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Evaluating the Dynamic Performance of Passenger Cars Having CNG Cylinders

Reza Fathollahi

Instructor, Department of Mechanical Engineering,
Khoy Faculty of Engineering - Urmia University, Iran.

Orcid: 0000-0003-1584-5711

Abstract

The most major physical effect imposed on a car due to the addition of a CNG cylinder, in addition to the increased sprung mass of the car, is the longitudinal and altitudinal displacements of the vehicle's center of mass, which increases the vehicle's under steering, changes its roll stability on turns, and increases its moment of inertia around the z axis. Also, the altitudinal increase in the vehicle's center of mass, increases the chance of rear axle wheels to lock up, and increases the vehicle's risk of instability in severe braking, which is undesirable. In this paper, we investigated the effects of the increased mass of a CNG cylinder on the main components of the vehicle's performance from a dynamic perspective, and then compared the results of the dynamic analysis with those of the practical tests. The results of the dynamic analyses were consistent with those of the practical tests.

Keywords: CNG cylinder, handling, the vehicle's center of mass, roll stability, braking, the locking up of wheels

INTRODUCTION

The addition of the mass of a CNG cylinder to a passenger car, in addition to increasing its sprung mass, causes the longitudinal and altitudinal displacements of the vehicle's center of mass. The physical changes mentioned, affect the main components of the vehicle's dynamic performance, such as: handling, braking, roll stability, and yawing stability. In this paper, we deal with investigating and analyzing these effects.

PREVIOUS RESEARCH WORKS

The studies conducted in the field of automobile engineering, do not have a very long history in Iran, and most of the studies conducted on automobiles, are focused on the dynamics of automobiles, and on topics such as: handling, ride comfort, the mechanism of passive and active suspension systems and optimizing them, and the automobile's stability and the parameters affecting it, which is worth appreciating and can be used in scientific studies. Investigating the effects of the mass of a CNG cylinder on the main components of the dynamic performance of vehicles; especially, passenger cars, which have been dealt with in this paper, is among the subjects which have been less studied and analyzed. In a paper titled "Changes in the Rollover and Sideslip Stabilities of CNG-Fueled City Buses", Shirali [1] et al. investigated changes in the stability and side slip of buses having CNG cylinders. This paper is among the few articles and studies conducted and published on the dynamic performance of hybrid vehicles.

Activities undertaken in domestic automotive industries, such as: Iran Khodro Company about the effects of CNG cylinders on the automobile's performance, are limited to referring the relevant tests to IDIADA test center in Spain, which is one of the most prestigious automotive test centers in Europe. And they have merely contented themselves with obtaining an approval from that center for the use of CNG cylinders in automobiles such as: Peugeot 405 and Samand, and doing some modelings and analyses using the ADAMS software, and no documented and comprehensive reports have so far been published in this regard by Iranian auto companies.

CHANGES IN THE VEHICLE'S CENTER OF MASS AND THEIR EFFECTS

The mass dispersion of a vehicle (the position of the center of gravity on the road plane) and the cornering stiffness of tires are primary parameters affecting the directional stability of a vehicle, and the mass distribution of a vehicle (the height of the center of gravity) and the wheel track width of a vehicle are primary parameters affecting the roll stability of a vehicle [2].

The cornering behavior of engine vehicles, is one of the important functions of cars, which is mainly referred to by the word handling. "Handling" is a broad term, which means the vehicle's sensitivity to the driver's input, and the simplicity of its control. Handling is an overall criterion of harmony and coordination between the vehicle and driver. The driver and vehicle make up a closed system, in which the driver looks at the direction and position of the vehicle, and corrects the steer input to achieve the desired direction [3]. The longitudinal displacement of the vehicle's center of mass due to adding the mass of a CNG cylinder to the vehicle, changes the weight distribution of the vehicle on the rear and front axles, and consequently changes the vehicle's handling; especially when the vehicle is turning, which will be discussed in detail in this paper.

Given the importance of the center of mass and its role in the performance and stability of a vehicle, it is necessary to analyze changes in the vehicle's center of mass due to the addition of the cylinder. Using the available information, we will determine the center of mass and its displacements due to the addition of a CNG cylinder for a sample car, and then benefiting from the governing dynamic equations, we will analyze the effects of the displacement of the center of mass.

