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INNOVATIVE TIRE MODELING BRICKS FOR LARGE MILITARY VEHICLES AND THEIR BENEFITS IN SIMULATION BASED CHASSIS DESIGN

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ABSTRACT

Vehicle chassis design can take great advantage from a virtual design approach, as it helps tackle the complexity of modern machines, bringing benefits in performance, development cost, and lead-time. For specific applications such as construction or defense vehicles, the simulation design chain may lack significant input model bricks due to the physical limitations of existing test equipment which limit their ability to characterize the large components and extreme loading conditions (high loads, large torques, extreme slip angles. etc.). Michelin SIMIX proposes / develops an innovative solution to fill the gap by combining physical real world measured data with virtual measurements, allowing the creation of digital models relevant to the full usage perimeter.

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1. INTRODUCTION

Vehicle makers are confronted with cost pressure and time constraints in their development. The benefits of a combined real and virtual development approach in the V-Cycle have been proven for many years in the automotive domain.

However, for larger vehicles such as defense vehicles, the benefits and efficiency of virtual design are limited by missing simulation bricks. Among them, three main domains are particularly lacking:

- Accessibility and availability of models capable of accurately predicting the behavior of large tires
- Realistic modeling of tires under low grip conditions (ice & wet)

- Accessibility of soft soil models for modeling the combined tire-vehicle performance under real life applications in extreme conditions (All-Terrain / soft ground, snow...)

SIMIX aims to tackle these three limitations by making use of digital tools to bridge the gap and render such simulations possible. This paper focuses on the first limitation and describes how a combined real and virtual approach made possible the creation of accurate models for large defense tires.

2. VIRTUAL V-CYCLE DEVELOPMENT

The classical development process used for complex systems development, and specifically in the vehicle industry, is the V-Cycle.

V-Cycle development consists of starting with a broad perspective for early specification steps and drilling down into simpler sub-systems until reaching the component level design. As the design moves forward, components are tested and evaluated individually and then combined into larger and larger assemblies. This process helps ensure that the bigger picture is kept in mind, while making sure each individual component meets its goal in an efficient manner.

Quite often the V-Cycle process relies heavily on physical prototypes as component development iterations induce design loops (and thus introduce a dose of trial and error).

Prototyping is a major source of cost and delay in the design process, making the combination of real and virtual approaches particularly interesting [fig.1]:

- In the early development loops, by helping make informed decision, thus narrowing down the number of technical scenarios [1]
- In the validation phase, to de-risk the homologation by identifying and understanding where the gap between the expected versus actual results comes from. It also allows for a direct loopback path between the integration branch (the right side of the V) and the specification branch (left side) without resorting to a full V-Cycle implementation during correction and adjustment phases [2]

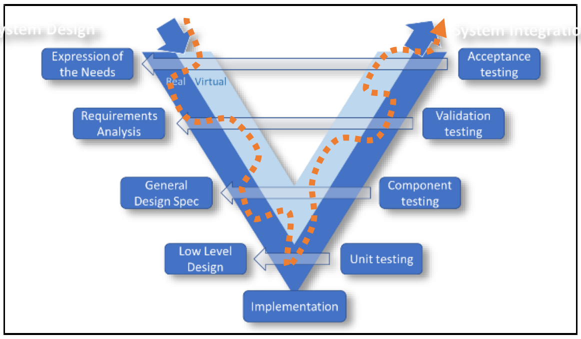

Figure 1: Browsing the V-Cycle in the real and virtual domains.

Thanks to simulation, the optimization of the V-cycle approach can take place at different stages of the development cycle, like [fig.2]:

- De-risking approach at the end of the integration phase (chassis setup and problem solving), with shortened loops
- Whole chassis synthesis engineering, with reduced number of global loops

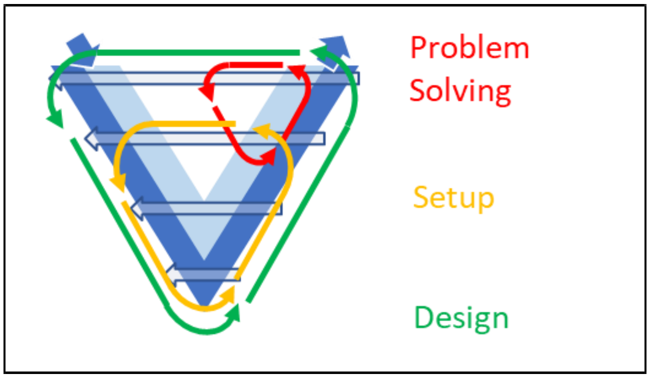

Figure 2: Making use of the V-Cycle in short loops adapted to the task at hand

Taking the example of the de-risking at the end of the design integration, if the vehicle's overall handling or stability performance as seen by the driver isn't at the expected target, chassis simulation can be used to:

