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Analysis of the weight supported by the wheels and its influence on the suspension system

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Abstract

The weight supported by competition cars can be decisive in the suspension, a competition of turns or ovals tends to direct more weight to the right side as it is the part that will have the first contact in a crash, that is why a configuration analysis is performed to align or better distribute the weight of the vehicle, avoiding problems that may alter the braking when they are at maximum speed, analyzing data such as camber, speed, radius and lateral force, each configuration should vary depending on the track on which the competition takes place.

Keywords: center of gravity, vehicle weight, suspension, competition vehicles.

1. INTRODUCTION

A Nascar series car can weigh 3450lb, with at least 1632lb of that weight in the right hand section of the car, which is usually the part that impacts when it hits the wall. Exactly as in other kinds of projects, the concept of trial and error is still being applied, due to the fact that new technologies are being incorporated to improve the performance of the car and the safety of the driver, which is not very favorable in the alignment issue, forcing the teams to replace components. Another disadvantage is that since the wheels are connected to the differential by means of axles, the vibrations produced by the action of irregularities or bumps that the track may have are transmitted from one wheel to the other; considering that it is a very robust system, the weight of the suspended mass increases notably due to the weight of the rigid axle, the weight of the conical differential group and to a lesser extent to the longitudinal tie rods and the bar.

Simulation work has been carried out to find the influence of engine weight on the wheels to analyze comfort in urban vehicles [1]-[3]. The influence of weight and its distribution are not only important in racing cars, as they are important in the handling of buses in conditions where it can make a turn when parked, showing that the degree of understeer increases when the weight distribution has a range between 40 and 50 percent on the front axle [4]. Undoubtedly, weight does not only affect the wheels with the suspension system, different parameters such as road conditions should also be analyzed, but much interest should be paid to the components of the same, which can improve or solve this drawback such as damping [5], [6]. Normal studies focus on analyzing the vehicle load and how it affects whether the vehicle is loaded or not, since the center of gravity influences the load, which affects the braking forces [7]-[10]. The advantage of simulation is quite interesting to determine how weight affects the handling of the vehicle, both with fixed and variable weights when the speed changes. Competition cars are lighter than a traditional car and that makes the front and rear weight of a vehicle different, normally the front should have 40% and the rear 60% of the weight, even when traveling at maximum speed, while a traditional car can have more weight in the front, even if it has to understeer in some curves [11], [12].

This article presents the necessary configurations to determine the influence of the weight supported by the wheels on the suspension system in cars used for competitions, selecting parameters such as curve radius, camber, maximum speed and time to obtain it, in order to achieve the most appropriate configuration.

2 METHODOLOGY

Cross weighting is adjusting the weight, if you raise the left rear corner and lower the right front corner you must increase the cross weight, that corner is now loaded with more weight because it is higher in order to distribute the weight over the diagonal of the car and in turn support the higher weight of the car.

If the left rear corner of the car is lowered, then the left front and right rear corners are set higher than the left rear corner. In this way, lowering the left rear corner decreases the cross weight, the weight on the left front and right rear corner increases and the weight on the right front and left rear corner decreases. Decreasing the cross weight makes the steering stiffer, allowing the front wheels to have better grip because the left front corner starts with more weight than the right front corner. In the rear section if the right rear wheel holds more weight than the left rear, the rear wheels do not grip as well as the front wheels, resulting in stiffer steering. With the same type of reasoning, you can see why increasing the "cross weight" creates soft steering. The cross weight (CR) of the car is calculated by the following equation 1.

$$\boldsymbol{CR} = \frac{\text{Wheel weight FI} + \text{Wheel weight PD}}{\text{Total Weight}} \text{X}100\% \qquad (1)$$

2.1 Center of gravity

The location of the center of gravity (CG) is one of the fundamental factors in the performance of a race car because the ability to grip depends on the vertical load applied. Changes to the chassis are made to shape the handling, in one way or another, is affected by the weight on the wheels. Such changes can be made by varying the CG position or by weight distribution during cornering. The location of the center of gravity has an effect on the dynamic response of the car. The lower the height, the higher the performance levels, such as lower rollover threshold and lower lateral load transfer. XY plane center of gravity location. For the location of the car's CG, the distance of the front and rear tracks must be known in order to determine if they are equal or if they differ from each other, the front track being shorter than the rear track. According to the technical specifications of the NASCAR series car, it has an allowable track width of 61.5 in, but the vast majority of teams use the same dimension for both the front and rear tracks. The general case is where the front and rear tracks are different and the CG is not necessarily on the longitudinal centerline of the car, as shown in Figure 1. For this calculation, the centerline of the car is defined as the line connecting the midpoints of the front and rear tracks.

