		Min speed m.p.h.	
m.p.h.	North	South	North	South	% of total	North	South	North	South
12.8	20'-56"	24' 39"	10-34"	7'-41"	40.1	44.6	35.5	9.7	9.7
20.7	12-46"	15'-22"	6-51"	4-07"	38.0	46.5	35.5	19.2	19.2
29.0	9-46"	10 20"	4 26"	2-21"	33.5	48.3	40.2	28.2	28.2
38.6	7-26"	7'-41"	3-17"	1-40"	32.7	51.2	44.6	37.2	37.2
47.1	6-06"	6 16"	2'-15"	0'-52	25.2	56.2	48.8	46.5	46.5
56.3	5-08"	5-13"	1-06"	0-05	18.5	61.0	57.3	56.2	56.2

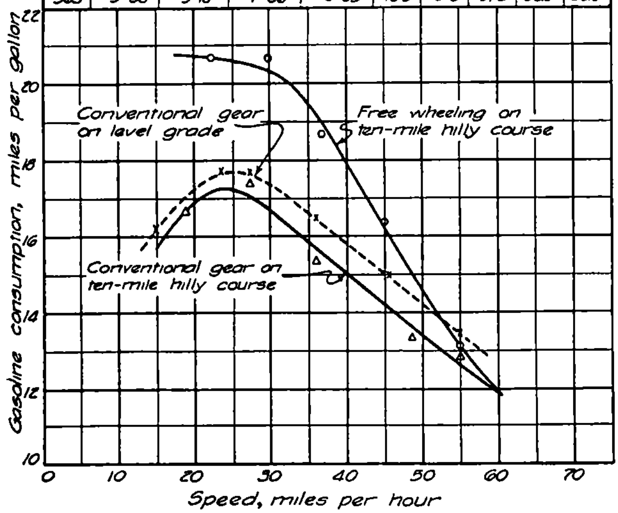

Figure 15. Gasoline Consumption on Ten-mile, Hilly Course in Free-wheeling and Conventional Gear, Studebaker Test Car.

about 3 percent The nature of the grades was indicated by the amount of time in freewheeling At an average speed of 20 miles an hour, the car was freewheeling 38 percent of the total running time, at 50 miles an hour this was reduced to 23 percent, and the indications are that at 60 miles an hour, freewheeling would not have been possible since with the maximum grade on this course not greater than six percent and the maximum coasting speed equal to 59 miles an hour, it would have been necessary to operate the car in gear to travel faster

While some of the advantages and disadvantages of operating in freewheeling are clearly indicated in the results of the tests, there were certain others which could not be evaluated so readily When operating in freewheeling, a definite decrease in the number of motor revolutions was indicated by the percentage of total running time in freewheeling It is reasonable to assume that the motor depreciation costs and the lubrication costs would be decreased on this account although the actual saving in these items would be difficult to determine An important disadvantage from the driver's point of view is the need for operating at low speeds and over a wide range of speed in order to realize any considerable saving in gasoline, since most drivers prefer to operate more nearly at constant speed On a road carrying moderately heavy traffic, excessive use of the brakes was required, especially on the 5 and 6-percent grades It was also necessary to raise the idling speed of the motor to prevent stalling when freewheeling

TABLE III

ROLLING RESISTANCE ON VARIOUS ROAD SURFACES DETERMINED WITH STUDEBAKER TEST CAR

Type of Surface	Rolling Resistance, Pounds Per Ton	
Portland Cement Concrete	19 0	(1)
Asphalt Filled Brick	20 0	(1)
Minnesota Oiled Gravel	21 5	(1)
Bituminous Macadam	23 0	(1)
Iowa Oiled Gravel	24 0	(1)
Untreated Gravel (dry and firm)	27 0	(2)
Loose Gravel	50 0	(2)
Soft, Wet Gravel	120 0	(2)
Iowa Mud	200 0	(2)

(1) Based on coasting tests
(2) Based on gasoline consumption tests

From the driver's point of view, the disadvantages in freewheeling seem to outweigh the slight advantage in operating cost and this is a possible explanation why freewheeling is losing favor with the driving public

Rolling, Air and Engine Resistance In the determination of the maximum grade on which a given vehicle can ascend and descend in the various gears at given rates of speed on the different types of road surfaces, it is necessary to know the variations in rolling, air, and engine resistances for the surface and vehicle under consideration

The rolling and air resistance was determined for each test car and truck by two methods, coasting at uniform speed on the various test grades and deceleration from various starting speeds on a level grade In both cases, the motor was declutched or in freewheeling while coasting or decelerating

Tests to determine the rolling and air resistance on various types of road surfaces were run only with the Studebaker test car. The results of these tests are given in Figure 16 and in Table III The results in Figure 16 are based on the coasting tests on various grades. The most complete tests were made on concrete since few grades suitable for coasting were available on the other types of surfaces, although at least one suitable for coasting, was found on each of the other four surfaces

All of the coasting tests were run at a time when the wind velocity averaged less than five miles an hour Since all of the runs on any grade had to be made in the same direction and the total resistance plotted on a no-wind basis, corrections in the air resistance force caused by the wind

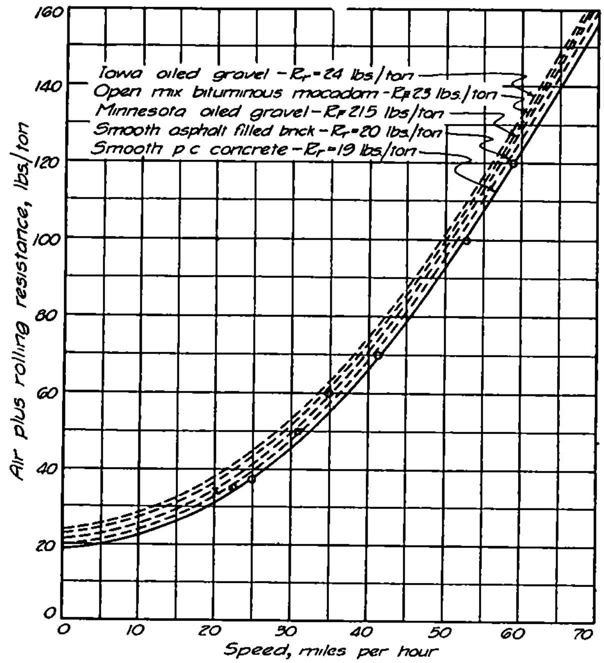

Figure 16. Tractive Resistance of the Studebaker Test Car on Various Surfaces Obtained by Coasting at Constant Speed on Various Uniform Grades