The value of $h_{V,0}$ for the height of a vehicle is considered with the curb weight[1]. When loading a vehicle, the vehicle's center of mass generally goes higher; that is to say, contrary to the height of the vehicle which decreases, the value of h_V or the height of the vehicle's center of mass increases. The extent to which the vehicle's center of mass goes high, when two, four and/or five people are riding it, depends on the spring rate of the rear and front axles, seat height, and the passengers' weight and body size. The following relations can be approximations of the height of the center of mass $h_{V,pl}$[2]:

$$\begin{aligned} &h_{V,pl} = h_{V,0} + \Delta h_V \\ &\text{two people} \quad \Delta h_{V,2} \approx +12\text{mm} \\ &\text{four people} \quad \Delta h_{V,4} \approx -8\text{mm to } +29\text{mm} \end{aligned} \tag{1}$$

In order to calculate changes in the height of the center of mass of Peugeot 405 due to the addition of the cylinder, as an example of vehicles having CNG cylinders, we can estimate the mass of a filled CNG cylinder made of steel, which is about 145 kg, equal to the mass of two medium size passengers. As a result, due to the addition of a CNG cylinder to a vehicle like Peugeot 405, the vehicle's center of mass will rise about 12 mm according to Equation (1). By balancing the torques around the points of impact; $m_{V,f}$ (the vehicle's mass on the front axle) or $m_{V,r}$ (the vehicle's mass on the rear axle), in the distance between the two axles (L) and in the longitudinal direction, we can obtain the center of mass and its distance from the front axle (l_f) and rear axle (l_r).

$$l_f = \frac{m_{V,r}}{m_{V,t}} L \; ; \; l_r = \frac{m_{V,f}}{m_{V,t}} L = L - l_f \tag{2}$$

Using Equation (2) and weights available for Peugeot 405 [4], we can easily calculate the displacement of the center of mass of Peugeot 405 due to the addition of a CNG cylinder with an approximate mass of 145 kg.

The center of mass of a Peugeot 405 car without a CNG cylinder:

$$l_f = \frac{m_{V,r}}{m_{V,t}} L = \frac{450\,(\text{kg})}{1144\,(\text{kg})} \times 2654\,(\text{mm}) = 1043.96\,(\text{mm})$$

$$l_r = \frac{m_{V,f}}{m_{V,t}} L = L - l_f = 2654 - 1043.96 = 1610.04\,(\text{mm})$$

The center of mass of a Peugeot 405 car with a CNG cylinder:

$$l'_f = \frac{m'_{V,r}}{m'_{V,t}} L = \frac{584\,(\text{kg})}{1290\,(\text{kg})} \times 2654\,(\text{mm}) = 1201.50\,(\text{mm})$$

$$l'_r = \frac{m'_{V,f}}{m'_{V,t}} L = L - l'_f = 2654 - 1201.50 = 1452.50\,(\text{mm})$$

Therefore, the center of mass of a Peugeot 405 car shifts by [$l_r - l'_r = 1610.04 - 1452.5 = 157.54\,(\text{mm})$] to the vehicle's rear axle due to the addition of a CNG cylinder with an approximate mass of 145 kg.

THE HANDLING OF THE VEHICLE [3]

The handling of a vehicle depends on a coefficient called under steer gradient (K). Depending on whether the sign of the under steer gradient is zero, positive and/or negative, a vehicle can be neutral steer, under steer, and over steer, respectively. The best handling mode is the neutral steer mode. But, since it is very difficult to achieve this mode in practice, vehicles are designed to be under steer.

To calculate the under steer gradient for a sample car, we use the equation [$K = (\frac{W_f}{C_{\alpha f}} - \frac{W_r}{C_{\alpha r}})(\frac{1}{g})$] to compare the under steer gradients of a sample Peugeot 405 car in two modes: with a CNG cylinder and without a CNG cylinder. Where; W_f is the load of the front axle in kilograms, W_r the load of the rear axle in kilograms, $C_{\alpha f}$ the cornering stiffness of the front tires in kg per degree, and $C_{\alpha r}$ the cornering stiffness of the rear tires in kg per degree.

In a Peugeot 405 car with 185/65 R14 size tires [4], the rim size is 14 inches, and the aspect ratio is 65. Thus, using the measured values of the vehicle's weight on the four wheels [4], the cornering stiffness of the tires can be calculated using the graphs of Figure (1).