The first step is to define the distances *a* and *b* that allow the calculation of the distance from the CG to the frontal and posterior pathways, these variables are calculated by means of equations 2 and 3.

$$b = \frac{W_f \cdot \ell}{W} \qquad (2) \qquad a = \ell - b \qquad (3)$$

Now a line is drawn parallel to the central axis of the car from the center of the left rear wheel to the left front wheel, this distance corresponds to the location of the CG on the Y-axis, this distance is given by equation 4. y' Corresponds to the location of the CG on the Y-axis, this distance is given by equation 4.

$$y' = \frac{W_2}{W} \cdot (t_F - d) - \frac{W_1}{W} \cdot (d) + \frac{W_4 \cdot t_R}{W} \qquad (4)$$

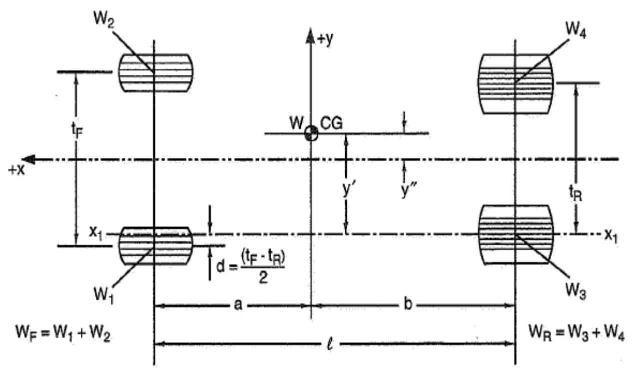

Fig. 1. Location of the CG in XY plane. Source: [13]

Where,

W_2 Weight on the right front wheel.

W_1 Weight on the left front wheel.

W_4 Weight on the right rear wheel.

W, Total weight of the car.

t_F Frontal route.

t_R , Back way.

d, is the difference between the rear track width minus the front track width divided by two.

Now, for the case where the front and rear tracks are equal, equation 4 reduces to equation 5.

$$y'' = \frac{W_2 + W_4}{W} \cdot t - \frac{t}{2} \qquad (5)$$

A positive (+) value indicates that the car's CG is located to the right of the car's center axis, while a negative value indicates that the car's CG is located to the left of the car's center axis, which is typical for cars competing on ovals.

Vertical location of the CG. One of the methods to determine the CG height is to raise the car an angle θ formed with the horizontal by the rear wheels, leaving the front wheels secured and in turn anchoring or making rigid the suspension systems, in order to have a higher accuracy in measuring the CG height. The required dimensions are referenced in Figure 2.

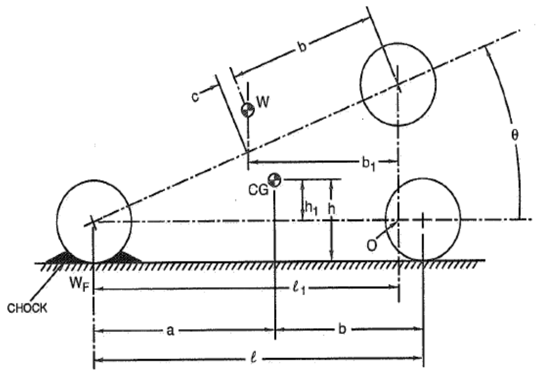

Fig. 2. Vertical location of the GC. Source: [13]

By means of trigonometry we obtain the expression

$$\ell_1 = \ell \cdot \cos\theta$$

Taking the reference point O in figure 2, we have that

$$W_f \cdot \ell_1 = W \cdot b_1$$

Where,

$$b_1 = (W_f/W) \cdot \ell \cdot \cos\theta$$

Also,

$$\frac{b_1}{b+c} = \cos\theta$$

Where,

$$c = \left(\frac{W_f}{W}\cdot \ell\right) - b$$

Using$(c/h_1 = \tan\theta)$equation 6 is obtained, which allows us to calculate the height of the CG on the line connecting the centers of the wheels, which are at a height of R_L. If the height R_L is the same in both the front and rear track, the vertical height of the CG is located above ground level and is expressed by Equation 7 and 8.

$$h_1 = \frac{W_F\cdot\ell - W\cdot b}{W\cdot\tan\theta} \tag{6}$$

$$h_{CG} = R_L + h_1 \tag{7}$$

R_L Height of the front and rear axle if they are the same.

