

CONSTRUCTION OF AN INTEGRATED HUMAN-VEHICLE MODEL FOR RESEARCHING ON ENHANCING THE COMFORT LEVEL OF PASSENGERS

XÂY DỰNG MÔ HÌNH PHƯƠNG TIỆN GIAO THÔNG TÍCH HỢP CON NGƯỜI PHỤC VỤ CHO VIỆC NGHIÊN CỨU NÂNG CAO MỨC ĐỘ THOẢI MÁI CỦA HÀNH KHÁCH

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ABSTRACT

In order to enhance the comfort level of passengers, constructing integrated human-vehicle model plays an importance role to save the cost and the time during experiment process while the accuracy still ensures in compared to reality. In this research, the integrated human-vehicle model was constructed based on the passenger model with 9 degrees of freedom and the 3-D vehicle model.

The evaluation results showed that the human-integrated vehicle model is suitable for research to enhance the comfort level of passengers.

Keyword: *Integrated human-vehicle model, Comfort level, Impact of vibration.*

TÓM TẮT

Để nâng cao sự thoải mái cho hành khách trên phương tiện giao thông, việc xây dựng mô hình phương tiện giao thông tích hợp với con người đóng vai trò quyết định để giảm chi phí và thời gian trong quá trình thử nghiệm mà vẫn đảm bảo được mức độ chính xác nhất định so với thực tế. Trong nghiên cứu này, mô hình phương tiện giao thông tích hợp con người được xây dựng dựa trên mô hình hành khách với 9 bậc tự do và mô hình xe 3-D. Kết quả đánh giá cho thấy, mô hình phương tiện giao thông tích hợp con người phù hợp cho việc nghiên cứu nâng cao sự thoải mái của hành khách trên phương tiện giao thông.

Từ khóa: *Mô hình phương tiện giao thông tích hợp con người; Mức độ thoải mái; Tác động của dao động.*

1. INTRODUCTION

The human body is exposed to vibration in many kinds of maneuver, e.g. sports, work performances, as well as during travelling. People will not only get tired quickly but

also can not attain high performance under vibration condition. Vibrations can result in discomfort, interference, and health impairment. Furthermore, many experimental investigations show that human body could be injured by vibrations. Vibrations cause 

osteoarthritis, traumatic fibrositis, herniated disks, lumbosacral and abdominal pain, and intestinal disorders.

Since the number of vehicles is increasing rapidly and there are now more traffic accidents than ever before, safety and cost play significant roles in automobile manufacture. As a result of vehicle safety insurance, people become more concerned about vehicle vibration, automobile researchers are seeking more comfortable environments for occupant, and many countries stipulate that all vehicles must meet national safety standards.

As we know, most of seated human subjects are complex dynamic systems whose properties vary from moment to moment and from one individual to another. From the average response in the large amount of experimental data, various biodynamic models have been developed to depict the human motion in single DOF (Degree Of Freedom) or multi DOF models. These models can be grouped as lumped-parameter models, multi-body models and finite element models. In 2000, a lumped-parameter model with four DOFs was employed by Wanger and Liu [1] for riding quality assessment with integration of full vehicle model. In 2001, a nine-DOF multi-body model was suggested by Cho and Yoon to simulate the human body in sitting posture [2]. In 2020, a nine-DOF multi-body model was selected to discuss and compare to a four-DOF lumped-parameter model. The comparison of the experimental data with those of four- and nine-DOF model shown that nine-DOF model produced better matching in transmissibilities (T.G. Nguyen et al., 2020 [3]).

As the mention of many previous researchers, a vehicle suspension system can control the transmission of oscillations to vehicle occupants from road surface excitation.