[1]- *Curb weight (US English) or kerb weight (English) is the weight of a vehicle without passengers, while loaded with a full tank of fuel, a spare wheel, and standard equipment such as: screwdrivers, etc.*

[2] - *index pl= partial loaded or partly laden*

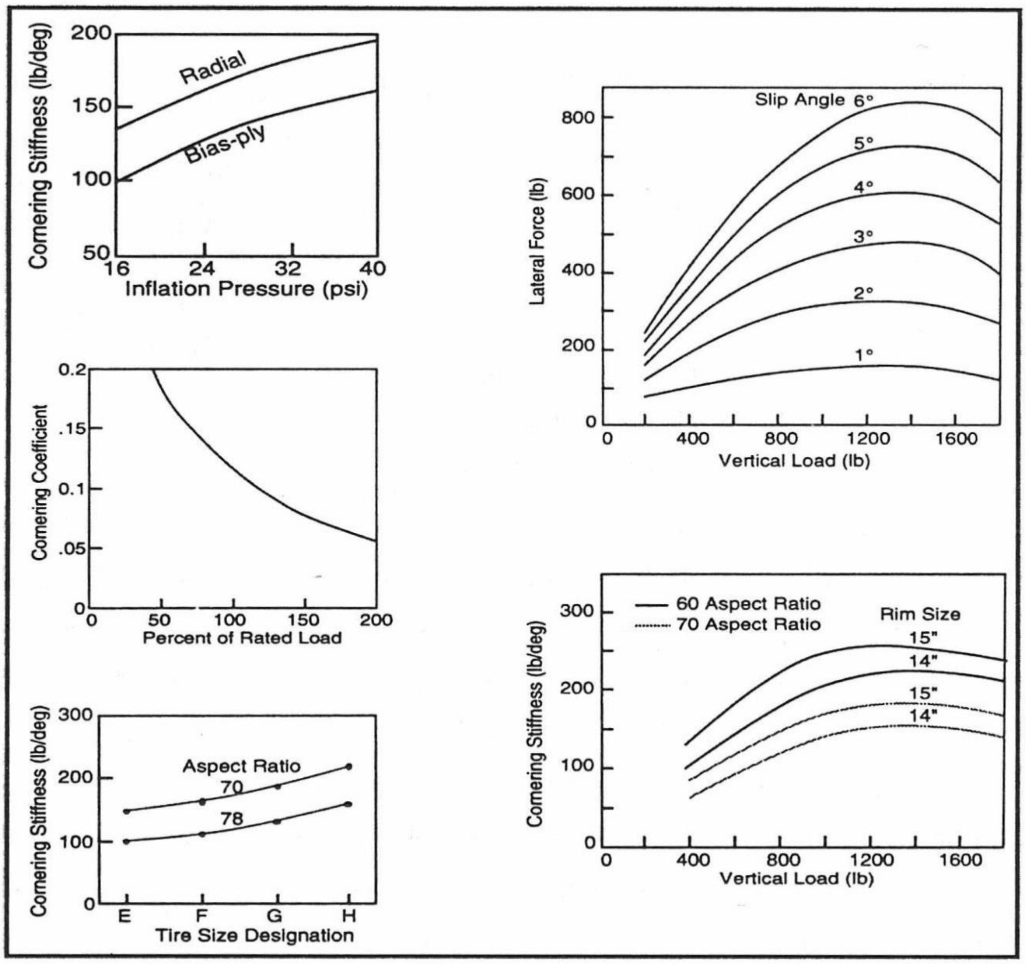

Figure 1: Variables affecting the cornering stiffness of the tire - [3]

The Peugeot 405 car without a CNG cylinder:

$$K = (\frac{W_f}{C_{\alpha f}} - \frac{W_r}{C_{\alpha r}})(\frac{1}{g}) = (\frac{694}{2\times 63.50} - \frac{450}{2\times 44.45})(\frac{1}{9.81})$$

$$= (\frac{5.464 - 5.061}{9.81}) = 0.041\ (\frac{deg}{m/s^2})$$

$$C_{\alpha f} = 63.50\ (\frac{Kg}{deg}),\ C_{\alpha r} = 44.45(\frac{Kg}{deg})$$

The Peugeot 405 car with a CNG cylinder:

$$K = (\frac{W_f}{C_{\alpha f}} - \frac{W_r}{C_{\alpha r}})(\frac{1}{g}) = (\frac{771}{2\times 68.04} - \frac{645}{2\times 62.59})(\frac{1}{9.81})$$

$$= (\frac{5.665 - 5.152}{9.81}) = 0.052\ (\frac{deg}{m/s^2})$$

$$C_{\alpha f} = 68.04\ (\frac{Kg}{deg}),\ C_{\alpha r} = 62.59(\frac{Kg}{deg})$$

It can be seen that by adding a CNG cylinder with a mass of about 145 kg to the Peugeot 405 car, it's under steer gradient slightly increases; and in fact, the vehicle becomes more under steer. Hence, it can be concluded that the handling of the car; and in fact, its directional stability does not change a lot.

