# THE NORTH CAROLINA TIRE TESTER

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The front wheel of an automobile when rolling freely on a hard, smooth, and level surface has its motion retarded by a force resulting from wheel-bearing friction, wheel windage, and tire-displacement resistance This retarding force usually is called rolling resistance Of its three components, the tire-displacement resistance is much the largest, because the wheel-bearing friction and wheel windage have been reduced to very small amounts Tire-displacement resistance is due to the constant flexing of the casing when the tire is flattened out as it comes in contact with the pavement As the wheel turns each part of the tire is deformed, and there is a continuous wave of displacement of materal which means energy loss and retarding force, and gives rise to the name tire-displacement resistance

In order to measure the rolling resistance of motor vehicle tires under varying conditions of speed, weight, temperature, and inflation pressure, the Engineering Experiment Station at North Carolina State College devised and constructed the "North Carolina Tire Tester" which is shown in Figure 1

The tire tester consists of a wheel and tire mounted so that the tread of the tire rests on top of the face of a large wooden drum, when the drum is rotated the tire is revolved by friction between the tire tread and the drum face The drum is made 17 6 feet in circumference in order to have the face travel one mile in 300 revolutions, like the Yale Drum Dynamometer The drum is carried on a $2\frac{7}{16}$-inch shaft, which also carried a 24-inch brake wheel and a 30-inch driving pulley, and runs in roller bearings Power for driving the drum is supplied by a 230-volt direct current motor, with field control of generator for setting the speed The Ward Leonard system of speed control will be used in a new design of tire tester

The wheel carrying the tire runs on the spindle of a front axle One end of the axle is held by a vertical pivot which allows the other end of the axle carrying the wheel to swing horizontally Weight is applied to the axle through vertical rods fastened to the ends of a truck spring, reproducing the spring condition of a motor vehicle A special weighing device was made to get the exact weight of the tire on the drum Weights totaling 2,000 pounds may be placed on the rods These, together with the weight of the wheel, axle, and spring, produce a weight of 1,777 pounds at the tire tread A careful calibration was made so that for any known weight on the roads, the weight at the tire tread is known

When the drum is rotated it exerts a tangential force on the tread of the tire, and as the end of the axle carrying the wheel is free to move horizontally, the force necessary to resist movement of the wheel is equal to the tangential force exerted by the drum face. This resisting force is measured on a platform scale by means of a horizontal rod with turn-buckle adjustment, a bell crank, and a vertical stand which rests on the platform of a scale.

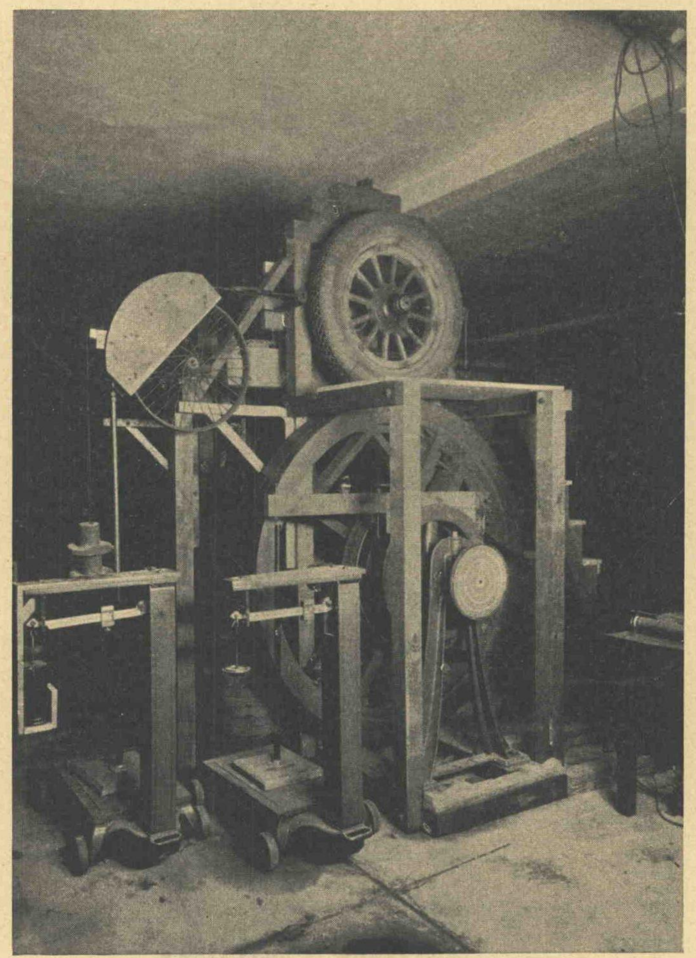

**Figure 1. The North Carolina Tire Tester**

An oil damper placed on the poise of the scale successfully damps all vibrations and makes accurate readings possible in a very short time. This damper is an essential part of the tire tester, because without it, accurate readings could not be obtained.