If the height R_L is different on both the front and rear tracks, the height of the line connecting the wheel centers is given by equation 8.

$$R_{LCG} = R_{LF}\cdot\left(\frac{b}{\ell}\right) + R_{LR}\cdot\left(\frac{a}{\ell}\right) \tag{8}$$

Where,

R_{LF} Height of the front end of the car.

R_{LR} Height of the car's rear axle.

Knowing the height of the line between the wheel centers in the side view, the vertical height of the CG is calculated using equation 9.

$$h_{CG} = R_{LCG} + h_1 \tag{9}$$

2.2 Load transfer

In a steady-state rotation, the ultimate load transfer, summed over all axes, is only related to the position of the center of mass above the ground. Lateral transfer. When cornering to the left with camber, the load of the car is transferred from the inside wheels to the outside wheels, because the CG of the car is at a certain height above ground level. When a car is stationary in a curve as shown in Figure 3, a reaction force called centrifugal force develops opposite to the lateral acceleration produced by the force of the wheels in the curve.

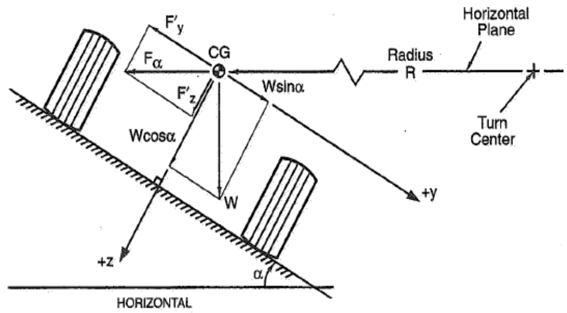

Fig. 3. Effects of superelevation on load distribution (front view). Source: [13]

The centrifugal force $F_\alpha$is no different for a car that takes the curve on a horizontal surface and is equal to $W\cdot A_\alpha$. The centrifugal acceleration is given by equation 10.

$$A_\alpha = \frac{V^2}{R\cdot g} \tag{10}$$

Where,

V, car speed (ft/seg)

R, Radius of the curve. (ft)

g, Acceleration of gravity. $(\mathrm{ft/seg^2})$

Decomposing the centrifugal force F_α acting on the car in the Y and Z axes**,** we have

$$F'_y = -F_\alpha\cdot\mathrm{Cos}\,\alpha$$

$$F'_Z = F_\alpha\cdot\mathrm{Sen}\,\alpha$$

Where,

α, Angle of the track camber.

In the same way the forces resulting from the weight of the car, W, on the Y and Z axis are decomposed.

$$W_Y = W\cdot\mathrm{Sen}\,\alpha$$

$$W_Z = W\cdot\mathrm{Cos}\,\alpha$$

Adding the components in the Y-axis and Z-axis directions respectively gives the equations

$$F_y = W\cdot(-A_\alpha\cdot\mathrm{Cos}\,\alpha + \mathrm{Sen}\,\alpha) \tag{11}$$
$$W' = F_Z = W\cdot(A_\alpha\cdot\mathrm{Sen}\,\alpha + \mathrm{Cos}\,\alpha) \tag{12}$$

The load on each of the wheels when the car is over the curve is calculated by equations 13, 14, 15 and 16 taking as reference the displacement coefficients Cx, the distance of the front and rear tracks to the CG and the wheelbase.

$$W_1 = C_{X1}\cdot W'\cdot\frac{b}{\ell} \quad (13) \qquad W_2 = C_{X2}\cdot W'\cdot\frac{b}{\ell} \quad (14)$$

$$W_3 = C_{X3} \cdot W' \cdot \frac{a}{\ell} \quad (15) \qquad W_4 = C_{X4} \cdot W' \cdot \frac{a}{\ell} \quad (16)$$

Equation 17 shows the effect of camber, which changes the load component on the wheels, the weight variation is called effective weight or W'. Note that if the expression $A_\alpha \sin\alpha$ is very small and α>0, W' will be much smaller than W since it will always be less than 1. $\cos\alpha$ will always be less than 1. In the opposite case where the value of expression $A_\alpha \sin\alpha$ is very large, W' will be larger than W.

$$A_Y = A_\alpha \cdot \cos\alpha - \sin\alpha, \; G's \quad (17)$$

Depending on the accelerations and forces experienced by the car, the lateral transfer in the front and rear axles is calculated by equations 18 and 19. Taking into account that cars competing in closed circuits (ovals) where curves are taken in one direction only (left or right), the weight distribution of the car is greater (slightly less than 60% of the car's weight) on the track in the direction of the curve in order to have a better predisposition to the turn.

