POTENTIAL EVALUATION OF SCALING AND SIMILARITY FOR TRACTOR TIRES

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Abstract

The common exercise in investigations and industrial applications for tires and specifically tractor tires is experimenting. However, there are difficulties which will be detailed in the text. Similar issues are encountered in fluid mechanics, but fluid mechanics studies sometimes involve scaled models and uses similarity approaches to overcome some of the difficulties. However only one significant study has been encountered in the literature about tire scaling and no study is encountered about tractor tires. In this report, scaling, similarity and dimensionless analyses are introduced first. Then the work about tire scaling is viewed. Points for scaling tractor tires are proposed. Some concluding remarks and propositions are made for future work.

Keywords: Scaling, Similarity, Tire, Tractor.

1. Introduction

The studies on tires of vehicles in general depends on three main approaches. The first one is experimentation and empirical tools such as correlations and tabular data are included in this approach. The second one is mathematical modeling by analytical analysis. The third approach uses the computational and numerical methods. There is a tradeoff between these approaches in terms of financial cost and labor cost. In other words, an approach that is easier to apply has higher financial cost. A cheaper approach is more likely to be harder to realize in terms of work load. Nevertheless, these aforementioned

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approaches work on full scale tires. For instance, tires at full scale are tested on a real ground with a real vehicle. Although results of those studies are very reliable, there are certain difficulties which can be listed as below:

- Safety issues: Working with full scale instrumentation imposes some safety risks on the operator/tester. Inertia of the system, hazardous effects, emissions, sharp machine elements and such are composing the risks.
- Applicability: It is not always possible to test full scale equipment.
- Work load: Establishing a facility, maintenance, monitoring, need of several disciplines other than the discipline of the investigation, hygiene duties and test operations compose a real work load.
- Financial cost: Experimentation is sometimes quite expensive. The instruments for measuring physical quantities add on the cost of the equipment to be tested.
- Limitations due to technique and technology: Recent technology is sometimes incapable of measuring the physical quantity. The temperature distribution in a material or stresses is normally calculated from measured magnitudes. Therefore, theoretical knowledge cannot be always validated by experiments directly. Another thing about limitations of the technique and technology is due to the sizes of the full-scale systems.
- Time cost: Another cost of the experimentation is time cost. Realizing a procedure depends on time and parameter combinations can lead to high numbers of tests.
- Hardness: Due to all above reasons for working with full scale equipment, there is a motivation issue of working with full scale systems. This perception of hardness is another fact to be considered for those studies.

Although tire studies are based on full scale, other disciplines such as fluid mechanics use scaling. By inspiration from fluid mechanics, it is thought to use scaling in tire mechanics. Since there is sufficient validation data, results of scaled tire investigations can be validated easily. Hence deciding and planning the procedure is what is left. The next section gives information about scaling, similarity and dimensionless systems. After that section, an example of scaled tire testing is given. The plans for scaling tractor tires are presented consequently. Finally, in the last section of conclusion, concluding remarks and proposition for future studies are given.

2. Scaling, Similarity and Dimensionless Analysis

Scaling is actually a geometrical concept. It means reproducing the geometry in a different size while satisfying a scale ratio. If a length of geometry is reduced in "x" times, other lengths of the geometry should satisfy this scale. By this way, geometrical similarity is attained. Geometrical similarity is tried to be explained by Figure 1.

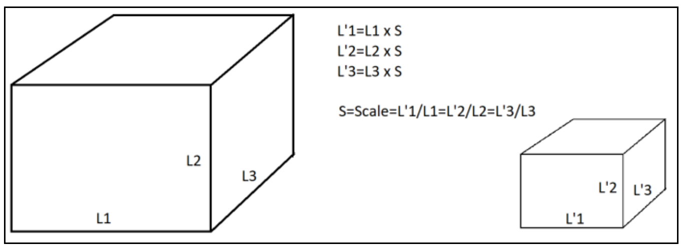

Figure 1. Schematic state of scaling and geometrical similarity

Geometric similarity is not enough for investigating and examining physical systems because there are structures, thermodynamic and physical properties like density, irregularities, forces, stresses and other environmental effects such as gravity, magnetism, etc. Another cause is for the search of a low-cost material and/or easy to handle material for scaling. When material is changed, simple scale is not enough. The other similarities for studying physical systems are static similarity, kinematic similarity and dynamic similarity. If the system is investigated for a static load, static similarity should be satisfied. If a moving system is analyzed in terms of velocity only, then kinematic similarity should be satisfied. If all the physical effects on a moving system are investigated, then dynamic similarity should be satisfied. In order to satisfy these similarities, geometrical scale is not enough.