were made in plotting the results The general formula for air resistance was used in making these corrections and in determining the air resistance of the car,

$$R_A = KAV^2 \qquad (1)$$

in which R_A = the total air resistance in pounds, K = the drag coefficient, depending on the form of the car, A = the projected cross-sectional area of the car in square feet and V = the speed of the car in miles per hour. In the coasting method the speed of the car on a given grade is constant if the wind velocity is constant The component of the vehicle weight which tends to roll the vehicle down the grade is equal to rolling plus air resistance This component, generally designated as grade resistance, may be assumed to be equal to 20 lb per ton for each percent of grade up to 10, without serious error On a 2-percent grade paved with concrete, the Studebaker test car had a coasting speed of 26 miles an hour, therefore, the air and rolling resistance of the car was equal to 40 lbs per ton. The air and rolling resistances for the higher speeds were determined in a similar manner The total resistance was then plotted for each of the various speeds and the rolling resistance determined by using the general formula for total resistance,

$$R = KAV^2 + R_r \qquad (2)$$

in which R = total air plus rolling resistance in pounds and R_r = the total rolling resistance in pounds By assuming that the rolling resistance remained constant at all speeds, a measure of rolling resistance was obtained by noting where the plotted curve cut the total resistance ordinate for zero speed, since at zero speed the air resistance portion of the curve reduced to zero The rolling resistances for the other surfaces in Figure 16 were determined in the same manner.

The values of rolling resistance in Table III cover a wide range of surface conditions and indicate the values which will need to be considered in establishing maximum grades for these surfaces. As indicated in Table III, the values for rolling resistance on the various untreated gravel surfaces and the Iowa mud were determined from the gasoline consumption tests. That is, by comparing the gasoline mileage obtained on these surfaces with the gasoline mileage obtained with the same car ascending various grades, the equivalent percent grade for the surface in question could be determined. The rolling resistance for the given surface was then obtained by adding the grade resistance for the equivalent percent grade to the rolling resistance on concrete. Considering the possible variations in rolling resistance for these surfaces, the values obtained in this way are sufficiently accurate for most purposes for which they may be used

The results of tests to determine the total air plus rolling resistance at the various speeds on concrete for each of the test cars and trucks are given in Figure 17 All of the values are based on coasting tests on the grades on which gasoline consumption determinations were made. The curves indicate the progress made in streamlining during the period from 1929 to 1933, a reduction in total resistance at 60 miles an hour of 20 percent having been observed in these tests. It was expected that the total resistance for the trucks would be high but it was rather surprising to find that the drag coefficient, K for the Reo moving van was the lowest K measured among the cars and trucks tested (Table II). This truck had a projected cross-sectional area about three times as large as that of the average car. Although there was a slight slant on the edges in the front where the cab joined the body all of the other edges were square and the back was square. On the basis of this construction a drag coefficient of about 0 0025 was expected. Apparently, the only explanation for the low value of K for this truck lies in the large projected area and possibly in the large clearance above the ground

The total rolling and air resistance of each test car and truck was checked by the deceleration method on the level grade of test course

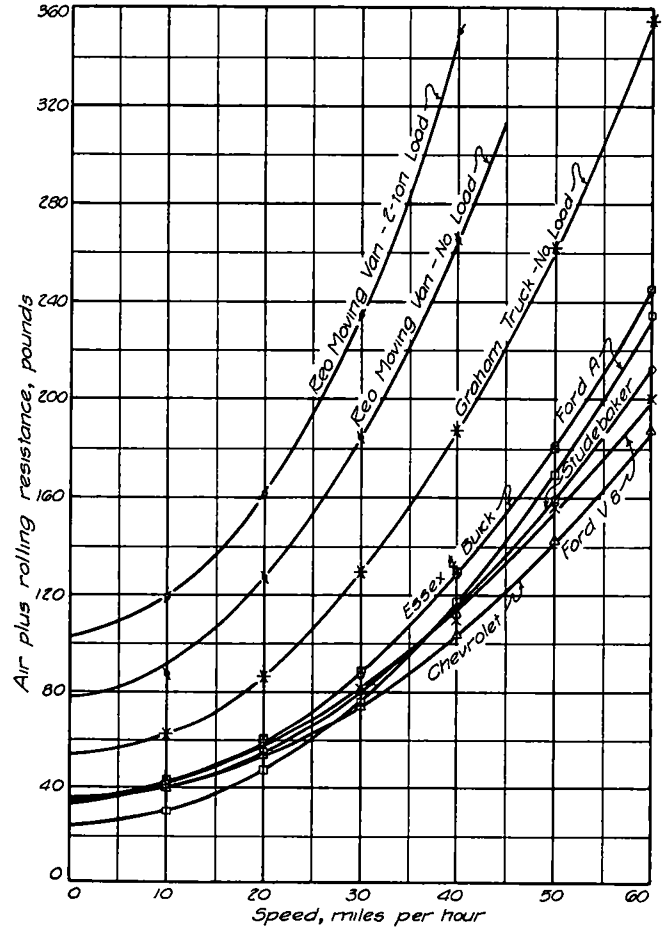

Figure 17. Total Air and Rolling Resistance of the Test Cars and Trucks on P C. Concrete Obtained by Coasting Method.

