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IMPACT OF FRONT AND REAR WHEEL TRACK ADJUSTMENT ON RACE CAR LAP TIME

Abstract

The dynamics of race cars is an extremely broad issue, as there are many factors which have an impact on a race car's behaviour on the road. This study examines the relationship between lap time of a race car and different adjustments of front and rear wheel tracks. The analysis is performed using VI-CarRealTime simulation tool provided by VI-grade, a global leader in racing simulation tools. To explain the difference between the front/rear wheel track ratios, the values of side slip angle in corners are used. The best adjustment is determined.

1. INTRODUCTION

VI-CarRealTime is a simulation program for testing car adjustments in a virtual environment. The use of the program substantially reduces the costs associated with real vehicle dynamic testing. Many racing companies use software of this kind. The VI-grade solution enables testing various changes in a virtual model in real time.

First, a virtual car model is loaded in a build mode. The car model is a collection of subsystems like suspensions, steering system or power-train. Many systems are predefined in order to shorten calculation time. Some parameters can be easily changed without rebuilding the whole subsystem. Moreover, it is

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possible to design your own subsystems. For example, a complete suspension could be created in VI-Suspension Gen.

After the car model has been loaded, the user selects simulation settings. There are many predefined simulations including checked lap time on a given road or acceleration on a given distance.

The last step involves performing results analysis in a postprocessor. The program generates animation and plots desired for physical values in a time function.

Vehicle dynamics analysis, both in real and virtual models, is based on numerous factors. The best race car must have a good power-train [1] and excellent handling [2]. In order to achieve mechanical advantage, power-train constructors should introduce high-efficiency engines and optimal transmission. Excellent handling can be achieved in two ways. The first one is mechanical grip derived from tire properties [2], car suspension adjustment and mass distribution. In race cars such as a Formula SAE vehicle a double wishbone suspension system is very often used [3]. This kind of suspension has 12 head points, which is important if perfect adjustment is be made [4]. Sometimes a double wishbone suspension with a push or pull rod is applied.

Another method for excellent handling is grip derived from downforce [5]. It could also be computer-modelled by CFD programmes. These programmes are used for testing airflow around the car exterior [6]. Nowadays, downforce is an important element of race car design.

The authors of this study analyse handling derived from different front and rear wheel track adjustments. A better front/rear track ratio implicates better lap time of a race car.

To better understand this topic, some definitions are introduced. The track t is the distance between the wheels on each axle. It is measured in the middle of the wheels. The wheelbase r is the distance between the car's axles.

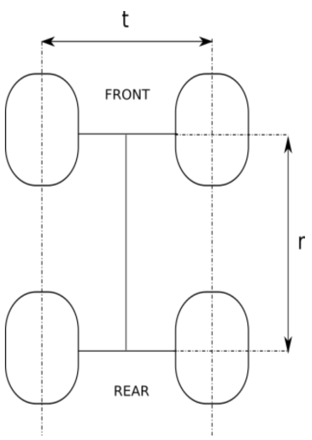

Fig. 1. Track and wheelbase measurement [source: own study]

The track and wheelbase measurements were made in accordance with the formula shown in Fig. 1. The chassis lateral acceleration is the quoined square of the car velocity and the corner radius [7]:

$$a_c = \frac{V^2}{r} \tag{1}$$

Another important terms are: side slip angle, camber angle and lateral force [7]. The side-slip angle α is the angle between the longitudinal force Fx and the velocity vector ν . The camber angle γ is the angle between the plane comprising the horizontal axis z and the tire plane. The lateral force Fy is the force tangent to the ground and orthogonal to both axis x and axis z [8].

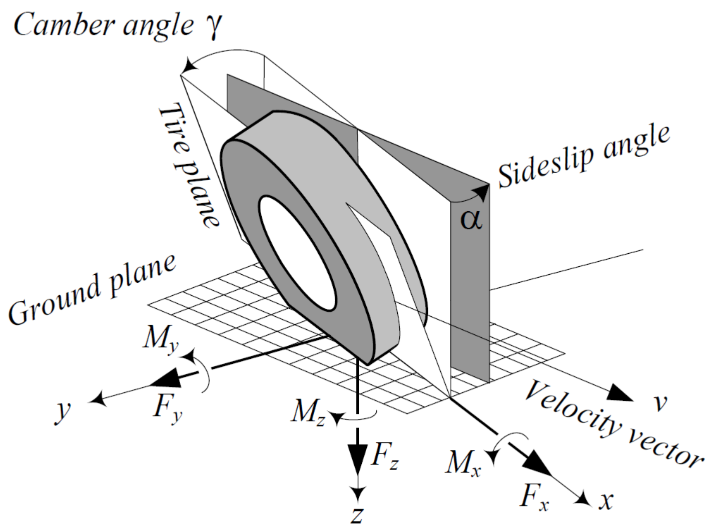

Fig. 2. SAE tire coordinate system [8]

The SAE tire coordinate system is shown in Fig. 2. The lateral force is generated when the car is going around a curve. The lateral force causes velocity vector deflection from axis x and the side-slip angle increases. The increasing lateral force causes an increase in the side-slip angle.