The conditions of a tire rolling on a hard, smooth surface are reproduced and the rolling resistance measured accurately. There is a small effect, however, due to the drum face having a little curvature.

A stroboscopic disc or speed setter is fastened on the end of the drum shaft which permits quick and accurate setting of the speed. The disc has four concentric rings of black and white sectors, each ring of sectors for a definite speed. The speed of the tire can be set at 15, 20, 25, or 30 miles per hour.

To make a run with the tire tester, weights are placed on the vertical rods until the desired axle load is obtained, the inflation pressure is adjusted, the drum started and set to speed by field control of the electric generator, then the platform scale, which measures the rolling resistance, is balanced and read. The tare on the scale is determined before the run and later subtraced from the gross reading to get the net reading which is the rolling resistance in pounds.

It was found necessary to center exactly the wheel spindle vertically over the drum shaft, because when the center of the wheel was a little to the right or left of a plumb line through the center of the drum shaft there was a considerable error. As the tire was moved further from the central position the per cent error became larger.

The tire was first centered vertically over the drum by use of plumb lines at each end of the shaft; later this central position was checked by reversing the direction of rotation of the drum and adjusting the position of the wheel, by means of the turn-buckle, until the net scale reading for both directions of rotation was the same. The fineness of this adjustment is evidenced by the fact that a movement of as little as $\frac{1}{64}$ of an inch from center caused a noticeable difference in the scale reading.

Another method, which may be called the "brake substitution method" also was used for obtaining the rolling resistance of a tire, as has been done elsewhere. A brake, with lever arm equal to the radius of the drum, is applied to the brake wheel on the drum shaft. A run is first made with the brake off and the tire on the drum. Accurate readings are taken of the speed of the tire, the terminal voltage and the ampere input of the driving motor. Then with the tire jacked up until it is clear of the drum, the brake is put on and adjusted until the speed, volts, and amperes are the same as for the first readings. Since the energy input to the motor and also the speed is the same with and without the brake, it is natural to expect that the readings of the scale at the end of the brake arm will be the same as the scale reading by the direct method. This, however, was found not to be true as the rolling resistance showed from 40 to 45 per cent higher than by the direct method. This error must be due to the increase bearing friction caused by the greater weight on main bearings when the tire is let down on the drum, and shows as greater brake load when the brake is adjusted to reproduce the same speed and input to motor.

The following table gives a comparison of the direct measurement of tire rolling resistance with the brake substitution method when using a 35 by 5 cord truck tire, inflation pressure of 77 pounds per square inch and speed of 30 miles per hour

*Tire Rolling Resistance*

| By direct measurement | By brake substitution method | Weight at tire thread | Per cent error of brake method | Ratio of error of weight |
|---|---|---|---|---|
| 13 85 lbs | 20 15 lbs | 1,777 lbs | 45 5% | 0 00355 |
| 7 3 lbs | 10 75 lbs | 1,043 lbs | 47 2% | 0 00330 |

In the above table, the correct values of rolling resistance by the direct method are equal to about 15 6 lbs per ton (or 31 3 watt-hours per ton-mile) at 1043 lbs per ton

The tire tester may be adapted to make other tests By placing cleats on the face of the drum the impact resistance corresponding to that on a rough or corrugated road may be measured It is the intention to use two sizes of drum to determine the effect of the curvature of the drum on tire-displacement resistance and to make corrections accordingly

In appearance this tire tester is quite like the apparatus used by Prof W C McNown of the University of Kansas for measuring tire wear. See "Relation of Road Type to Tire Wear," *Proceedings of the Advisory Board on Highway Research*, November 8–9, 1923, p 43

Prof E H Lockwood of Yale University uses the brake substitution method with the Drum Dynamometer in the Mason Laboratory to measure rolling resistance of the front tires of a motor vehicle, and for measuring rolling resistance and "chassis friction" of the rear tires See *Automotive Industries*, April 20, 1922