One of the other important parameters in the evaluation of the dynamic performance of a vehicle, which also plays a role in its handling, is the static margin of the vehicle, which is like the under steer gradient, a criterion for the static handling behavior of the vehicle.

The static margin is determined by a point of a vehicle, at which exerting a cornering force does not create a static yawing velocity (the neutral steer point). A neutral steer line is a geometric location of points on the x-z plane, along which the external cornering forces do not create a static yawing velocity.

The static margin of a car is the distance between the neutral steer point and the center of gravity, which becomes dimensionless using the distance between the axles. Therefore:

$$\frac{e}{l}\ \text{Static Margin=} \qquad (3)$$

When the neutral steer point is before the center of gravity, the static margin is positive, and the vehicle is under steer. At the center of gravity, the static margin is zero, and the vehicle is neutral steer. And when the point is after the center of gravity, the static margin is negative, and the vehicle is over steer. Static margins in vehicles, are generally in the interval [0.05/0, 0.07] [3].

The distance between the neutral steer point and the rear axle of the vehicle can be calculated using the following equation:

$$c = L\frac{C_{\alpha f}}{C_{\alpha f} + C_{\alpha r}} \quad (4)$$

Where; c is the distance between the neutral steer point and the rear axle, L the distance between the two axles (the wheelbase), $C_{\alpha f}$ is the cornering stiffness of the front axle, and $C_{\alpha r}$ is the cornering stiffness of the rear axle.

The distance between the neutral steer point and the center of gravity (e) for a Peugeot 405 car with a wheelbase of 2,654 mm can be calculated as follows:

The Peugeot 405 car without a cylinder:

$$c = L\frac{C_{\alpha f}}{C_{\alpha f} + C_{\alpha r}} = 2654 \times \frac{63.5}{63.50 + 44.45} = 1560.55 \text{ (mm)}$$
$$e = l_r - c = 1610.04 - 1560.55 = 49.49 \text{ (mm)}$$

The Peugeot 405 car with a cylinder:

$$c' = L\frac{C_{\alpha f}}{C_{\alpha f} + C_{\alpha r}} = 2654 \times \frac{68.04}{68.04 + 62.59} = 1380.08 \text{ (mm)}$$
$$e' = l'_r - c = 1452.50 - 1380.08 = 72.42 \text{ (mm)}$$

According to the above definitions and calculations and Figure 2 about the static margin, it can be concluded that after the addition of the CNG cylinder to the Peugeot 405 car, the neutral steer point is still before the center of mass, and the vehicle's under steering has increased with an increase in the aforesaid distance.

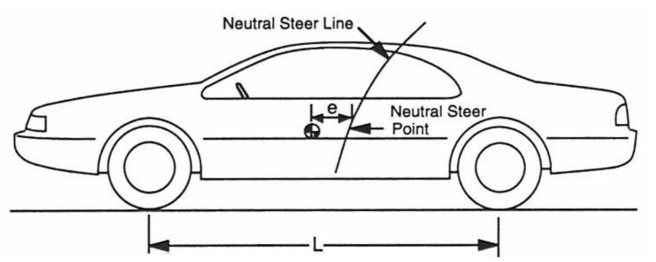

Figure 2: The neutral steer line of the vehicle - [3]

CHANGES IN THE STABILITY OF A VEHICLE WITH A CNG CYLINDER

The stability and overturning of a vehicle, which is called "rollover" in the vehicle dynamics, are considered among the important behaviors of a car. Among the parameters affecting this behavior, are the vehicle dimensions, weight distribution, and finally the height of important centers including the height of the center of mass, and the height of the roll center. In fact, rollover is the vehicle's response to external forces exerted by the road on the car [6].

Taking the suspension system into consideration, especially on turns, the stability of a vehicle is inversely related to the distance of the center of mass (h_V) from the roll axis ($h = h_V - h_r$); that is to say, the greater the distance between the center of mass and the roll axis is, the smaller the vehicle's stability is, and the smaller this difference is, the greater the stability will be. The inverse relation between this distance and the vehicle's stability is because the external force exerted on the vehicle, especially the radial centripetal force when the vehicle turns, is exerted on the center of mass, and obviously, these forces generate torques around the vehicle's neutral axle. The amount of this torque will play a fundamental role in the vehicle's stability and instability. Therefore, if the amount of this torque, which is directly related to h, exceeds the allowed level, will cause the vehicle's rollover.

