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STUDY OF THE OCCUPANT'S KINEMATICS DURING THE FRONTAL IMPACT

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Abstract: *A simplified lumped mass mechanical model dedicated to study the unbelted occupant's kinematics in automobile's interior during a frontal impact is presented. The model allows the evaluation of the kinematic parameters of the segments which simulate the human body, which can be used later for evaluating the occupant's level of injury during the crash event. It was started from the Lagrange's equations and due to the complexity of the obtained equations, it was created a Matlab programme, based on the numerical method Runge-Kutta of fourth order, which helped us to obtain the results presented in this paper-work. Also a model developed with the Simulink-SimMechanics software (multibody dynamics) is presented and the results obtained by using both methods are compared.*

1. INTRODUCTION

The European Union proposes a provocative goal, that consists in reducing until the year 2010 the number of fatal car accidents at half of year 2003' level. The European Union intends to reach this objective through two sets of actions [1]: the first – *by creating more restrictive legal prescriptions which refers the road safety rules* and the second – *by developing new technologies and/or improving the actual ones in order to increase the road safety level.* In such conditions, it is obvious that it must be made important developments in order to decrease the number of the car accidents (especially lethal ones and those from which results major injuries), and the main challenge in order to achieve this objective is for the researchers in the automotive field. The study of the fundamental principles of the occupant dynamics is essential for the analysis of problems occurred in the occupant's safety field. Reducing the occupant's velocity requires the applications of a restraint force on him, but is very important to know the maximum value of this force which can be applied on the occupant, without producing injuries. In order to evaluate the level the occupant's injury by computing the performance injury criteria during a road event, it is necessary to be known the motion's kinematics of this one, in the presence of the restraint systems or in absence of them. Particularly, the evaluation of the kinematics parameters in this work paper is made in order to calculate the HIC *(Head Injury Criterion)*, in case of the impact between the occupant's head and the instrument panel.

2. THE ANALYTICAL OCCUPANT MODEL

Mathematical modeling of the human body, coupled with the mathematical description of the automobile structure and with the different passive safety systems represents a very economical, versatile and efficient method for analyse the responses of the complex dynamic system which is the automobile and the passengers, in case of an impact. The dynamic models used for studying the behaviour of the passenger body in car interior, during the impact, are: *lumped mass models* (usually, uni- or bi-dimensional), *multi-body* (usually, bi- or tri-dimensional), *finite elemente models* (usually, tri-dimensional) [2], [3], [7].

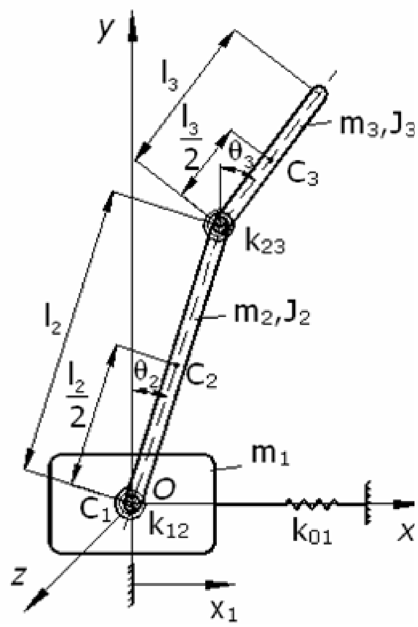


Figure 1. The simplified unbelted occupant model.

2.1. The presentation of the model

The presented model (figure 1) represents a *lumped mass* one, *bi-dimensional*, and it allows the evaluation of the kinematic parameters (displacements, velocities, accelerations, angular displacements, angular velocities and angular accelerations) of the occupant's body in the car interior during the frontal impact and also the evaluation of the responses of the human body segments, during a such event.

The automobile is simulated by the mass m_1, which has a translational motion on longitudinal direction, and *the occupant's human body* is considered to be composed of three segments, as follows:

1. the inferior segment, which simulates the legs and the pelvian area and it is considered to have only translational motion on the longitudinal direction, in the same time with the seat, the car interior and the entire car; the inferior segment mass it is considered to be included in the automobile mass m_1;

2. the middle segment with mass m_2, which simulates the abdominal area, the thorax area and the arms, and which is considered to have a plan-parallel motion, composed by the translational motion in the longitudinal direction and the rotation arround the joint between the inferior segment and the middle one;

3. the superior segment, with mass m_3, which simulates the occupant's neck and head, and which is considered to have a plan-parallel motion, composed by the translational motion in the longitudinal direction and the rotation arround the joint between the middle segment and the superior one.

