Tires in race simulations

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Introduction

It started out as an idea to write one or two pages about tires and simulations. Soon however it got out of hand just a little bit. I started feeling like making a point, which I never seem to do in few words.

I've been working with simulators and a few actual race teams for a number of years now. There are many things I still do not know, but at least I have seen a lot. What I'm writing down is by no means the one and only truth; it just shows where I stand and what I think.

I want to show the process that starts at the tire manufacturer and ends when you drive laps in the simulator. Along the way I will try to raise points regarding tire modeling in simulators. I had this idea because new simulators now boast 'physical tire models'. Is that good news for the end user or just a nice challenge for the physics programmer and something for the marketing department?

The tire model itself is just one link in the complex chain of "tire stuff" starting at the manufacturer and ending with your driving experience behind the computer. Having created cars for rFactor for about 5 years, methodically working with a huge variety of tires, perhaps my views are worth reading.

I can't stress enough that I don't claim everything to be exactly the way I say it, and I can't go too deep into certain things trying to keep this document somewhat compact and without giving away too many things I've learned!

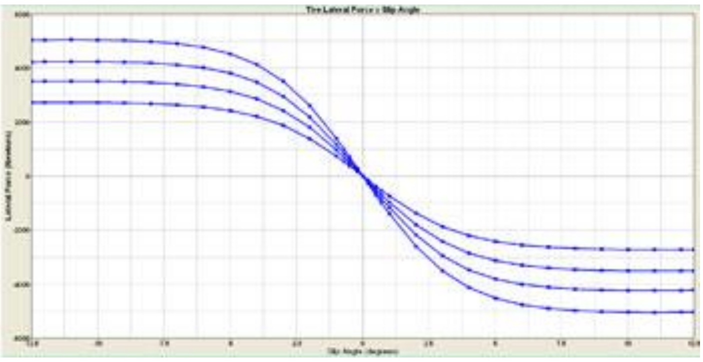
The tire manufacturer

Black Art

The car you're driving in the simulator will have tires from a certain manufacturer on them. Usually there is a code printed on the side walls showing you the brand, size, and sometimes compound of the tire. Manufacturers are very secretive about the exact ingredients and manufacturing processes. It is extremely unlikely you will ever find really detailed information how the tire is made. It has even been referred to as "black art". There are so many different materials used and bonded in specific ways, manufacturers won't give their 100 years of experience away!

Data from the manufacturer

Still the tire manufacturer often releases tire data to racing teams who use their tires. This could be a PDF file with some slip curves, self-aligning torque curves, and some information about the rolling radius of the tire. You get curves like:



This tells you how the tire grip changes with slip angle, at four different loads in this example. It looks great: perfectly smooth curves giving you exact grip levels! Just plug this into your simulator and you'll have the perfect experience right?

How is this tire data created?

Weighing car parts is simple, and you can get a good idea measuring springs, bump rubbers and dampers. Wind tunnels can give a good picture of aerodynamics, but as the things you measure get more complex, the margin for error increases. Tires are notoriously hard to measure.

Phase 1: Measuring the tire grip

There are machines created specifically for measuring the cornering, braking and acceleration forces of a tire. They tend to be heavy metal machines, where a tire is mounted, and then it rolls either over a rotating drum, a belt or an actual road. As it rolls, the tire is steered to create a slip angle, and the forces are measured.

Left to right: Drum, belt and trailer machines

The first problem is each type of machine, even each make, will measure different forces mainly because the test surface varies. Below is a chart showing the same tire measured on 8 different test machines. The spread in the results is huge given that they were supposed to measure the same thing on the same tire!

