

Surface- and Pressure-Dependent Characterization of SAE Baja Tire Rolling Resistance

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Abstract

Rolling resistance is an important and somewhat controllable force opposing road vehicle movement. This complex phenomenon is a function of many variables, including tire temperature, tire construction, rubber compound, and inflation pressure. While the first element is not easily controllable, the other elements can be controlled by tire selection and pressure adjustment. Road vehicle race teams desire to minimize rolling resistance whenever possible to maximize performance and minimize fuel consumption.

This study aimed to characterize the surface- and pressure-dependent rolling resistance of tires for an SAE Baja off road vehicle. In this study, rolling resistance force was experimentally measured via load cell for a range of tire pressures on asphalt. From this, rolling resistance coefficients were extracted for each pressure using a linear model. Tire pressure values corresponding with minimal rolling resistance were tabulated for each tire type and road surface. Armed with this information, the Baja team can adjust tire pressure or consider changing tires according to road surface type in order to optimize performance.

Introduction

Rolling resistance is important to automakers and drivers because the effect it has on fuel economy. The lower the rolling resistance, the less force required to move the vehicle forward, reducing fuel consumption. Lower rolling resistance also results in faster acceleration.

For a race vehicle, acceleration and fuel consumption become competitively critical. These are not the only important parameters in racing, of course; traction and handling, among others, cannot be ignored. The optimal race set up will be one which minimizes rolling resistance without significantly compromising other parameters.

The purpose of this project was to conduct this type of analysis for an SAE Baja off-road vehicle. Ideally, this type of analysis would include all road surfaces that the Baja vehicle would expect to encounter in competition. Competitions comprise multiple short “dynamic” events such as a drag strip, maneuverability, rock crawl, sled pull, and suspension and traction tests, as well as a four-hour endurance race. Some events may take place on asphalt, some on hard-packed dry dirt, some in gravel or mud.

The preliminary work reported herein was done to establish and validate the test equipment and methodology, though it includes rolling resistance measurements on just one surface, asphalt. Follow up work will be done to expand the analysis to multiple surfaces, but these initial results will enable the Ohio Northern Baja team to determine the optimum tire pressures on an asphalt surface to minimize rolling resistance.

Methods

Typical published rolling resistance data is for tires which have warmed up and achieved thermal equilibrium, which only stabilizes after the tire has rolled at least 20-40 miles.² Most portions of a Baja competition only last for at most a couple of minutes so the steady-state results aren't as valuable for the data needed. The data gathered from the tests was performed in 13°F. This temperature is not ideal for testing, because the tire compound is much stiffer; even so, some regional Baja events are conducted in these conditions, making these results valuable to the team.

To accurately measure the force required to pull the Baja car, an S-type load cell manufactured by Amcell was used. A calibration check was performed on the load cell by using known weights suspended from the load cell to test its accuracy for a range of loads. LabVIEW was used to gather, display, and store the data into the form needed. (See the appendix for the LabVIEW VI.)

Rolling resistance is the force resisting the motion when a body rolls on a surface.¹ The equation for the rolling resistance force, R_x , is given by:

$$R_x = f_r W \quad [1]$$

where f_r is the rolling resistance coefficient and W is the total weight of the vehicle.² R_x and W were measured experimentally.

To perform the test the Baja car was pulled with a winch, as shown in Figure 1. A winch was the chosen method for pulling the Baja car because of its ability to maintain a relatively constant speed and force. The load cell was placed between the vehicle and the winch and was wired to a NI 9239 data acquisition module, which was connected to a laptop in order to run the LabVIEW program.

The pulling force was post-filtered in MATLAB to eliminate fluctuation caused by wind and vibration in the cable. The script used to filter the signal can be found in the appendix.



Figure 1: Test surface and set up. Load cell visible in right photo.

The vehicle was fitted with the Maxxis RAZR2 AT22x7-10 tires shown in Figure 2. The Baja team currently uses around eight pounds per square inch tire pressure. The tires are rated up to a maximum of thirty-six pounds per square inch of pressure. The testing consisted of changing the tire pressure in small increments and measuring the rolling resistance at each step.



Figure 2: Maxxis RAZR2 AT22x7-10 tires used for testing

Results

The Baja car was pulled for approximately thirty seconds for each pressure interval. The weight of the car was approximately 360 lb_f, weight of the driver was approximately 133 lb_f, and an added 5 lb_f due to laptop, batteries, and extras needed for data collection. The filtered rolling resistance is shown in Figure 3.

