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Prediction of Car Ground Clearance

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***Abstract*— In layout drawing, one of the basic components that it must have is the estimation of ground lines that will enable engineers to measure the clearance of car components especially the lower part to ground. This paper explains how to formulate simple equations in order to estimate the location of ground lines by taking into account the suspension characteristics of the car as well as three cases of weight loadings. Furthermore a program is written in assembly language in order to ease engineers in getting the ground lines coordinates at specific loadings. The result of program calculation will provide the estimation of the wheel centers as well as the ground lines. In the modeling, car body is placed as static whereas the ground lines moves vertically. Of course in real case the vice versa happens, however this method is unavoidable since in car drawing, one does not want to move the car drawing from its datum due to its dependability to the datum of other components. The result from the wheel center coordinates and the ground lines location will enable engineer to estimate the displacement of spring and at the same time the vertical deformation of tire. In conclusion, this method of ground lines will help design engineers or packaging engineers in automotive development company to speed up the layout making and hence will minimize costly error later at development stage.**

***Keywords*:** automotive ground line, ground clearance.

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I. INTRODUCTION

During early car development stage, one of the important engineering decisions is to ascertain the suitable ground clearance for the car.

This ground clearance has direct impact to the overall looks of the car as well as to the design of suspension system and underbody design. This ground clearance dimension must be decided early before the process of engineering design started, because once the design of components has taken place, it will be costly to change the dimension.

Design stage of a car will involve much money in terms of design cost as well as manufacturing preparation cost. Late decision to change ground clearance will mean that the suspension part vendor will have to alter the initial design and to retest the design. This will cost a lot of money to the automotive company. This has not taken into account the hassle involved to other component suitability such as tire and exhaust system design. In short, alteration to ground clearance will cause a lot of concerns toward the overall car components especially to components and surfaces adjacent to the ground. The end result could be that the manufacturer has to delay the car launching which will subsequently affect car sales at the end, much of the time losing the opportunity to other competitor.

Car companies has been practicing own method in determining the ground clearance for their production cars. The method used is considered their know-how often not known to the general public even to research and academic institutions. However, most car companies rely on the same source of engineering guidelines with regard to automotive engineering. Society of Automotive Engineers (SAE) based in Pennsylvania, USA has long been the research body that most car companies adhere to [1]. Based on the design guidelines proposed by SAE, many design departments of car companies has adopted the propositions albeit modified. The values of suitable ground clearance for different ground vehicles were published in the SAE Book published by SAE [1]. However the values suggested are quite big and this is not good to aerodynamicist's point of view. Hence car companies around the world would decide on their own guides with regard to the design feasibility as well as road conditions which the cars will be marketed. For example, cars exported to the Middle East region often require them to be a little higher that those exported to countries where the road conditions are uniformly smooth.

As defined by SAE, there are often more than two conditions of ground clearance specifications practiced. As for this study, three conditions are studied. There are curb clearance, design clearance and lastly the gross vehicle weight clearance. These clearances names apply to different allowance to ground clearance dimension. As for illustration, three lines are shown in figure 1 to demonstrate the different elevations. The lowest line represents the curb clearance line where the weight condition is without occupants but at full fuel capacity. The middle line represents the condition with two occupants with luggage and full fuel. The uppermost line represents the full weight capacity with all five occupants plus luggage and full fuel. For clarification, the car geometry is fixed whereas the ground lines are free to move. This is due to the nature of car CAD geometries where it is easier to fix the car body due to its dependency to the datum of all other components.

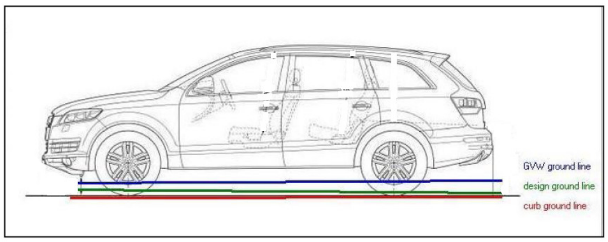

Figure 1 Ground clearance lines

II. METHOD

Taking into account the three ground lines depicted in SAE guidelines, a formulation of weight distribution of the car must be determined. Using equation of equilibrium for static condition, the weight concentration is analyzed together with the proposed tire size, spring stiffness and center of gravity for each weight factor.

The first thing that has to be done is to calculate the weight of the car and the weight distribution between the front and rear axle. The data that is needed for creating a ground clearance layout are the weight of front and rear axles. Often in the early stage, there are only weight targets for the new car, with the distribution is assumed to be 60/40; this means 60% of the car weight pushes the front axle while the balance is concentrated on rear [2]. Some designer opt to choose the 55/45 distribution. If curb weight value is already assumed, the design weight and gross vehicle weight can be calculated.