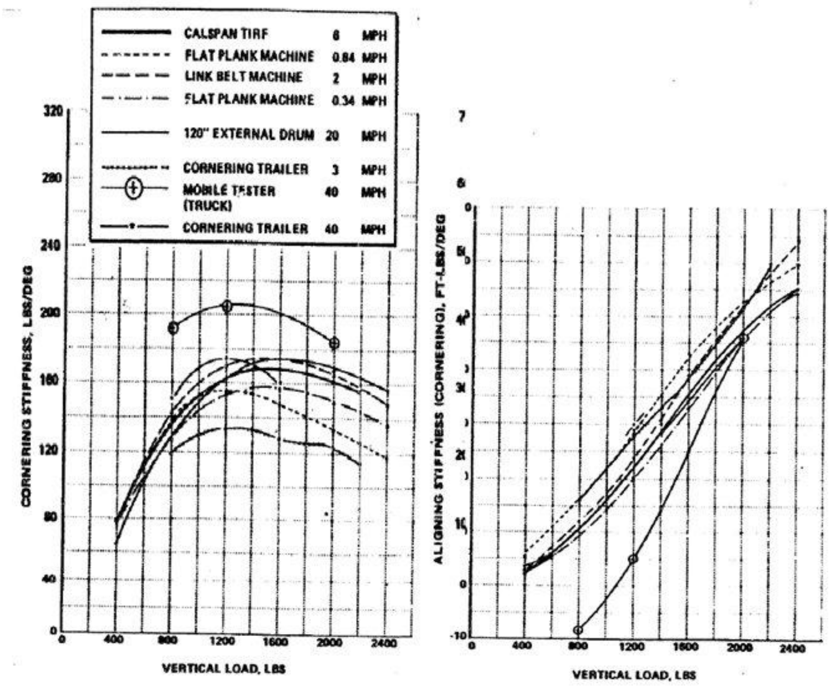
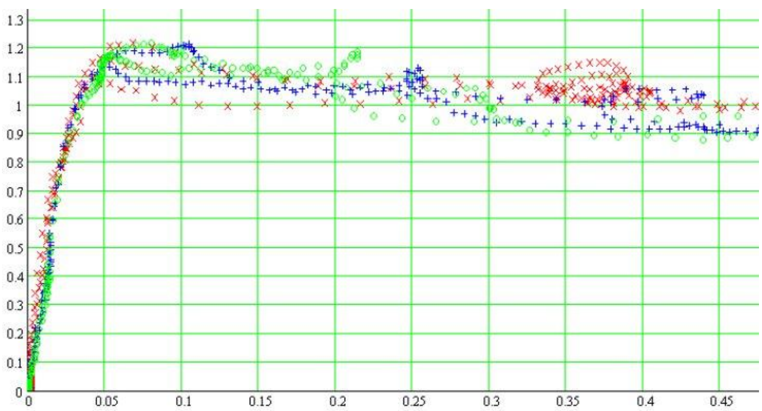


Figure C-2 FACILITY VALIDATION RESULTS: CORNERING STIFFNESS AND ALIGNING TORQUE STIFFNESS VS VERTICAL LOAD FOR A G78-15 TIRE AT 28 PSI

Cornering stiffness of the same tire on 8 different machines

The second problem is how noisy the data is. When you see tire grip curves they are beautifully smooth curves. The reality is not like that. Below is one example of raw test data. Each color represents a different tire load at which the test was run. You can see it is quite messy and it is impossible to really tell much difference between the three loads.



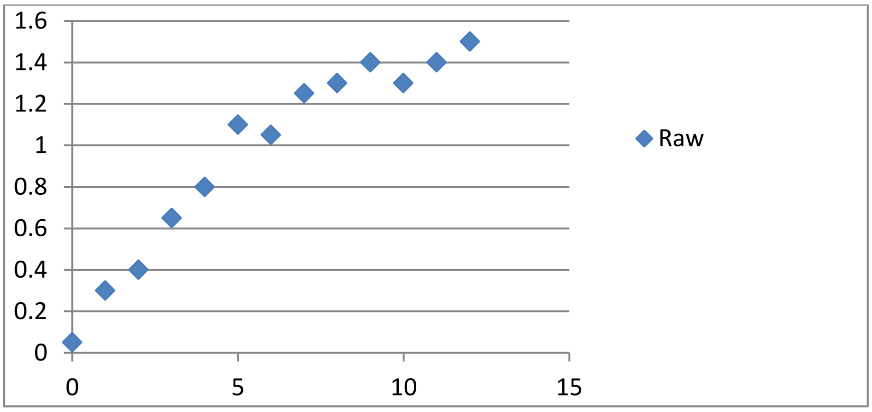
Raw longitudinal slip versus friction coefficient data

Concluding phase 1 it is clear that the measured tire grip will be very different based on the machine used, and the generated data will be very noisy. So where do these perfectly smooth grip curves come from?