If Figure 1 is examined again, there is only one physical reference dimension which is length. For a system in which other dimensions are exist such as time, mass, temperature, etc., more scales are needed, and the number is at least the number of the dimensions. This is obviously difficulty and leads to complexity. The dimensions can be related with each other and they may have a cumulative effect on the result to be investigated. Also, parameters having different dimensions can be related with each other by combining dimensions. Therefore, there is a technique in which parameters having different dimensions are put in mathematical relations in order to get a dimensionless scale. By this way, dimensionless scales include the relationships between parameters and dimensions leading to less number of scales. For instance, Reynolds number is a dimensionless scale for kinematic viscosity while there are a lot of parameters and dimensions. A small object in a wind channel for a given Reynolds number can do the kinematic representation of a big object in a real road. For a dynamic representation, additional dimensionless scales are needed but still the total of the scales are less, and application is easier. Nevertheless, obtaining a dimensionless scale is not a very easy task. A very common way of using dimensionless scales or numbers are looking to the literature and using readily presented numbers. In some rare cases, dimensionless numbers can be derived special to the case. Buckingham Pi theorem is a well-known method to obtain such dimensionless numbers.

Buckingham Pi theorem is a procedure to obtain the necessary dimensionless numbers or sometimes it is used for deciding to select the dimensionless number to be used. For instance, 1/Re can be found as a result of Buckingham pi theorem; however, the applicant can select Re as the dimensionless scale as the proper number.

In the Pi theorem, n number of parameters with dimensions can be reduced into n-r number independent dimensionless variables where r is the number of reference dimensions. Mathematically;

$$p_1 = f\left(p_2, p_3, \cdots, p_n\right) \tag{1}$$

$$\Pi_1 = f\left(\Pi_1, \Pi_2, \cdots, \Pi_{n-r}\right) \tag{2}$$

By means of dimensionless analysis and dimensionless numbers as scales, similarities can be attained and following advantages can be achieved.

- Low cost
- Ease in handling
- Safety
- High number of experiments in unit time

- More control with less personnel

There are plenty of scaling examples, but it can be said that there is almost no example of tire scaling except one work. It is mentioned in the next section.

3. Tire Scaling

Tire scaling hadn't been encountered in scientific works till 2003. So, a comprehensive Master Dissertation dedicated to the details of scaled tire testing is reported in 2003 [1]. Scientific reports can also be found originating from that thesis in 2004 [2] and 2006 [3]. The only references that are encountered in the literature so far are those reports. In this section, those reports are evaluated and summarized.

The specific motivation of the mentioned study (references given above) is said that scaling vehicle studies are done only the interval of linear region of tire steady state response. In other words, the tires in the modeled vehicle cannot represent the nonlinear or transient responses of a real tire. Therefore, some of the scaled vehicle tests are restricted for a response interval of substitute tires which are not properly scaled and physically similar [1].

Tire testers, whether they are for a full-scale test or scaled test, are explained to have some properties for arranging testing conditions and to be able to measure some quantities. Those properties are slip angle, camber angle, caster angle, speed, percent slip, normal load, bouncing frequency, etc. Those quantities to be measured are moments along each tire axis, temperature, inflation, wear, deformation and geometry [1].

The author emphasized that scaled tire testing necessitates lesser amount of forces. Therefore, stationary experimental setups become attractive. Another important point against mobilized test setups is that environmental effects on the measurements would be higher since the quantities are smaller in the scaled tests. So, author established a stationary tire testing setup. The solid model and a picture of the setup are given in Figure 2.