Since the speed that NASCAR series cars reach is high (close to 200 mph) the speed reduction when cornering is low, therefore the lateral load transfer takes place from the inside wheels (left track) to the outside wheels (right track).

$$\Delta W_F = \frac{K_F \cdot \lfloor W \cdot A_Y \cdot H - (W' - W) \cdot y'' \rfloor}{t_R \cdot (K_F + K_R - W \cdot A_Y \cdot y'' - W' \cdot H)} + W \cdot A_Y \cdot \left(\frac{b}{\ell}\right) \cdot \left(\frac{Z_{RF}}{t_F}\right) \quad (18)$$

$$\Delta W_R = \frac{K_R \cdot \lfloor W \cdot A_Y \cdot H - (W' - W) \cdot y'' \rfloor}{t_R \cdot (K_F + K_R - W \cdot A_Y \cdot y'' - W' \cdot H)} + W \cdot A_Y \cdot \left(\frac{a}{\ell}\right) \cdot \left(\frac{Z_{RR}}{t_R}\right) \quad (19)$$

A positive (+) value indicates an increased load on the left front or left rear wheel, while a negative (-) value indicates a reduced load on the right front or right rear wheel.

2. 3 Longitudinal transfer. The load transferred to the axle does not depend on the lateral acceleration on the CG. However, if the center of gravity is displaced in the XY plane to the left, the wheels on that side of the car will take a smaller proportion of the load than those on the opposite side. To account for the displacements of the CG, it can be shown that the load transfer need only be multiplied by a coefficient Cx, to obtain the load transfer for each of the wheels.

The coefficients that determine the longitudinal load transfer are given by equations 20, 21, 22 and 23, these are:

$$C_{X1} = \frac{1}{2} \cdot \left[1 - \delta_f\right] \quad (20)$$

$$C_{X2} = \frac{1}{2} \cdot \left[1 + \delta_f\right] \quad (21)$$

$$C_{X3} = \frac{1}{2} \cdot \left[1 - \delta_r\right] \quad (22)$$

$$C_{X4} = \frac{1}{2} \cdot \left[1 + \delta_r\right] \quad (23)$$

The longitudinal load transfer on each wheel is expressed by equations 24, 25, 26 and 27.

$$\Delta W_1 = -C_{X1} \cdot W \cdot \frac{h_{CG}}{\ell} \cdot A_X \quad (24)$$

$$\Delta W_2 = -C_{X2} \cdot W \cdot \frac{h_{CG}}{\ell} \cdot A_X \quad (25)$$

$$\Delta W_3 = +C_{X3} \cdot W \cdot \frac{h_{CG}}{\ell} \cdot A_X \quad (26)$$

$$\Delta W_4 = +C_{X4} \cdot W \cdot \frac{h_{CG}}{\ell} \cdot A_X \quad (27)$$

2.4 Asymmetry effects

On closed tracks (ovals), a race car always turns 360º more per lap on one side than the other. This is most evident on ovals where completing a lap requires turning left 360º but not right. Even on racetracks, a car turns 360º to the right more than to the left to complete a lap. Because of this, it is advantageous to set the turning ability of the car according to the track conditions. One of the ways to set up the car is to make it asymmetrical. Particularly in oval race cars the following configurations are included:

- Displacement of the CG from the centerline of the car to the left.
- *Wedge* cross (*wedge*).
- Preloaded stabilizer bar.
- Types of wheels and tire pressure variation.
- Wheels of different diameters.
- CG height and drop angle characteristics.
- Divergence and convergence.

The reason for an asymmetric configuration is to alter the cornering performance of the car, and this in turn is related to the basic characteristics of the wheels. With the exception of camber angle, all of the above parameters affect the static wheel loads.

3. RESULTS

Considerations:

- In the first instance we deal only with steady-state conditions, which are: uniform track (no bumps), constant velocity in curves, constant longitudinal acceleration, etc.
- It is assumed that all basic car data used in the calculations are variable (roll rate, spring rate, etc.) and that the basic

dimensional data (front and rear track, wheelbase, CG height, etc.) are constant, if any of these factors vary in the respective calculation the solution is not completely accurate. A solution is valid in practice when the car data is available.