No. 1. This method consisted of letting the car coast to a stop in neutral or freewheeling from speeds of 40, 50, and 60 miles, while at the same time measuring the time required for each 5 mile per hour decrease in speed with the space-time recorder. Space-time curves and deceleration curves were obtained from these records (Fig. 18) and the air and rolling resistance computed according to the formula,

$$F = Ma = \frac{W}{g} a = R_r + R_a \tag{3}$$

in which W = gross weight of the vehicle in pounds, g = the acceleration due to gravity in feet per second per second and a = the rate of deceleration for the vehicle in feet per second per second In the above equation it is assumed that all of the kinetic energy stored in the vehicle is that due to its linear motion However, additional energy is stored in

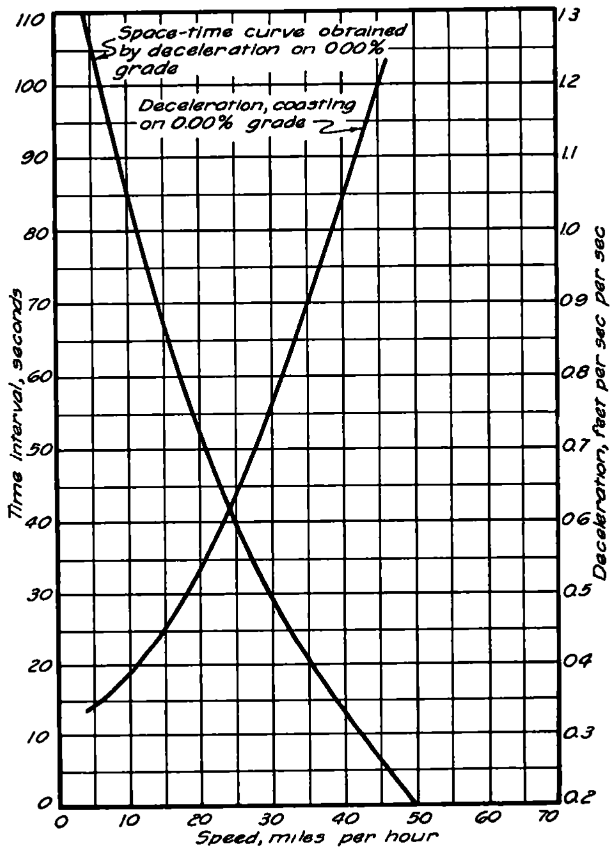

Figure 18. Space-time and Deceleration Curves Obtained on Level Grade with Studebaker Test Car

parts which have not only linear but also rotary motion so that the total kinetic energy is:

$$\text{K E.} = 1/2 \frac{W}{g} V^2 + 1/2\ I\ \omega^2 \tag{4}$$

in which V = vehicle velocity in feet per second per second, I = moment of inertia of the rotating parts, and ω = angular velocity of rotating parts in radians per second Since the kinetic energy due both to its linear motion and rotating parts varies as the square of the speed of the vehicle, the latter may reasonably be assumed to be proportional to the former for any given vehicle

In Figure 19, the rolling and air resistance for the Studebaker test car and the Graham truck are given as determined by the coasting method and the deceleration method In the coasting tests no correction for the kinetic energy of the rotating parts was made since these tests were made at constant speed No correction in the values obtained in the

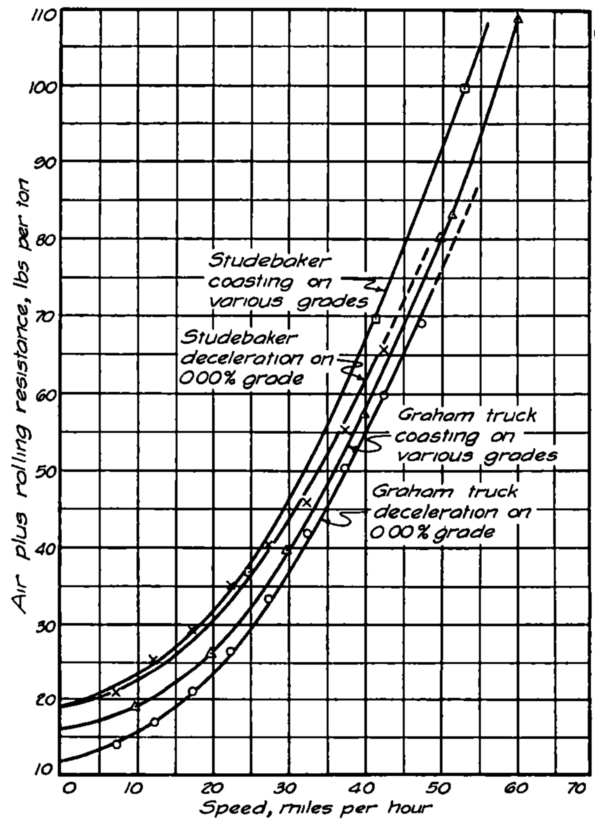

Figure 19. Comparison of Rolling Plus Air Resistance Obtained by Coasting Method and by Deceleration Method with Studebaker Test Car and Graham Truck.

deceleration tests was made and, therefore, the difference in the values obtained by the two test methods represents the force which is developed by the kinetic energy of the rotating parts. For the Studebaker test car this amounted to about 8 percent of the total air plus rolling resistance at 40 miles per hour and for the Graham truck about 5 percent of the total resistance at the same speed. In Bulletin 65 of the Iowa Engineering Experiment Station, Dean Agg reported values of 5 and 6 percent

It should be stated here that an accuracy within 2 or 3 percent is difficult to achieve in these tests because of the variations introduced by wind effects. Although these tests were run with low wind velocities and average values with and against the wind were used in the deceleration tests, a difference in wind velocity of one mile an hour provided very nearly the same difference in resistance as that attributed to the inertia effects of rotating parts

