Rolling Resistance Force vs. Rolling Resistance Coefficient

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What is Tire Rolling Resistance Force?

A pneumatic tire under a vertical load requires that a force be applied at the wheel axle to cause it to roll in a forward direction. This applied force is necessary to overcome the Tire Rolling Resistance Force. This Rolling Resistance Force is generated at the tire-pavement contact interface and is the result of viscoelastic energy loses occurring within the tire as it is flexed during rolling (Figure1). In a motor vehicle, the engine provides the power to overcome the tire Rolling Resistance Force. The Rolling Resistance Force is designated by the symbol **RRF** and is measured in pounds-force. For a normal midsized vehicle the rolling resistance force for each tire is typically on the order of 10 pounds or 40 pounds for all four tires. The Rolling Resistance Force has been shown by testing to vary directly with the amount of vertical load that the tire is carrying. Therefore, on an actual vehicle, the magnitude of the Rolling Resistance Force is not constant but rather depends on the total weight of the vehicle including any passengers, and cargo. Clearly, all other things being equal, tires with lower Rolling Resistance Forces will be more fuel efficient than those with higher values. It is tempting then to characterize a tire's fuel efficiency in terms of its rolling resistance force. But because this force varies directly with vertical load, it is essential, when quoting values for Rolling Resistance Force to identify the tire load condition at which the force was measured. This greatly complicates the use of Rolling Resistance Force as a general metric for overall tire fuel efficiency.

How is the Tire Rolling Resistance Force (RRF) determined?

There are a variety of ways to measure~~s~~ Rolling Resistance Force but the most common method utilizes an instrumented roadwheel in a tire test laboratory. An illustration of a typical tire Rolling Resistance Test is shown in Figure 2 below. It consists of a large diameter steel drum driven by an electric motor. The speed of the drum is controlled by varying the amount of electrical power delivered to the drum drive motor. The test tire is mounted on a precision test wheel then attached to a solid axle. The tire-wheel-axle assembly is mounted on an instrumented carriage which is part of the test machine. The test load is applied to the tire usually by means of a hydraulic ram which is used to press the tire against the roadwheel surface, thereby applying the test load. The carriage is equipped with a series of load cells that can directly measure the applied load **L** and the Rolling Resistance Force **RRF**, while the tire is rolling.

What is the Tire Rolling Resistance Coefficient (RRC)?

As noted above, when a tire is operated at various values of load **L** there are a corresponding set of values for the Rolling Resistance Force. Experiments show that the load values and Rolling Resistance Force values are related in a straight line or linear manner. This means that if the vertical load is increased by a certain percentage, the rolling resistance force will be increased by an equal percentage. When the values of Rolling Resistance Force are plotted against the corresponding vertical loads a straight line plot is obtained (Figure 3). The slope of this line is obtained by dividing the Rolling Resistance Force by the corresponding load. The slope of the Load vs. Rolling Resistance line is the definition of the Rolling Resistance Coefficient. It is denoted by the symbol **RRC**. In mathematical terms

$$RRC = RRF / L$$

Because of the linear relationship between RRF and L, the Rolling Resistance Coefficient is a constant, not depending on tire load. As will be discussed below, this makes RRC a much more suitable metric for characterizing tire fuel efficiency than RRF.

Why is a Fuel Efficiency rating system using Tire RRC more useful to Consumers than a rating system using Tire RRF?

NHTSA included in the NPRM package a report titled "NHTSA Tire Fuel Efficiency Consumer Information Program Development: Phase 2 – Effects of Tire Rolling Resistance Levels on Traction, Treadwear, and Vehicle Fuel Economy". In this report (p86), the agency explains why Rolling Resistance Coefficient is more useful than Rolling Resistance Force to characterize the inherent fuel efficiency of tires. The report states "The coefficient of rolling resistance is a convenient concept since it allows one to compare **various tires for use on the same vehicle** (emphasis added). The load carried by a tire will be the same on a given vehicle in a given tire position, so a comparison of the rolling resistance coefficient will show **which tire is the most efficient** (emphasis added) for a given application. On the other hand, tests of tire rolling resistance (force) are usually carried out at the tire rated load or at some relatively high fraction of it, such as 80 percent of the tire rated load. Direct presentation of rolling resistance (force) under these conditions is dependent on the load carried by the tire, which of course, varies for different tire sizes. Hence, the concept of the coefficient is a generalizing and extremely useful one for both the presentation and interpretation of data."