In order to simplify the model, it is considered the fact that deformation force of the frontal automobile structure is constant (directly proportional with the its stiffness k_{01}, considered as well, constant) and the fact that the masses of the segments described above are concentrated in their centers of gravity. It is also considered that k_{12} is the stiffness of the joint between the inferior segment and the middle one (the stiffness of the joint between the pelvian area and the abdominal area) and k_{23} is the stiffness of the joint between the middle segment and the superior one (the stiffness of the joint between the thorax area and the neck/head area).

2.2. The equations of motion

For writing the equations of motion of the masses's gravity centers described above, it was started with *Lagrange's equations* for four degrees of freedom systems, considering as generalised coordinates: x_1 (the displacement of body 1 on the direction Ox), θ_2 (the rotation of body 2 around axis Oz) and θ_3 (the rotation of body 3 around axis Oz) [3], [6]:

$$\begin{cases} \dfrac{d}{dt}\left(\dfrac{\partial E_c}{\partial \dot{x}_1}\right) - \dfrac{\partial E_c}{\partial x_1} + \dfrac{\partial V}{\partial x_1} = 0 \\ \dfrac{d}{dt}\left(\dfrac{\partial E_c}{\partial \dot{\theta}_2}\right) - \dfrac{\partial E_c}{\partial \theta_2} + \dfrac{\partial V}{\partial \theta_2} = 0 \\ \dfrac{d}{dt}\left(\dfrac{\partial E_c}{\partial \dot{\theta}_3}\right) - \dfrac{\partial E_c}{\partial \theta_3} + \dfrac{\partial V}{\partial \theta_3} = 0 \end{cases} \quad (1)$$

The system's kinetic energy form is:

$$E_c = \frac{m_1 v_{CG_1}^2}{2} + \frac{m_2 v_{CG_2}^2}{2} + \frac{J_2 \dot{\theta}_2^2}{2} + \frac{m_3 v_{CG_3}^2}{2} + \frac{J_3 \dot{\theta}_3^2}{2} \quad (2)$$

where inertia moments of the segments 2 and 3 have the forms: $J_i = \frac{m_i \cdot l_i^2}{12}$, $i = 2,3$.

The velocities of the gravity centers of the bodies 1, 2 and 3 are:

$$v_{CG_1}^2 = \dot{x}_{CG_1}^2 + \dot{y}_{CG_1}^2 = \dot{x}_1^2 \quad (3)$$

$$v_{CG_2}^2 = \dot{x}_{CG_2}^2 + \dot{y}_{CG_2}^2 \quad (4)$$

where: $\dot{x}_{CG_2} = \dot{x}_1 + \frac{l_2}{2}\dot{\theta}_2 \cos\theta_2$ and $\dot{y}_{CG_2} = -\frac{l_2}{2}\dot{\theta}_2 \sin\theta_2$.

It results: $v_{CG_2}^2 = \dot{x}_1^2 + \frac{l_2^2}{4}\dot{\theta}_2^2 + l_2 \dot{x}_1 \dot{\theta}_2 \cos\theta_2$ (4')

$$v_{CG_3}^2 = \dot{x}_{CG_3}^2 + \dot{y}_{CG_3}^2 \quad (5)$$

where: $\dot{x}_{CG_3} = \dot{x}_1 + l_2\dot{\theta}_2 \cos\theta_2 + \frac{l_3}{2}\dot{\theta}_3 \cos\theta_3$ and $\dot{y}_{CG_2} = -l_2\dot{\theta}_2 \sin\theta_2 - \frac{l_3}{2}\dot{\theta}_3 \sin\theta_3$