1. Analyze the subjective driving maneuvers and identify physical objective criteria to describe the observed vehicle performance
2. Based on those criteria, understand where the gaps come from
3. Intelligently evaluate design evolutions to find the least intrusive solution for the chassis that has already been designed and built. For instance, could the performance gaps be filled by changing springs, dampers, rollbars, and static settings [fig.3] or would they require a full re-design of the suspension arms themselves? The latter case would need a strong justification before entering such a difficult loop, and simulation helps to reduce the risk of choosing the wrong direction or even preventing it from being necessary.

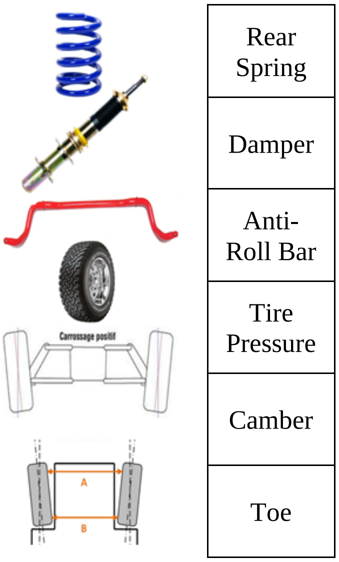

Figure 3: Some low design-intrusive chassis tuning levers

3. LIMITS TO THE USE OF VIRTUAL DESIGN

Component models used in simulation are the digital representation of the component characteristics, described by a set of static or dynamic parameters and algorithms. These models are used by simulation software to mimic complex dynamic behavior.

Simple components such as springs may be modeled using computer and simulation tools knowing the characteristics of the material used, but for more complex components, physical testing is required.

Tires for example are a complex composite object made up of several layers of both linear and nonlinear, visco-elastic, hysteretic materials. To make matters worse, tires are used in a wide range of physical solicitations: with varying load, slip, camber, torque, ... all coupled together during use. [3]

This makes tires very difficult to model without resorting to a wide set of physical measurements: typically, an animation of combined input solicitations is used, and force and moments responses are measured. These responses are fitted according to mathematical formulas. The Pacejka "Magic Formula" mathematical representation is one of the most widely used.

For various reasons, many tied to physical limitations of existing test equipment, even a "classical" but robust Pacejka model may be difficult to obtain:

- Tires may be physically too big to fit in measurement equipment
- Loads may be too high
- Longitudinal slip or lateral slip angle levels and resulting forces and

moments may exceed the capacity of test equipment.

- Grip levels may not be representative of the total tire traction forces. This can be true not only for soft soil conditions, but also for “hard” road surface

In many instances, when the solicitation exceeds the levels typical of car and truck tires, designers have been forced to either use inaccurate tire models or abandon the use of simulation in the domain of handling and NVH.

The solution proposed here is to circumvent these limitations by using a combined approach of virtual simulations and experimental measurement to generate a more complete tire model and bring value to the vehicle simulation domain.

4. SIMIX INNOVATIVE MODELIZATION PROCESS

Among the variety of possible tire models, Pacejka (MF) and F-tire are generally interesting for vehicle chassis simulation and specifically with military vehicles.

The classical fitting process for those models relies on measurements of a real tire in various individual and combined conditions (load, torque, slip angle, pressures, …). These measurements are then used as the basis for a mathematical model whose coefficients are obtained by an optimization and fitting process. This process currently requires that the measurements be taken over the full range of characterization conditions (load, pressure, …). In the case where this range of measurements cannot be performed (e.g. because of limited machine capabilities), then the tire characterization is normally impossible. That’s where a different approach, with the help of simulation, is possible.

The goal is to generate virtual measurements thanks to simulation.

4.1 Principle

As previous mentioned, often the limitation of the characterization process comes from measurement equipment: due to the large size and load requirements of large off-road military tires, our principle is to make use of the complementary capabilities of different machines to work around their specific limitations.

