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Effects of The Number of Axles on Vehicle Behavior Traversing Bump Terrain

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Abstract. Vehicle configurations with the same hull have been developed to survey different military requirements. This procedure reduces RD and production costs, as well as simplifies the logistical supply chain. In this sense, the choice of the number of axles is relevant in the project of military vehicles, modifying the vehicle capabilities to transport soldiers, materials and weapons. This work analyzes the effects of the number of axles on vehicle behavior travelling on a terrain with a step. A half car model is employed to evaluate the 4x4, 6x6 and 8x8 vehicle configurations. All of the wheels have independent and passive suspensions with springs and dampers. The system of ordinary differential equations, which represents the half car model, is solved by a fourth order Runge-Kutta algorithm implemented in SciLab software. The results describe the pitch and bounce displacements of the hull. The influence of the vehicle velocity passing on the bump is also analyzed.

Keywords. half-car model, passive suspension, vehicle dynamics

1 Introduction

Nowadays, many vehicles configurations with the same hull have been developed to survey different military requirements [8]. Some of these families of vehicles share over 90% common components [13]. This procedure reduces RD and production costs, as well as simplifies the logistical supply chain.

The choice of the number of axels is relevant to design different versions of military vehicles as armoured personal carriers (APC), infantry fighting vehicles (IFV) and armoured combat vehicles (ACV), using the same hull [8]. Moreover, the number of axles

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is also important to design unmanned ground vehicles (UGV), attending severe off-road and mobility requirements [10].

The comfort of the crew is an important aspect in the vehicle design, which is related with the suspension system. Such system must provide comfort and safety for the crew and mobility for the vehicle [1, 2, 4–6, 12, 14, 15].

The suspension filters the vibrations produced by the vehicle-terrain interaction, protecting the crew, the vehicle components and the transported materials [7, 9, 11, 17].

The half car model has been used to study the dynamics of military vehicles, mainly the vibrations imposed by the terrain, but also the vibrations promoted by weapons mounted on the hull [1, 3, 6, 7, 12, 14, 16].

The present work employs a half car model to describe the hull dynamics imposed by the vehicle-terrain interaction, analyzing the effects of the number of axles on the pitch and bounce displacement of the hull.The suspension is the main subsystem in the proposed model. 4x4, 6x6 and 8x8 vehicle configurations are analyzed.

2 Mathematical Modelling

The present longitudinal half car model is based on the one proposed by [1] and the following assumptions are made: the hull is a rigid body; the terrain is rigid; the roll movement is not considered; the tire and springs stiffness are constants; the damping coefficient of the suspensions are constants; and the damping effects of the tires are not considered.

The proposed model describes half vehicles with N axles and the subscript i identifies the position of the wheel-suspension set in the hull. Bounce and pitch motion of the hull are modeled in equations (1-2) and bounce motion of each axle i is modeled in equation (3).

$$m_b\dot{Z}_b + \sum_{i=1}^{N} C_{bi}\big(\dot{Z}_b + l_i\dot{\theta} - \dot{Z}_{wi}\big) + \sum_{i=1}^{N} K_{bi}\big(Z_b + l_i\theta - Z_{wi}\big) = 0 \tag{1}$$

$$I_y\dot{\theta} + \sum_{i=1}^{N} C_{bi}\big(\dot{Z}_b + l_i\dot{\theta} - \dot{Z}_{wi}\big)l_i + \sum_{i=1}^{N} K_{bi}\big(Z_b + l_i\theta - Z_{wi}\big)l_i = 0 \tag{2}$$

$$m_{wi}\dot{Z}_{wi} - C_{bi}\big(\dot{Z}_b + l_i\dot{\theta} - \dot{Z}_{wi}\big) - K_{bi}\big(Z_b + l_i\theta - Z_{wi}\big) + K_{wi}\big(Z_{wi} - Z_{ri}\big) = 0 \tag{3}$$

where m_b is the body mass (kg), I_y is the body inertia (kg m^2),K$_{bi}$ is the suspension stiffness (N/m), C_{bi} is the damping coefficient (Ns/m), l_i is the distance between the hull center of gravity (C.G.) and the suspension (m), K_{wi} is the tire stiffness (N/m) and m_{wi} is the wheel mass (kg). In equations (1-3) Z_b is the hull bounce, Z_{wi} is the wheel bounce and θ is the hull pitch.