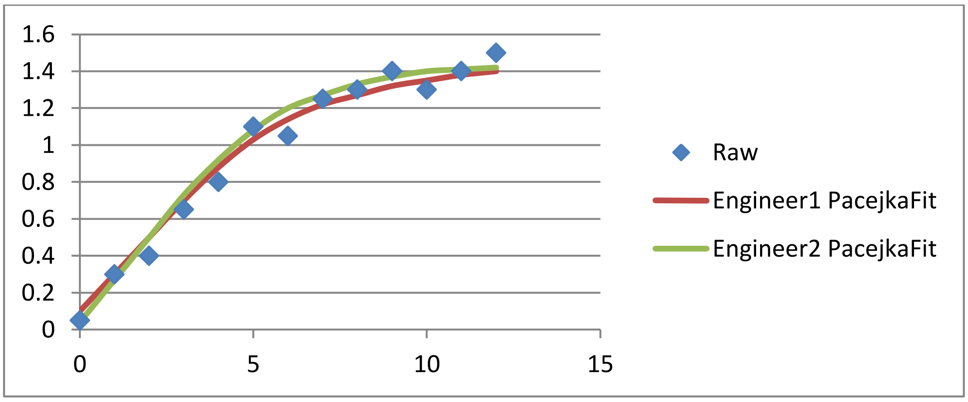
Phase 2: curve fitting

Now that the engineers have measured the tire, they are looking at the noisy raw data. Don't forget that on a different machine, the tire could have measured 20% more or less grip! The next step is to fit the raw data to an empirical model, often being Pacejka. The Pacejka tire model is basically a big mathematical function with quite a few variables that draws smooth grip curves. Engineers tweak the parameters until the curves fit the raw data. The Pacejka model is convenient as it can do a good job describing how critical variables such as load and camber affect the tire slip curve.

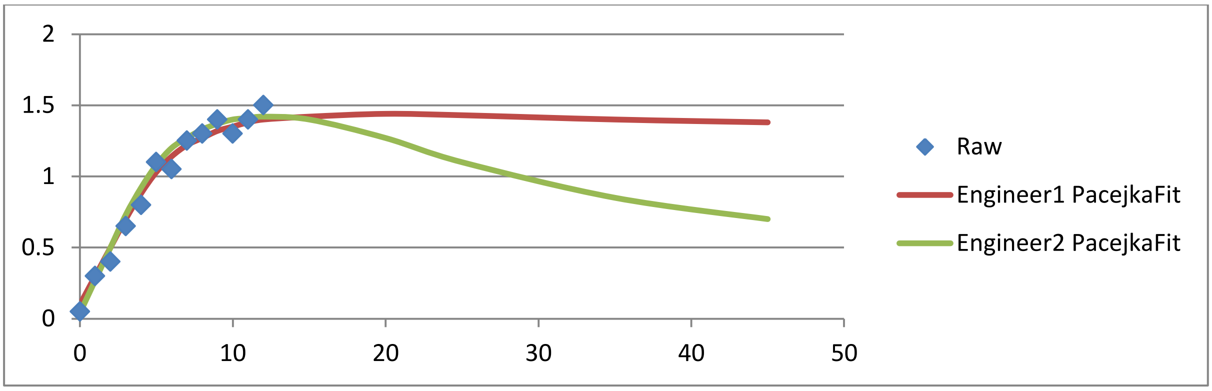
Below is our fictional raw data, for a tire that is measured between 0 and 12 degrees slip angle.



Now we put two engineers in separate rooms and ask them to tweak the Pacejka variables until they get a good fit of the data. You could end up with two slightly different curves as seen below.



While there is a difference between the two engineers, it appears to be small. It is very rare to see tire data measured beyond 12 degrees slip angle. Yet in simulations, you want the tire to work at larger slip angles. Now let us zoom out and see what the different engineers did:



The slight difference turns into a huge difference at greater slip angles. Pacejka can go all the way to 90 degrees, but engineers only fit the raw data in the measured slip angle range. After that, anything can happen depending on the engineers 'style' in fudging the Pacejka parameters.