2. COMPUTER SIMULATION ASSUMPTIONS

The simulations based on a complete model of a representative Formula SAE vehicle are performed using VI-grade. This model was entered in the Virtual Formula 2015 Competition [9]. The authors modified some construction parameters and the driver's path. The aim of these modifications is to achieve the best possible lap time on a given road. The following parameters are modified:

- the wheelbase is set to 1525 mm,
- brake front bias is set to 66%,
- pressure in the brake system is set to 0.068 MPa,
- front wheels toe angle is set to 2 degrees and the camber angle is set to 1 degree,
- the rear wheels toe angle is set to 0 degree and the camber angle is set to -1 degree.

The engine and transmission are not modified. The engine is set behind the driver's back. The car has a rear wheel drive. The differential is of the LSD type [10-12]. The mass distribution (front/rear) is equal to 48.5/51.5. The front and rear suspension is Double Wishbone with Push Road [13, 14]. The car's exterior is not equipped with elements increasing downforce like front or rear wings.
The simulations have been performed in MaxPerformance event included in the VI-CarRealTime software. Performance factors were as follows [15]:

- Longitudinal Acceleration Performance Factor = 1.11,
- Longitudianal Brake Performance Factor = 1.04,
- Lateral Performance Factor = 1.015.

Such a combination of performance factors allows us to do a lap without drifting. Another assumption is that any wheel cannot leave the road completely on visualisation. In order to assure comparability of the results, the adjustments (excluding tracks) and the driver's path are maintained unchanged in each simulation. The difference between the front and the rear wheel tracks is about 8%.

3. SIMULATION RESULTS

Table 1 gives the statistics of each simulation. These statistics are generated by a Phyton console of the VI-CarRealTime software. The simulations proceeded smoothly and without any complications.

The differences between the cases are significant. The best lap time is achieved by a car with a wider rear wheel track. The lateral acceleration force is the highest for this car. The values of maximum speed are almost equal. Based on the simulation statistics, it can be claimed that the car with a wider rear track is the fastest of the described profiles.

Tab. 1. Simulation statistics [source: own study]

Simulation Statistics – car with wider rear track (front track – 1100 mm rear track – 1200 mm)		Simulation Statistics – car with wider front track (front track – 1200 mm rear track – 1100 mm)	
Lap Time	110.190 s	Lap Time	111.160 s
Lateral Acceleration MAX	1.1916 G	Lateral Acceleration MAX	1.1331 G
Lateral Acceleration MIN	-1.2680 G	Lateral Acceleration MIN	-1.1445 G
Speed MAX	163.126 km/h	Speed MAX	162.786 km/h
Simulation Statistics – car with both tracks 1100 mm		Simulation Statistics – car with both tracks 1200 mm	
Lap Time	111.040 s	Lap Time	110.360 s
Lateral Acceleration MAX	1.1233 G	Lateral Acceleration MAX	1.1268 G
Lateral Acceleration MIN	-1.2495 G	Lateral Acceleration MIN	-1.1648 G
Speed MAX	162.763 km/h	Speed MAX	163.133 km/h

A preview of collocation in the sample corner is shown in Figs. 3–6. This image comes from VI-Animator software for previewing simulation results.

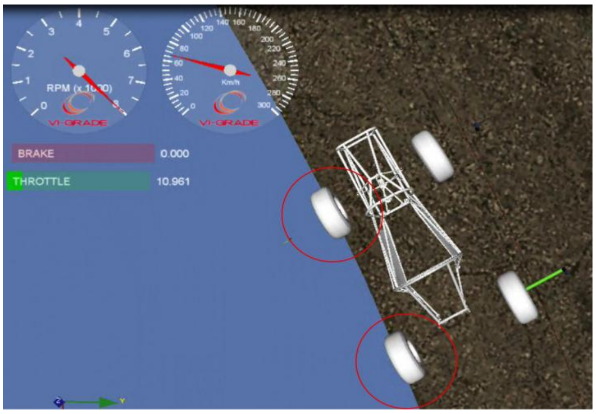

Fig. 3. Preview of collocation in the sample corner, car with wider rear wheel track [source: own study]