- Linearity implies that the principle of superposition is valid. The state principle refers to the fact that the concurrence of the effects considered is equal to the individual sum of the effects, so numerically the loads on the wheels can be changed, thus altering the lateral load transfer, longitudinal load transfer and aerodynamics, to produce loads that are valid for the operating conditions.

- All calculations presented are based on the car chassis being rigid; if the chassis is not fully torsionally rigid, the calculations will not be fully accurate (Table 1).

Table 1. Dimensional data.

Required data	
Car weight (with pilot and fluids)	3450 lb
Wheelbase	11 in
Front track	61.5 in
Rear track	61.5 in
Distance from the ground to the center of the wheel $\mathbf{R_L}$	14 in

Source: www. NASCAR.com

The study of the loads supported by the rear suspension is important since it has as a reference a maximum possible value of the load transfer, for this, the operating conditions are evaluated in the circuits that have all the NASCAR Sprint Cup season taking into account the technical characteristics of construction such as: radius of the curves and camber. Thanks to the considerations described above and the reference of the configurations with which the behavior of the suspension will be evaluated, the calculation of the loads supported by each of the wheels is made. Figure 4 below shows the calculations according to the weight distribution and the weight crossover. By having multiple configurations in the weight distribution of the car, the maneuverability can be altered, with the variation of such weight, the CG of the car changes its position. This calculation is made with a distribution of a little less than 60% of the total weight in order to facilitate cornering to the left while maintaining the best track layout.

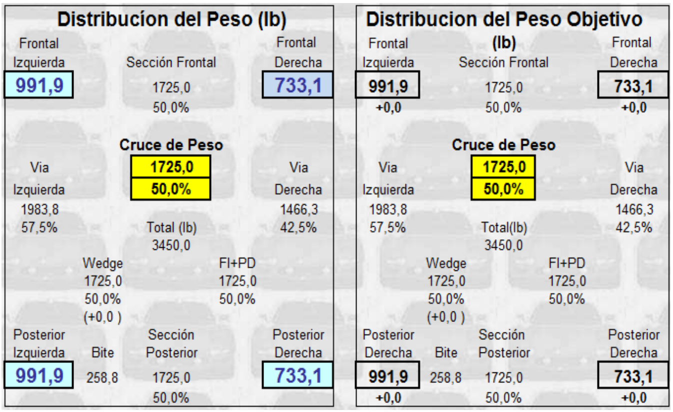

Fig. 4. Ideal weight distribution and weight distribution.

In order to determine the maximum operating conditions that the suspension system to be designed will face, both longitudinal and lateral accelerations experienced by the car are calculated together with the lateral force generated, taking into account the maximum speed and the record lap time in the season's circuits. The parameters that were calculated in Table 2 were made according to the construction characteristics of the circuits in which the car competes.

The weight distribution calculated in Table 6 refers to a maximum configuration in the weight distribution of the car on the left track of 57.5%, the distribution is asymmetric because it is a characteristic of the cars that compete in closed circuits (ovals), whose purpose is to offer a better response at the time of cornering. As for the weight distribution adjustments, this should be done only on the left track and the weight crossover.

All changes made to the cross weight, anti-roll bar preload and different diameter wheels affect the load distribution but have no effect on the CG position. These variations result in an increase of the load on the diagonal formed from the right front wheel to the left rear wheel and a decrease on the opposite diagonal, thus shifting the maximum force from the front to the rear.

In order to calculate the CG of the car it is necessary to have the weight distribution of each of the wheels, so the data obtained in the calculation of the weight distribution for a 57.5/42.5 configuration is used.

Using Equation 3 and 4 the geometrical parameters for the definition of the center of gravity are determined, the calculation of the center of gravity for the weight distribution of Table 8 is

Location of the CG in the XY plane

$$\mathrm{b} = \frac{1725\mathrm{lb} \cdot 110\ in}{3450\ \mathrm{lb}} = 55\ in$$

$$\mathrm{a} = 110\ in\text{-}55\ \mathrm{in} = 55\ \mathrm{in}$$

Since the front and rear tracks of the car are equal, equation 5 is used.