Concluding phase 2, we can summarize:

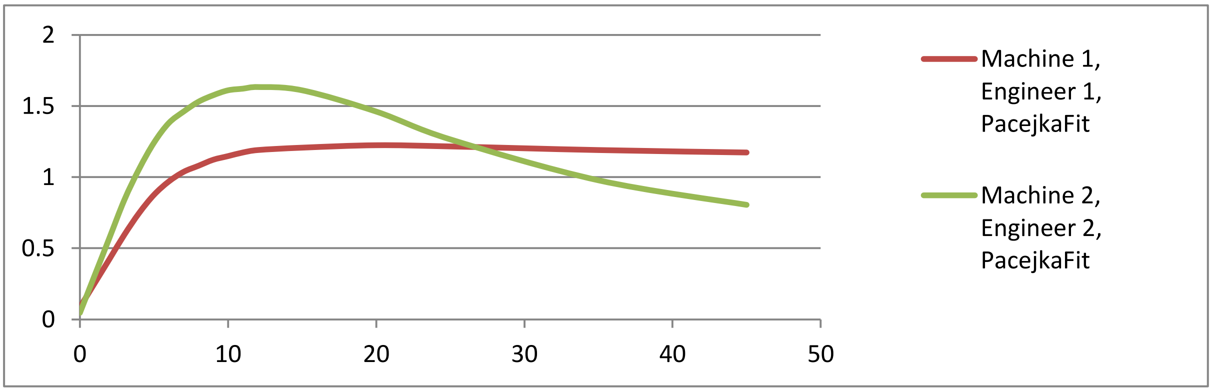
- there is a big spread in measured forces depending on the machine that is used
- The raw data is quite coarse and allows for some interpretation by different engineers
- Tire data cannot be used outside the measured slip angle range

Margin of error in the resulting data

The tire is measured, the engineers did their job, and they've put the results in a nice PDF file ready to go to the race team customers. Sadly at this point:

- We don't know for sure how much grip the tire has
- We made a subjective interpretation of this unknown grip to fit a tire model
- That, even if it is accurate, only applies to a small range of slip

To visualize the problem, here is the **same tire** measured on **two different machines** by **two different engineers.**



Same tire, machine 1 -15% grip, machine 2 +15% grip

It must be stressed again: these are measurements of **the same tire**, just done by different engineers on different test machines, handed over as a shiny "real data" PDF file to the customers.

This much hyped real tire data that is so hard to find is basically still almost useless. Often the data does not include longitudinal measurements (traction and braking) as that is even harder to measure. Even the largest manufacturers often only describe lateral (cornering) performance.

The number of variables that play a role between mounting the tire on the test rig and publishing the tire test report is enormous and the results are likely to not be directly usable in simulations. There are many more problems such as the tire changing temperature and pressure as it is being tested, possibly skewing the results somewhat more.

The manufacturer made the tire, measured it, gave its customers the data, and its likely to be mostly useless for figuring out the grip properties.

Working with tire models in simulators

You are lucky if you're a physics guy like me to get some of this real data, but I've just spent some pages explaining that the real data is mostly useless. So how on earth do I recreate a certain tire in a simulator? There is no easy way; after 5 years, not a day goes by where I don't look at data, scratch my chin and try something new.

Tires are so important because they are the main force generators that make the car accelerate, brake and turn. When working with a tire model, you want to adjust how the tire generates these forces when subject to a set of conditions like load and camber

Regardless of the tire model used in the simulator, you will have to set various parameters. With Pacejka models you may require 25 or so seemingly meaningless numbers. With a physical model you may require information about rubber compound, ply angles and construction. *It does not matter what model you use because the only thing you know for sure is there is no real data that you can just plug in.*

What I spent the last 1800 days doing is slowly making sense of how tire sizes and compounds might affect certain tire properties. I try to explain it to friends that perhaps I have a rare gene deficiency making me enjoy this type of work. I have also been very fortunate to know people like Todd Wasson and Gregor Veble, far more knowledgeable when it comes to making tire models. Sure there are "physics guys" like me but I think I might take the gene deficiency crown, which is a dubious honor if ever there was one! I don't know why I love doing this work but I can't stop. Doctor!

Using rFactor1 or Pacejka style tire models

rFactor is really rather good. Despite using a 'simpler' model that basically has a base slip curve which is stretched or shrunken depending on conditions. It still has a considerable number of variables to set. There is enough information available for a dedicated user to recreate the model in a spreadsheet so you know exactly what the tire does at any slip angle, load, camber, pressure and temperature.

The great thing about rFactor is that I can design tires very specifically. In a matter of minutes I can create different tires with exactly known properties. If I want to test load sensitivity I can create 3 tires that lose 5%,20% and 35% of their initial grip per unit of added load. I can compare tires that have 1000N/deg cornering stiffness at 5000N load with ones that have half this or ten times this.