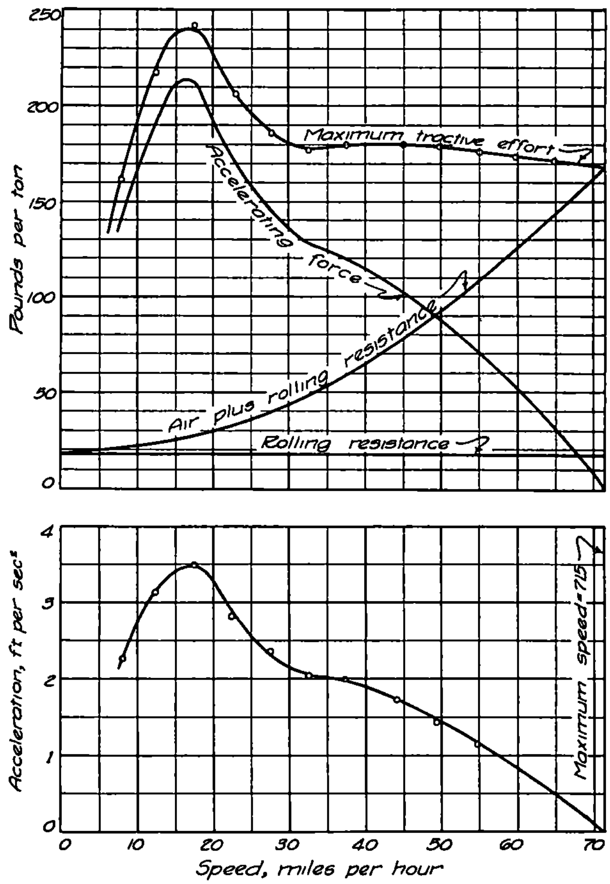

Figure 20. Maximum Acceleration Tractive Effort in High Gear at Various Speeds, Studebaker Test Car.

Engine Resistance is an important factor in motor vehicle operation on grades if the normal operation of the car and truck continues to be in conventional gear To determine engine resistance, the uniform coasting speed on each of the various grades was found for high, second, and low gear. The difference between the total resistance of the car determined in this way and the air and rolling resistance obtained in the coasting tests when the motor was declutched or in freewheeling, represented the engine resistance at the various coasting speeds In these tests engine resistance increased with speed The values obtained ranging from 17 pounds per ton at 10 miles an hour to 100 pounds per ton at 40 miles per hour in high gear, from 20 pounds per ton at 5 miles an hour to 150 pounds per ton at 25 miles an hour in second gear, and a resistance of 160 pounds per ton at 6 miles per hour in low gear The effect of engine resistance on the speed of the car is best illustrated by the results with the Studebaker test car for which the coasting speed, in freewheeling on a 6-percent grade was 59 miles per hour as compared with 32 miles per hour in conventional high gear, 12 miles per hour in second gear and it was necessary to open the throttle to coast at constant speed on this grade in low gear. The same general effect was observed with the trucks

TABLE IV

MAXIMUM ACCELERATION IN HIGH, SECOND AND LOW GEAR ON LEVEL GRADE WITH FORD V-8 AND STUDEBAKER TEST CARS

Speed m p h	Acceleration, Ft per Sec per Sec					
	Ford V-8			Studebaker		
	High	Second	Low	High	Second	Low
7 5	2 7	8 0	7 1	2 2	3 8	5 6
10 0	3 4	9 0	10 0	2 8	5 4	6 7
15 0	3 3	8 6	9 9	3 4	5 9	9 2
20 0	3 1	4 8	6 4	3 4	5 9	8 4
25 0	3 3	5 1	3 6	2 6	5 3	6 3
30 0	3 2	4 9	2 1	2 3	4 7	
35 0	3 0	3 6		2 0	4 7	
40 0	2 7	3 3		1 9	4 9	
45 0	2 6	3 1		1 6	4 7	
50 0	2 5	2 9		1 4	4 4	
55 0	2 4	2 8		1 2		
60 0	2 3			0 9		
65 0	2 2			0 5		
70 0	2 1			0 1		

as with the cars except that the increased weight of the trucks caused the values for engine resistance in pounds per ton to be proportionately higher and the coasting speeds on the same grades to be higher.

Acceleration and Tractive Effort. Acceleration tests at full throttle were run in the various gears for each test car and truck on a level grade. The same general procedure was used in running these tests that was used in running the deceleration tests, the maximum acceleration being computed from the space-time curves. The tests with the Ford V-8 and Studebaker test cars in Table IV show typical acceleration values for passenger cars The increase in power and maximum speed of 1933 and 1934 model cars was accompanied with corresponding increases in acceleration ability and therefore the Ford V-8 results would apply to such cars rather than the values obtained with the Studebaker

TABLE V

Maximum Tractive Effort for Passenger Cars and Trucks

Car	Speed m p h	Max tractive effort lbs per ton	Car	Speed m p h	Max tractive effort lbs per ton
High Gear					
Studebaker 1932	10	193 5	Ford A 1931	10	168 0
Coupe	20	241 0	Coach	20	169 5
	30	186 0		30	199 0
	40	183 5		40	190 0
	50	178 5		50	183 0
	60	174 5		55	181 5
Ford V-8 1933	10	237 0	Essex 1929	10	219 0
Coach	20	221 0	Coach	20	194 5
	30	246 5		30	169 0
	40	235 5		40	172 0
	50	241 0		50	174 0
	55	247 0			
			Buick "8"	10	147 0
Chevrolet 1933	10	231 5	1931 Sedan	20	182 0
Coach	20	241 5		30	160 0
	30	203 0		40	166 0
	40	193 0		50	160 5
	50	197 0			
	55	198 0	Reo Moving	10	97 5
			Van (no	20	85 0
Graham Truck	10	155 5	load)	30	75 0
(no load)	20	124 5		40	80 0
	30	131 5			
	40	124 5			
	50	142 0			
Second Gear					
Studebaker 1932	10	355 0	Ford A 1931	10	318 0
Coupe	20	398 5	Coach	20	258 0
	30	338 0		30	211 5
	40	369 0		40	172 5
	50	362 5			
			Essex 1929	10	296 5
Ford V-8 1933	10	582 5	Coach	20	282 5
Coach	20	331 0		30	197 5
	30	335 5			
	40	265 0	Buick "8"	10	183 0
	50	268 0	1931 Sedan	20	274 0
	55	271 0		30	208 0
				40	174 5
Chevrolet 1933	10	294 5			
Coach	20	283 0	Reo Van (no	10	140 0
	30	243 0	load)	20	107 0
	40	200 5		30	85 0
Graham Truck	10	240 0			
(no load)	20	185 5			
	30	152 0			

