IOWA STATE COLLEGE
OF AGRICULTURE AND MECHANIC ARTS
OFFICIAL PUBLICATION

Vol. XX | May 31, 1922 | No. 53

RESISTANCES TO THE TRANSLATION of MOTOR VEHICLES

By
T. R. AGG

BULLETIN 64

ENGINEERING EXPERIMENT STATION

AMES, IOWA

Published weekly by Iowa State College of Agriculture and Mechanic Arts, Ames, Iowa. Entered as Second-class matter, and accepted for mailing at special rate of postage provided for in Section 429, P. L. & R., Act August 24. 1912, authorized April 12, 1920.

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The purpose of the Engineering Experiment Station is to afford a service, through scientific investigation, evolution of new devices and methods, and tests and analyses of materials:

For the manufacturing and other engineering population and industries of Iowa;

For the industries related to agriculture, in the solution of their engineering problems;

For all people of the state in the solution of the engineering problems of urban and rural life.

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INVESTIGATION OF RESISTANCES TO THE TRANSLATION OF MOTOR VEHICLES

In 1919 the Iowa Engineering Experiment Station began an investigation of the economics of grades for highways and before the work had been under way very long it became apparent that the magnitude of the resistances to the translation of the vehicle would be important factors in the economic theory of highway grades. An investigation of the subject of road and vehicle resistance was immediately inaugurated and has proceeded until the present time.

The magnitude of the problem and the widespread interest therein resulted in a cooperative investigation of the subject being arranged between the Iowa Engineering Experiment Station and the Bureau of Public Roads, effective in the spring of 1922. Under that arrangement the investigation is proceeding rapidly and will be completed early in 1923.

This report covers the methods and results obtained prior to the inauguration of the cooperative project mentioned above and deals in part with abortive attempts to measure the somewhat illusive quantity, loosely termed, tractive resistance. There is also included a description of the methods finally adopted and the results obtained thereby.

Personnel. The investigation was carried out by the Iowa Engineering Experiment Station at Ames of which Dean Anson Marston is Director. In addition to the author, Prof. W. L. Foster of the civil engineering department was employed on the work. The Iowa Highway Commission cooperated throughout by loaning trucks and small equipment. Dr. H. C. Dickinson, research director, Society of Automotive Engineers, loaned equipment and assisted in various other ways. J. B. Davidson, professor of agricultural engineering at Ames, loaned a dynamometer and David L. Gallup of Indianapolis, Indiana, loaned an accelerometer.

Vehicles. There are listed in Table I the vehicles employed, their equipment and weights.

Determinations with the Davidson Dynamometer

At Ames the first attempts were to measure the resistance to the translation of motor vehicles by means of a dynamometer which was placed between a towing truck and the vehicle under test.

Prof. J. B. Davidson of the department of agricultural engineering had made some tractive resistance measurements in California a few years prior to that, employing for the purpose a dynamometer of his

TABLE I

SHOWING EQUIPMENT OF VEHICLES FOR TRACTIVE RESISTANCE INVESTIGATION

Vehicles	Gross Weight	Size and Type of Tires	Remarks
Buick 21-45 touring car. Used with top up.	1.85 tons	33x4 U. S. Royal cord, inflation 65 to 70 lb. per sq. in.	Weight includes apparatus, driver and observer. Car and tires nearly new at beginning of series of runs.
Light aviation army truck.	Loaded—4.14 tons. Empty—3.14 tons* *Except as otherwise noted.	Front 35x5 Goodyear cord all weather tread; rear, twin 35x5 Goodyear cord all weather tread; inflation 85-90 lb. per sq. in.	Truck and all equipment new at beginning of the series of runs.
Heavy aviation army truck.	Loaded—8 tons.	Front 36x6 solid; rear 36x 10 dual solid.	Truck and all equipment new at beginning of the series of runs.

own design. His work had been for the most part with horse-drawn vehicles. Through the courtesy of Professor Davidson one of his instruments was secured for use in this investigation.

The Davidson dynamometer is designed so that one may obtain a record of the drawbar pull for a comparatively short distance during which it is assumed that conditions can be kept constant. It was found most convenient to use courses having lengths of either 50 or 100 feet. The dynamometer is of the spring type and is equipped with a recording device that plats a curve showing the variation in drawbar pull and mechanically integrates the area under the curve.

TABLE II

RESISTANCE TO TRANSLATION ON BITULITHIC PAVEMENT

(Rolling, impact, and air resistances and internal resistance up to the neutral gear.)

Draft in Pounds Per Ton					
Run	East	West	Run	East	West
1	48.7	21.2	13	23.8	25.0
2	38.2	36.9	14	30.0	24.4
3	39.4	37.5	15	30.6	25.0
4	35.6	39.4	16	34.4	17.5
5	35.6	36.2	17	34.4	23.1
6	28.8	35.7	18	40.0	18.5
7	28.2	41.2	19	35.6	16.5
8	28.2	36.2	20	40.0	21.9
9	24.4	35.7	21	36.3	21.2
10	27.5	13.8	22	40.6	40.6
11	28.2	20.0	Average for all determinations 30.5 lb. per ton.		
12	24.4	21.8			

Remarks—Heavy aviation truck. Gears in neutral. Runs on bithulithic pavement, Lincoln Way, Ames, Iowa. Speed approximately 8 miles per hour. Gross load 8 tons. Temperature 65° F.

Fig. 1 shows the general arrangement of towing truck, dynamometer and the vehicle under tests as they were used at Ames. Fig. 2 is the calibration curve for the dynamometer and Fig. 3 shows a part of one of the records.

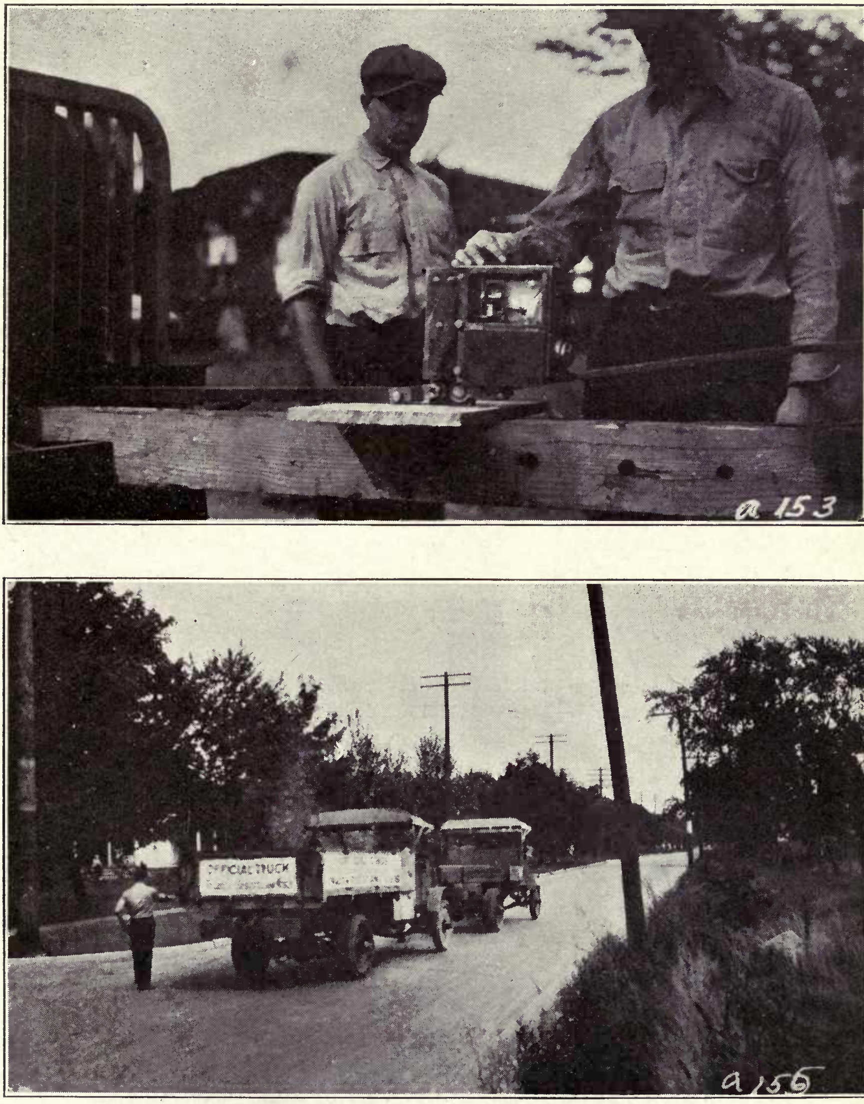

FIG. 1. DAVIDSON DYNAMOMETER AND METHOD OF TOWING

From the beginning, difficulty was found in securing concordant results with this method. The dynamometer operated satisfactorily, but due to the slight unevennesses of the pavement surface, the vehicles would surge in an erratic manner. This introduced impact effects into the records which are plainly indicated by the curve of drawbar pull in Fig. 3. Also, considerable difficulty was experienced in maintaining uniform speed during the period when the record was being made. Undoubtedly many of the records were affected by acceleration. It was thought that if the records were made by towing the

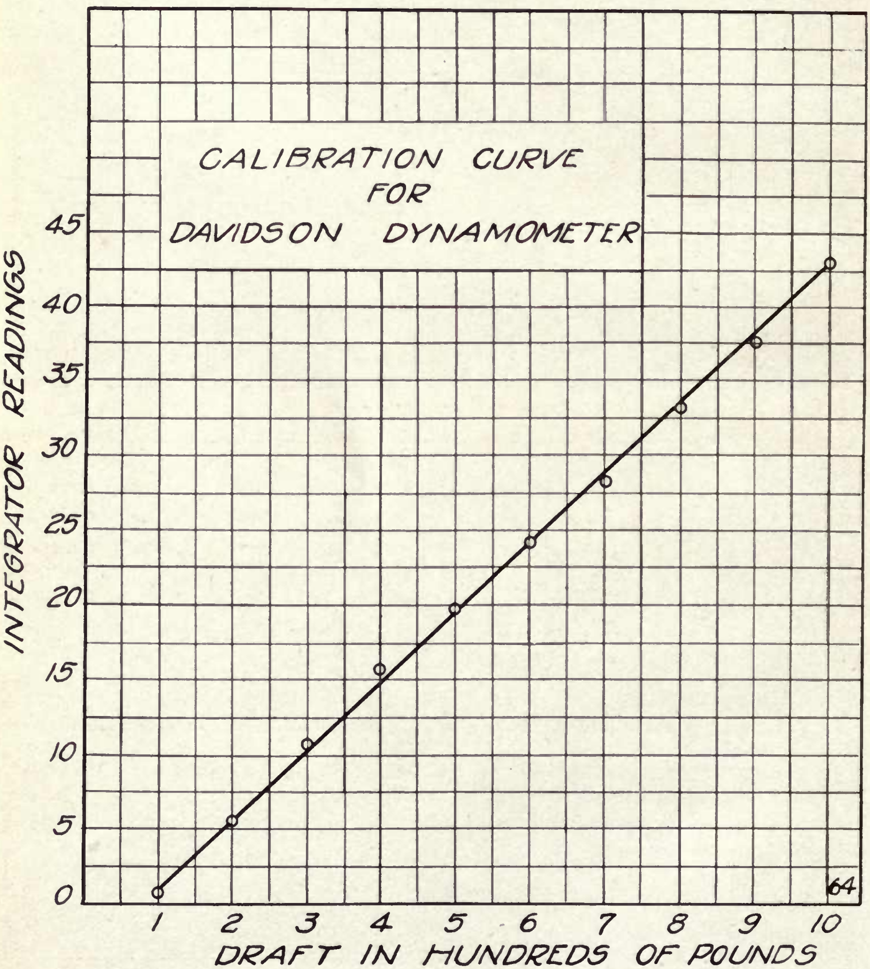

FIG. 2. CALIBRATION CURVE FOR DAVIDSON DYNAMOMETER

truck up a stiff grade, most of the impact effects would be eliminated. This did not prove to be the case as is indicated in the tables which follow, but the records so made are much more dependable than those taken on level roads or on slight grades.