To calculate the different loads on the axle, it is necessary to do a sequence of equilibrium equations. The data which is needed is the position of driver, rear passenger, center of luggage compartment and wheelbase dimension. Taking moment ∑M = 0 will result to the finding of Center of Gravity location of the car, and eventually getting the applied load at front axle and rear axle.

In practice, there are usually 3 weight conditions of a passenger car:

i) Curb Weight : Car body weight (with standard working fluids and full fuel tank)

ii) Design Weight : Car body weight (with standard working fluids and full fuel tank) + 2 person's weight at front side + 60 kg luggage

ii) Gross Vehicle Weight : Car body weight (with standard working fluids and full fuel tank) + 2 person's weight at front side + 3 person's weight at rear side + 60 kg luggage

Normally, one person weight is taken at 95% percentile which is around 70 – 85 kg depending on the targeted population [1].

III. WEIGHT DISTRIBUTION

By taking moment equals to zero at front wheel center (without occupant), force on front and rear axle can be calculated at all load cases; for case below, design load is considered. Symbols are predefined as:

FWC : Front wheel center
RWC : Rear wheel center
A : Downward force at front axle
B : Downward force at rear axle
F : Force by sprung car weight at car center of gravity
F1 : 2 person's weight at driver seating reference point
F2 : 3 person's weight at rear passenger seating reference point
F3 : Luggage weight at center of luggage area

$$\sum M_{RWC} = 0$$
$$F_f = [\ 2\times(F1(X4-X1) - F(X4-X2)\ ]/X4 \qquad (1)$$

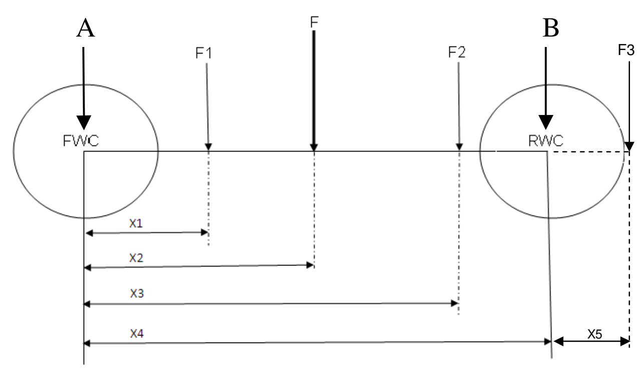

Figure 2 Weight distribution

The same procedure is used for GVW condition but this includes 5 passengers and 70 kg weight in the luggage compartment. F is the weight of the car body without the tire and suspension system. If the ratio of front and rear axle weight distribution is taken as 60/40, 60% of the F is concentrated to the front axle, and 40% is pushing down the rear axle. From equation 1, the center of gravity of the car body is obtained. Figure 2 is the simplified free body diagram on which the calculation takes place.

At 60/40 weight distribution and curb weight condition,

$$\sum M_{FWC} = 0$$
$$F \times X2 = B \times X4 \qquad (2)$$
$$X2 = (0.4 \times F \times X4)/F = 0.4 \times X4$$

While at Design weight,

$$\sum M_{FWC} = 0$$
$$F1 \times X1 + F \times X2 + F3(X4 + X5) = B \times X4 \qquad (3)$$
$$B = (F1 \times X1 + F \times X2) + F3(X4 + X5)/X4$$

$$\sum M_{RWC} = 0$$
$$A \times X4 = F1(X4 - X1) + F(X4 - X2) - F3 \times X5 \qquad (4)$$
$$A = (F1 \times X1 + F \times X2) + F3(X4 + X5)/X4$$

And at Gross Vehicle Weight,

$$\sum M_{FWC} = 0$$
$$F1 \times X1 + F \times X2 + F2 \times X3 + F3(X4 + X5) = B \times X4 \qquad (5)$$
$$B = [\ (F1 \times X1 + F \times X2) + F2 \times X3 + F3(X4 + X5)\ ]/X4$$

$$\sum M_{RWC} = 0$$
$$A \times X4 = F1(X4 - X1) + F(X4 - X2) + F3(X4 - X3) - F3 \times X5 \qquad (6)$$
$$A = [\ F1(X4 - X1) + F(X4 - X2) + F3(X4 - X3) - F3 \times X5\ ] / X4$$

Depending on the value of a person selected, the weight distribution to the front and rear axle will vary for the design and gross vehicle weight. If the initial 60/40 distribution is approximated for the curb condition, the design distribution will become more level such that the front axle will exert less than 60% and rear axle will exert more than 40%. Similar situation will happen to the GVW condition compared to design condition.