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$$y'' = \left[\frac{733.125\ \mathrm{lb} + 733.125\ \mathrm{lb}}{3450\ \mathrm{lb}} \cdot (61.5\ \mathrm{in})\right] - \frac{61.5\ \mathrm{in}}{2}$$

$$y'' = -4.6125\ in$$

Equations 47 and 48 are used to obtain the height of the center of gravity (CG), the respective calculations are as follows:

Vertical location of the GC.

$$h_1 = \frac{[1725\ \mathrm{lb} \cdot 110\ \mathrm{in}] - [3450\ \mathrm{lb} \cdot 55\ \mathrm{in}]}{3450\ \mathrm{lb}\tan(22.5°)} = 0$$

The distance h_1 measured from the line joining the wheel centers to the IQ in figure 2 is zero, because the weight distribution is uniform in the front and rear section, that is, 50% of the car's weight is in the front section and the remaining 50% in the rear section. By having a 50/50 configuration, the CG of the car is at the midpoint of the wheelbase, if you had an asymmetrical configuration of the front and rear distribution (which is possible) the CG would vary in position across a longitudinal axis. Another reason is that these cars use wheels of the same diameter for both the front and rear sections and the only thing that varies is the pressures (left track 35 *PSI* and right track 45 *PSI*), therefore the value of R_L is equal to 14 *in* since, as previously mentioned, it is the distance from ground level to the front or rear axle. It is also the same to say that it is half the wheel diameter without taking into account the deflection or crushing it suffers due to the static vertical load applied.

$$h_{CG} = R_L + h_1$$

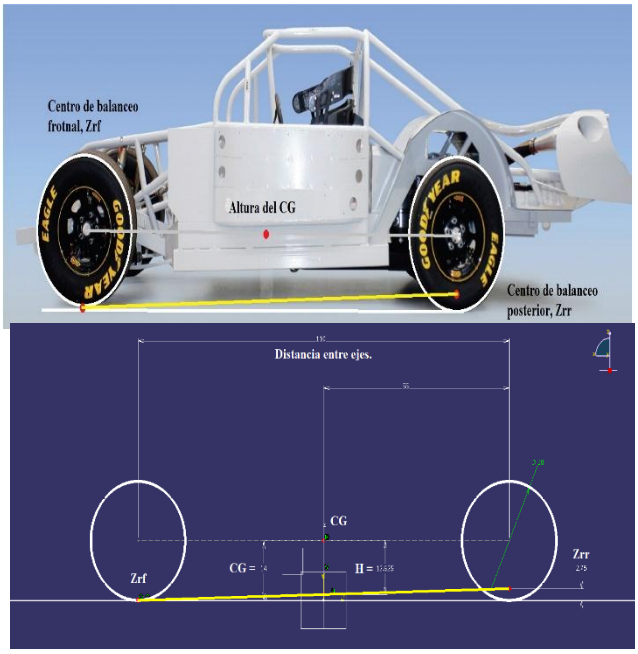
$$h_{CG} = 14\ in$$

The global location of the CG is on the X-axis at 0 in, on the Y-axis at a distance of -4.6125 in which indicates a shift to the left with respect to the car's center axis and on the Z-axis at a height of 14 in. The displacement of the CG of the car to the left is typical in cars that race on ovals, where the curves are taken in only one direction, examples of this are the IRL race cars and the cars of the different NASCAR Series.

A shift of the CG to the left from the centerline of the car compensates for the lateral load transfer that occurs during cornering and therefore increases the maximum lateral force available. Wheel loads will be more uniform on both the left and right during load transfer.

Roll rates. The front and rear roll rates are chosen a priori in order to adjust them to make the selection of the springs for the front or rear suspension, for this it is necessary to know the heights of the roll centers for the front and rear suspension, the height of the roll center for the rear suspension is known, which is located at a height of 2.75 *in* measured from the level of the running surface of the track, while that of the front suspension should be between 0 *in* and 3.5 *in* measured equally, for the calculation the lower 0 *in* is used. The location of both centers is shown in Figure 5.

Fig. 5. Location of the balancing centers.



The adjusted indexes are:

Front roll rate

$$K\varphi_f = 80000\ {}^{\mathrm{lbf \cdot ft}}/_{\mathrm{rad}}$$

Rear roll rate

$$K\varphi_R = 58500\ {}^{\mathrm{lbf \cdot ft}}/_{\mathrm{rad}}$$

For racing cars the typical roll gradients are between 3 deg.(°)/G extremely firm and 1.5 deg.(°)/G hard, as shown in Table 2. Knowing these characteristics we proceed to perform the respective calculation of the suspension frequency. Therefore, the assumed values are correct because they satisfy the gradient roll value that this type of car must have.