There are given herein a number of tables of values of resistance to translation obtained by the Davidson dynamometer. Later investigations indicate that some of these values for resistance are somewhat too high, but they are of interest and value despite the great variation in individual determinations. No method was discovered for entirely eliminating the objectionable characteristics of the determinations made with the Davidson dynamometer and it was therefore decided to try some other method.

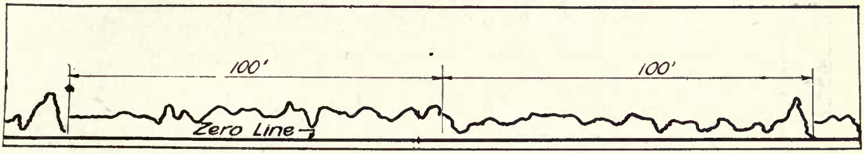

FIG. 3. PART OF A RECORD FROM THE DAVIDSON DYNAMOMETER

Determinations with Gulley Dynamometer

The next attempts to measure resistances to the translation of motor vehicles were made with the Gulley dynamometer. The Gulley dynamometer consists of a pressure cylinder, shown in Fig. 4, which is attached to the drawbar between the towing vehicle and the one under test, and a recording device, shown in Fig. 5, which plats a curve of the drawbar pull. The connection between the pressure cylinder and the recording mechanism is a flexible pressure tube. It was thought that the column of oil in the tube and pressure cylinder would serve to damp out some of the impact effects. A number of trials were made, but no satisfactory results were obtained. This was perhaps partly due to friction in the instrument. It is being partly redesigned and may produce some reliable records.

Accelerometer Determinations of Resistance to Translation

There are several instruments in use that are intended to measure resistance to translation by the deceleration method. The instruments are also intended to be used in measuring motor car performance, such as accelerating ability.

The Wimperis accelerometer was developed by H. E. Wimperis, Hampstead, England, and is manufactured by Elliott Bros. Co., Lt., London. In principle the instrument is an unbalanced disc mounted horizontally, with a spring for resisting the rotation of the disc and for returning it to the zero point, a pointer, and a scale on a horizontal

TABLE III

RESISTANCE TO TRANSLATION ON GRAVEL SURFACE

(Rolling, impact, and air resistances and internal resistance up to the neutral gear.)

Draft in Pounds Per Ton

Run	North	South	Run	North	South
1	63.4	58.7	22	78.0	76.2
2	77.0	70.6	23	84.4	88.0
3	77.5	87.6	24	77.5	75.0
4	81.2	66.2	25	72.0	75.0
5	70.0	70.0	26	61.2	75.0
6	59.4	85.0	27	78.7	71.8
7	66.2	64.4	28	76.2	64.0
8	76.2	91.0	29	77.0	75.0
9	76.3	84.0	30	68.7	61.1
10	70.0	69.3	31	60.0	76.2
11	60.0	77.0	32	81.2	78.7
12	82.5	79.0	33	83.7	68.7
13	87.5	90.6	34	88.7	84.3
14	88.7	63.7	35	70.0	62.0
15	70.0	76.2	36	65.6	78.1
16	62.5	76.2	37	78.7	83.7
17	77.5	76.2	38	79.3	77.5
18	78.0	87.6	39	71.2	70.6
19	66.0	75.0			
20	87.5	70.0			
21	63.7	78.7			

Average of all determinations **75** lb. per ton.

Remarks—Heavy aviation truck. Runs on gravel roads on I. S. C. Campus. Road smooth, hard, and dry. North, —0.12% grade. Speed approximately 6 miles per hour. Gross weight 8 tons. Gears in neutral.

dial. It is shown in Fig. 6. The instrument is mounted on the car and by means of a leveling screw the pointer is brought to zero when the vehicle is standing on a truly level place.

Any acceleration or deceleration of the vehicle causes the disc to rotate and moves the pointer to the proper dial reading.

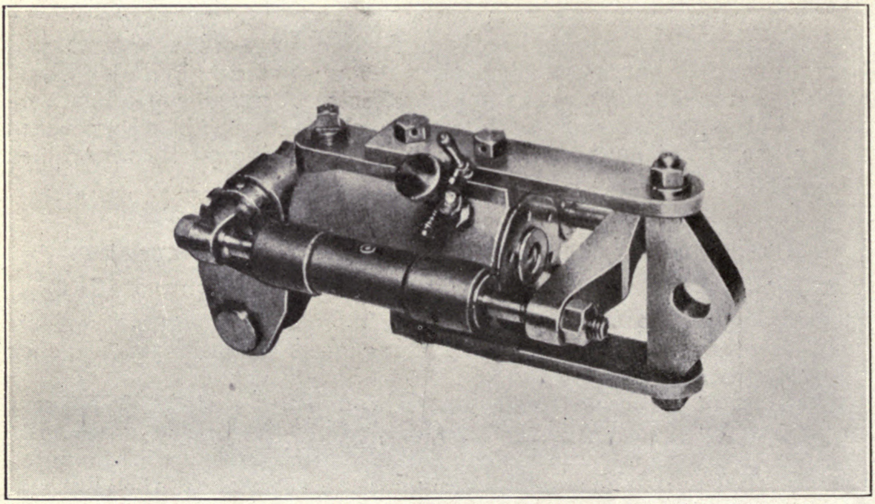

FIG. 4. GULLEY DYNAMOMETER

In using the instrument for determining tractive resistance, the vehicle is driven at speed to the beginning of the section of road upon which tractive resistance is to be determined. The vehicle is then allowed to coast and simultaneous readings of deceleration and speed are taken as rapidly as the observer is able to do so, or the vehicle may be allowed to coast down grade from rest or up grade with initial velocity. The instrument is calibrated and the dial marked to read deceleration or acceleration in pounds per British ton. A reliable and sensitive speed indicator must be attached to the car, as the ordinary speedometer does not indicate speed with sufficient accuracy for the purpose. Fig. 7 shows some values for tractive resistance obtained with this instrument and the somewhat scattered values for individual readings of the instrument should be noted.

It was found that certain difficulties were likely to be encountered in using the instrument. The first was the effect of uneven road surfaces on deceleration. The vehicle does not decelerate uniformly but, instead, travels with a succession of erratic changes in speed which are slight but which are truly reflected in the indication on the instrument. By taking a large number of observations and averaging them, most of the erratic points can probably be eliminated. A similar effect is produced by the change in the relative position of the body of the vehicle and the wheels, resulting from spring action.

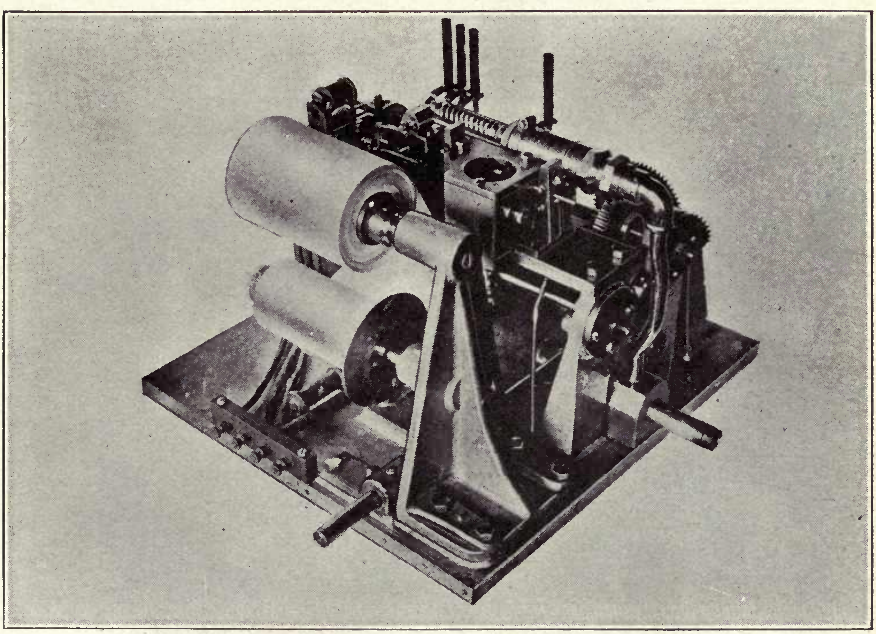

FIG. 5. RECORDING MECHANISM FOR GULLEY DYNAMOMETER

TABLE IV

RESISTANCE TO TRANSLATION ON OILED GRAVEL SURFACE

(Rolling, impact, and air resistance and internal resistance up to the neutral gear.)

Draft in Pounds Per Ton					
Run	North	South	Run	East	West
1	50.0	96.2	20	58.7	86.2
2	57.5	87.5	21	48.7	77.0
3	50.6	77.5	22	63.7	88.7
4	68.7	87.5	23	57.5	92.5
5	57.0	88.1	24	48.7	97.5
6	76.2	91.2	25	57.5	87.5
7	50.0	97.5	26	51.2	77.2
8	54.6	87.5	27	63.1	88.1
9	57.0	77.5	28	56.2	90.0
10	63.1	87.5	29	76.2	97.2
11	57.0	90.6	30	48.7	97.5
12	77.0	97.5	31	51.2	82.5
13	47.5	97.5	32	57.5	82.5
14	52.5	81.2	33	63.8	86.2
15	58.1	82.5	34	61.2	91.2
16	17.1	86.2	35	76.2	97.5
17	56.2	90.0			
18	76.2	95.0	Average of all determinations **74** lb. per ton.		
19	45.0	96.2			

Remarks—Heavy aviation truck. Runs on campus drive at Ames. Road smooth, hard, and free of dust. Speed approximately 8 miles per hour. North, —0.79% grade. Gears in neutral.