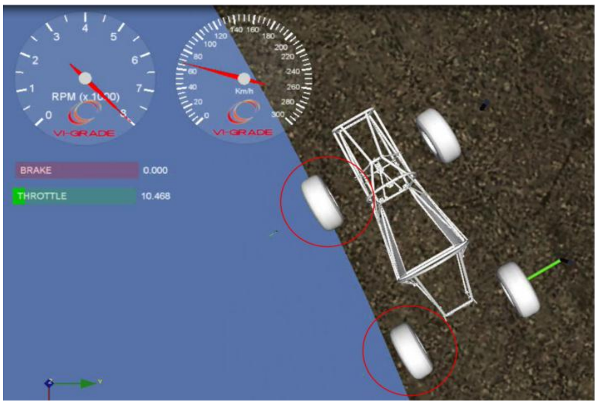

Fig. 4. Preview of collocation in the sample corner, car with wider front track [source: own study]

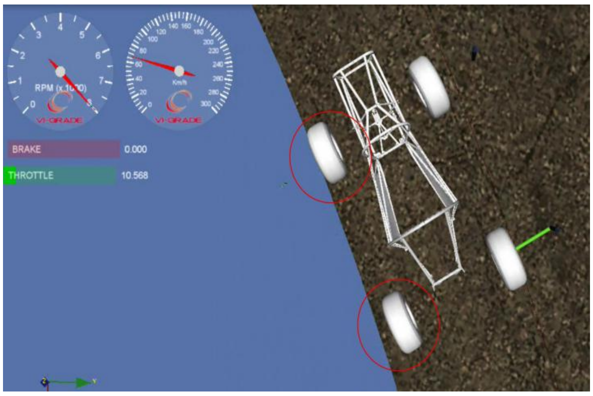

Fig. 5. Preview of collocation in the sample corner, car with both tracks equal to 1100 mm [source: own study]

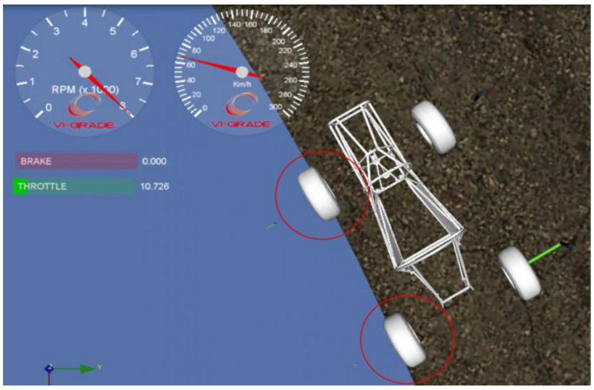

Fig. 6. Preview of collocation in the sample corner, with both tracks equal to 1200 mm [source: own study]

The car in Fig. 3 could get the most of the road width. The car in Fig. 6 is really close to falling short of the condition saying that no wheel can leave the road completely. The cars in Fig. 4 and Fig. 5 cannot get the most of the road width. If the driver's path is changed, the car with both tracks set equal to 1100 mm could shorten the lap time.

The greatest differences between the side-slip angle and the chassis lateral acceleration in each case are presented in Figs. 7–10.

Points 1–10 indicate differences in the side-slip angle. In Fig. 7 the side slip angle is the highest. This can be best seen in points 3 and 7.

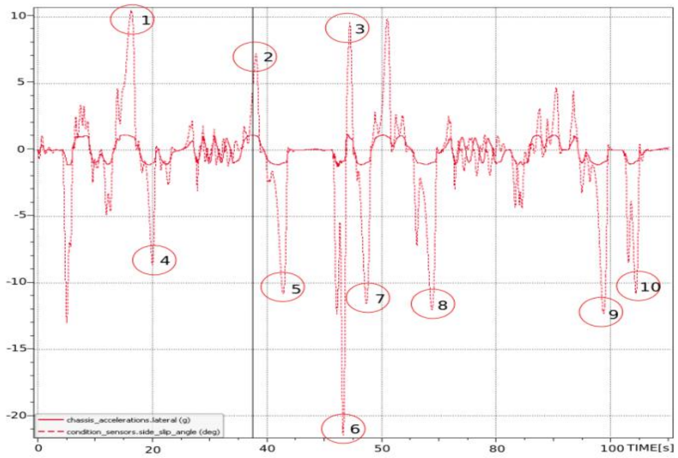

Fig. 7. Side-slip angle in degrees (dotted line) and chassis lateral acceleration in G rate (solid line) of a car with wider rear track [source: own study]