The more the centripetal force increases, the more the acceleration of the vehicle's rollover factor increases. The lateral acceleration, in which rollover begins, is called the acceleration of rollover threshold, which is related to the height of the center of mass and the height of the roll center through the following equation [3]:

$$\frac{a_y}{g} = \frac{t}{2h_V\left[1 + R_\varphi\left(1 - \frac{h_r}{h_V}\right)\right]} \quad (5)$$

Where; t is the wheel track, $: R_\varphi$ the roll rate, h_V the height of the vehicle's center of mass, h_r : the height of the roll center from the road surface in the direction of the center of mass.

As previously mentioned, due to the addition of a CNG cylinder, the height of the center of mass of a sample Peugeot 405 car shifts by about 10-12 mm upward, and about 157 mm toward the vehicle's rear axle. Therefore, in a Peugeot 405 car, in which the suspension system of the front axle is of the McPherson type and the suspension system of the rear axle is of the trailing arms type, the status of the axis roll is as shown in Figure 3. Due to the displacement of the vehicle's center of mass, the distance between the vehicle's center of mass and roll axis ($h = h_V - h_r$) increases. And as mentioned in the previous section, the increase in the aforesaid distance, will reduce the roll stability of the Peugeot 405 car.

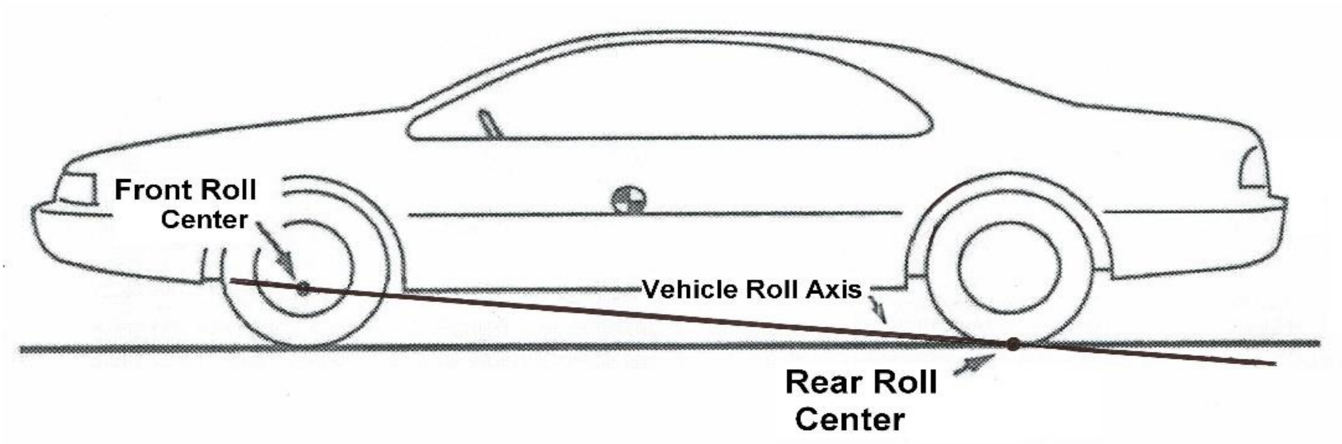

Figure 3: The schematic diagram of the roll centers and the roll axis of the Peugeot 405 car

MASS MOMENT OF INERTIA [5]

In addition to the type of thrust, the moment of inertia of a vehicle around the vertical axis ($J_{Z,V}$), is a determining factor for the turning performance of the vehicle. As the moment of inertia decreases, the maneuvering capability increases. Whereas the driving stability of a vehicle, when moves on a straight line and S-shaped bends, decreases to the same extent.

If, in the following equations, the vehicle length is considered to be L_t and the wheelbase l, the vehicle's moment of inertia around the z axis, can be obtained from the following equation:

$$J_{Z,V} = 0.1269\, m_{V,t}\, l L_t + \Delta m l_X^2 \quad (kg\, m^2) \qquad (6)$$

Where; l_X is the distance between the loading mass (Δm) and the vehicle's center of mass.

According to Relation (6) and the sizes available in Reference [4], it is possible to calculate changes in the mass moment of inertia around the z axis for the sample Peugeot 405 car in two modes: without a cylinder and with a cylinder:

The Peugeot 405 car without a cylinder:

$m_{V,t} = 1144$ (kg) , $L_t = 4.407$ (m) , $l = 2.654$ (m)

$J_{Z,V} = 0.1269\, m_{V,t}\, l L_t = 0.1269 \times 1144 \times 2.564 \times 4.407 = 1697.97$ (kg m^2)

The Peugeot 405 car with a cylinder:

$m_{V,t} = 1290$ (kg) , $L_t = 4.407$ (m) , $l = 2.654$ (m)

$\Delta m = 145$ (kg) , $l_x \cong 1.35$ (m)

$J_{Z,V} = 0.1269\, m_{V,t}\, l L_t + \Delta m l_x^2 =$

$0.1269 \times 1290 \times 2.564 \times 4.407 + 145 \times 1.35^2 = 1962.23$ (kg m^2)

According to the above results, it becomes clear that due to the addition of a CNG cylinder to a vehicle, the vehicle's moment of inertia around the z axis increases, thus it can be concluded that the vehicle's maneuvering capability decreases but its stability increases on a straight path and S-shaped bends.