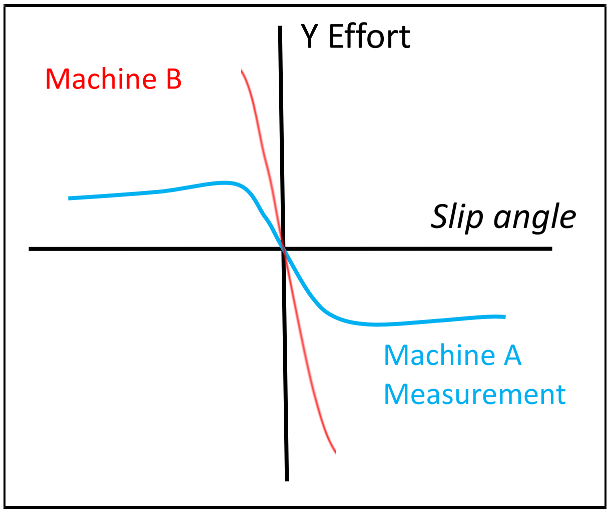

Figure 4: Machine measurements and limitations

[Fig 4] shows a simple example. Machine A covers the needed slip angle range but is limited in load. Machine B covers the Z load but has limited slip angle ability.

In this situation, we take advantage of the limited perimeter of both machines and gather measurements over the attainable range. We then supplement the experimental data with detailed tire simulations and use numerical interpolation and physical extrapolation to extend the measurement domain.

Additionally, when combining machine measurements and/or simulation, quite often the resulting curves and their coefficients will need to be re-calibrated. This provides improved alignment between the tire model and its measurement. A method to do this is as follows:

1. For the required measurements needed to characterize a tire, gather as many as possible from several machines
2. Generate, through detailed tire simulations, some of the actual measurement conditions obtained in the previous step. Evaluate the obtained simulation results against the measurements and calculate a relative error correction, R, between them.
3. Generate the missing measurement conditions (or some representative sub-sample of conditions) in the extended perimeter through simulation, large data analysis, or other techniques.
4. Apply the correction R to either the simulation inputs or results. The goal of this correction step is to improve the prediction of the simulated measurement to the (unobtainable) measurements of the actual tire.
5. Perform the fitting process (which depends on the targeted tire model) on the extended perimeter to the full set of actual measurements and recalibrated simulated measurements.

A visual representation of this approach for a Pacejka MF model is summarized on [fig.5].

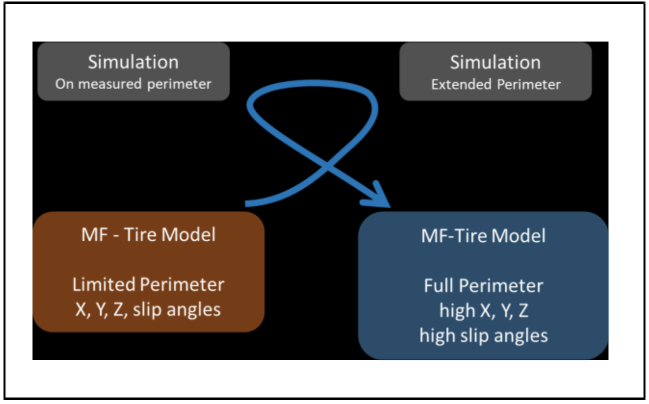

Figure 5: How to combine measurements and simulation wisely

A key factor in this method is that while simulation results are very often relevant for relative prediction, they sometimes can show gaps in their prediction of the absolute values for forces & moments versus measurement. This is the result of various modeling limitations and assumptions (e.g. ground effects, characterization conditions, etc.). The correction R allows us to bridge the simulation/measurement gap with a good confidence level.

Through data combination and calibration, the resulting perimeter for the fitted tire model may cover the entire range of tires and solicitation conditions with a high level of accuracy [fig.6].

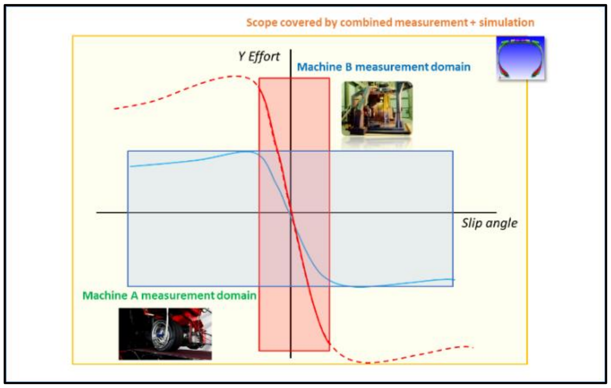

Figure 6: How to combine measurements and simulation wisely

4.2 Simulation: Which Tools

At his point, we have not specified what model(s) might be used to perform the tire simulations needed to generate the virtual measurements. Two main options are anticipated, finite element models [fig 7] and functional models [fig 8 and 9].