IV. SPRING DISPLACEMENT AND TIRE LOADING

After getting the forces exerted to the front and rear axle, one can now calculate how much the deformation to the spring and tire for each of the weight condition. To do that, static loading radius of the tire must be known as well as the stiffness constant of the spring [2]. Static loading radius of tire depends to the manufacturer specification. Original manufacturer of tire usually has their own manual about their product's behavior.

If deformation constant of a tire is known as k, force exerted by each axle is divided by 2, to get force exerted per tire.

From F=kx, vertical deformation of tire = A/2k

Tire original vertical dimension = R - r

Tire vertical dimension on loading = R- r – A/2k

Hence, static loading radius = rim radius + tire vertical dimension on loading

$$SLR = r + R - r - A/2k = R - A/2k \qquad (7)$$

r : Rim radius
k : Tire deformation constant
R : Overall tire radius

Similar method to get the deformation of the spring,

From F=kx, spring displacement = A/2k_2 where k_2 is the spring stiffness coefficient

If at curb condition, the FWC is assigned as (0,y,0) and RWC as (x,y,0), the displacement to the spring and tire can be calculated after applying force exerted at design and GVW conditions.

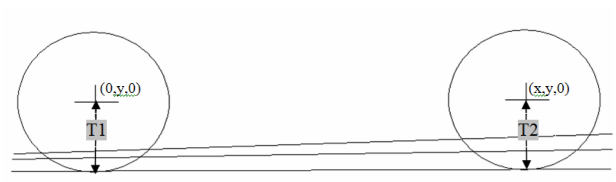

Figure 3 Wheel center to ground

Static loading radius will vary according to weight exerted to the axle, as 3 conditions are applied, the static loading radius will give 3 values. So as the spring deforms, the spring displacements will vary according to curb, design, and gross vehicle weight conditions.

By specifying the height T1 for front tire and T2 for rear tire at any of the three conditions, the tire centers to ground at the two others can be obtained. Since the height T1 and T2 depends to the tire and spring deformation, it is sufficient to specify the coordinate of FWC that one is using for their car layout drawing. It is normal to take the FWC as the datum at curb or design condition.

If one to take design load condition as the reference to the datum level, then the FWC at design condition can be assigned as (0,y,0). Similar case to the RWC where the coordinate of RWC will be (x,y,0). This is sketched in Figure 3. In that case one only has to find where to locate the curb and gross vehicle weight wheel centers. Since the wheel centre is preferred to be static in car layout drawing, then the ground lines are the ones actually be moved in drawing. Relatively in layout drawing, the car drawing is fixed, whereas the ground lines are moved accordingly. Of course in real scenario, vice versa happens.

The target of analysis is to obtain the z-displacements (vertical displacements) of front and rear wheel centre at specified loadings. In order to do so, spring stiffness values must be decided as well as the suitable tire size [3]. Since the weights applied at front and rear axles have been calculated, the displacement of the spring and tires can be estimated.

V. COMPUTER PROGRAM

A program is written in C language to ease the process of determining the z-displacements upon loadings. First, the calculation was done in MS-Excel and further tested in the program written.

Shown in Figure 4, user has to key in curb weight, wheelbase, front wheel center, track distance, spring coefficient as well as tire size, the program will calculate the z-coordinate of ground lines at curb and design vehicle weight condition. At design condition, the FWC is assigned as 0 in z-displacement.

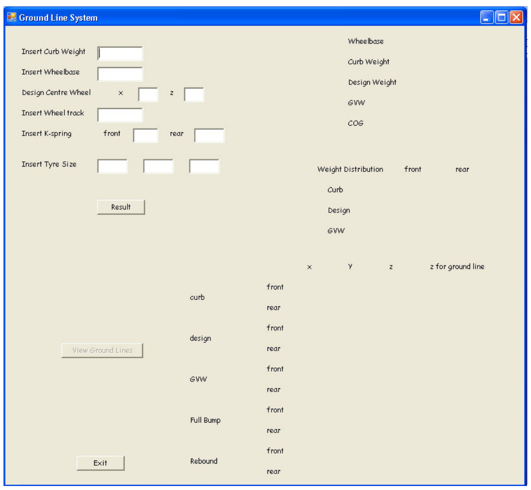

Figure 4 Program window

For a car that has a 1300 kg curb weight, 2600 mm as wheelbase, 750 mm as track length, k-spring as 43 N/m and tire size of 205/55/R16; the ground lines are calculated as illustrated in Figure 5.