Therefore, to attenuate vibrations transmitted from the road surface to vehicle occupants is an important issue for the minimization of discomfort levers. A vehicle suspension system can also be considered as a lumped-parameter model. In 2021, two kinds of vehicle models (2- and 3-D model [4, 5]) were selected to evaluate the impact of vibration on driver with two different road surfaces. In this case, the passenger was considered as a driver. The simulation results showed that, the 2-D model was restricted to the analysis of uniform road surfaces with the same input to both left and right tires. The 3-D model was recommended for analyzing the impact of vibration on passengers due to unevenness in the road (T.G. Nguyen et al., 2021 [6]).

In this research, the nine-DOF multi-body model was considered as a driver. An integrated human-vehicle model was constructed by integrating the nine-DOF multi-body model with the 3-D vehicle model for the purpose of enhancing the comfort level of passengers.

2. CONSTRUCTION OF MODELS

2.1. Seated human model

The nine-DOF multi-body model is suggested by Cho and Yoon (2001) [3]. The mass m_1 is for the lower body representing the sacrum and legs, the mass m_2 is for the upper body representing the trunk plus the arms, and the mass m_3 represents the head. In this model, the foot support is ignored as the vibration input through the foot support is small and transferred to the trunk only partially. Thus, the model has a total of nine DOFs as each body may have planar motion in x-z plane as shown in Figure 1, the biomechanical parameters of the model and geometrical parameters of joints and contact positions are listed in Table 1.

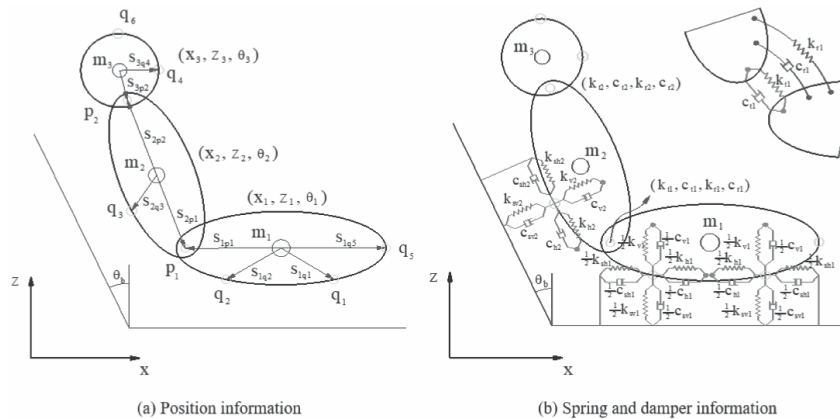


Figure 1. Nine-DOF multi-body model [3]

Table 1. Biomechanical parameters of nine-DOF model [4]

Biomechanical parameters						Geometrical parameters			
Mass (kg) Inertia (kg.m ²)		Damping (Ns/m)		Stiffness (N/m)		Length (m)		Angle (degree)	
m_1	15.30	c_{v1}	29.4	k_{v1}	72000.0	$l_{1p1} = 0.213$	$l_{2q3} = 0.106$	$\alpha_{11} = -72.5$	$\alpha_{01} = -27.4$
m_2	36.00	c_{h1}	447.0	k_{h1}	46300.0	$l_{2p1} = 0.204$	$l_{3q4} = 0.111$	$\alpha_{12} = -134.7$	$\alpha_{02} = -54.8$
m_3	5.50	c_{v2}	0.4	k_{v2}	2300.0	$l_{3p2} = 0.131$	$l_{0q1} = 0.270$	$\alpha_{23} = -48.7$	$\alpha_{03} = 140.3$
I_1	0.90	c_{h2}	446.0	k_{h2}	20200.0	$l_{1q1} = 0.114$	$l_{0q1} = 0.152$	$\alpha_{34} = 66.8$	$\alpha_b = 21.0$
I_2	1.10	c_{t1}	380.6	k_{t1}	17200.0	$l_{1q2} = 0.167$	$l_{0q1} = 0.156$		
I_3	0.03	c_{t2}	182.1	k_{t2}	25000.0				
		c_{r1}	2576.5						