For finite element models, one must be able to describe in sufficient detail for the tire of interest, its internal structure. Of particular importance are the materials used, their precise locations and properties. The model must be robust and precise enough to reach the right level of prediction by the simulation. This kind of approach is powerful but is often time consuming and can be hard to deploy for someone who is not the tire manufacturer itself.

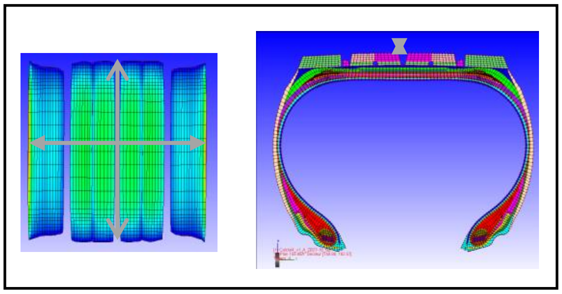

Figure 7: Finite elements models of a tire

For functional models, the principle is to describe the tire behavior with analytical equations and physical laws. This approach also requires the ability to characterize material properties, but the mechanical structure itself is described in a more functional way than with the finite element method. With a functional model, the tire is typically seen as a complex combination of spring and dampers (shear and torsional stiffnesses, damping, …) that make the link between the ground and wheel center. [4]

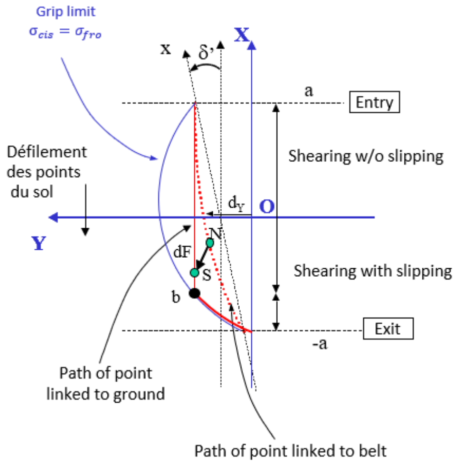

Figure 8: Functional model of a tire summit (rubber in the contact patch) [1]

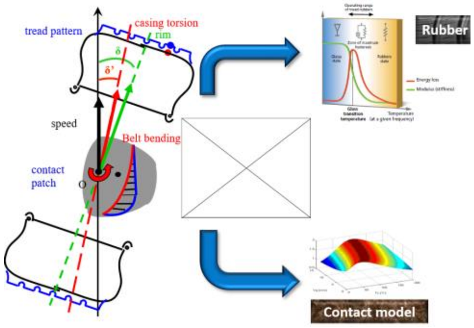

Figure 9: General overview of a the principal of a Functional model of a tire

In both approaches, the key differentiating factor is to be able to describe the internal structure of the tire (in detail or functionally), and to describe material properties with a high level of accuracy. Not only is rubber a viscoelastic non-linear thermally dependent material but several different rubber formulations (each with unique properties) are used in a single tire.

Having reliable simulations implies the ability to digitally reproduce tire structural characteristics and operating states (stress, strain, thermal, etc.) and include their impact on the rubber compound. [5] This obviously applies to absolute predictions but is equally true when the simulation is limited to a relative prediction (delta comparison) vs a known reference.

4.3 Extrapolation and Further use

Some tires are too large to fit any measurement machine. As a result, the partial measurements may be on an even a smaller solicitation (or non-existing) perimeter.

In such cases, one may have to use existing possibly smaller tires that have been measured and characterized to make a homothetical scaling, using simulated data generation for both tires as a starting base for the scaling.

4.4 Feedback from experience

In the methodology validation process, the approach was applied to a tire using partial measurements and simulation, and later compared to a known valid reference that was obtained through measurement on the full perimeter.

The results achieved are valid with an accuracy of +/-5% on all significant variables. An illustration of the simulated vs measured curves is shown in Fig 10 This shows that the results are in line with the expectation for the component.