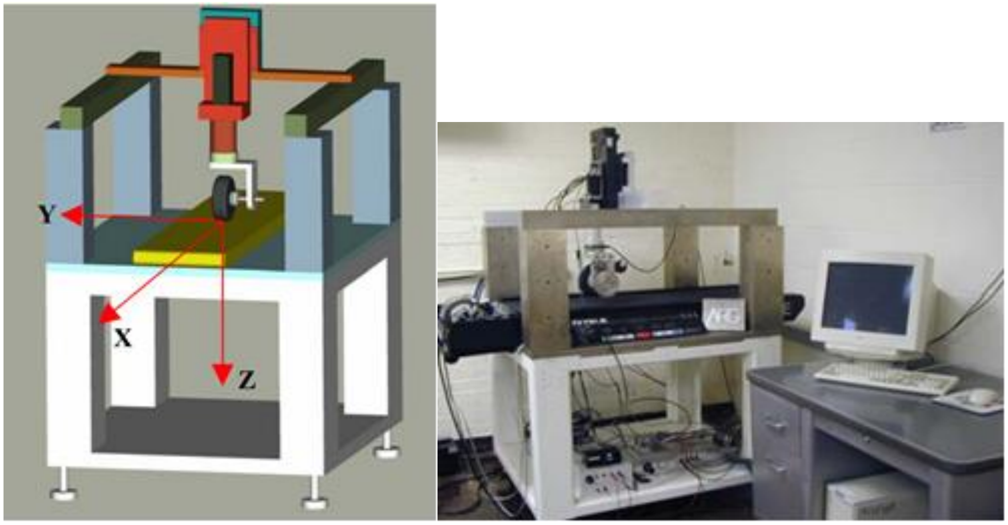

Figure 2. Stationary scaled tire test setup [1]

About the tires, it is explained that the full-size vehicle tires are limited to an interval in such way that the smallest sizes cannot be used in scaled tire testing. Therefore, new tires should be manufactured specifically to the testing, but this imposes financial costs. The last option is to use a tire from a different application. Finally, it is stated that a proper small tire could only be found in remote control air plane market. The tires that are used for scaling are shown in Figure 3 and comparison of those tires with full scale ones are given in Figure 4.

Differences of the scaled tires from full size tires are listed as;

- Tread patterns
- Internal linings
- Belts and plies

which are completely missing in the scaled tires. However, it is still proposed that the scaled tires can be used for testing since the experimentation of full sized tires represents tire response plus the missing properties above specifically to the tire. The tire response is assumed to be the common part.

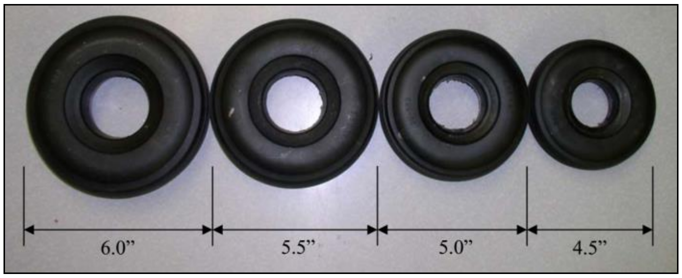

Figure 3. Remote control air plane tires for scaling [1]

Figure 4. Comparison of scaled tires and full-scale tires [1]

An image from the experiments is given in Figure 5. A comparison of scaled tire results and full-scale tire results are given in Figure 6. As it can be seen from the figures, a scaled pneumatic tire can be put into test for nonlinear steady responses. The results of the test bench is not equal in quantity for scaled and full sized tires but the trends have similar and suggest that results can be used for assessment after a dimensionless conversion is made. The critical point here is calculating dimensionless result in order to use the outcomes of the scaled tire testing.

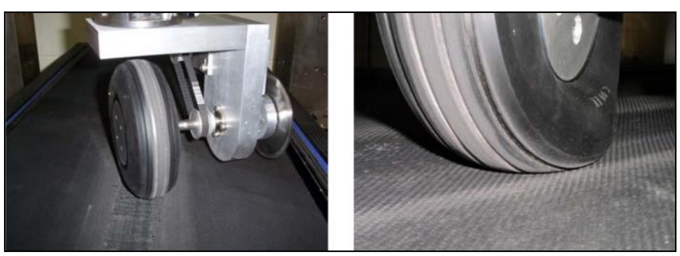

Figure 5. An instance from the experiments [1]

As a conclusion, it is understood that scaled tire testing is suitable for steady non-linear tire response. But there is no work for scaled tires for tire mechanics.