2.2. Vehicle model

A 3-D vehicle model is selected and shown in Figure 2. This model was further analyzed by Zuo and Nayfeh [4] to optimize

vehicle suspensions based on multi-wheel models. In this model, the driver located at r_x and r_y from the vehicle's center of gravity (CG) in x- and y-axis directions is considered as one lumped mass interconnected by a set of seat

spring k_d and damper c_d with the vehicle body. A vehicle body of mass m_{v5} and mass moment of inertia I_x in the x -axis direction and I_y in the y -axis direction is assumed to have three DOFs, representing bouncing motion z_{v5} , pitch motion θ , and rolling motion ϕ . A suspension system is modeled by four unsprung masses m_{v1} , m_{v2} , m_{v3} , and m_{v4} connected to the vehicle body by four sets of springs k_{s1} , k_{s2} , k_{s3} , and k_{s4} and dampers c_{s1} , c_{s2} , c_{s3} , and c_{s4} , respectively. These four masses only consider bouncing motion and the four springs k_{t1} , k_{t2} , k_{t3} , and k_{t4} represent tire properties. The CG is allocated at l_f to the front axle and l_r to the rear axle; and t_{Lf} to the left-front tire, t_{Rf} to the right-front tire, t_{Lr} to the left-rear tire, and t_{Rr} to the right-rear tire, respectively. As a result, this 3-D model has a total of eight DOFs, while the inputs originate

from the tire-ground contact points, z_{01} , z_{02} , z_{03} , and z_{04} , respectively. All parameters are listed in Table 2.

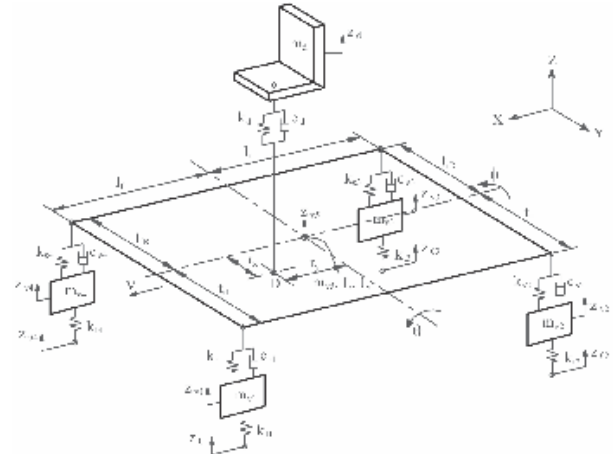


Figure 2. A 3-D vehicle model [4]

Table 2. Parameters of a 3-D full-car model [4]

Symbol					Value
Suspension parameters	Spring constants	Front	k_{s1}, k_{s4}	(N/m)	20984.8
		Rear	k_{s2}, k_{s3}	(N/m)	19121.7
	Damping coefficients	Front	c_{s1}, c_{s4}	(N·s/m)	1306.0
		Rear	c_{s2}, c_{s3}	(N·s/m)	1470.0
	Unsprung mass	Front	m_{v1}, m_{v4}	(kg)	40.0
		Rear	m_{v2}, m_{v3}	(kg)	40.0
	Tire spring constants	Front	k_{t1}, k_{t4}	(N/m)	182087.0
		Rear	k_{t2}, k_{t3}	(N/m)	182087.0
Seat parameters	Spring constant		k_d	(N/m)	10507.1
	Damping coefficient		c_d	(N·s/m)	875.6
	x -axis distance from CG		r_x	(m)	0.24
	y -axis distance from CG		r_y	(m)	0.34
Vehicle parameters	Distance from CG to axles	Front	l_f	(m)	1.125
		Rear	l_r	(m)	1.511
	Distance from CG to tires	Front	t_{Lf}, t_{Rf}	(m)	0.72
		Rear	t_{Lr}, t_{Rr}	(m)	0.72
	Mass of vehicle body		m_{v5}	(kg)	1375.9
	Mass moment of inertia	x -axis	I_x	(kg·m ²)	484.4
		y -axis	I_y	(kg·m ²)	2344.4
Driver	Vehicle speed		V	(m/sec)	30
	Mass		m_d	(kg)	60