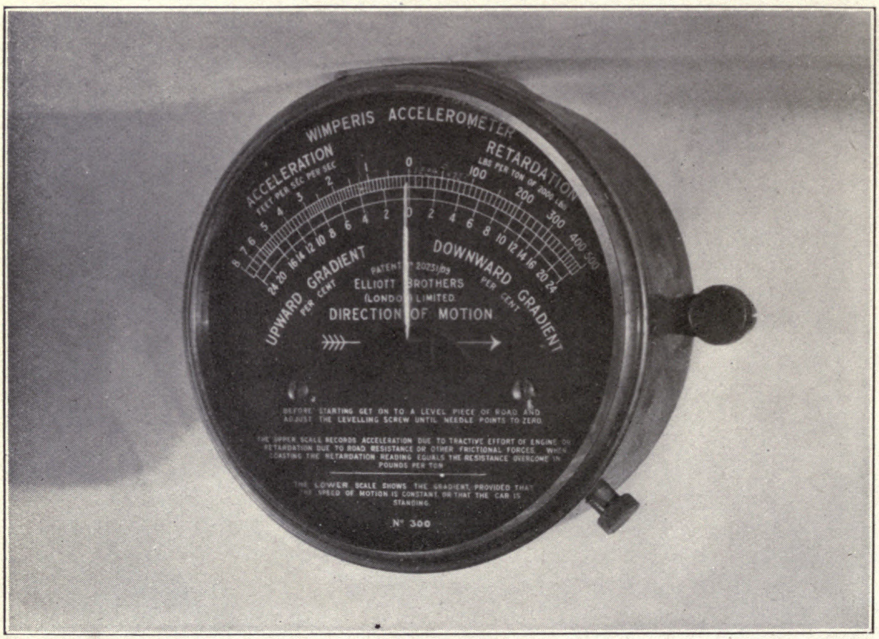

FIG. 6. WIMPERIS ACCELEROMETER

TABLE V

RESISTANCE TO TRANSLATION ON BITULITHIC PAVEMENT

(Rolling, impact, and air resistance and internal resistance up to the clutch.)

Draft in Pounds Per Ton					
Run	North	South	Run	North	South
1	65.1	43.4	6	65.1	43.4
2	63.9	48.2	7	59.1	48.2
3	65.1	41.0	8	67.5	47.0
4	73.5	43.4			
5	72.4	43.4	Average of all runs **55.6** lb. per ton.		

Remarks—Light aviation truck, running declutched. Runs on bithulithic pavement, Clark Ave., Ames, Iowa. Inflation 75 lb. per sq. in. Speed approximately 8 miles per hour. Temperature 65° F. Gross load 8300 lb.

TABLE VI

RESISTANCE TO TRANSLATION ON BITULITHIC PAVEMENT

(Rolling, impact and air resistance and internal resistance up to the neutral gear.)

Draft in Pounds Per Ton					
Run	North	South	Run	North	South
1	49.5	38.6	10	59.0	41.0
2	65.1	42.4	11	57.9	45.9
3	66.4	41.0	12	67.5	41.0
4	72.2	42.2	13	70.0	43.4
5	70.0	41.0	14	67.5	43.4
6	68.7	46.8	15	59.0	37.4
7	71.2	47.0	16	63.9	43.4
8	65.1	42.2			
9	50.6	42.2	Average of all determinations **53** lb. per ton.		

Remarks—Light aviation truck. Gear shift in neutral. Runs on Clark Ave., Ames, Iowa. Tire inflation 73 lb. per sq. in. Speed approximately 8 miles per hour. Gross load 8300 lb. Temperature 65° F.

TABLE VII

RESISTANCE TO TRANSLATION ON GRAVEL SURFACE

(Rolling, impact, and air resistances and internal resistance up to the neutral gear.)

Draft in Pounds Per Ton					
Run	West	East	Run	East	West
1	81.9	69.9	17	80.7	30.2
2	62.6	62.6	18	38.6	67.5
3	65.1	41.0	19	53.0	26.5
4	51.8	35.0	20	71.1	49.4
5	97.5	74.7	21	57.8	38.6
6	59.0	27.8	22	50.6	43.4
7	65.1	59.0	23	50.6	55.4
8	59.0	55.4	24	102.3	54.2
9	57.8	49.4	25	45.8	42.2
10	56.6	62.6	26	55.4	33.8
11	90.3	55.4	27	47.0	62.6
12	69.9	43.4	28	38.6	27.8
13	63.8	30.2	29	37.4	54.2
14	74.7	62.6			
15	84.3	55.4	Average of all determinations **56** lb. per ton.		
16	55.4	43.4			

Remarks—Light aviation truck. Gear shift in neutral. Speed 7 miles per hour. Road smooth, with thin covering of loose, dry sand. Gravel moistened slightly, but firm. 0.0 grade. 8300 lb. gross load. Inflation 75 lb. per sq. in.

TABLE VIII

RESISTANCE TO TRANSLATION ON GRAVEL SURFACE

(Rolling, impact, and air resistance and internal resistance up to the neutral gear.)

Run	East	West	Remarks
	Draft in Pounds Per Ton		
1		114.4	Dynamometer tests were made up a 5.85% grade with a good, hard, smooth, gravel surface. Speed approximately 6 miles per hour. Tires inflated to 75 lb. per sq. in. Gross load 8300 lb. Gear shift in neutral.
2		187.8	
3		174.6	
4		175.9	
5		143.4	
6		173.3	
7		121.6	
8		91.6	
9		146.9	Average of all determinations 148.5
10		122.8	Subtract for effect of grade 117.0
11		186.6	
12		174.6	Equivalent average draft for 0.0 grade 31.5 lb. per ton*
13		174.6	
14		144.5	
15		177.2	*This is probably a good average for this particular road.
16		127.7	
17		91.6	

TABLE IX

RESISTANCE TO TRANSLATION ON BITULITHIC PAVEMENT

(Rolling, impact, and air resistance and internal resistance including part of motor friction.)

Draft in Pounds Per Ton

Run	North	South	Run	North	South
1	67.5	63.9	6	73.5	73.5
2	70.0	63.9	7	78.4	68.6
3	73.5	68.6	8	73.5	66.4
4	79.6	70.0			
5	79.6	65.0	Average of all runs **71** lb. per ton.		

Remarks—Light aviation truck. Clutch in and motor running, throttled to lowest point. Runs on Clark Ave. Ames, Iowa. Speed approximately 8 miles per hour. Gross load 8300 lb. Temperature 65° F. Tires inflated to 75 lb. per sq. in.

TABLE X

RESISTANCE TO TRANSLATION ON GRAVEL SURFACE

(Rolling, resistance with tires underinflated, air and impact resistance and internal resistance up to the neutral gear.)

Draft in Pounds Per Ton

Run	North	South	Run	North	South
1	66.3	62.6	11	71.1	31.3
2	57.8	53.0	12	62.6	74.7
3	61.4	45.8	13	77.1	32.6
4	48.2	49.4	14	103.5	81.9
5	98.7	51.8	15	63.8	26.5
6	48.2	27.8	16	62.6	45.8
7	84.3	56.6	17	65.0	38.6
8	51.8	43.4	18	54.2	36.2
9	72.3	93.9			
10	92.7	74.7	Average of all determinations **60.2** lb. per ton.		

Remarks—Light aviation truck. Road smooth with thin covering loose sand. Gravel slightly moist, but firm. 0.0 grade, but slightly wavy. Gross load 8300 lb. Inflation of tires, 57 lb. per sq. in. Gear shift in neutral.

TABLE XI

RESISTANCE TO TRANSLATION ON EARTH ROAD

(Rolling, impact, and air resistance and internal resistance up to the neutral gear.)

Draft in Pounds Per Ton					
Run	West	East	Run	West	East
1	68.6	57.8	17	97.7	55.4
2	59.1	39.8	18	95.1	85.5
3	51.8	44.6	19	60.2	60.2
4	97.5	31.3	20	57.8	69.9
5	35.0	32.6	21	53.0	66.3
6	119.0	35.0	22	68.7	75.9
7	83.2	29.8	23	69.9	102.5
8	92.9	36.2	24	50.6	96.3
9	83.2	43.4	25	114.7	78.3
10	41.0	54 2	26	81.9	84.3
11	32.6	90.3	27	98.9	63.8
12	35.0	98.7	28	87.9	95.1
13	45.8	103.5	29	79.5	50.6
14	73.5	60.2	30	78.3	79.5
15	97.5	112.3			
16	69.9	77.1	Average of all determinations **70** lb. per ton.		

Remarks—Light aviation truck. Road surface apparently smooth and firm, but slightly moist due to cloudy weather and some mist. Truck tires inflated to 75 lb. per sq. in. Gross load 8300 lb. Speed approximately 7 miles per hour. Gear shift in neutral.

A second difficulty was that of accurately reading the indicator if there was any vibration and there was usually appreciable vibration at speeds in excess of 10 or 15 miles per hour. The graduations on the dial are fairly close together and it is exceedingly difficult to read the instrument closely when the accelerometer is being used on trucks or on passenger vehicles at high speed.

It is believed that this instrument could be used satisfactorily for measuring car performance but not for the small values of deceleration obtained in measuring resistance to translation.

TABLE XII

RESISTANCE TO TRANSLATION ON BITULITHIC PAVEMENT

(Rolling resistance with tires underinflated, impact and air resistances and internal resistance up to the neutral gear.)

Draft in Pounds Per Ton					
Run	North	South	Run	North	South
1	43.4	31.3	10	53.0	33.8
2	45.8	36.1	11	59.0	36.2
3	47.0	37.2	12	72.2	33.8
4	59.0	36.1	13	66.5	27.7
5	45.8	37.2	14	59.0	32.6
6	67.5	37.2	15	50.6	33.8
7	58.5	25.3	16	53.2	30.2
8	53.0	36.6			
9	50.6	36.2	Average of all runs **45** lb. per ton.		

Remarks—Light aviation truck. Clutch in neutral. Inflation 57 lb. per sq. in. Speed approximately 8 miles per hour. Gross load 8300 lb. Runs on Clarke Ave., Ames, Iowa. Temperature 60° F.

TABLE XIII

RESISTANCE TO TRANSLATION ON EARTH ROADS

(Rolling resistance with tires underinflated, impact and air resistances and internal resistance up to the neutral gear.)