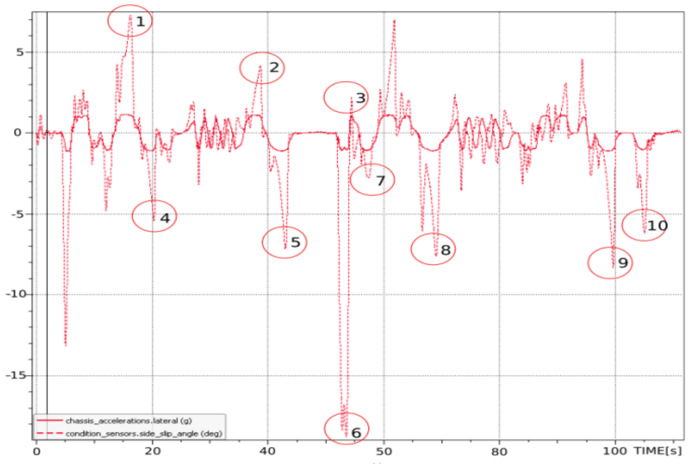

Fig. 8. Side-slip angle in degrees (dotted line) and chassis lateral acceleration in G rate (solid line) of a car with wider front track [source: own study]

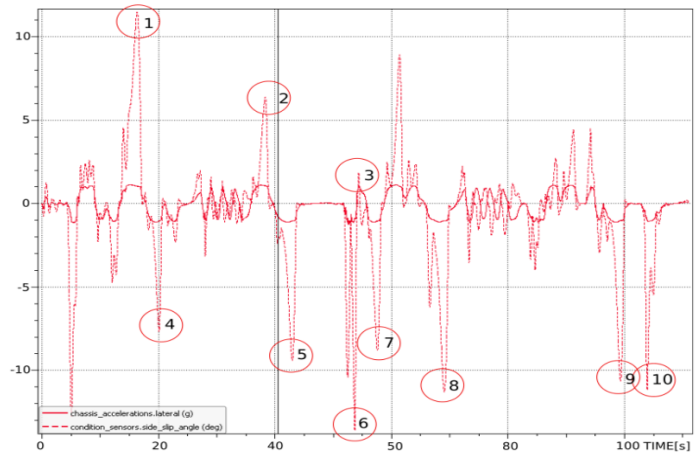

Fig. 9. Side-slip angle in degrees (dotted line) and chassis lateral acceleration in G rate (solid line) of a car with both tracks set equal to 1100 mm [source: own study]

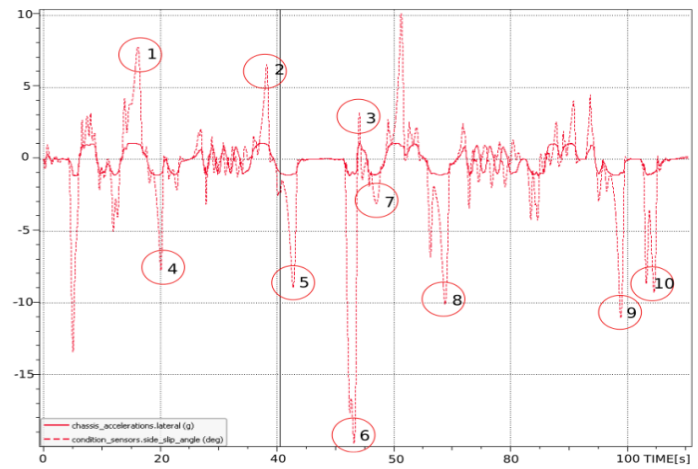

Fig. 10. Side-slip angle in degrees (dotted line) and chassis lateral acceleration in G rate (solid line) of a car with both tracks set equal to 1200 mm [source: own study]

Since the car's motion is slip-free, the side-slip angle is proportional to the lateral force [4]. The sum of the lateral forces on the wheels is equal to lateral force of the chassis. The chassis lateral force is the product of the chassis lateral acceleration and the car mass. According to Equation (1), the chassis lateral acceleration depends on the car velocity and the corner radius. The road for each case is the same. The car velocity in the corners is the highest in Fig. 7.

3. CONCLUSIONS

The numerical results and their analysis enable us to verify basic assumptions of the model already at the stage of preliminary design. This will reduce both manufacturing time and costs of the production process. Given today's technological development, computer-based simulation tools have become an essential part of the manufacturing process.

The results demonstrate that the best performance is achieved by a car with a wider rear wheel track. The car with this adjustment can transfer a higher lateral force prior to losing traction. As a result, the car can take corners faster and achieve a better lap time. Nonetheless, it is also worth noting that this adjustment enables setting the engine in central position. Consequently, mass balance is better. It must be noted that the results hold for a situation when the car is not provided with aerodynamic equipment such as front and rear wings. If the front wing generating considerable downforce is applied, the results could be different.

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