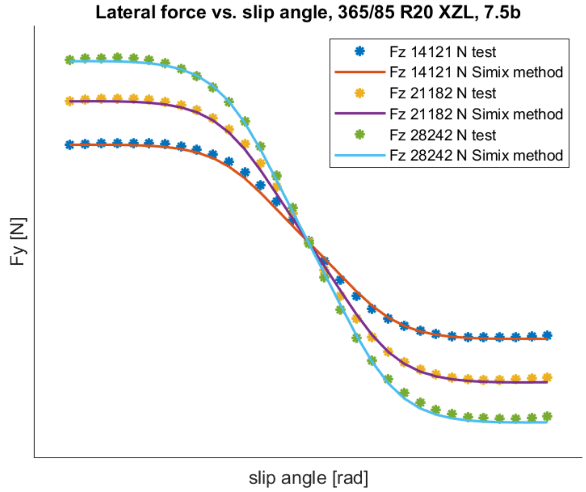

Fig. 10: comparison of curves between a SIMIX generated model and a known good reference

Figure 11 illustrates the improvement achieved through the method: comparing the curve obtained outside of the measured perimeter through extrapolation of the basic numeric fit vs the recalibrated curve obtained through a combination of partial measurements and simulation: improvement is all the more significant that we look further away from the measurement limits, which is critical for simulations performed at the limit.

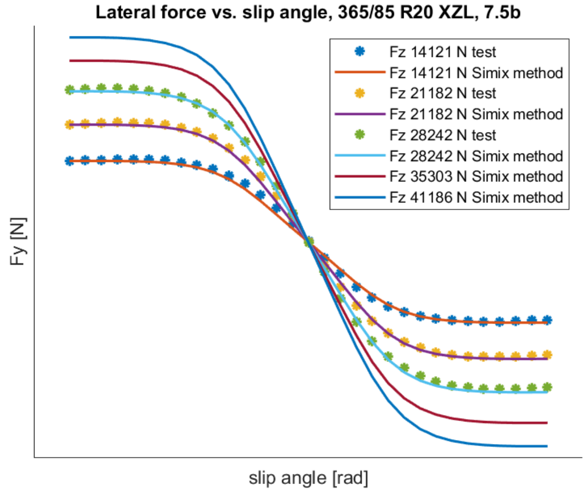

Fig. 11: extrapolation on high loads with built trust in simulation allows vehicle simulation beyond measurement limits

It is also important to validate that the performance of a model is retained once integrated in an ensemble of components: a global simulation accuracy is only as good as the sum of its components, and could be jeopardized by a single characterization discrepancy. When tested on the first applications simulation engineers mentioned that the simulation performance made a quantum leap: “gains in terms of theoretical curves are really significant. Impact on results is very substantial”.

Figure 12: SIMIX Engineering Roadmap.

Further applicative tests have been performed as the database of models increased, and customer feedback from users have been used to further validate and refine the methodology.

5. NEXT STEPS for SIMIX

Based on the tire modelling needs for vehicle chassis design, we have a progressive roadmap to develop incremental simulations bricks for the industry [fig.12]:

1. Provide availability to accessible and accurate tire models for large tires: this is the approach described in this paper
2. Realistic modeling of low grip conditions (wet)
3. Soft tire-soil models for applications in extreme conditions (All-Terrain, mud, …) applicable to tactical as well as support vehicles.

Steps 2 and 3 will be the object of further work and publications

6. COLLABORATIVE APPROACH

This paper documents an approach to providing improved tire models for simulations where existing measurements cannot be made to characterize the tire due to physical limitations in tires, testing machines, and methods. Vehicle models have many other needs for improved tire models.

Michelin SIMIX has the ambition to provide these bricks but cannot do it alone.

Vehicle manufacturers, test and measurement companies, software suppliers, simulator suppliers, numerical experts have complementary competencies and expertise and all have a role to play in this eco-system.

We look forward to working in collaboration with various partners.

7. REFERENCES

[1] P. Pallot (Michelin), “Digital design of the chassis and tire: virtual is real!”, Chassis.tech+ 2020, Munich, Germany, June 24th 2020

[2] M.Carna, and A.Orlandi (Ferrari), M.Grob, J.Vayssettes and J.Levray (Michelin), “From the Track to a Driving Simulator: A tire journey from a component to a model”, 2018 VI-GRADE USERS CONFERENCE, Lainate (Milan), Italy, May 7th-9th, 2018

[3] M. Grob M, O. Blanco-Hague, and F. Spetler, “Tametyre’s testing procedure outside Michelin”, 4th International tyre colloquium: tyre models for vehicle dynamics analysis, University of Surrey, Guildford, April 2015.

[4] X. Maume, and M. Grob, “Physical & functional tire Modelling with TameTire”, tire Modelling short course, Tire Technology Expo, Hannover, 2018

[5] J. Levray and C. Heinry, “Working on driving simulators with TAMETIRE: A physical tire model for virtual design”, 2019 VI-GRADE INTL CONFERENCE, Hanau (Frankfurt), Germany, May 13th-15th, 2019