The Bureau of Standards has made extensive tests of tire losses and rolling resistance for many sizes and types of tires See "Research on Rubber Tires," by W L Holt, *Proceedings Advisory Board on Highway Research*, November 8–9, 1923, p 58 Two "electric absorption dynamometers," with the tire carried on the shaft of one and the drum (representing the road surface) carried on the shaft of the other, were used The power loss in the tire was measured by mechanical rather than electrical means

Table I shows the effect of operation upon tire-displacement resistance This test was started when the tire was at a room temperature of 74 degrees Fahrenheit and the inflation pressure at 70 pounds per square inch Readings were taken every 5 minutes for an hour, at which time they became constant At the beginning and at the end of the run readings were taken of the tire temperature and inflation pressure The temperature of the tire increased 32 degrees and the inflation pressure increased 10 pounds during the run The readings of rolling resistance fell off rapidly for the first 20 minutes, after which there was a slow decrease until they became constant after about 55 minutes of running This decrease in rolling resistance is due to both increase in temperature and increase in inflation pressure Since no readings were

TABLE I

EFFECT OF OPERATION UPON ROLLING RESISTANCE

35 × 5 Hood Cord Truck Tire No H W 772088

Constant during the run

Speed at 30 miles per hour

Weight on tire tread 1,777 pounds

Room temperature 75 degrees Fahrenheit

| Minutes after start | Pounds of rolling resistance | Inflation pressure lbs per sq in | Temperature of tire tread degrees F |
|---|---|---|---|
| 0 | 22 75 | 70 | 74 |
| 5 | 20 75 | | |
| 10 | 19 90 | | |
| 15 | 19 15 | | |
| 20 | 18 75 | | |
| 25 | 18 45 | | |
| 30 | 18 20 | | |
| 35 | 18 00 | | |
| 40 | 17 95 | | |
| 45 | 17 85 | | |
| 50 | 17 75 | | |
| 55 | 17 65 | | |
| 60 | 17 65 | 80 | 106 |

TABLE II

EFFECT OF TEMPERATURE UPON ROLLING RESISTANCE

35 × 5 Hood Cord Truck Tire No H W 772088

Constant during the run

Speed at 30 miles per hour

Weight on tire tread 1,777 pounds

Inflation pressure 70 pounds per square inch

Room temperature 71 degrees Fahrenheit

| Temperature of tire tread degree F | Rolling resistance of tire lbs |
|---|---|
| 74 | 22 75 |
| 84 | 22 25 |
| 89 | 21 50 |
| 93 | 21 00 |
| 96 | 20 75 |
| 98 | 20 75 |
| 99 | 20 60 |
| 100 | 20 50 |

taken of tire temperature and inflation pressure except at the beginning and end of the run, straight lines are drawn connecting these points which show the range of these variables rather than the exact change with duration of operation

To get the effect of temperature upon tire-displacement resistance a test was made during which the inflation pressure was kept adjusted to a constant value so that temperature rise was the only variable factor affecting the tire-displacement resistance In Table II it is seen that a temperature rise of 26 degrees Fahrenheit causes a decrease of 2 3 pounds, or about 10 per cent in the tire displacement resistance

TABLE III

EFECT OF WEIGHT UPON ROLLING RESISTANCE

35 × 5 Hood Cord Truck Tire No H W 772088
Constant during the run
Speed at 30 miles per hour
Inflation pressure at 70 pounds per square inch
Room temperature 75 degrees Fahrenheit

| Weight on tire tread lbs | Pounds of rolling resistance | Temperature of tire tread degrees F | Calculated pounds per ton of rolling resistance |
|---|---|---|---|
| 1,777 | 19 25 | 106 | 21 66 |
| 1,631 | 17 05 | | 20 91 |
| 1,484 | 14 65 | | 19 74 |
| 1,337 | 12 60 | | 18 85 |
| 1,190 | 11 05 | | 18 57 |
| 1,043 | 9 35 | | 17 93 |
| 898 | 7 65 | | 17.04 |
| 750 | 6 15 | | 16 40 |
| 601 | 4 75 | | 15 81 |
| 454 | 3 35 | | 14 76 |
| 304 | 2 20 | 95 | 14 47 |

TABLE IV

EFFECT OF SPEED UPON ROLLING RESISTANCE

35 × 5 Hood Cord Truck No H W 772088
Constant during the run
Weight on tire tread at 1000 pounds
Inflation pressure at 76 pounds per square inch
Temperature of tire tread 94 degrees Fahrenheit
Room temperature 74 degrees Fahrenheit

| Speed m p h | Pounds of rolling resistance |
|---|---|
| 15 | 9 10 |
| 20 | 9 50 |
| 25 | 9 80 |
| 30 | 10 20 |