Run	West	East
	Draft in Pounds Per Ton	
1	77.0	74.8
2	63.9	97.7
3	70.0	91.6
4	76.0	73.6
5	68.7	76.0
6	86.8	66.3
7	83.2	53.1
8	100.1	72.3
9	100.0	73.6
10	90.4	72.3
11	69.9	76.0
12	66.6	107.0
13	85.6	72.3
14	71.1	53.0
15	72.1	76.0
16	94.0	65.0
17	85.6	83.2
18	108.7	82.0
19	107.2	69.9

Average of all runs **79** lb. per ton.

Remarks——Light aviation truck Gears in neutral. Earth road; smooth, hard and slightly moist. Tire pressure 57 lb. per sq. in. Speed approximately 8 miles per hour. Gross load 8300 lb.

It is intended to make some additional trials with this instrument later, but since the particular problem in hand involved accurate measurements of resistances, it was necessary to find some other method of measuring the quantity.

Drewery Testometer

The Drewery Testometer is a liquid accelerometer consisting of a U tube attached to a small reservoir and arranged so that the retardation or acceleration of the instrument causes the liquid to flow in the tube

TABLE XIV

COMPARISON OF INTERNAL RESISTANCES OF LIGHT AVIATION TRUCK

Condition	Resistance in Pounds Per Ton
(a) Clutch in and motor running at lowest throttle	71.0
(b) Gears in neutral position	53.8
(c) Declutched	49.3
(d) Transmission all removed	48.8

TABLE XV

COMPARISON OF RESISTANCE AT VARIOUS TIRE PRESSURES

(Gear-shift in neutral-light aviation truck.)

Surface	Tire Pressure	Resistance in Pounds Per Ton
Earth road	75 lb. per sq. in.	70.0
	57 lb. per sq. in.	79.0
Gravel road	75 lb. per sq. in.	56.0
	57 lb. per sq. in.	60.2
Bitulithic pavement	75 lb. per sq. in.	53.8
	57 lb. per sq. in.	45.0

TABLE XVI

COMPARISON OF RESISTANCES TO TRANSLATION ON VARIOUS SURFACES

(Rolling, impact, and air resistance and internal resistance up to the neutral gear.)
Resistances in pounds per ton.

Vehicle	Kind of Surface			
	Earth Road	Gravel Road	Oiled Gravel	Bitulithic Pavement 65° F.
Light aviation Inflation 75 lb. per sq. in.	70.0	56.0 *31.5		53.8
Light aviation Inflation 57 lb. per sq. in.	79.0	60.2		45.0
Heavy aviation Solid tires		75.0	74.0	30.5

*(See Table VIII.)

to a position of equilibrium, thus indicating the accelerating or decelerating force. The instrument is attached to the vehicle and by means of an adjusting screw, set at zero when the car is standing on a level place. Dr. H. C. Dickinson, loaned the Drewery Testometer owned by the Society of Automotive Engineers and it was calibrated against a space-time recorder. The results are shown on the calibration curves in Fig. 8. In general the indications on the instrument lagged some-

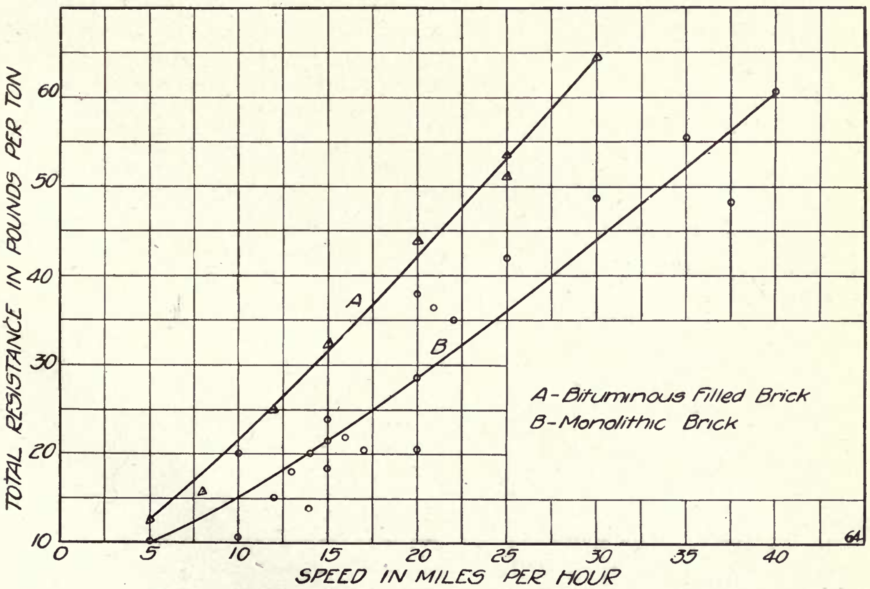

FIG. 7. RESISTANCE CURVES FOR BUICK FIVE-PASSENGER CAR (RUNNING DECLUTCHED) FROM DATA TAKEN WITH WIMPERIS ACCELEROMETER

what and it was otherwise open to the same objections as the Wimperis instrument and being used in the same way, gave similar results.

Space-Time Recorder

Several years ago David Gallup, consulting engineer for the Nordyke-Marmon Co., of Indianapolis, Ind., served as chairman of a committee of the Society of Automotive Engineers that developed an accelerometer for use with motor vehicles and used it in some research work. The instrument and its uses are described in "*The Automobile*" for June 28, 1918, page 1230. Mr. Gallup was so kind as to loan the instrument to the station for a time and after giving it a thorough trial it was found that it offered a most dependable means of measuring tractive resistance by the deceleration method. Mr. Gallup had to recall his instrument before the work was completed and therefore a simple space-time recorder was designed to use in the completion of the work.

In its final form, the instrument, which is illustrated in Fig. 9, consists of a paper feed that moves the paper along at a fixed ratio to the distance the vehicle travels and a pen line to indicate time intervals. The paper is drawn along by a feed roll which is driven from a gear

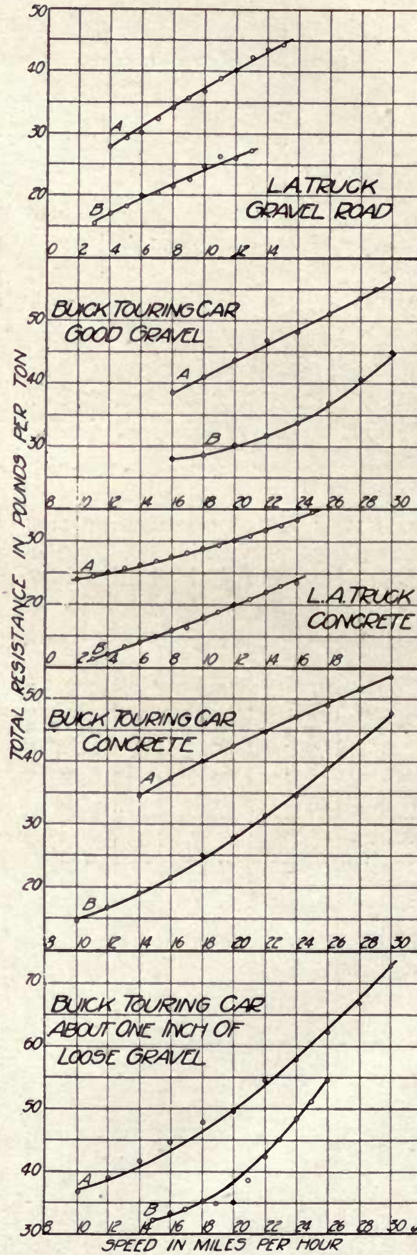

FIG. 8. "A" CURVES FROM SPACE-TIME RECORDER. "B" CURVES FROM DREWERY TESTOMETER. Buick five-passenger car and pneumatic tired truck on gravel roads and concrete pavements. These curves show how the testometer indicator lags.

on the front wheel of the vehicle by means of a speedometer cable. A clock mechanism actuates a pen so that a break occurs in the ink line every one-half second. By measuring the distance the paper travels for each second of time, the acceleration can be computed accurately. Fig. 10 shows a section of one of the records from the instrument.

FIG. 9. THE AMES SPACE-TIME RECORDER ATTACHED TO F. W. D. TRUCK

When a vehicle is coasting freely on a zero grade, the following formula applies:

$$R = \frac{2000 W a}{g} + \Sigma I \frac{\alpha}{r} \qquad (1)$$

Where:

R = total resistance to translation in pounds.

a = linear acceleration of vehicle in feet per second.²

W = total weight of vehicle in tons.

$\Sigma I \alpha$ = summation of the moment of inertia times angular acceleration for all rotating parts of vehicle.

I is constant for each rotating part and α varies directly as a.

r = radius of wheel to point of road contact or radius of any other rotating part.

By determining experimentally the value of the quantity $\Sigma I \frac{\alpha}{r}$, for a particular vehicle, the value of the constant C in the following equation can be determined.

$$\Sigma I \frac{\alpha}{r} = C \left(\frac{2000W}{g} a\right) \qquad \text{or}$$

$$C = \frac{\Sigma I \frac{\alpha}{r}}{\frac{2000W\,a}{g}}$$

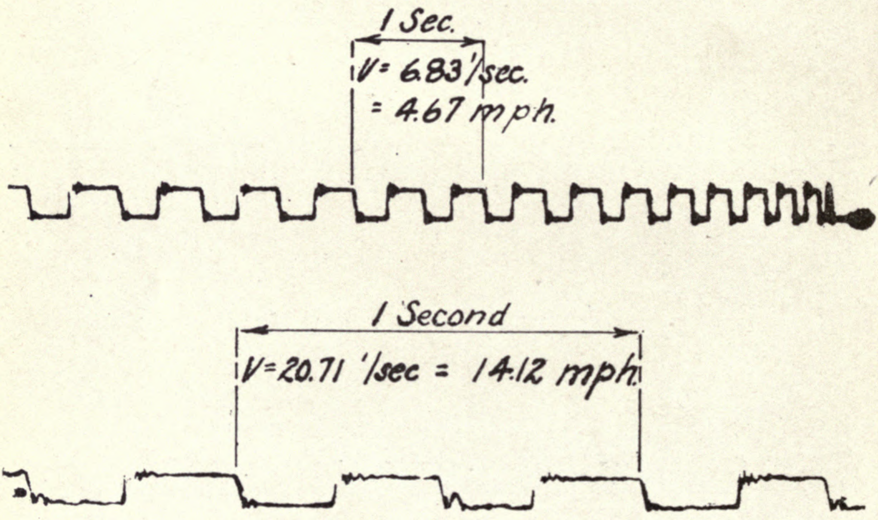

FIG. 10. PART OF A RECORD FROM THE AMES SPACE-TIME RECORDER

Equation (1) may be written

$$R = (1 + C) \frac{2000W\,a}{g} \qquad (2)$$

In most of the investigations recorded herein the vehicles were allowed to coast in neutral gear and the term $\Sigma I \frac{\alpha}{r}$ included the values of $I \frac{\alpha}{r}$ for the wheels, axle shaft, propellor shaft and certain gears. The only significant quantity is $I \frac{\alpha}{r}$ for the wheels. In the later work trailers are being used and therefore the only rotating parts to consider are the wheels.