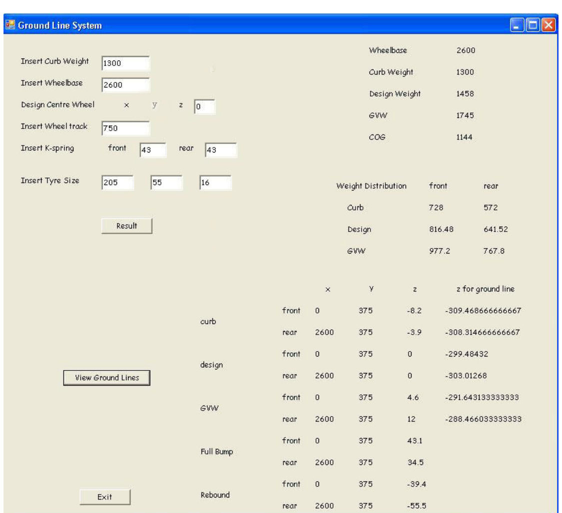

Figure 5 Program window result

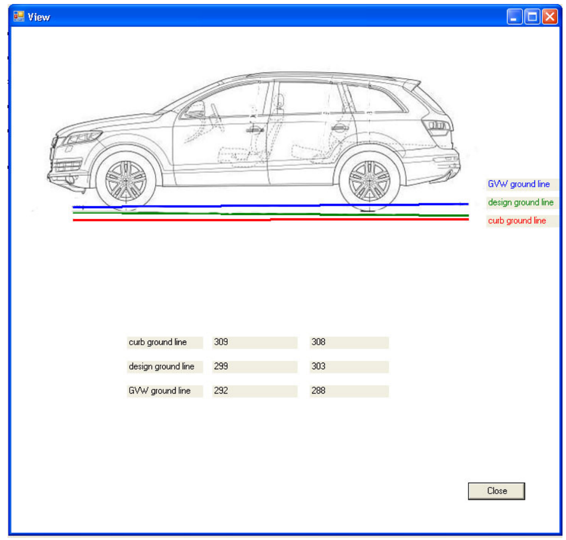

Figure 6 Graphic window

Figure 6 shows the illustration of the ground lines with its respective z-coordinate for front rear tires. These z-coordinates then can be input into car layout drawing in CAD software to determine the ground clearance for all necessary underbody areas.

In a table the coordinate of the front and rear wheel centers at different loadings can be put as in the table below, note that the (X,Y,Z) are the tire centers coordinates in reality whereas the z-coordinate refers to the movement of the grounds in drawing at the 3 loading conditions.

Table 1 Wheel center vertical displacement

CONDITION		X	Y	Z	Z FOR GROUNDLINE
FR	GVW	0.00	750	4.6	-292
	DESIGN	0.00	750	0	-299
	CURB	0.00	750	-8.2	-309
RR	GVW	2600	750	12	-288
	DESIGN	2600	750	0	-303
	CURB	2600	750	-3.9	-308

The purpose of putting z-coordinate of wheel centers is to show the displacement of wheel center. This can be used in determining the location of drive shaft and engine mounting. It can be seen that the displacements of z coordinate for wheel centers are not similar to the z-displacements of grounds. The reason is z-displacements of grounds are taken as overall deformation to spring plus tire, whereas z coordinates of wheel centers depends on the spring displacements minus tire vertical displacement or deformation.

This can be illustrated in 2 linear equations, taking example from table above by using information of z-coordinate of wheel center and z-coordinate for ground line at curb and design conditions.

Spring Displacement + tire vertical deformation
= -309 – (-299) = -10

Spring displacement – tire vertical deformation
= -8.2 – 0

Solving the 2 equations will result to:

Spring displacement = 9.1;

Tire vertical deformation = 0.9

Means that from curb weight condition to design weight condition, the spring will displace by 9.1 mm while the tire will compressed by 0.9 mm.

VI. CONCLUSION

The devise of a simple program in order to determine the predicted ground lines will greatly assist automotive design engineers in designing cars. The cost saving due to enhanced prediction of ground clearance will also be amplified by the development time reduction at development stage. The result obtained by the static approach is sufficient to ascertain the amount of spring compression and hence the car ride height. The chain effect of ground lines prediction may carry as far as to the production stage if it was not properly tuned. To improve accuracy of the result, detail weight distribution of the vehicle platform can be simulated in other finite element softwares. Due to variation in development process, it is therefore uncertain whether such detail work will carry a significant weight in automotive development processes.

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