Table III shows the effect upon tire-displacement resistance of changing the weight on the tire The weight on the tire tread was varied from 304 pounds to 1,777 pounds This caused the tire-displacement resistance to change from 2 2 pounds to 19 5 pounds This change in tire-displacement resistance is not exactly proportional to the change in weight since the slope of the curve increases considerably as the weight is increased

Table IV shows the effect of speed upon rolling resistance The rolling resistance increased uniformly with the speed It was 12 per cent higher at 30 m p h than at 15 m p h

Table V shows the variation of tire-displacement resistance with change of inflation pressure, the tire-displacement resistance decreasing considerably as the inflation pressure is increased Increasing the inflation pressure from 40 to 80 pounds per square inch decreases the rolling resistance from 14 6 to 10 25 pounds per 1,000 pounds weight on tire, that is, an increase of 100 per cent in inflation pressure gives a

TABLE V

Effect of Inflation Pressure upon Rolling Resistance

35 × 5 Hood Cord Truck Tire No H W 772088

Constant during the run

Speed of 30 miles per hour

Weight on tire tread 1,777 pounds

| Inflation pressure lbs per sq in | Rolling resistance of tire per 1000 pounds weight on tire | Temperature of tire tread degrees F | For comparison rolling resistance per 1000 lbs weight on tire tread for 5-inch cord tires—by United States Bureau of Standards | |
|---|---|---|---|---|
| | | | Maximum values | Minimum values |
| 80 | 10 25 | 110 | 13 50 | 8 20 |
| 75 | 10 50 | | 13 75 | 8 55 |
| 70 | 10 90 | | 14 10 | 8 90 |
| 65 | 11 25 | | 14 45 | 9 35 |
| 60 | 11 65 | | 14 90 | 9 85 |
| 55 | 12 15 | | 15 50 | 10 50 |
| 50 | 12 85 | | 16 10 | 11 15 |
| 45 | 13 65 | | | |
| 40 | 14 60 | | | |
| 35 | 15 70 | 122 | | |

30 per cent decrease in rolling resistance For comparison the maximum and minimum values of rolling resistance for 5-inch cord tires obtained by the United States Bureau of Standards are given on this sheet. See *Technologic Papers of the Bureau of Standards, No 283*, by W. L Holt, and P L Wormeley It will be seen that the results obtained with the tire tester lie between these values, somewhat nearer the curve of minimum values

There was a remarkable check between the rolling resistance of the four tires of the North Carolina Road Test Truck measured individually on the Tire Tester and the rolling resistance determined by analysis of the results obtained in operating the Road Test Truck on a smooth level concrete road The analysis was made using the formula for air resistance, lbs per ton air resistance equals 0 0025 $A\ V^2/W$. Each of these tests shows that the rolling resistance of all four tires is approximately 67 pounds, i e , 21 6 pounds per ton for the 3 1 tons of gross weight of the Road Test Truck

## AIR RESISTANCE OF AUTOMOBILES

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Wind resistance and air resistance are terms in common use for the force which air exerts on a moving vehicle Air resistance is more properly used when the air is at rest and the vehicle in motion, and this assumption will be made throughout this discussion unless otherwise noted

1 The force which air exerts on a moving vehicle can be measured in two ways First, by holding the vehicle, or a reduced model, in a current of moving air, with appliances for measuring the force produced Second, by causing the vehicle to travel in still air at a known velocity, and measuring the resisting force Examples of both methods will be given in a later article

2 Air resistance of a vehicle will depend on a number of different factors, such as,

*a* Speed of the vehicle
*b* Density of the air
*c* Projected frontal area of the vehicle
*d* Contour of body, rounding of corners, etc
*e* Roughness of the road, and trees, bushes, walls, etc along the roadside

The first three factors are of chief importance, and their influence on air resistance can be treated by mathematical analysis The last two items are of minor importance and for the present will be dealt with by experimental coefficients

3 The mathematical theory of resistance of a flat plate to a current of moving air is based on the assumption that the surface causes the stream of air to turn 90 degrees, moving off at right angles to its initial direction The pressure on the plate will be equal to that of a column of air of height $\frac{V^2}{2g}$ feet The pressure in pounds per square foot will be equal to density times $\frac{V^2}{2g}$, where $V$ is feet per second The density of air at 70°F. and atmospheric pressure will be 0 075 pounds per cubic foot