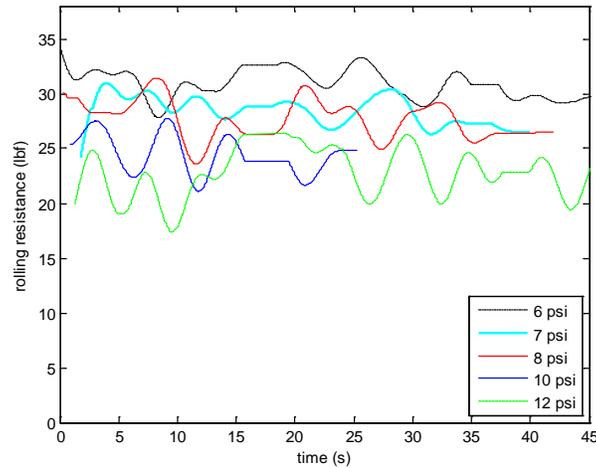


Figure 3: Filtered rolling resistance values for specified pressures

The rolling resistance for each tire pressure fluctuated significantly, which the filter helped but did not eliminate the problem completely. The large variations were due to factors such as surface imperfections, wind gusts, and the winch cable not coiling evenly. These sources of error could be reduced by removing the firewall on the Baja car to reduce wind resistance and ensure that the winch cable coils more evenly.

The rolling resistance coefficient for the various pressures tested was calculated using Equation 1. In Table 1 below, the average rolling resistance and rolling resistance coefficients can be found.

Table 1: Rolling resistance and coefficients for specified pressures

| Tire Pressure (psi) | Mean Rolling Resistance (lbf) | Rolling Resistance Coefficient (f_r) |
|---------------------|-------------------------------|--|
| 6 | 30.7 | 0.0614 |
| 7 | 28.6 | 0.0572 |
| 8 | 27.9 | 0.0558 |
| 10 | 24.6 | 0.0492 |
| 12 | 22.7 | 0.0454 |

Given the very low tire pressures, the extreme cold, and the fact that the tires were not warmed before the test, these values of rolling resistance are reasonable. Automotive tires at 10 psi have rolling resistance coefficients around 0.05 when tested on asphalt.² The commercial tests are conducted at room temperature with tread as much as 80°F above ambient.

As seen in the table, the average rolling resistance decreased with an increase in tire pressure. The most considerable difference in coefficient values was for 7 psi and 6 psi, where resistance apparently dropped over one pound per psi.

The rolling resistance coefficients were plotted versus tire pressure in Figure 4. The plot helps to illustrate graphically the changing rolling resistance between the different tire pressures.

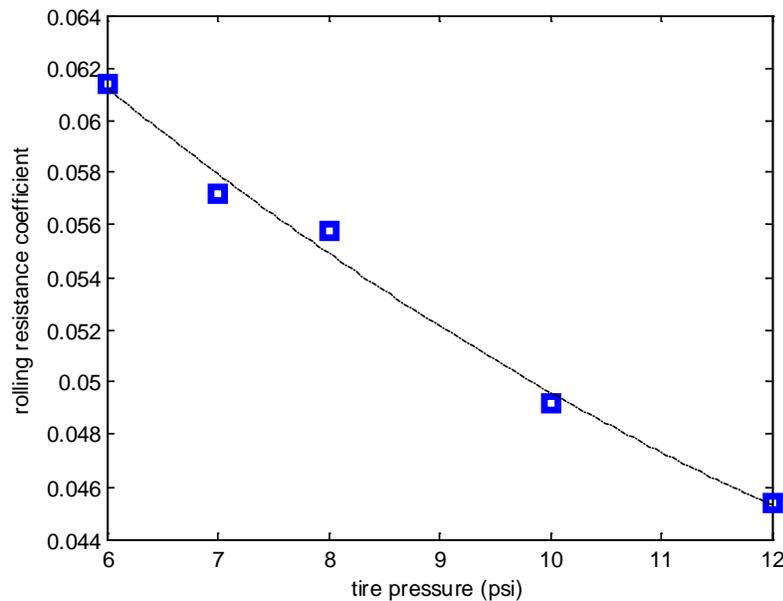


Figure 4: Rolling resistance vs. tire pressure

Conclusion

The research tests conducted produced anticipated results as far as decreasing rolling resistance as tire pressure is increased. The larger rolling resistance coefficient difference between 6 and 7 psi was very crucial to see that the tire pressures can be between 7 and 8 psi with no significant impact on rolling resistance but below 7 psi the rolling resistance becomes a greater factor.