The roll gradient for the car is calculated by equation 28, which represents the roll gradient that the springs must withstand, this deflection suffered is given by degrees per lateral force incident on the springs given in G's.

$$\frac{\Phi}{A_y} = \frac{-W \cdot H}{K\varphi_f + K\varphi_R} \tag{28}$$

Now we proceed to calculate the load transfer that occurs on the car when it passes through the curves at high speed, for this we need the geometric data mentioned in Table 6, the longitudinal and lateral accelerations that the car experiences calculated from Table 8. Equation 12 is used to determine the effective weight W' on the curve. After this calculation, the effective weight on each of the wheels needs to be known, for this purpose equations 13, 14, 15 and 16 are used.

The results are detailed in Table 3, it is observed that the maximum loads were obtained in the Bristol circuit since it presents the highest lateral acceleration reaching a maximum value of -3.6887 G's in the layout of the curves with a cant of 26º and in the layout of the curves with a cant of 30º the lateral acceleration is limited to -3.4768 G's thus reducing the incident lateral force as can be seen in Figure 4.

Knowing the operating conditions for the evaluated circuits, we proceed to calculate the spring rates according to the calculated load on the outer wheels (right track), in order to divide the applied load by the total travel of the suspension, in this case ± 2 in by means of equation 29 and 30.

$$K_{RF} = \frac{w_2}{\text{Recorrido de la suspension}} \tag{29}$$

$$K_{RP} = \frac{w_4}{\text{Recorrido de la suspension}} \tag{30}$$

The calculated indexes are as follows:

$$K_{RP} = \frac{3569.173\ \text{lb}}{2\ \text{in}} = 1784.5865\ \frac{lb}{in} \approx 1800\ {}^{\text{lb}}/_{\text{in}}$$

$$K_{RR} = \frac{3488.451\ \text{lb}}{2\ \text{in}} = 1744.2255\ \frac{lb}{in} \approx 1800\ {}^{\text{lb}}/_{\text{in}}$$

Evaluating the natural frequency of the system, this must be between 3 Hz and 5 Hz. To corroborate this, the following calculation is made using equation 31.

$$\omega_R = \frac{1}{2\pi} \cdot \sqrt{\frac{K_R}{W}} \tag{31}$$

$$\omega_R = \frac{1}{2\pi} \cdot \sqrt{\frac{1800\ {}^{\text{lb}}/_{\text{in}} * 12 * 32.2}{733.125\ \text{lb}}} = 4.902\ \text{Hz} \sim 294.123\ \text{cpm}$$

The calculated suspension frequency is within the established values for this type of application, it should be noted that this parameter is linked to the spring rate, the higher the spring rate the lower the roll gradient (table 4).

Table 2. Typical roll gradients.

Swing gradients	
Very soft: Economical and basic family transportation, domestic and imported.	8.5 Degrees.(º)/G
Soft: Basic family transportation, domestic and imported.	7.5 Degrees.(º)/G
Semi-soft: Sedan, domestic or imported.	7.0 Degrees.(º)/G
Semi-firm: Imported sports sedans	6.0 Degrees.(º)/G
Firm: Domestic depositive sedans	5.0 Degrees.(º)/G
Very strong: High-performance domestic cars, such as the Z-28 Camaro and Firebird Trans Am.	4.2 Degrees.(º)/G
Extremely firm: High performance sports cars, such as Corvette. Street cars modified to increase roll resistance.	3.0 Degrees.(º)/G
Hard: For racing cars only	1.5 Degrees.(º)/G
Active suspension: Servo-controlled, zero roll resistance.	–

Source: [13]

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Table 3. Accelerations and lateral forces generated.