BRAKING [5]

Obviously, the braking force necessary to slow and stop the vehicle is directly related to the friction coefficient between the tires and road surface, as well as the vertical force exerted by the wheels on the road surface. Adding the mass of a CNG cylinder to the vehicle's sprung mass typically increases the vehicle's weight by about 10 to 12%, thus increasing the vertical force exerted on the contact area of the wheels, which increases the braking force when the vehicle is slowing down or stops. But the more important is the braking behavior and stability of the vehicle when braking, which will be investigated in what follows.

When the driver brakes, the equivalent braking force acts as a reaction force in the center of mass (V) of the whole vehicle:

$$F_{X,V,B} = \mu_{X,W}\, F_{Z,V,t} \qquad (7)$$

It means that the coefficient of friction ($\mu_{X,W}$) multiplied by the total weight force of the vehicle ($F_{Z,V,t}$) equals the braking force.

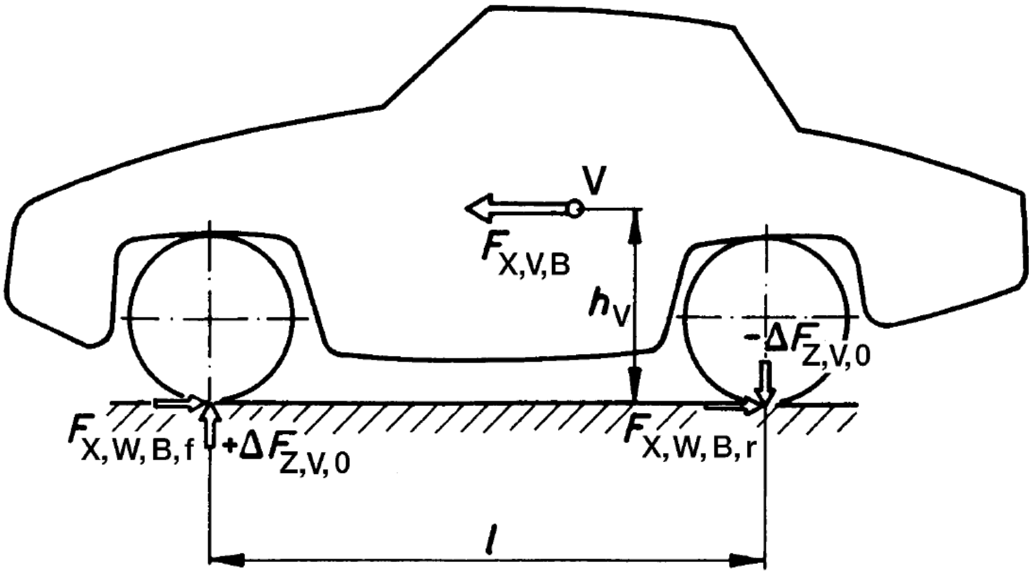

Figure 4: The braking force, which acts on the vehicle's center of mass (V), shifts the loads of the axles by the amount of $\pm\Delta F_{Z,V,0}$, and exerts the braking forces $F_{X,W,B,f}$ on the front axle and $F_{X,W,B,r}$ on the rear axle. If aerodynamic and roll resistances are ignored, the forces can easily be calculated. [5]

The braking force $F_{X,V,B}$, which acts on the vehicle's center of mass, creates the longitudinal forces $F_{X,W,B,f}$ and $F_{X,W,B,r}$ in the centers of the contact points of the front axle and rear axle wheels, as well as causing an increase of $+F_{Z,V,0}$ in the front axle load and a decrease of $-F_{Z,V,0}$ in the rear axle load, assuming the vehicle as a rigid body. According to Figure 4, the equations will be as follows:

$$\Delta F_{Z,V,0} = \mu_{X,W} F_{Z,V,t} \chi \text{ (kN)} \tag{8}$$

$$\chi = h_V / l \tag{9}$$

The parameter χ is a dimensionless coefficient representing the direct effect of the height of the vehicle's center of gravity (h_V) as well as the inverse effect of its wheelbase (l) on the amount of load transmitted from the rear axle to the front axle ($\Delta F_{Z,V,0}$) during braking.