Why is Rolling Resistance Force in General Inappropriate to Characterize a tire's Fuel Efficiency

As has been illustrated above, Rolling Resistance Force for a given tire is not a constant value, but instead depends on the tire operational vertical load. In contrast, the

Rolling Resistance Coefficient is a constant value due to the linear relationship between the vertical load and Rolling Resistance Force. Standards setting organizations such as ISO have chosen to test tires at certain reference conditions of load, speed, pressure, etc. In the case of ISO Standard 28580, the reference tire operating load is taken to be 70% of the maximum rated load stamped on the sidewall of the tire. Using the 70% max load reference condition, the tire Reference Rolling Resistance Force and Rolling Resistance Coefficient can be measured. The Rolling Resistance Force value at the reference condition is what has been proposed by NHTSA to characterize the tire overall fuel efficiency in the NPRM. To distinguish this value from all other values of RRF it will be designated here as $RRF_{ref.}$ Obviously, the RRF_{ref} is now a constant value, but it clearly does not capture the effects of the variable loads that a tire is exposed to when operating in the real world. Therefore, to use this as a representation of a tire's fuel efficiency for the entire duty cycle of a tire is misleading and erroneous. On the other hand, Rolling Resistance Coefficient, is a valid characterization regardless of the tire operating load. It is for this reason that tire engineers have used Rolling Resistance Coefficient to characterize the inherent rolling efficiency of tires for more than 50 years.

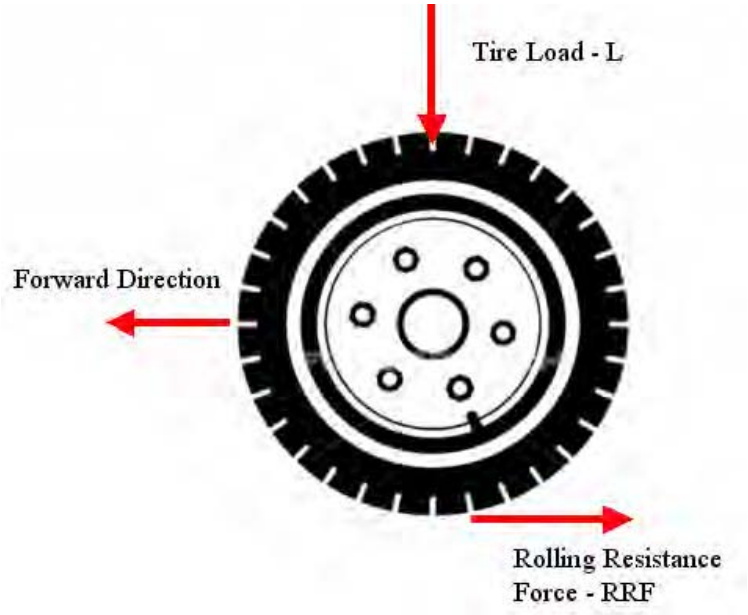

Figure 1 – Definition of Rolling Resistance Force

Figure 2 – Test Machine Used to Measure Tire Rolling Resistance

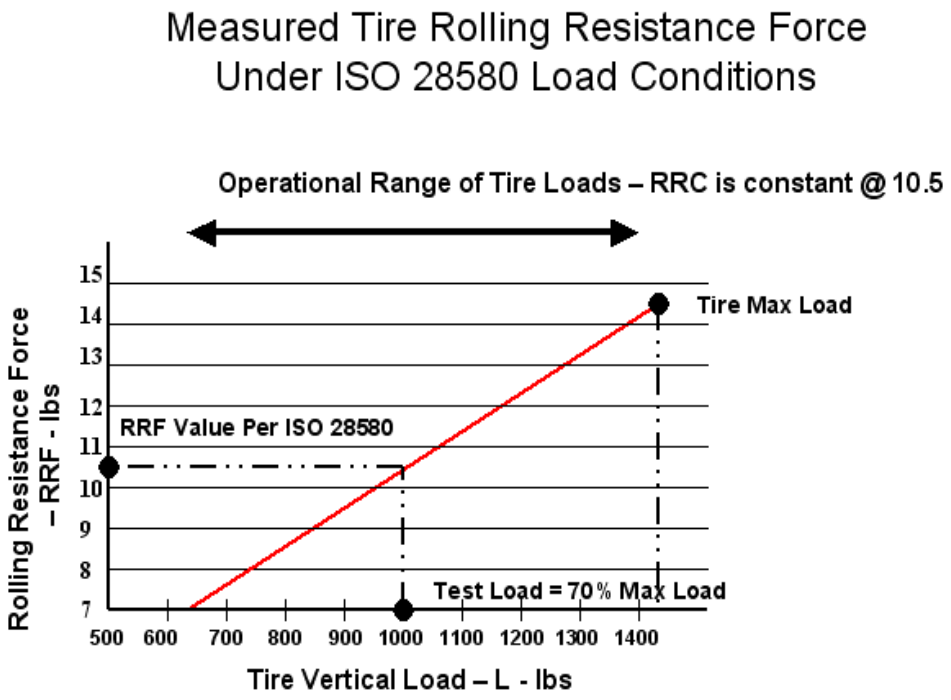

Figure 3 – How Rolling Resistance Force Varies with Tire Load