The input terrain excitation z_{ri} is applied in each wheel following equations(5-6). Furthermore, the bump is represented by a step function in equation (5) and the excitation delay τ_i (s) is a function of the vehicle velocity v(m/s) and of the distance between the first wheel and the wheel i, following equation (6).

$$\tau_i = \frac{(l_1 - l_i)}{v} \tag{4}$$

$$Z - r1(t) = \begin{cases} 0.1, \text{ t} \geq 1 \\ 0, \text{ otherwise} \end{cases} \tag{5}$$

$$z_{ri}(t) = z_{r1}(t + \tau_i) \tag{6}$$

where t is the time (s) and h is the bump height (m). Moreover, the initial condition is the mechanical equilibrium state.

The system of ordinary differential equations is solved by a fourth order Runge-Kutta algorithm implemented in SciLab software.

3 Results and Discussion

The effects of the number of axles on vehicle behavior traversing bump terrain are investigated, employing the proposed model described in equations (1-6).

The vehicle configurations 4x4, 6x6 and 8x8 are studied and they are, respectively, represented in the half car model for the cases with 2, 3 and 4 axles.

The input values adopted in these simulations are in Table 1, where $l_{C.G.}$is the position of the center of gravity of the hull.

Table 1: Model parameters.

Symbol	Value
m_b	11000 kg
I_y	57499.2 kg m^2
K_{bi}	200000 N/m
C_{bi}	28000 Ns/m
k_{wi}	1250000 N/m
m_{wi}	190 kg
l_1	2.38 m
l_2	0.79 m
l_3	-0.79 m
l_4	-2.38 m
$I_{C.G.}$	0 m

The model of the 8x8 vehicle configuration considers the axles in the positions l_1, l_2, l_3 and l_4; the 6x6 version considers the axles in the positions l_1, $l_{C.G.}$ and l_4; and the 4x4 case considers the axles in the positions l_1 and l_4.

The Figures 1 to 6 shows bounce and pitch of the hull for the simulation of the half car model with 2, 3 and 4 axles, considering the vehicle velocity equal to 10, 40 and 60 km/h.

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Comparing Figures 1 to 6, it is observed that increasing the vehicle velocity, bounce maximum values are also increased, but pitch has different behavior. In these figures, pitch maximum value is found for the vehicle velocity equal to 40 km/h. The bounce behavior is explained by the energy transferred to the axles when it hits the bump. So, more energy results in large bounce displacement. Otherwise, it is not observed in the pitch displacement, because for high velocities, the wheels are excited almost in the same time, resulting in lower angular displacement of the hull. Observing equation (4), it is verified that when the velocity tends to infinity the excitation delay tends to zero, consequently the terrain excitations are imposed simultaneously on all wheels and pitch becomes null.

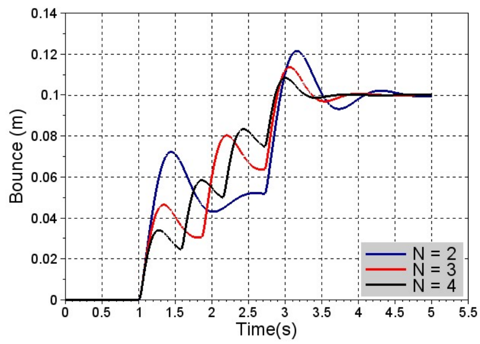

Figure 1: Bounce (10 km/h).

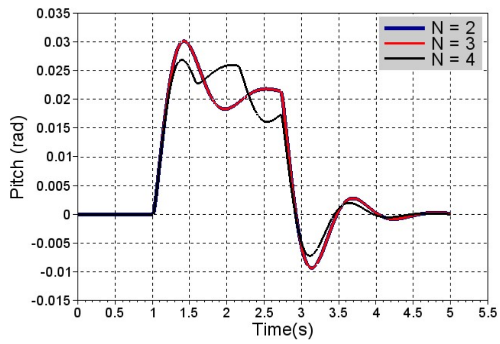

Figure 2: Pitch (10 km/h).