$$F_{Z,V,f,dyn} = F_{Z,V,f} + \Delta F_{Z,V,0} \quad \& \quad F_{Z,V,r,dyn} = F_{Z,V,r} - \Delta F_{Z,V,0} \tag{10}$$

The braking force of the front axle:

$$F_{X,W,B,f} = \mu_{X,W} F_{Z,V,f,dyn} \tag{11}$$

The braking force of the rear axle:

$$F_{X,W,B,r} = F_{X,V,B} - F_{X,W,B,r} = \mu_{X,W} F_{Z,V,r,dyn} \tag{12}$$

The lower center of mass and longer wheelbase cause a lower load transmission $\Delta F_{Z,V,0}$ (which is undesirable), and vice versa.

For instance, in a hybrid Peugeot 405, whose center of mass has shifted by 10 to 12 mm upward relative to the base mode, $\Delta F_{Z,V,0}$ increases, which increases the braking force of the front axle's wheels.

Stability in braking

If due to not using an anti-lock braking system (ABS), both wheels of an axle lock up; that is to say, they skid on the road, friction decreases not only in the longitudinal direction, but also in the lateral direction. If the rear axle locks up, lateral forces will occur in the front axle wheels which are rolling, which exacerbates the problem, and in case of even a slight yawing,

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the situation becomes unstable (Figure 5). But if the front axle locks up, the rear wheels, which are still rolling, generate stable lateral forces, and the situation is stable (Figure 6).

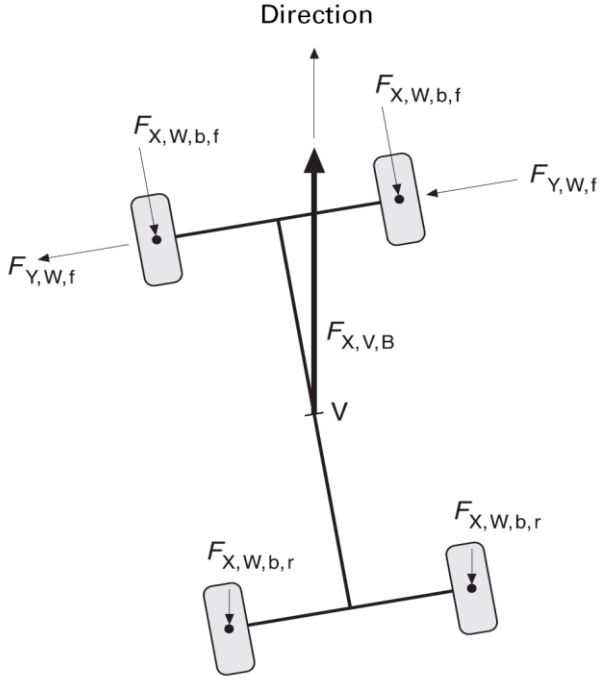

Figure 5: A rear wheel lockup will result in unstable driving conditions. [5]

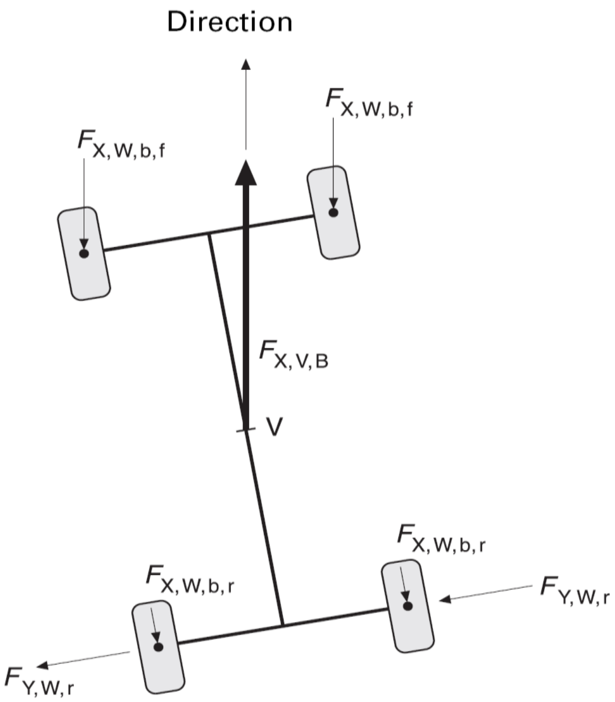

Figure 6: When the front wheels lock up, the vehicle condition remains stable, even though it is no longer possible to steer the vehicle. [5]

Obviously, the smaller the braking force is in the rear axle, the more it is possible for the rear axle wheels to lock up, and for the vehicle to be unstable. Hence, the increase in the mass of the CNG cylinder, which causes the vehicle's center of mass to shift upward, which consequently increases the amount of load transmitted from the rear axle to the front axle, and which as a result increases the braking force of the front axle and reduces the braking force of the rear axle, increases the locking possibility of the rear axle wheels, and allows the instability of the vehicle in severe braking events by the driver, which is undesirable. As a result, it is necessary to use proportioning valves and/or ABS for vehicles, to which a CNG cylinder is added, to eliminate the risk of locking up and instability due to it [7].