2.3. Integration of Seated Human and Vehicle Model

In the formulation of the 3-D vehicle model for riding quality evaluation, a driver is often assumed to be a rigid mass connected to the vehicle body by a set of seat spring and damper. Also, as shown in Figure 2, the pelvis and the upper part of body are supposed to absorb the vibrations transmitted through the hip support and backrest support, respectively. In this case, the motions of each part of seated human model is considered in plane motion (translational motions in x and z directions, rotational motion respect to y-axis). So the pitch motion of the vehicle also is considered as a role of input excitation to seated human model. Accordingly, an integrated human-vehicle system can be achieved by deleting the driver mass from 3-D vehicle model and substituting the seated human model. Assume that, the vehicle body and the vehicle seat are interconnected by a system of parallel linear springs and dampers with corresponding stiffness coefficient k_d and damping coefficient c_d , these coefficients were determined by increasing of the initial ones until the biodynamic response errors between the vehicle body and the vehicle seat were less than 1%. For this reason, the translational motion in vertical direction and the rotational motion respect to y-axis of the vehicle seat are considered as the translational motion in vertical direction of vehicle-seat position on vehicle body and rotational motion of vehicle body respect to y-axis.

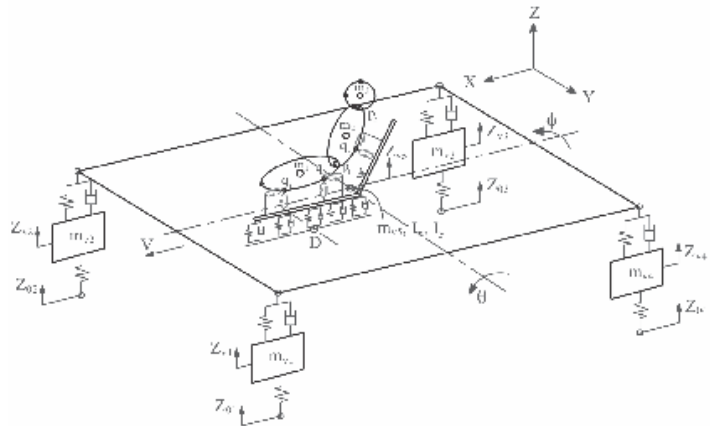


Figure 3. Schematic of integrated human-vehicle model

The integrated human-vehicle model is shown in Figure 3. Based on the system of EOMs of the nine-DOF multi-body model [3] and the system of EOMs of the 3-D vehicle model [6], the EOMs of a completely integrated human-vehicle model can be expressed by the following matrix form:

$$\mathbf{M}\ddot{\mathbf{X}} + \mathbf{C}\dot{\mathbf{X}} + \mathbf{K}\mathbf{X} = \mathbf{F} \quad (1)$$

The terms $\mathbf{M}$, $\mathbf{C}$ and $\mathbf{K}$ in Equation (1) are the 17×17 mass, damping and stiffness matrices of the integrated human-vehicle model, respectively; and $\ddot{\mathbf{X}}$, $\dot{\mathbf{X}}$, and $\mathbf{X}$ are the acceleration, velocity and displacement vectors of the system; $\mathbf{F}$ is the force input due to road excitation.

3. SIMULATION RESULTS AND MODEL EVALUATIONS

To assess the influence of the human model on the evaluation of riding quality, the integrated human-vehicle model is assumed to pass over the double-bump surface described in Figure 4 at a speed of 30 m/s [6]. In addition, the driver's mass of 60 kg, from Figure 2 describing a 3-D vehicle model, is replaced by 56.80 kg, representing the total mass of nine-DOF human model [1]. Stiffness coefficient k_d and damping coefficient c_d are replaced by stiffness coefficient $k_{sv1} = 30 \text{ kN/m}$ and

damping coefficient $c_{sv1} = 200$ Ns/m of seat properties, respectively.