TABLE V—*Concluded*

Car	Speed m p h	Max tractive effort lbs per ton	Car	Speed m p h	Max tractive effort lbs per ton
Low Gear					
Studebaker 1932	10	435 5	Ford A 1931	10	516 0
Coupe	20	549 5	Coach	15	310 0
	25	429 0			
			Essex 1929	10	333 5
Ford V-8 1933	10	644 5	Coach	15	327 0
Coach	20	430 5			
	30	176 0	Buick "8"	10	338 0
			1931 Sedan	20	302 5
Chevrolet 1933	10	464 0		25	233 0
Coach	20	296 5			
	25	223 5	Reo Van (no	10	100 5
			load)	15	61 5
Graham Truck	10	256 5			
(no load)	15	191 0			

The maximum tractive effort at the various speeds for each car was determined from the maximum acceleration curves by computing the acceleration force at each speed according to the formula,

$$F = Ma \tag{5}$$

and then adding to this force the total resistance for the car at the given speed as indicated in the curves for total resistance (Fig. 17). The results of the tests with the Studebaker (Fig 18) illustrate the nature of the curves used in these computations Values for maximum tractive effort in high, second, and low gear at the various speeds for all of the test cars and trucks are given in Table V. The values for the trucks are given in pounds per ton for the no load condition Since no appreciable change in maximum tractive effort should be obtained whether the truck is loaded or not, the values for maximum tractive effort in pounds per ton for the loaded condition can be obtained by reducing the values in this table to pounds per ton for the weight of the loaded truck

An interesting check on the maximum tractive effort of a given car or truck was obtained by noting the maximum uniform speed, at which the car or truck could climb a given grade. At this speed the maximum tractive effort was equal to the grade resistance plus the air and rolling resistance

APPLICATIONS TO TYPICAL GRADE REDUCTION PROBLEMS

The following illustrations are intended to show how the results on gasoline consumption and related data may be applied to typical grade reduction problems. No marked differences in the fuel consumption characteristics on grades of cars built during a five-year period were observed in these tests and it is, therefore, reasonable to assume that the results obtained for these cars are fairly typical of the cars of today and will remain so until fundamental changes in motor design are made The data obtained with the two trucks have a limited application for the reason that they represent operating characteristics for only two of many types of trucks, the high speed, 2-ton, platform type and the low speed moving van type, with a heavy body. While the results obtained in the following illustrations are not typical of all trucks, they are fairly typical of a large number of trucks They also indicate a general relationship between savings made by grade reductions which may be attributed to truck operation as compared to those savings which may be attributed to passenger car operation.

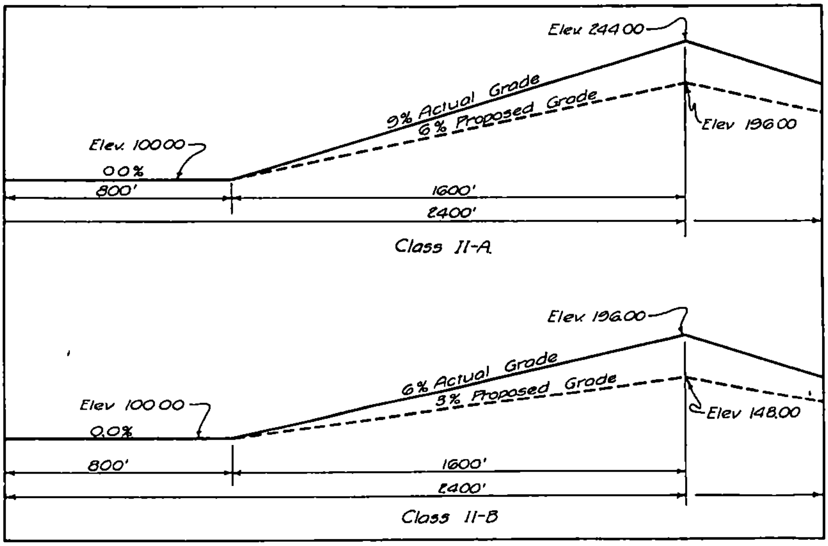

Figure 21. Typical Grade Reduction Problem, Class II

In establishing highway grades, there are two general methods of grade reduction which are designated as Class I and Class II in Figure 21 The Class I type of grade reduction is that in which the grade is reduced by lengthening it without changing the rise and fall The Class II type of grade reduction is accomplished by reducing the grade without increasing the length of grade but by reducing the rise and fall. Two typical problems were selected in each Class, the first (A) involving the reduction of 1600 feet of 9-percent grade to 6-percent grade and the second (B) the reduction of a 6-percent grade, 1600 feet long to a 3-percent grade The courses were brought to the same length in each case by adding the necessary length of level grade Vertical curves were eliminated in each case to simplify the solution of the problem. For comparative purposes the final result would not be changed materially if the vertical curves were eliminated in all of the cases under consideration.

The gasoline consumption factors used in solving this problem were the average values for 1932 and 1933 passenger cars and the observed values for the Graham and Reo trucks The volume of traffic was assumed to be 1,000,000 tons per year for each type of vehicle, in each direction, that is ascending and descending the given grades The maximum ascending and descending grades over which the three types