Tables XVII, XVIII and XIX show the values of $\Sigma I \frac{\alpha}{r}$ for the wheels of certain vehicles that are being used in the Ames investigations. These tables indicate the magnitude of the correction for angular acceleration of wheels. If an ordinary vehicle is employed with all working parts intact, the correction to apply would include the $I \frac{\alpha}{r}$

TABLE XVII

AMES TRACTIVE RESISTANCE INVESTIGATION

Correction table for effect of rotation of wheels—F. W. D. Truck, gross weight 8300 lb. Tires: 40x8 inch U. S. Cords. Weight of 4 wheels 1320 lb.

A = Acceleration. C = Correction in pounds per ton.

Note: Add when speed is decreasing.

A	C	A	C	A	C	A	C	A	C	A	C
.01	.05	.26	1.3	.51	2.5	.76	3.7	1.01	4.9	1.26	6.1
.02	.1	.27	1.3	.52	2.5	.77	3.8	1.02	5.0	1.27	6.2
.03	.1	.28	1.4	.53	2.6	.78	3.8	1.03	5.0	1.28	6.2
.04	.2	.29	1.4	.54	2.6	.79	3.9	1.04	5.1	1.29	6.3
.05	.2	.30	1.5	.55	2.7	.80	3.9	1.05	5.1	1.30	6.3
.06	.3	.31	1.5	.56	2.7	.81	4.0	1.06	5.2	1.31	6.4
.07	.3	.32	1.6	.57	2.8	.82	4.0	1.07	5.2	1.32	6.4
.08	.4	.33	1.6	.58	2.8	.83	4.1	1.08	5.3	1.33	6.5
.09	.4	.34	1.7	.59	2.9	.84	4.1	1.09	5.3	1.34	6.5
.10	.5	.35	1.7	.60	2.9	.85	4.1	1.10	5.4	1.35	6.6
.11	.5	.36	1.8	.61	3.0	.86	4.2	1.11	5.4	1.36	6.6
.12	.6	.37	1.8	.62	3.0	.87	4.2	1.12	5.5	1.37	6.7
.13	.6	.38	1.9	.63	3.1	.88	4.3	1.13	5.5	1.38	6.7
.14	.7	.39	1.9	.64	3.1	.89	4.3	1.14	5.6	1.39	6.8
.15	.7	.40	2.0	.65	3.2	.90	4.4	1.15	5.6	1.40	6.8
.16	.8	.41	2.0	.66	3.2	.91	4.4	1.16	5.7	1.41	6.9
.17	.8	.42	2.0	.67	3.3	.92	4.5	1.17	5.7	1.42	6.9
.18	.9	.43	2.1	.68	3.3	.93	4.5	1.18	5.8	1.43	7.0
.19	.9	.44	2.1	.69	3.4	.94	4.6	1.19	5.8	1.44	7.0
.20	1.0	.45	2.2	.70	3.4	.95	4.6	1.20	5.9	1.45	7.1
.21	1.0	.46	2.2	.71	3.5	.96	4.7	1.21	5.9	1.46	7.1
.22	1.1	.47	2.3	.72	3.5	.97	4.7	1.22	6.0	1.47	7.2
.23	1.1	.48	2.3	.73	3.6	.98	4.8	1.23	6.0	1.48	7.2
.24	1.2	.49	2.4	.74	3.6	.99	4.8	1.24	6.1	1.49	7.3
.25	1.2	.50	2.4	.75	3.7	1.00	4.9	1.25	6.1	1.50	7.3

factor for all rotating parts. For example, if the retardation took place with the gear shift in neutral the correction would be different from that which would be necessary if the retardation was with the clutch out or the ignition off and clutch in.

Results of Observations

The diagrams showing resistance to translation under various conditions are those obtained at various stages of the investigation and show the progress and development of the test methods, although most of the diagrams also show reliable values of resistance to translation. These results may be considered as preliminary only and subject to verification or modification.

Of particular interest are the curves in Fig. 11. These show the difference a comparatively thin layer of loose gravel will make in the resistance to translation. Likewise the diagrams in Fig. 12 show the range of resistance to translation on two gravel roads that to the casual observer are much alike. The resistance to translation on gravel under adverse conditions may be three or four times as large as it is on the same road under favorable conditions.

TABLE XVIII

AMES TRACTIVE RESISTANCE INVESTIGATION

Correction table for effect of rotation of wheels—Light aviation truck, gross weight 6600 lb.
Tires: 35x5 inch Firestone Cords. Weight of 4 wheels 750 lb.
A = Acceleration. C = Correction in pounds per ton.

Note: Add when speed is decreasing.

A	C	A	C	A	C	A	C	A	C	A	C
.01	.0	.26	1.0	.51	2.0	.76	2.9	1.01	3.9	1.26	4.9
.02	.1	.27	1.0	.52	2.0	.77	3.0	1.02	3.9	1.27	4.9
.03	.1	.28	1.1	.53	2.0	.78	3.0	1.03	4.0	1.28	4.9
.04	.2	.29	1.1	.54	2.1	.79	3.0	1.04	4.0	1.29	5.0
.05	.2	.30	1.2	.55	2.1	.80	3.1	1.05	4.0	1.30	5.0
.06	.2	.31	1.2	.56	2.2	.81	3.1	1.06	4.1	1.31	5.0
.07	.3	.32	1.2	.57	2.2	.82	3.2	1.07	4.1	1.32	5.1
.08	.3	.33	1.3	.58	2.2	.83	3.2	1.08	4.2	1.33	5.1
.09	.3	.34	1.3	.59	2.3	.84	3.2	1.09	4.2	1.34	5.2
.10	.4	.35	1.3	.60	2.3	.85	3.3	1.10	4.2	1.35	5.2
.11	.4	.36	1.4	.61	2.3	.86	3.3	1.11	4.3	1.36	5.2
.12	.5	.37	1.4	.62	2.4	.87	3.4	1.12	4.3	1.37	5.3
.13	.5	.38	1.5	.63	2.4	.88	3.4	1.13	4.4	1.38	5.3
.14	.5	.39	1.5	.64	2.5	.89	3.4	1.14	4.4	1.39	5.4
.15	.6	.40	1.5	.65	2.5	.90	3.5	1.15	4.4	1.40	5.4
.16	.6	.41	1.6	.66	2.5	.91	3.5	1.16	4.5	1.41	5.4
.17	.6	.42	1.6	.67	2.6	.92	3.5	1.17	4.5	1.42	5.5
.18	.7	.43	1.7	.68	2.6	.93	3.6	1.18	4.5	1.43	5.5
.19	.7	.44	1.7	.69	2.7	.94	3.6	1.19	4.6	1.44	5.5
.20	.8	.45	1.7	.70	2.7	.95	3.7	1.20	4.6	1.45	5.6
.21	.8	.46	1.8	.71	2.7	.96	3.7	1.21	4.7	1.46	5.6
.22	.8	.47	1.8	.72	2.8	.97	3.7	1.22	4.7	1.47	5.7
.23	.9	.48	1.8	.73	2.8	.98	3.8	1.23	4.7	1.48	5.7
.24	.9	.49	1.9	.74	2.8	.99	3.8	1.24	4.8	1.49	5.7
.25	1.0	.50	1.9	.75	2.9	1.00	3.9	1.25	4.8	1.50	5.8

The diagrams in Fig. 13 show very graphically the impossibility of the ordinary earth road serving economically any considerable amount of traffic. They also show how greatly the resistance to translation is affected by the moisture content of the earth.

In Fig. 14 there is shown a comparison between a good concrete road surface and one carelessly finished and therefore very rough. Curves A, B and D are for ordinary good surfaces while curve C is

TABLE XIX

AMES TRACTIVE RESISTANCE INVESTIGATION

Correction table for effect of rotation of wheels—Buick touring car, gross weight 3650 lb. Tires: 33x4 inch U. S. cords. Weight of 4 wheels 340 lb.

A = Acceleration. C = Correction in pounds per ton.

Note: Add when speed is decreasing.

A	C	A	C	A	C	A	C	A	C	A	C
.01	.0	.26	.8	.51	1.6	.76	2.5	1.01	3.3	1.26	4.1
.02	.1	.27	.9	.52	1.7	.77	2.5	1.02	3.3	1.27	4.1
.03	.1	.28	.9	.53	1.7	.78	2.5	1.03	3.3	1.28	4.1
.04	.1	.29	.9	.54	1.7	.79	2.6	1.04	3.4	1.29	4.2
.05	.2	.30	1.0	.55	1.8	.80	2.6	1.05	3.4	1.30	4.2
.06	.2	.31	1.0	.56	1.8	.81	2.6	1.06	3.4	1.31	4.2
.07	.2	.32	1.0	.57	1.8	.82	2.6	1.07	3.5	1.32	4.3
.08	.3	.33	1.1	.58	1.9	.83	2.7	1.08	3.5	1.33	4.3
.09	.3	.34	1.1	.59	1.9	.84	2.7	1.09	3.5	1.34	4.3
.10	.3	.35	1.1	.60	1.9	.85	2.7	1.10	3.6	1.35	4.4
.11	.4	.36	1.2	.61	2.0	.86	2.8	1.11	3.6	1.36	4.4
.12	.4	.37	1.2	.62	2.0	.87	2.8	1.12	3.6	1.37	4.4
.13	.4	.38	1.2	.63	2.0	.88	2.8	1.13	3.6	1.38	4.5
.14	.5	.39	1.3	.64	2.1	.89	2.9	1.14	3.7	1.39	4.5
.15	.5	.40	1.3	.65	2.1	.90	2.9	1.15	3.7	1.40	4.5
.16	.5	.41	1.3	.66	2.1	.91	2.9	1.16	3.7	1.41	4.6
.17	.5	.42	1.4	.67	2.2	.92	3.0	1.17	3.8	1.42	4.6
.18	.6	.43	1.4	.68	2.2	.93	3.0	1.18	3.8	1.43	4.6
.19	.6	.44	1.4	.69	2.2	.94	3.0	1.19	3.8	1.44	4.7
.20	.6	.45	1.5	.70	2.3	.95	3.1	1.20	3.9	1.45	4.7
.21	.7	.46	1.5	.71	2.3	.96	3.1	1.21	3.9	1.46	4.7
.22	.7	.47	1.5	.72	2.3	.97	3.1	1.22	3.9	1.47	4.7
.23	.7	.48	1.6	.73	2.4	.98	3.2	1.23	4.0	1.48	4.8
.24	.8	.49	1.6	.74	2.4	.99	3.2	1.24	4.0	1.49	4.8
.25	.8	.50	1.6	.75	2.4	1.00	3.2	1.25	4.0	1.50	4.8

for a rough surface. A part of the difference may be due to temperature effects in the vehicle in this particular case, but not more than a few pounds per ton.