Remember that tires are important 'force generators' and the things I change directly affect how the tire generates forces at certain conditions.

Real data can be a hint for these parameters but there is no way around trying various tires within certain limits of what is reasonable. Having an rFactor1 type tire model is a great way to methodically change the key properties in a matter of minutes. Then you can iterate towards a good working tire. There is no getting away from the fact that subjectivity will always remain part of the process.

It is up to the guy involved to decide what is reasonable and what not. What can you say about wide tires with small aspect ratios in relation to narrow tires with high sidewalls? With this type of tire model the user has to decide how to translate the physical properties of the tire into the model. This is easy to do, but also easy to do badly.

As impressive as rFactor 1 is, there are some issues with the model. They are not the result of the type of model however; you can 'fix' the issue just fine without making a completely different model.

Using physical models (rFactor 2, possibly iRacing, LFS)

I don't know too much about these models as rFactor 2 has very recently been released as a beta and the inner workings of the tire model are not really known. However, the very basic idea behind the physical model is that in some way you 'build' the tire, its shape and construction. This goes into a very complex iteration program that has to run tests for about 4 hours, creating a large lookup table of what the tire does under all imaginable conditions. This is rFactor 2.

You're not having a slip curve as input, the model actually works out how the tire grips in each situation based on its current deformation, construction and materials properties. From a programming point of view this is mightily impressive. But is it as good and flexible for the people who end up working with it? It is too early to tell though I think I am slightly worried.

The best model in the world will not result in good tires if it is not easy to work with by end users. While I am sure the model will do logical things most of the time, how can I design certain load sensitivity into a tire and go for a target cornering stiffness versus tire load curve? Can these be predicted or do I have to wait hours for the new tire to be computed before I can test it out? How can I ever draw these curves that I need to interpret the performance of the tire?

With this type of model it is less up to the guy making the mod and more about the model deciding how tires respond to load, slip, temperature etc. It may be harder to do something badly but a lot of trust has to be placed into the model.

When there is no usable real data, and there never really is, there is an unavoidable subjective part in tire modeling. Since tires are 'force generators', it makes the most sense to have a model where the user is in direct control over how these forces are generated. I do not know exactly how the new tire models work but it appears it might not be so easy to change specific force generation aspects in a way that you can test in a spreadsheet (and on the track) in minutes.

Which is better?

The main job of the tire model is to deliver the desired forces (cornering, braking , and accelerating) for each occurring slip, load, speed, temperature, camber, wear etc.

With a curve based model you are in **direct** control over the way the forces change with these main properties. With a physical model you might be in **indirect** control over the way the forces change with these main properties.

With both models, there is either no real data available or real data is not trustworthy. I don't believe that a physical model can be good enough so you can just copy / paste the real tire construction and materials and have the perfect tire. There is too much mechanical, thermal and bonding stuff going on in my subjective opinion, and Michelin will never give you the details.

With both types of models the only certainty is that there will always be a need to change parameters. To me it makes more sense to have parameters in direct control over the tire forces rather than constructing shape and plies that are in indirect control over these forces.

The Big Disclaimer

The huge disclaimer here is that I don't really know much about rFactor 2 yet, and could be wrong on all accounts! I really hope the beta period will teach us more about the model and that we end up with something that is both technically superior and easy to 'design' for the end user.

Final words

Today I felt like writing some words (yeah just a few!) about where real tire data comes from. I hope that it was an interesting read. The next time you read that "real tire data was used", take that with a bucket of salt. Simulators need tire engineers wary of the complexities of tires and with years of neglected lacking social life in order to get tires working realistically.

I also wanted to show that despite having choices in tire models, in the end there will always be a need to adjust the tire behavior. Even a really clever physical tire model (as seen recently in simulators) might just make it harder to adjust the tires compared to a simpler curve based model.

Finally I will say again that it is very early days for these physical tire models and I do not know exactly how they work. The goal of this document was to show how I go about my ways as a physics guy. We seem to read a lot about the programmers making new tire models, but not so much about how the model is used by people who make the cars for these simulators that the players end up driving.

It is just so easy for a physics guy to focus on a small part, and for a physics programmer to bury himself in tire physics coding. Soon you forget the big picture, where tire data is never available and you just want a decent model that allows easy adjustment of the key tire force generation properties.

Have fun racing!

Niels Heusinkveld, February 2012