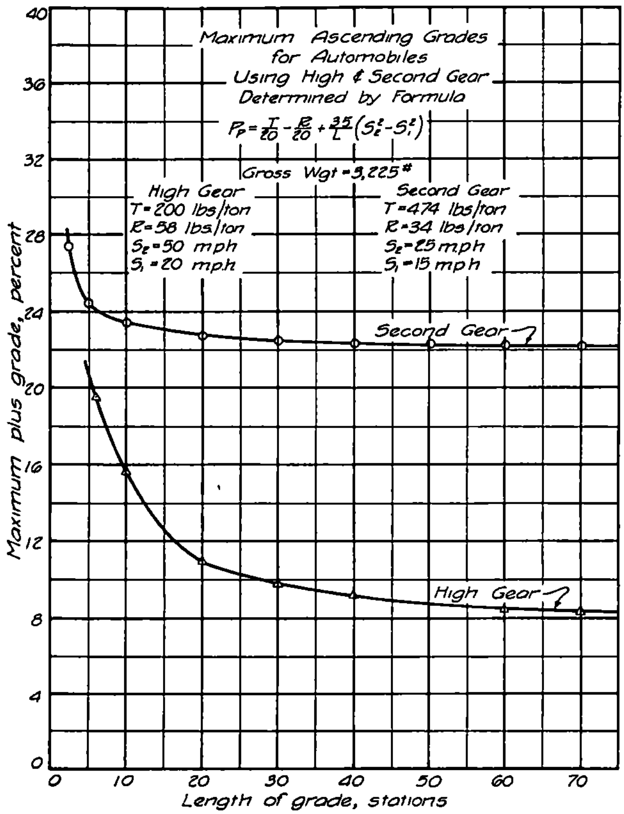

Figure 22

of vehicles could operate at given rates of speed in the various gears were determined from the curves in Figures 22 to 25 These curves were based on the operating characteristics of the vehicles as determined in this investigation and applied in the general formulas for economic grades, derived by Dean Agg in Bulletin 65 In this investigation, however, the maximum grade of a given length on which the vehicle could be operated without shifting gears or without using the brakes, was determined for a wider range of speeds than was used by Agg. Typical results based on these curves were that the maximum grade 2000 feet long which could be ascended in high gear was 11 percent for the cars, 6 percent for the Graham truck and 4 percent for the Reo moving van The maximum grade of the same length when descending was found to be 10 percent in conventional high gear and 6 percent in free-wheeling for the cars, and 6½ percent for both the Graham and Reo trucks in high gear Similar characteristics were determined for second and low gear for the various vehicles. The speeds, gears and gasoline

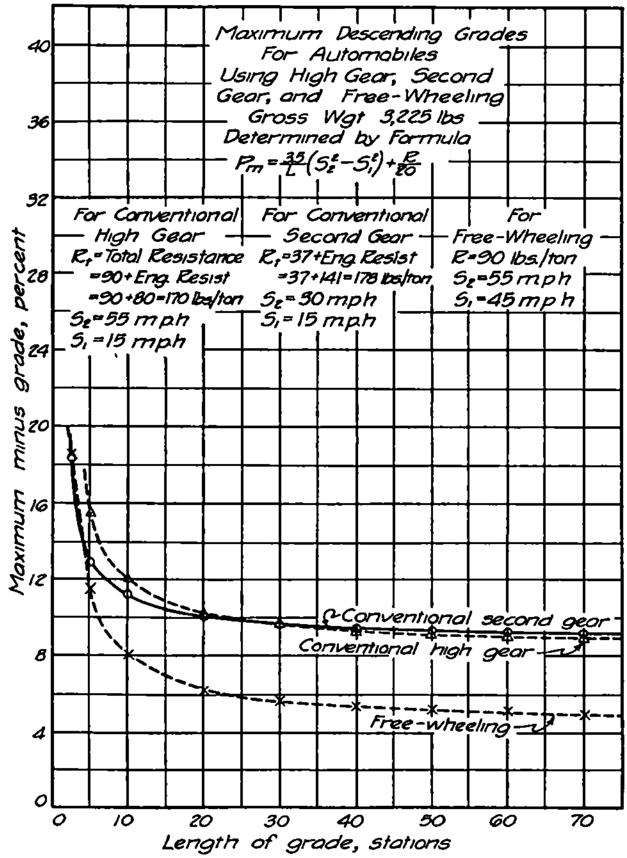

Figure 23

units used in the solution of the four grade reduction problems are given in Table VI.

The savings, in gasoline in gallons per year and on a cost basis per year, are given for both classes of grades in Tables VII and VIII Grade reduction resulted in savings for both passenger cars and trucks in all cases except for the Reo truck on a Class I-A grade. In this case the operation on the 9-percent grade with the level grade approaches was cheaper than on a continuous 6-percent grade of the same total length and the same rise and fall The reduction in rise and fall on the Class

II grades made possible larger savings than on the Class I grades where no change in the rise and fall was made

The savings with passenger cars when reducing from a 9 to a 6-percent grade were 4 times greater on a Class I grade and 10 times greater on a Class II grade than when reducing from a 6 to a 3-percent grade. The savings for the trucks were notably higher than for the cars, although the same tonnage was used in each case

TABLE VI

SPEEDS, GEARS, AND GASOLINE CONSUMPTION UNITS USED ON DIFFERENT GRADES, BY THE THREE TYPES OF VEHICLES IN THE FOUR TYPICAL GRADE REDUCTION PROBLEMS

Type of vehicle	Grade %	Ascending				Descending			
		Gear	Speed m p h	Gas cons gal per ton mile	Class of grade	Gear	Speed m p h	Gas cons gal per ton mile	Class of grade
Passenger cars	0 00	High	40 0	0 034	I and II	High	40 0	0 034	I and II
	3 00	High	40 0	0 049	I and II	High	40 0	0 024	I and II
	6 00	High	40 0	0 064	I and II	High	40 0	0 014	I and II
	9 00	High	40 0	0 090	I and II	High	40 0	0 009	I and II
Graham truck (Gross load 10,000 lb)	0 00	High	20 0	0 015	I and II	High	20 0	0 015	I-A, II-A
	0 00	High	40 0	0 020	II-B	High	40 0	0 020	I-B, II-B
	3 00	High	25 0	0 034	I-B, II-B	High	40 0	0 009	I-B, II-B
	6 00	Second	20 0	0 060	I and II	High	40 0	0 0055	I and II
	9 00	Low	10 0	0 091	I-A, II-A	Low	10 0	0 027	I-A, II-B
Reo Van (Gross load 13,150 lb)	0 00	High	15 0	0 013	I and II	High	15 0	0 013	I-A, II-A
	0 00	High	30 0	0 016	II-B	High	35 0	0 018	I-B, II
	0 00					High	30 0	0 016	II-B
	3 00	High	17 5	0 026	I-B, II-B	High	30 0	0 009	I-B, II
	6 00	Low	5 0	0 067	I and II	High	35 0	0 004	I and II
	9 00	Low	5 0	0 071	I-A, II-A	Low	10 0	0 016	I-A, II-A

The results for the cars indicate that the greatest savings were obtained by reducing grades from 9 to 6-percent and that no very large savings can be expected in the reduction of grades below 6 percent unless there is a large volume of traffic Furthermore, the results seem to indicate that the use of gentle rolling grades of 3 percent and less should introduce only slight increases in fuel costs and their use within limits may, therefore, be justified