Figs. 15, 16 and 17 show values of resistance to translation on ordinary surfaces of the types indicated. They indicate the range of values that may be expected with pneumatic tires on average surfaces. In all cases the values for resistance to translation include a part of the vehicle resistance. For some purposes it is very desirable to know this combination of resistances. In other instances it would be desirable to eliminate the internal resistances. This can be done by applying as a correction the value of internal resistance shown in Table XIV.

The Nature of Resistance to Translation

Power applied to a motor vehicle does the following:

1. Propels the vehicle against the resistance due to distortion of road and tire as the wheel rolls over the road surface.
2. Propels the vehicle against the resistance to change of direction of motion on curves.
3. Supplies the energy dissipated by impact between the wheels and the road surface.
4. Supplies the energy required to operate the mechanism of the vehicle against internal friction.

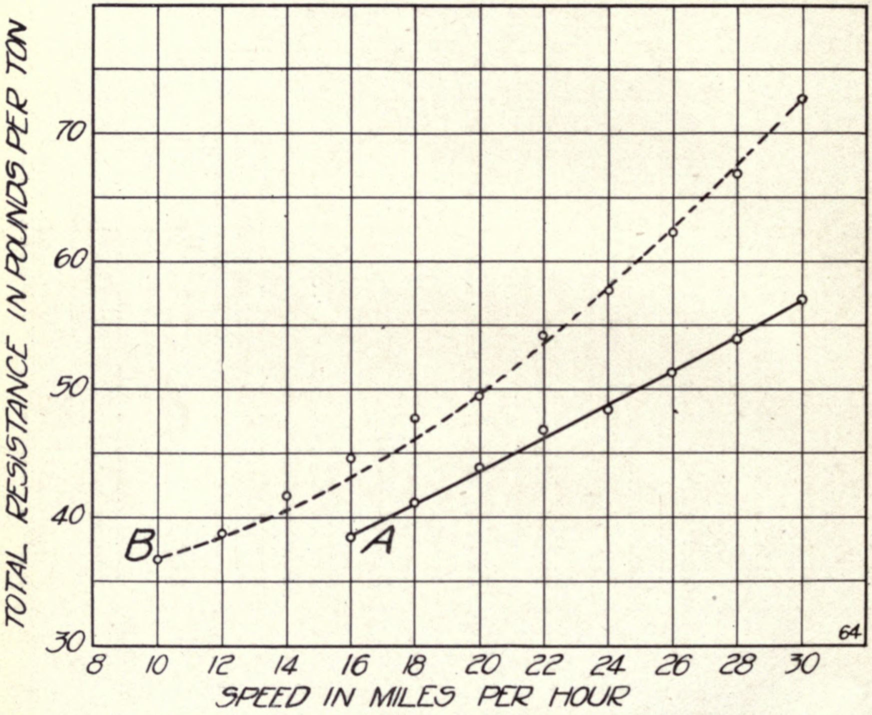

FIG. 11. EFFECT OF LOOSE GRAVEL IN THE RESISTANCE TO TRANSLATION. Curve A was obtained by driving in the well worn track of a good gravel road, Curve B was obtained by the same vehicle when driven in the slightly loosened material outside the wheel track.

5. Propels the car against the resistance of the air.
6. Operates the cooling fan, water circulating pump, generator and valve and timer mechanisms.

It will be of interest to note the significance of these various factors.

1. **Rolling Resistance.** The magnitude of the resistance due to distortion of road surface and tire depends upon the kind of tire and its

condition and the type of road surface structure. With good paved surfaces and good tires the magnitude of this factor is probably less than 25 pounds per ton of weight of vehicle. For low grade surfaces

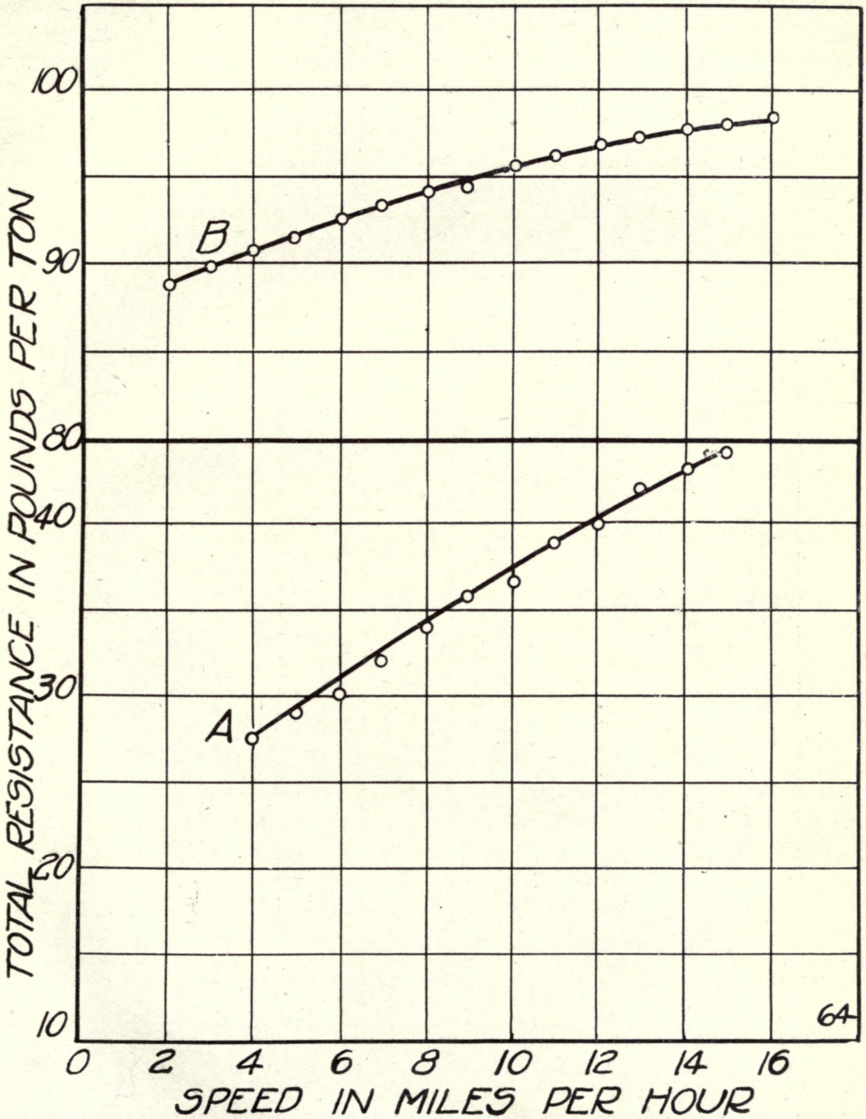

FIG. 12. RANGE OF RESISTANCE TO TRANSLATION ON GRAVEL ROAD. Curve A shows the resistance to translation up to neutral gear of Light Aviation Truck on good gravel road. Curve B is for same truck on a soft gravel road.

it may reach 100 pounds per ton. This factor is primarily of interest to the highway engineer, as it serves as a basis for comparing the economy of various classes of surfaces.

2. **Resistance Due to Curvature.** A vehicle in motion will not change its direction without the application of power. The amount of power required to affect a change depends upon the rapidity with which the change takes place and that has a bearing on highway design with reference to acceptable standards for curvature. No experimental data are at hand to indicate the magnitude of this factor for vehicles

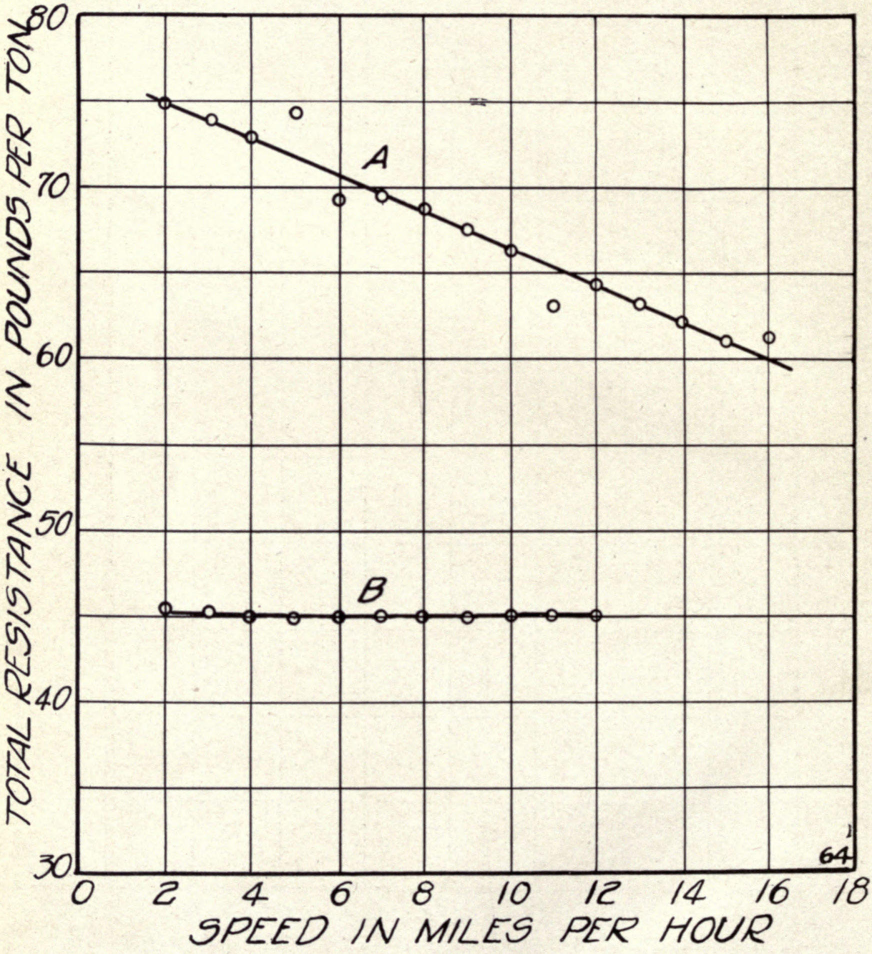

FIG. 13. RESISTANCE CURVES UP TO THE NEUTRAL GEAR OF LIGHT AVIATION TRUCK ON EARTH ROAD. Curve A was taken when the road had dried slightly after a long rainy period. Curve B was taken after the road had dried for two weeks. One end of the section of road was somewhat softer than the other.