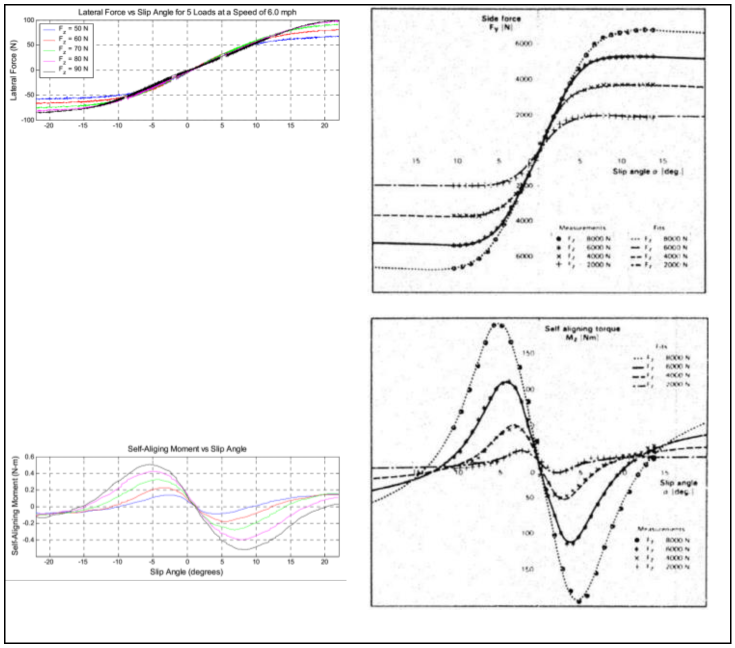

Figure 6. Comparison of scaled and full-sized tire results [1]

4. Scaling Tractor Tires

Scaled tires for tire mechanics and scaled tractor tire testing has not been encountered in the literature. Tractor tires are a key point for the industry and have an enormous impact on energy consumption and soil compaction. However, working with full sized tires is really hard because of the big loads acting on them and much diversified soil types. It can be clearly suggested that scaled tire testing has a potential for tractor tires.

The plan for such testing is given in bullet points below:

- The parameters (whether independent or dependent) should be decided for investigation.
- The reference dimensions of the parameters should be determined.
- Pi theorem should be applied to determine the dimensionless numbers/parameters.
- Scaled tires should be manufactured/produced.
- A proper design of test setup for the scaled tractor tires should be developed and implemented.
- Results of the tests should be compared to full sized tractor tires by using results with

dimensions and dimensionless results.

- After validation is done by the comparison, extreme cases or cases that have not been tested can be investigated.

The point to be emphasized here is details of scaling for complete similarity. Soil, for instance, could not be used for scaled tests. Instead, wheat flour, concrete powder and finer grains would be used. The sensors would have higher sensivity due to smaller magnitudes.

Here, a reference in the literature will be given in order to have some inspiration though the tire is not scaled. Ekinci reported a rigid wheel that was made of metal and metal tire lugs can be mounted on it with different mounting angle [4]. It is very interesting to see such work in respect of two points; 1rst, the rigid wheel has a geometrical similarity although it is not responding as the rubber tire does; and 2^{nd}, tire lugs are found to have a significant role in traction performance. The study that is examined in the previous section mentioned that treads and patterns have a lesser effect on the tire performance because it focuses on the passenger vehicles. However, this study reveals that tire lugs should be scaled too. And another outcome of this paper is that logs can be separately scaled and can be separately investigated.

In the last section, as conclusion, it is tried to summarize the observations and evaluation on the topic.

5. Conclusion

Scaling for acquiring similarity in order to make scientific investigations is a well-known technique, especially in fluid mechanics. Dimensionless analysis and numbers are tools of the technique. Although research about tire mechanics can benefit from such technique, only a single work has been encountered in the literature so far. And no work has been encountered about scaled tractor tires. Following remarks are given for future work.

- Graduate studies can be dedicated to develop a plan and strategy in order to facilitate a scaled tractor tire and its test setup.

- The proposed setup and research is not only for commercial companies, but it has a potential for agriculture since a huge diversity of soil types can be tested and strategies can be developed in two key issues; soil compaction and fuel consumption.

- The scaled tractor tire testing is much suitable than the full-sized equipment for academia.

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