In addition to the fuel savings, large time savings in truck operation resulted from the reduction in grades A summary of the time saved on the different grades for the two trucks is given in Table IX

TABLE VII

SAVINGS IN GASOLINE CONSUMPTION, IN GALLONS PER YEAR, AND COST PER YEAR, FOR THE THREE TYPES OF VEHICLES IN THE FOUR GRADE REDUCTION PROBLEMS

Class I-A	Class I-B
A *Passenger Cars*, average gross weight 3,225 lbs, assuming 1,000,000 tons per year ascending and 1,000,000 tons per year descending	
Grade 9% Ascending 32,370 gal per yr Descending 11,180 Total = 43,550 gal per yr	Grade 6% Ascending 24,570 gal per yr Descending 9,350 Total = 33,920 gal per yr
6% Ascending 29,170 gal per yr Descending 6,340 Total = 35,510 gal per yr	3% Ascending 22,410 gal per yr Descending 10,710 Total = 33,120 gal per yr
Saving on 6% over 9% = 8,040 gal per yr Saving @ $ 20 gal = $1,608 per yr	Saving on 3% over 6% = 800 gal per yr Saving @ $ 20 gal = $160 per yr
B *Graham Truck*, gross weight 10,500 lbs, assuming 1,000,000 tons per year ascending and 1,000,000 tons per year descending	
Grade 9% Ascending 29,790 gal per yr Descending 10,490 Total = 40,280 gal per yr	Grade 6% Ascending 20,610 gal per yr Descending 4,670 Total = 25,280 gal per yr
6% Ascending 27,440 gal per yr Descending 2,510 Total = 29,950 gal per yr	3% Ascending 15,580 gal per yr Descending 4,150 Total = 19,730 gal per yr
Saving on 6% over 9% = 10,330 gal per yr Saving @ $ 20 gal = $2,066 per yr	Saving on 3% over 6% = 5,550 gal per yr Saving @ $ 20 gal = $1,110 per yr
C *Reo Moving Van*, gross weight 13,150 lbs, assuming 1,000,000 tons per year ascending and 1,000,000 tons per year descending	
Grade 9% Ascending 23,340 gal per yr Descending 6,700 Total = 30,040 gal per yr	Grade 6% Ascending 22,410 gal per yr Descending 4,000 Total = 26,410 gal per yr
6% Ascending 30,650 gal per yr Descending 2,000 Total = 32,650 gal per yr	3% Ascending 11,610 gal per yr Descending 4,150 Total = 15,760 gal per yr
Increased cost on 6% over 9% = 2,610 gal per yr Increased cost @ $ 20 gal = $522 per yr	Saving on 3% over 6% = 10,650 gal per yr Saving @ $ 20 gal = $2,130 per yr

TABLE VIII

SAVINGS IN GASOLINE CONSUMPTION, IN GALLONS PER YEAR, AND COST PER YEAR, FOR THE THREE TYPES OF VEHICLES IN THE FOUR TYPICAL GRADE REDUCTION PROBLEMS

Class II-A	Class II-B
A *Passenger Cars*, average gross weight 3,225 lbs , assuming 1,000,000 tons per year ascending and 1,000,000 tons per year descending	
Grade 9% Ascending 32,370 gal per yr Descending 7,750 Total = 40,120 gal per yr 6% Ascending 24,570 gal per yr Descending 9,350 Total = 33,920 gal per yr	Grade 6% Ascending 24,570 gal per yr Descending 9,350 Total = 33,920 gal per yr 3% Ascending 20,040 gal per yr Descending 12,260 Total = 32,300 gal per yr
Saving on 6% over 9% = 6,200 gal per yr Saving @ $ 20 per gal = $1,240 per yr	Saving on 3% over 6% = 1,620 gal per yr Saving @ $ 20 per gal = $324 per yr
B *Graham Truck*, gross weight 10,500 lbs , assuming 1,000,000 tons per year ascending and 1,000,000 tons per year descending	
Grade 9% Ascending 29,790 gal per yr Descending 10,490 Total = 40,280 gal per yr 6% Ascending 20,610 gal per yr Descending 4,670 Total = 25,280 gal per yr	Grade 6% Ascending 20,610 gal per yr Descending 10,490 Total = 25,280 gal per yr 3% Ascending 13,400 gal per yr Descending 5,770 Total = 19,170 gal per yr
Saving on 6% over 9% = 15,000 gal per yr Saving @ $ 20 per gal = $3,000 per yr	Saving on 3% over 6% = 6,110 gal per yr Saving @ $ 20 per gal = $1,222 per yr
C *Reo Moving Van*, gross weight 13,150 lbs , assuming 1,000,000 tons per year ascending and 1,000,000 tons per year descending	
Grade 9% Ascending 23,340 gal per yr Descending 6,700 Total = 30,040 gal per yr 6% Ascending 22,410 gal per yr Descending 4,000 Total = 26,410 gal per yr	Grade 6% Ascending 22,410 gal per yr Descending 4,000 Total = 26,410 gal per yr 3% Ascending 10,150 gal per yr Descending 5,170 Total = 15,320 gal per yr
Saving on 6% over 9% = 3,630 gal per yr. Saving @ $ 20 per gal = $726 per yr	Saving on 3% over 6% = 11,090 gal per yr Saving @ $ 20 per gal = $2,218 per yr