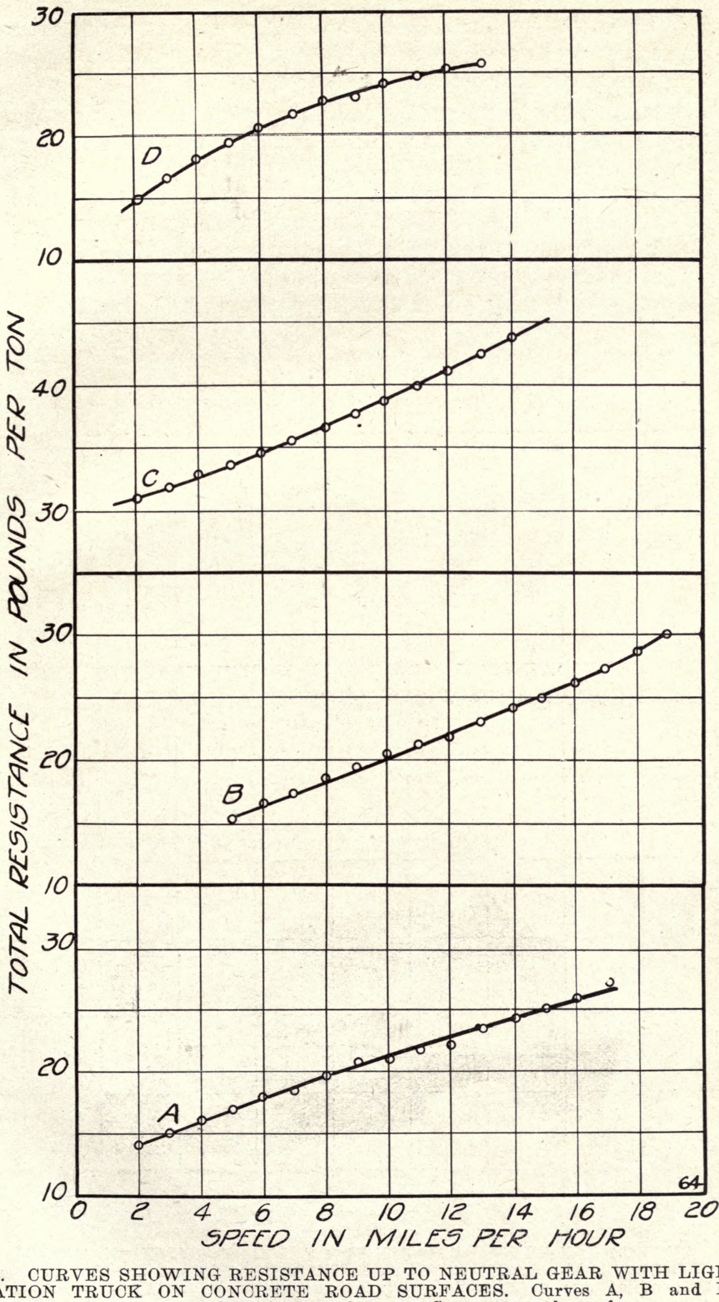

FIG. 14. CURVES SHOWING RESISTANCE UP TO NEUTRAL GEAR WITH LIGHT AVIATION TRUCK ON CONCRETE ROAD SURFACES. Curves A, B and D were on normal surfaces and curve C on a rough surface.

that do not travel in a fixed path, but many records that were taken on straight sections of highway showed the effect of the vehicle turning out in passing other vehicles on the road.

3. **Resistance Due to Impact.** When a vehicle moves over a rough road surface, impact is set up which is in part transferred to the tires and springs of the vehicle, and dissipated in the form of heat and in part contributes to the destruction of the road surface. The extent to which this impact effect adds to the resistance to translation is indicative of the refinements that can logically be introduced into the construction of the road surface. There is an easily measured effect due to roughness which may be of considerable magnitude.

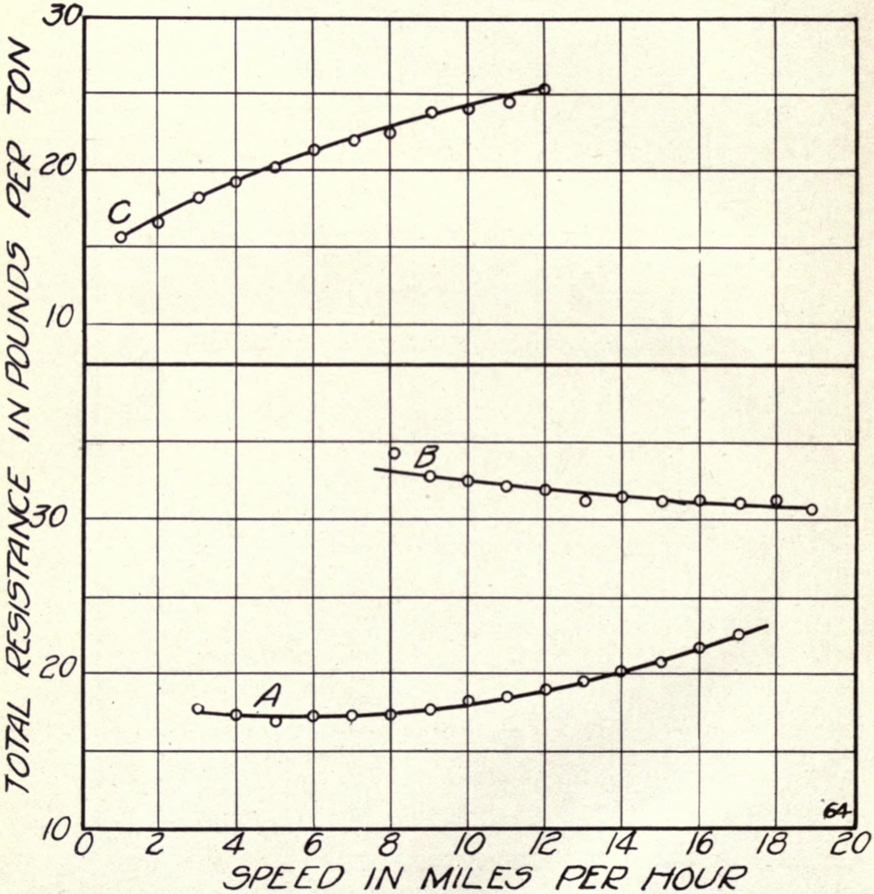

FIG. 15. CURVES SHOWING RESISTANCE OF LIGHT AVIATION TRUCK UP TO NEUTRAL GEAR ON ASPHALTIC CONCRETE SURFACES. A and B show variation to be expected due to differences of road surface temperature and difference of temperature of lubricant. Curves A and C represent average conditions.

4. **Internal Resistance.** Friction is held to a low amount in motor vehicles by the use of roller or ball bearings and by filling gear housings with lubricant. The friction of the motor, which is sliding friction, is considerable. This factor is of interest to vehicle designers and is required in studies of resistance to translation in any method of observation that requires correction for internal friction. It also is significant in connection with the theory of highway grades. The

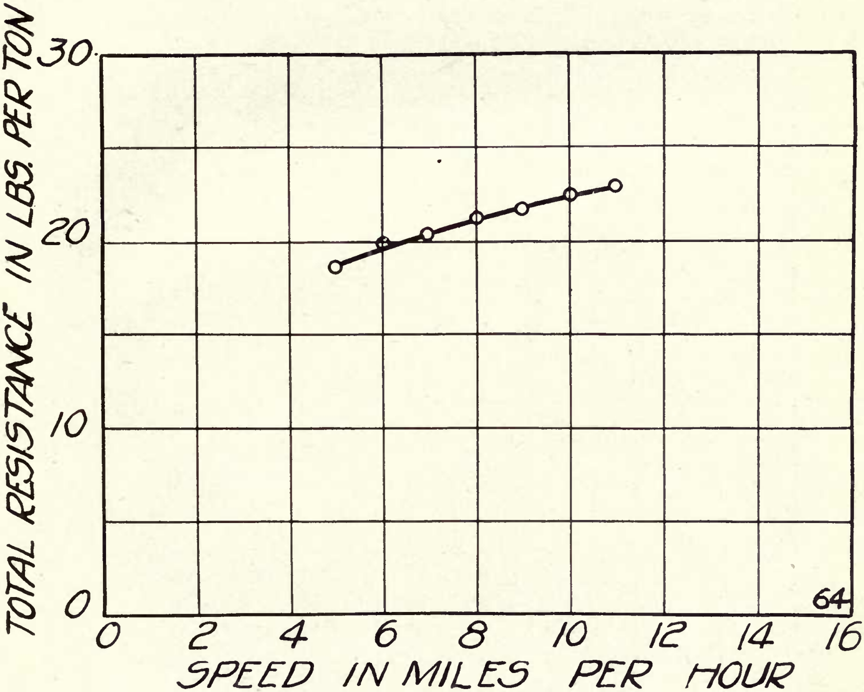

FIG. 16. SHOWING RESISTANCE TO TRANSLATION OF LIGHT AVIATION TRUCK UP TO NEUTRAL GEAR ON SHEET ASPHALT SURFACE UNDER NORMAL CONDITIONS

magnitude of the factor varies through a wide range, especially that part which is due to the churning of the lubricant in gear boxes, and the part that is due to sliding friction in the motor.

The significance of internal resistance may be illustrated in the following manner: Let the line ABC in Fig. 18 represent a section of a road profile and let it be assumed that a vehicle is to move from A to B along the road surface ABC. The energy required to move the car from A to C, if the vehicle travels with the clutch in and the motor therefore operating is:

$$E_1 = E_f + R(L_1 + L_2) - 2000W(h_1 - h_2) \text{ ——————— } (3)$$

R is the total of all resistances to translation up to the clutch and E_f the energy required to operate the mechanism ahead of the clutch, which varies with the speed of the motor. If the car could move along the line ADC, the energy required would be

$$E_2 = E_f + Rl - 2000W(h_1 - h_2) \text{ ——————— } (4)$$

The difference between equations (3) and (4) is the difference between $(L_1 + L_2)$ and l, which is negligible for ordinary highways.