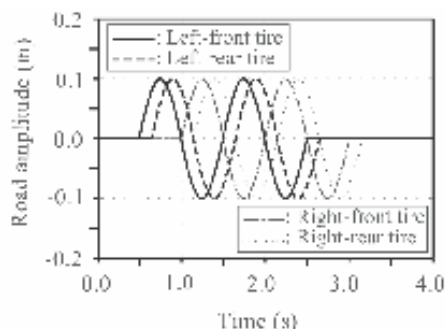
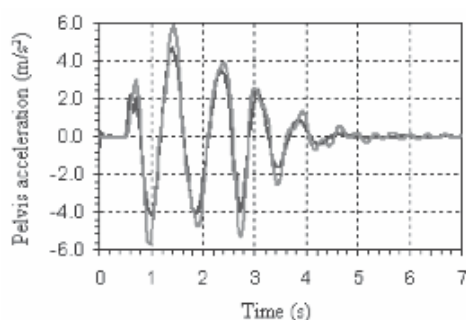
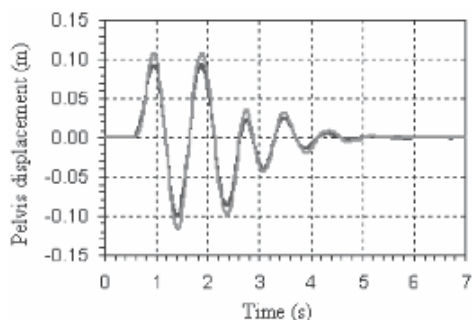


Figure 4. Road input for integrated human-vehicle model

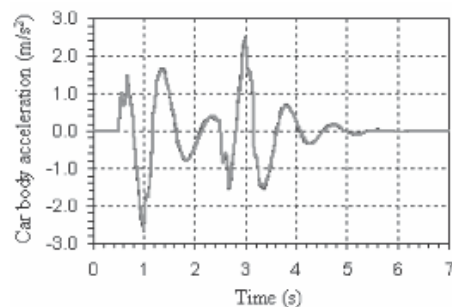
The simulation results for both cases are shown in Figure 5. The curve denoted as “one-DOF human model” representing the driver’s acceleration in the 3-D vehicle model is in comparison with the pelvic acceleration from the integrated human-vehicle model (denoted as “nine-DOF human model”).



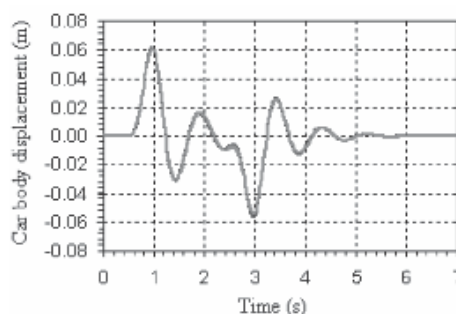
(a) Pelvis acceleration



(b) Pelvis displacement



(c) Car body acceleration



(d) Car body displacement

Figure 5. Evaluated results of the integrated human-vehicle model

It should be noted that certain difference is exhibited between the two results, because the human is considered as a system consisting of masses, springs and dampers. The damping inside tends to reduce the peak amplitude in its dynamic behavior. However, since the mass of pelvis is smaller than the entire body, the damping out is slower.

4. CONCLUSIONS

In this research, an integrated human-vehicle system with seventeen DOFs is constructed by integrating the nine-DOF multi-body model with the 3-D vehicle model to analyze the biodynamic response of the seated human body in driving condition. The simulation results show that the integrated human-vehicle model get better approximate the actual measurement of human vibrations

and/or riding evaluation. The integrated human-vehicle model is recommended for further research to enhance the comfort level of passengers. ❖

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