More time will be allocated to determining how rolling resistance is effected below 6 psi as well as above 12 psi. Another situation that would be interesting to investigate is how rolling resistance changes in mud compared to dry soil. The conditions for the tests conducted proved to be difficult, which would be more difficult in mud and dry soil because of the constantly changing and uneven surface conditions. This would make it more difficult to put an exact value on optimum tire pressure.

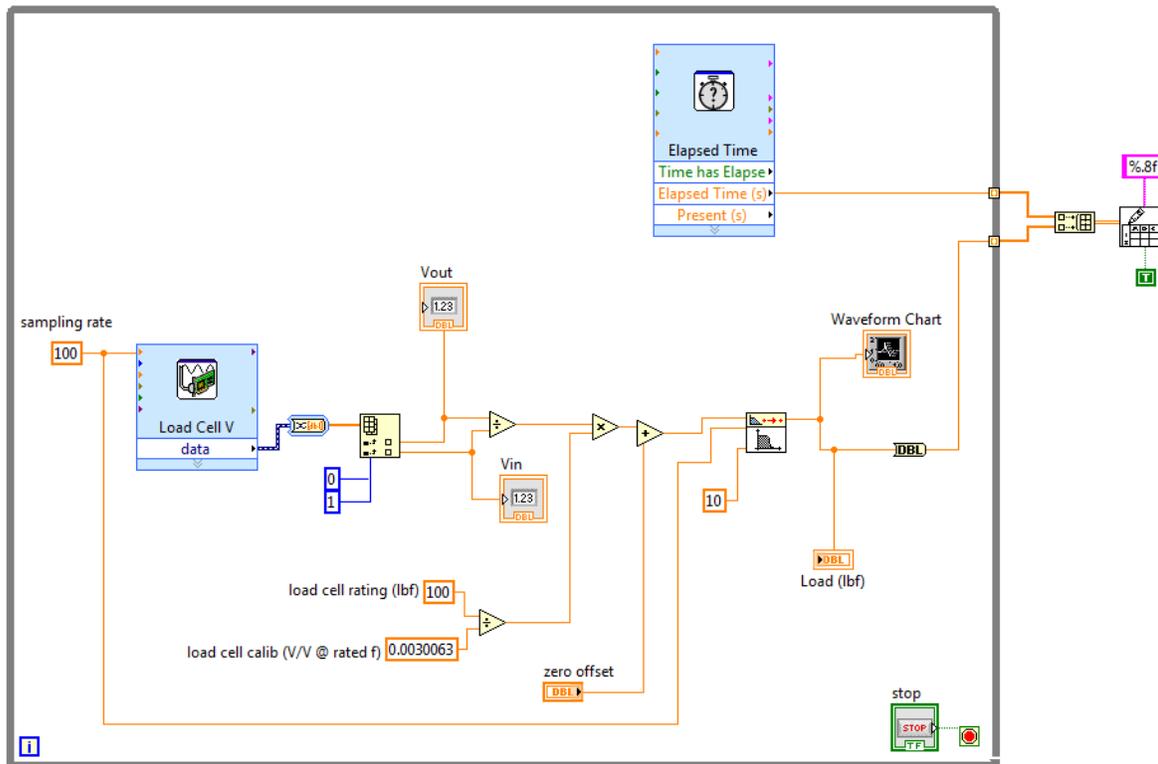
Although the results of the tests were not very comprehensive, the Baja team now will know not to operate the vehicle under 6 psi. They will also know that they can run between 7 and 8 psi without any substantial changes in rolling resistance. If they use a higher tire pressure they will have an even lower rolling resistance. Rolling resistance

results must naturally be balanced with the effect of higher tire pressure on traction and handling, framing additional future work.

Bibliography

1. "NHTSA Tire Fuel Efficiency Consumer Information Program Development: Phase 2-Effects of Tire Rolling Resistance Levels on Traction, Treadwear, and Vehicle Fuel Economy," National Highway Traffic Safety Administration. August 2009.
2. Gillespie, T. *Fundamentals of Vehicle Dynamics*, SAE Press, 1992.

Appendix 1: LabVIEW VI for Recording Rolling Resistance Force



Appendix 2: MATLAB Script for Filtering Signal

```

1 - x='Initial_Testing.xlsx';
2 - F=xlsread(x);
3
4 - n=6; %filter order
5 - sample=6; %data sampling rate, Hz
6 - wc=.2; %cutoff freq, Hz
7 - [b,a]=butter(n,wc/(sample/2));
8 - xfilt=filtfilt(b,a,F);
9
10
11 - [plot(xfilt)]
12 - M=mean(xfilt)

```