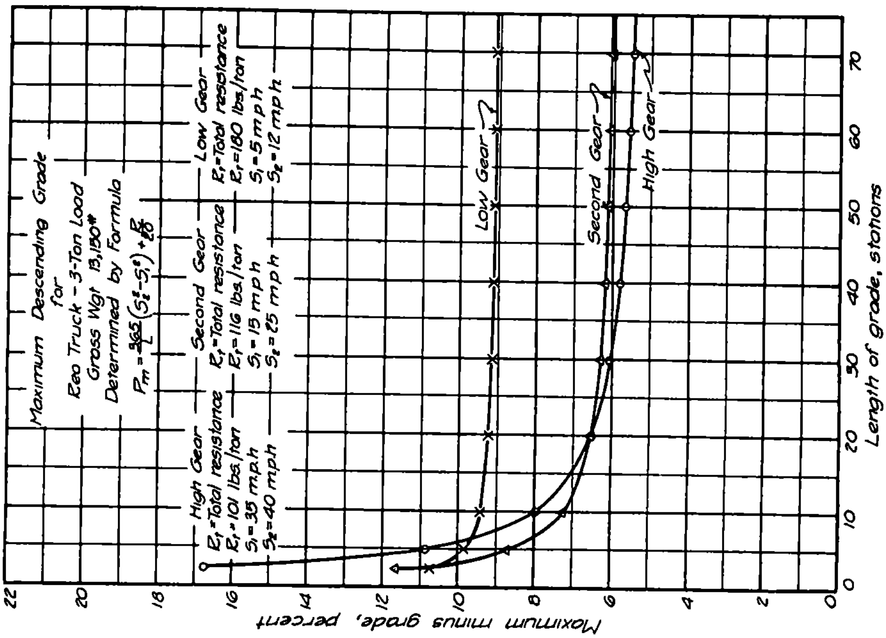

Figure 25

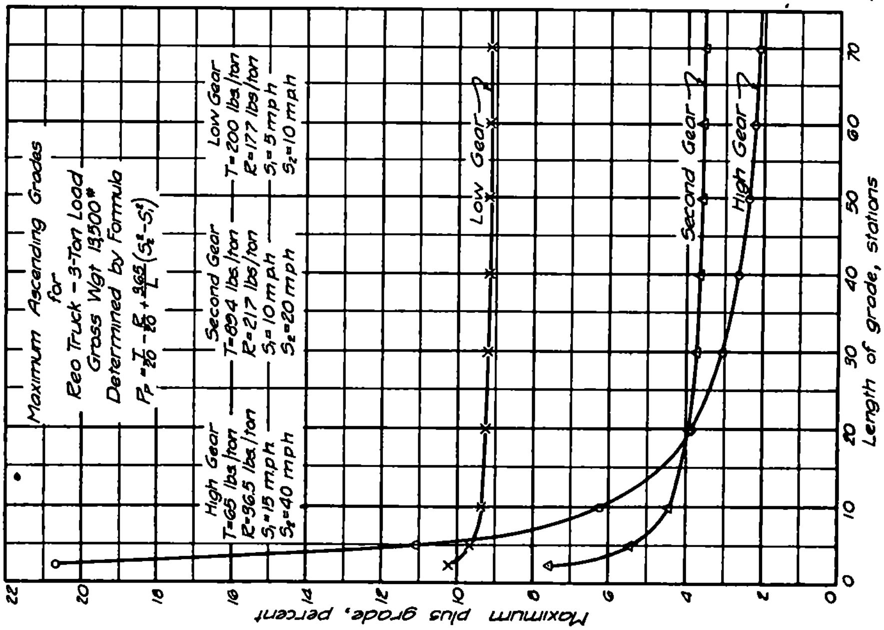

Figure 24

TABLE IX

SUMMARY OF TIME SAVED ON DIFFERENT GRADES WITH THE TWO TYPES OF TRUCKS IN THE FOUR TYPICAL GRADE REDUCTION PROBLEMS

Truck	Class of grade	Grade reduction	Time saved ton-minutes per year
Graham Gross load (10,500 lb)	I	9% to 6%	13,130,000
	I	6% to 3%	1,420,000
	II	9% to 6%	13,130,000
	II	6% to 3%	2,100,000
Reo Van Gross load (13,150 lb)	I	9% to 6%	6,900,000
	I	6% to 3%	16,830,000
	II	9% to 6%	10,850,000
	II	6% to 3%	18,280,000

SUMMARY AND CONCLUSIONS

The results of this investigation may be summarized as follows.

1. In conventional gear, the average gasoline consumption, ascending and descending grades at a constant speed, increased uniformly with each percent increase in grade above a level grade

2. In freewheeling, a fuel saving was obtained when ascending and descending on grades between 1 and 5 percent, at speeds less than 48 miles per hour as compared to operation on a level grade, at the same average speed

3. A maximum increase in gasoline mileage of about 20 percent was obtained when operating in freewheeling at 32 miles per hour on a 10-mile hilly course as compared to conventional gear. No advantage in gasoline mileage when operating in freewheeling as compared to conventional gear was obtained on this course at speeds greater than 52 miles per hour

4. Chassis dynamometer tests with the Studebaker test car indicated that with no air resistance the gasoline mileage of this car would have been increased by not more than 1 to 5 miles per gallon, for speeds of 25 to 50 miles per hour, respectively

5 The dynamometer tests indicated that rolling resistance on rigid, smooth surfaces decreases with an increase in speed

6. Engine resistance is an important factor in motor vehicle operation on grades It increases with speed and is greater in magnitude than air resistance for the average car

7. A more accurate measure of the maximum tractive effort of a car can be obtained from acceleration tests and tests on steep grades than from the chassis dynamometer tests

8. The overall thermal efficiency of the average passenger car varies from $3\frac{1}{2}$ percent at 10 miles an hour to a maximum of $16\frac{1}{2}$ percent at 60 miles an hour The overall efficiency increases with an increase in load

produced by operation on steep grades The rate of change in efficiency increases with an increase in load

9 The savings in fuel costs, resulting from grade reduction, were greater for trucks than for passenger cars, although the total tonnage was the same

10 For passenger cars, operating in high gear at constant speed, the savings in fuel costs resulting from reducing a 9-percent grade to a 6-percent grade were 10 and 4 times greater than the savings in reducing from a 6- to a 3-percent grade for the Class I and Class II grades, respectively.

11. Gentle rolling grades of 3 percent or less should introduce only slight increases in fuel costs and their use is, therefore, justifiable.

12 For grades lower than 9 percent, the time saving obtained from grade reduction is negligible for automobiles but is an important factor in truck operation on grades steeper than 3 percent

13 Truck operating characteristics on grades vary considerably, depending on the type and capacity of the truck

14 Further road tests of carefully selected trucks of various makes and capacities are necessary to indicate definitely the truck operating characteristics on grades