The Figures 1, 3 and 5 shows that increasing the number of axles, the bounce is reduced. It is explained by the action of the dampers, since each wheel is linked to a damper. Then, in the configurations with more dampers, more energy is dissipated and the bounce is reduced. The same conclusion can be found when the configurations with 2 and 4 axles are compared for the pitch displacement (Figures 2, 4 and 6), but it is not observed for the case with 3 axles. The pitch behavior for the 4x4 and 6x6 simulated vehicles is the same for each vehicle velocity. Such results is a consequence of the position of the central axle in the half car model with N = 3, since it is at the center of gravity of the hull. Thus, the central axle does not influence the angular motion of the hull and it is predicted by equation (2).

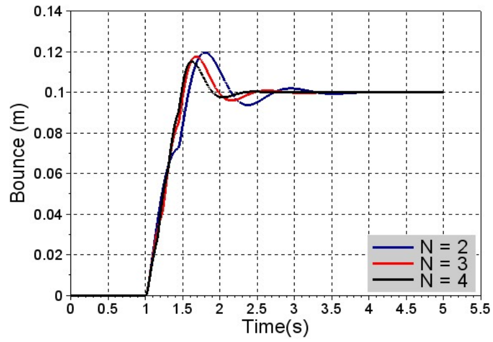

Figure 3: Bounce (40 km/h).

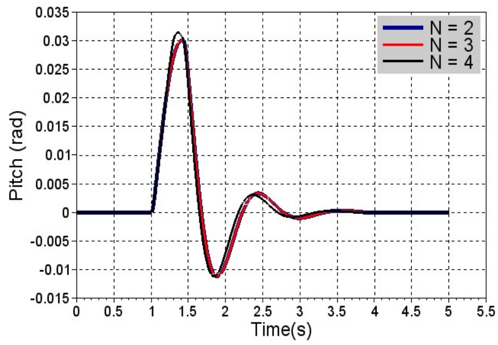

Figure 4: Pitch (40 km/h).

It is possible to observe in Figure 1 the displacement of each axle climbing the bump. It is represented by the sequence of local maximum in the plotted curves, which shows the influence of terrain excitation on each axle.

4 Conclusion

The present work proposed a half car model able to represent ground vehicles with different numbers of axles. The effects of the vehicle velocity and of the numbers of the axles on the hull behavior, considering a vehicle traversing a step were analyzed.

The results show that the number and the position of the axles modify the vehicle dynamics. Besides, increasing the number of axles, bounce is reduced, but it is not observed in pitch, because, the axle positioned in the vicinity of the hull center of gravity, become the effects of such axle negligible in the angular motion of the hull.

Furthermore, improving the vehicle velocity, more energy is furnished to the system, increasing the bounce. The other hand, it is not observed in the pitch, where initially the pitch increases with the velocity, but increasing more the velocity the pitch is reduced. It

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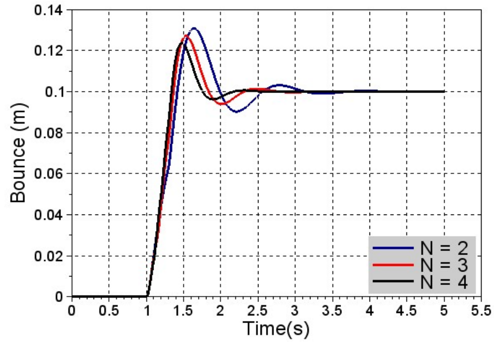

Figure 5: Bounce (60 km/h).

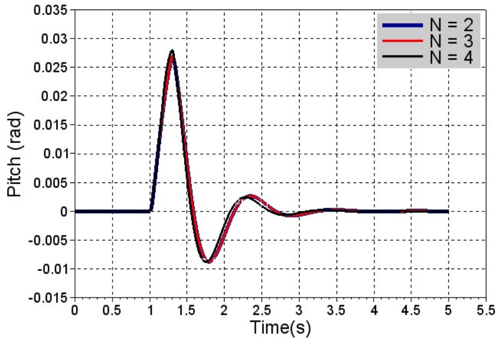

Figure 6: Pitch (60 km/h).

is explained since the reduction of the excitation delay is so severe for high velocities that the terrain bump hit the axles almost at the same time.

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