THE TESTS CARRIED OUT ON THE SAMPLE VEHICLE

Since in the study and analysis of the vehicle performance in the form of theoretical calculations, many simplifications are done in differential equations to avoid the complexity of the equations, and to make them solvable, many operating parameters involved in the vehicle performance, are removed, and the proper and safe performance of the vehicle cannot be ensured based on the results of theoretical analysis. Hence, it is necessary to perform a series of standard and practical tests on vehicles under certain conditions, to ensure the performance and safety of the vehicle in the new situation.

The constant radius-steady state test is one of the common tests to measure the vehicle's under steer gradient, which is carried out based on ISO 4138, 1996 (E). This test can be performed in several methods. The test is usually done using the constant radius-variable speed method under continuous conditions.

The obstacle avoidance lane change maneuver test is also one of the common tests, in which the results of a severe lane change maneuver are presented. At the beginning, the test is usually done at a low and balanced speed of about 55 Km/hr increasing at steps of about 5 Km/hr until reaches the desired range. And 3 rounds of driving are done for each test speed. The maximum speed is obtained, when the vehicle cannot pass the determined path without collision with the cones (obstacles).

CONCLUSION

As explained in detail in the text of this paper, in addition to increasing its sprung mass, the most major physical effect imposed on the vehicle due to the addition of a CNG cylinder, is the longitudinal and altitudinal displacements of the vehicle's center of mass, which has the greatest impact on handling, the braking behavior, stability in braking, and the roll stability of a vehicle, especially when the vehicle is turning at a high centripetal acceleration.

The under steer gradient of a vehicle, to which a CNG cylinder is added, increases due to the change in the vehicle's dispersion of mass; that is to say, a vehicle, which is usually designed to be under steer, continues to remains under steer as a result of this change.

As a result of changes in the distance between the vehicle's roll axis and center of mass, the torque caused by the radial centripetal force imposed on the vehicle's center of mass when turning, also changes, thus changing the rollover possibility of the vehicle on turns, corresponding to the increase or decrease in the distance between the center of mass and roll axis.

The increased height of the vehicle's center of mass due to the addition of the cylinder to the vehicle, will have multiple effects on different functions of the vehicle, as a result of which, the vehicle's mass moment of inertia around the z axis, which is a determining factor for the turning function of a vehicle, and which is usually taken into consideration in the studies of vehicle stability, increases. Due to the increase in the vehicle's mass moment of inertia around the z axis, the vehicle's maneuvering decreases, but the vehicle stability slightly increases on a straight path and S-shaped bends.

The increase in the sprung mass of a vehicle, increases the vertical force exerted on the contact area between the wheels and the road, thus increasing the braking force of both axles when the vehicle is slowing down or stops, which results in the improved braking function of the vehicle. But the more important is the braking behavior and stability of the vehicle when braking. Due to the increased height of the vehicle's center of mass, the amount of load transmitted from the rear axle to the front axle, will also increase during braking. As a result, the braking force of the front axle increases, and the braking force of the rear axle decreases, which in turn increases the locking possibility of the rear axle wheels. Consequently, the possibility of yawing instability increases in severe and sudden braking events, which is undesirable.

SUGGESTIONS

According to the results of the above-mentioned dynamic investigations, and given that the negative effects of adding the mass of a CNG cylinder to the sprung mass of a car, are more than its positive effects, it is suggested that the Iranian automakers take action to design and manufacture CNG-fueled vehicles instead of making changes to the configuration of gasoline-fueled vehicles.

In order to increase the ride comfort of vehicles having CNG cylinders, it is suggested that gas dampers (shock absorbers) are used in the rear suspension system of the vehicles, if there is necessary physical space. It is also suggested that the static loss at the rear axle due to the weight of the cylinder, should be compensated for, by selecting springs with higher hardness, as well as increasing the air pressure of the rear tires.

Considering the increased possibility of yawing instability in vehicles with CNG cylinders due to the increase in the locking possibility of the rear wheels in severe and sudden braking events, it is necessary to use ABS brakes in vehicles having CNG cylinders.

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