If the vehicle moves along ABC, with the clutch out from A to B, the energy required is

$$E_3 = R(L_1 + L_2) - 2000W(h_1 - h_2) + E_f^1 \text{ ——————— } (5)$$

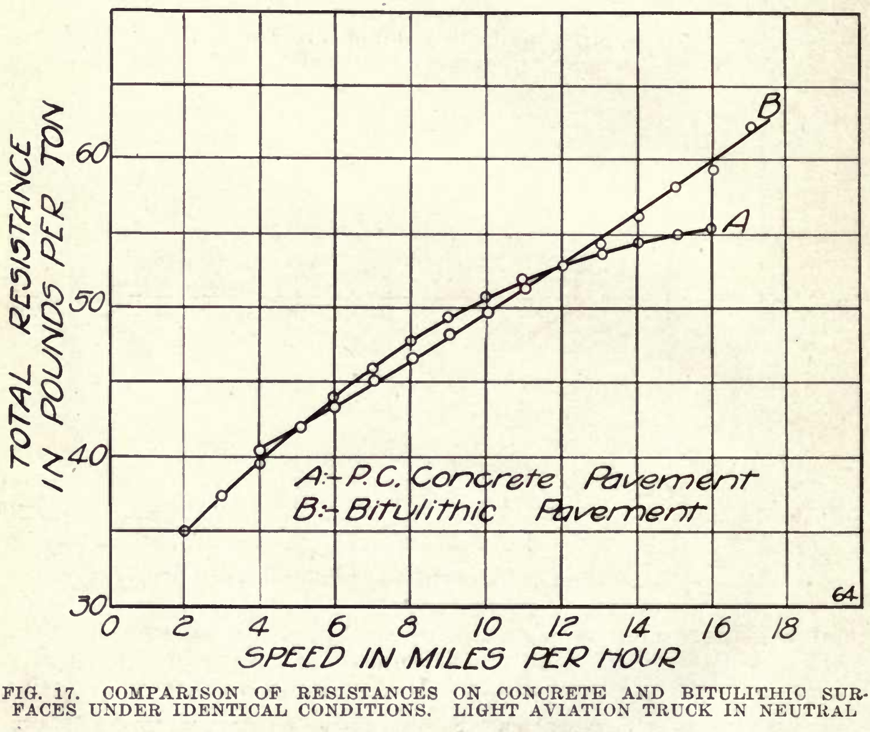

FIG. 17. COMPARISON OF RESISTANCES ON CONCRETE AND BITULITHIC SURFACES UNDER IDENTICAL CONDITIONS. LIGHT AVIATION TRUCK IN NEUTRAL

in which all symbols have the same significance as in (3), except E_f^1 which is the energy required by friction in the motor. From equations (3) and (5)

$$E_1 - E_3 = E_f - E_f^1 \text{ ——————— } (6)$$

In many instances during the investigation it was found that $E_f - E_f^1$ was a very appreciable amount, because E_f^1 is energy required to operate the motor at low speed from A to B plus that required at high speed from B to C while E_f is the energy required at high speed from A to C.

This shows that considerable care should be exercised to avoid confusion in discussing internal resistance of motor vehicles. It will be necessary to evaluate E_f and E_f^1 for typical vehicles in order to secure a value for total resistance to translation that is applicable to the establishment of highway grades. This is likely to be an exceedingly variable quantity, depending upon the conditions under which the motor is operating.

5. **Air Resistance.** The motion of the vehicle is opposed by the air through which it moves which is a function of the relative speed of the vehicle and air. If the air is in motion it may assist in the translation of the vehicle or it may augment the retardation. It is to no purpose to try to design roads to compensate for wind effects since that is a variable, but the effect of relative air speed is one factor in

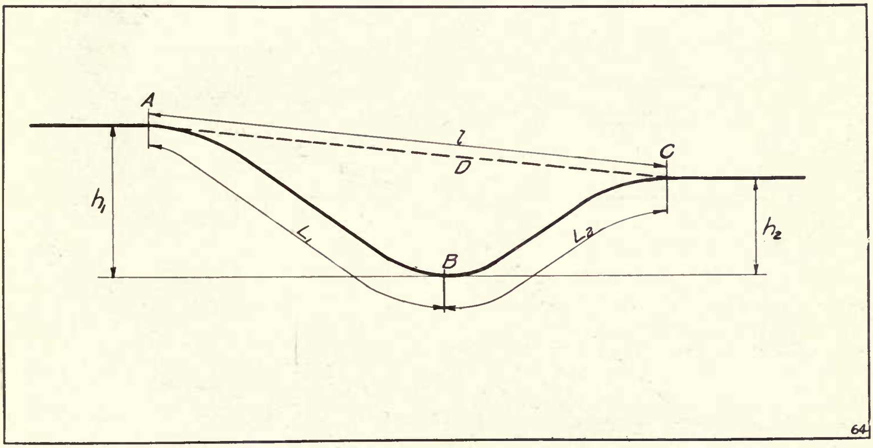

FIG. 18. DIAGRAM TO SHOW SIGNIFICANCE OF INTERNAL RESISTANCE

total resistance that is significant because of its magnitude. The results of determinations of the magnitude of resistance due to relative air speed are also of significance to the designers of motor vehicles.

6. **Resistance of Accessories.** So far as the theory of grades is concerned it would seem unnecessary to separate the resistance of the fan, pump, valve mechanism and generator from motor friction and therefore in the work done so far these resistances have been included in motor resistance. The automotive engineer may be interested in these as separate items. In any case they are readily determined in the dynamometer laboratory.

Fuel Consumption Tests

In order to secure a check on the relation between resistance to translation and fuel consumption, a number of trial runs were made on a few types of road surface on highways with very low grades for the purpose of securing data on fuel consumption on various types of surfaces. Needless to say these are comparative only and even the same vehicle will give periodic material variations in fuel consumption under apparently similar operating conditions. It would not be safe to assume that exactly the same number of ton-miles per gallon of gasoline could be obtained on the same road with another vehicle even of the same type. The runs were all with the heavy aviation army truck with a gross load of 8 tons and net load of 3.5 tons.

TABLE XX

SHOWING COMPARISONS OF FUEL CONSUMPTION

Run	Kind of Road Surface	Total Distance Traveled in Miles	Ton-miles Per Gallon of Gasoline
1	Gravel—Some soft places	60.00	19.8
2	Gravel—Hard and smooth	51.00	21.7
3	Gravel—After summer shower	6.00	18.5
4	Gravel—Hard and dry	10.50	21.9
5	Gravel—After summer shower (Same road as in run 4)	10.50	19.0
6	Gravel—Hard and smooth	71.00	22.0
7	Monolithic brick in excellent condition	10.78	29.4
8	Same as run 7 on another day	10.78	30.0
9	Portland cement concrete—excellent condition	68.00	30.7
10	Bitulithic, excellent, in August	13.00	22.7
11	Bitulithic, excellent, in September	8.00	24.3

AVERAGES FOR ALL RUNS

Type of Surface	Ton-miles Per Gallon of Gasoline
Gravel	21.2
Monolithic brick	29.7
Portland cement concrete	30.6
Bitulithic	23.4

TABLE XXI

SHOWING RELATIVE FUEL CONSUMPTION WITH VARIOUS GEARS

Gear	Miles	Ton-miles Per Gallon of Gasoline	Relative Efficiency
High	17.0	20.20	100.0
Second	17.0	16.70	82.8
Third	10.0	10.90	54.0
Low	6.5	6.25	30.9

In order to check the conclusion that in general more gasoline is required when the vehicle is operated in the lower gears than when on high gear, a number of runs were made at a stated speed on each gear. These are not comparable with results obtained when the vehicle is operated at very low speed with full throttle, as the high gear becomes inefficient in such cases. In general, however, these runs indicate the comparative economy of the various gears on this particular vehicle.

SUMMARY

As a result of the work already completed it seems to be apparent that rolling resistance is about half of the total resistance to translation when a motor vehicle with good tires is operated on hard, smooth road surfaces, and that the resistance due to impact is very small on such surfaces. It is equally apparent that resistance due to impact may become a significant factor if the road surface is poorly finished or becomes rough through inadequate maintenance. It is also clearly shown that a high toll in fuel bills is exacted by low grade surfaces.

It seems necessary to determine separately each of the elements of total resistance to translation herein enumerated so that any desired combination may be effected when the values of the various resistances are being used.

This report indicates merely the progress made by the Iowa Engineering Experiment Station up to the beginning of active field work in 1922. The work is going forward rapidly here as elsewhere.

The curves in Fig. 8 and 11 to 16 show reliable values of resistance to translation for the vehicles and road surfaces noted thereon.

The data in Tables VIII to XIX show results of dynamometer determinations of tractive resistance which are believed to be approximate only on account of conditions discussed in the preceding pages, but which are sufficiently accurate for most uses.

The space-time recorder method seems to offer a dependable and practical method of measuring resistance to translation and one which is particularly useful in detecting small differences in resistance to translation.

It is believed that the term "tractive resistance" should be discarded and the following terms used as defined at a conference of research workers held July 14, 1922, under the auspices of the Division of Engineering, National Research Council.

Rolling Resistance. Is the resistance to translation arising from the interaction of road and vehicle, but excluding resistances in the engine and transmission system.

> **Explanatory Note.** As ordinarily measured this includes wheel bearing resistance, which in case of well conditioned cars should not exceed 5 lb. per ton. Rolling resistance by the definition also includes the resistance in the framework and spring suspension system of the vehicle arising from the road. Rolling resistance as measured contains various degree of impact effects and road displacement effects depending upon the condition of the road and design of the vehicle. Resistance due to horizontal curvature of road should be measured in the experiments.

Air Resistance. Resistance arising from relative velocity of air and vehicle.

> **Explanatory Note.** Ordinarily this resistance is included in tested resistance, and should be subtracted to obtain rolling resistance.

Rolling and air resistances are those resistances determined when a vehicle is towed with the power transmission mechanism disconnected at the rear wheel. However, the difference between a self-operated and towed vehicle in respect to tire losses and slipping may make some difference in results, especially in high speeds.

Transmission System Resistance. Transmission system resistance is the force required at the rear axle, or tire periphery, to overcome all internal resistance from the clutch to the rear axle.

The transmission system resistance depends upon the gear ratio in mesh and the power transmitted, as well as upon other conditions such as speed, temperature of lubricant, etc. These losses are best determined in the laboratory.

Engine Resistance. Engine resistance is the force required at the rear axle, or tire periphery, to overcome the resistance of engine, including cooling system and accessories.

Engine resistance depends upon the operation of the engine as regards throttle opening, speed, temperature and mechanical condition of the engine. These resistances are best determined in the laboratory.

For some purposes it will be desirable to obtain a large number of determinations of average values for combinations of the above resistances, but for most purposes it will be more useful if each group of resistances is determined.