Circuit	Features		Maximum speed reached (mph)	Record time (sec)	Ax (G's)	Ay (G's)	Lateral Force (Lbf).
	Curve radius (ft)	**Superelevation (º)**					
Atlanta Motor Speedway	1320		197.478	28.074	0.320	-1.3963	-4817.179
Charlotte Motor Speedway	685		192.376	28.070	0.312	-2.8905	-9972.178
	625		192.376	28.070	0.312	-3.2070	-11064.218
Chicagoland Speedway	955		188.147	28.704	0.299	-2.0461	-7058.895
Daytona International Speedway	1000		210.364	42.783	0.224	-2.0190	-6965.595
Martinsville Speedway	588		98.084	19.306	0.231	-0.8612	-2971.201
Richmond International Raceway	**Curve 1 and 4** 1198.68		129.983	20.722	0.286	-0.6717	-2317.469
	Turns 2 and 3		129.983	20.722	0.286	-2.7586	-9517.039
Talladega Superspeedway	1100		212.809	44.998	0.215	-1.7620	-6079.010
Texas Motor Speedway			196.235	27.518	0.325	-2.7268	-9407.311
Darlington Raceway	**Curve 1 and 2**		181.250	27.131	0.304	-2.8924	-9978.820
	Curve 3 and 4 525		181.250	27.131	0.304	-3.4572	-11927.416
Bristol Motor Speedway	241		128.709	14.908	0.393	-3.6889	-12726.867
	241		128.709	14.908	0.393	-3.4768	-11995.106
Dover International Speedway	498.687664		161.522	22.288	0.330	-2.7861	-9611.922
Phoenix International Raceway	**Curves 1 and 2**		137.279	26.240	0.238	-2.2809	-7868.995
	Curves 3 and 4		137.279	26.240	0.238	-2.3305	-8040.240
Indianapolis Motor Speedway	800		155.912	48.311	0.147	-1.8485	-6377.258

Table 4. Operating conditions for the suspension design

Circuit	Effective weight W' (Lbf)	Load on each wheel (Lbf)				Longitudinal transfer (Lbf)			
		W1	W2	W3	W4	(-)W1	(-)W2	(+)W3	(+)W4

Atlanta Motor SpeedWay	5921.241	1702.357	1258.264	1702.357	1258.264	-80.893	-59.791	80.893	59.791
Charlotte Motor Speedway	8 216.395	2362.214	1745.984	2362.214	1745.984	-78.815	-58.254	78.815	58.254
	8702.603	2501.998	1849.303	2501.998	1849.303	-78.815	-58.254	78.815	58.254
Chicagoland Speedway	5921.119	1702.322	1258.238	1702.322	1258.238	-75.379	-55.715	75.379	55.715
Daytona International Speedway	8210.237	2360.443	1744.675	2360.443	1744.675	-56.545	-41.794	56.545	41.794
Martinsville	4158.624	1195.604	883.708	1195.604	883.708	-58.426	-43.184	58.426	43.184
Richmond International Raceway	4133.427	1188.360	878.353	1188.360	878.353	-72.136	-53.318	72.136	53.318
Curves 2 and 3	5928.482	1704.438	1259.802	1704.438	1259.802	-72.136	-53.318	72.136	53.318
Talladega Superspeedway	8061.409	2317.655	1713.049	2317.655	1713.049	-54.387	-40.199	54.387	40.199
Texas Motor Speedway	7964.900	2289.909	1692.541	2289.909	1692.541	-82.008	-60.615	82.008	60.615
Darlington Raceway	8459.854	2432.208	1797.719	2432.208	1797.719	-76.826	-56.785	76.826	56.785
Curves 3 and 4	8810.831	2533.114	1872.302	2533.114	1872.302	-76.826	-56.785	76.826	56.785
Bristol Motor Speedway	10045.785	2888.163	2134.729	2888.163	2134.729	-99.286	-73.385	99.286	73.385
	10909.095	3136.365	2318.183	3136.365	2318.183	-99.286	-73.385	99.286	73.385
Dover International Speedway	8055.999	2316.100	1711.900	2316.100	1711.900	-83.341	-61.600	83.341	61.600
Phoenix International Raceway	5044.150	1450.193	1071.882	1450.193	1071.882	-60.164	-44.469	60.164	44.469
Indianapolis Motor Speedway	4503.063	1294.631	956.901	1294.631	956.901	-37.113	-27.432	37.113	27.432

4. CONCLUSION

The joint of the wheels is transmitted to the opposite side of the axle by the vibrations that are produced, due to the speed or defects on the track. But it has the advantage that the weight of the suspended mass increases notably due to the weight of the rigid axle and the weight of the conical differential group in cars with rear wheel drive and high power. Calculating both the suspended and unsprung mass taking into account the other mechanical components such as the brake system, wheels and the drive system there was an increase in the unsprung mass by 7.37 % and a decrease in the suspended mass by 41.311 %, summarizing the results the overall weight of the system was reduced by 23.33 %.

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