It results:

$$v_{CG_3}^2 = \dot{x}_1^2 + +l_2^2\dot{\theta}_2^2 + \frac{l_3^2}{4}\dot{\theta}_3^2 + 2l_2\dot{x}_1\dot{\theta}_2 \cos\theta_2 + l_3\dot{x}_1\dot{\theta}_3 \cos\theta_3 + l_2 l_3 \dot{\theta}_2\dot{\theta}_3 \cos(\theta_2 - \theta_3) \quad (5')$$

By replacing the relations (3), (4') şi (5') in (2), the kinetic energy form becomes:

$$E_c = \frac{1}{2}(m_1 + m_2 + m_3)\dot{x}_1^2 + \left(\frac{m_2 l_2^2}{6} + \frac{m_3 l_2^2}{2}\right)\dot{\theta}_2^2 + \frac{m_3 l_3^2}{6}\dot{\theta}_3^2 + $$
$$+\left(\frac{m_2 l_2}{2} + m_3 l_2\right)\dot{x}_1\dot{\theta}_2 \cos\theta_2 + \frac{m_3 l_3}{2}\dot{x}_1\dot{\theta}_3 \cos\theta_3 + \frac{m_3 l_2 l_3}{2}\dot{\theta}_2\dot{\theta}_3 \cos(\theta_2 - \theta_3) \quad (6)$$

The system's potential energy form is:

$$V = \frac{m_2 l_2 g}{2}\cos\theta_2 + m_3 l_2 \cos\theta_2 + \frac{m_3 l_3 g}{2}\cos\theta_3 + \frac{k_{01}x_1^2}{2} + \frac{k_{12}\theta_2^2}{2} + \frac{k_{23}(\theta_3 - \theta_2)^2}{2} \quad (7)$$

As following, it is calculated the expresions which are involved in the relation (1):
$\frac{d}{dt}\left(\frac{\partial E_c}{\partial \dot{x}_1}\right)$, $\frac{d}{dt}\left(\frac{\partial E_c}{\partial \dot{\theta}_2}\right)$, $\frac{d}{dt}\left(\frac{\partial E_c}{\partial \dot{\theta}_3}\right)$, $\frac{\partial E_c}{\partial x_1}$, $\frac{\partial E_c}{\partial \theta_2}$, $\frac{\partial E_c}{\partial \theta_3}$, $\frac{\partial V}{\partial x_1}$, $\frac{\partial V}{\partial \theta_2}$ and $\frac{\partial V}{\partial \theta_3}$.

We have:

$$\frac{d}{dt}\left(\frac{\partial E_c}{\partial \dot{x}_1}\right) = (m_1 + m_2 + m_3)\ddot{x}_1 + \left(\frac{m_2 l_2}{2} + m_3 l_2\right)\left(\ddot{\theta}_2 \cos\theta_2 - \dot{\theta}_2^2 \sin\theta_2\right) + $$
$$+\frac{m_3 l_3}{2}\left(\ddot{\theta}_3 \cos\theta_3 - \dot{\theta}_3^2 \sin\theta_3\right) \quad (8)$$

$$\frac{d}{dt}\left(\frac{\partial E_c}{\partial \dot{\theta}_2}\right)=\left(\frac{m_2 l_2^2}{3}+m_3 l_2^2\right)\ddot{\theta}_2+\left(\frac{m_2 l_2}{2}+m_3 l_2\right)\left(\ddot{x}_1\cos\theta_2-\dot{x}_1\dot{\theta}_2\sin\theta_2\right)+ \\ +\frac{m_3 l_2 l_3}{2}\left[\ddot{\theta}_3\cos(\theta_2-\theta_3)+\dot{\theta}_3\left(\dot{\theta}_3-\dot{\theta}_2\right)\sin(\theta_2-\theta_3)\right] \tag{9}$$

$$\frac{d}{dt}\left(\frac{\partial E_c}{\partial \dot{\theta}_3}\right)=\frac{m_3 l_3^2}{3}\ddot{\theta}_3+\frac{m_3 l_3}{2}\left(\ddot{x}_1\cos\theta_3-\dot{x}_1\dot{\theta}_3\sin\theta_3\right)+ \\ +\frac{m_3 l_2 l_3}{2}\left[\ddot{\theta}_2\cos(\theta_2-\theta_3)+\dot{\theta}_2\left(\dot{\theta}_3-\dot{\theta}_2\right)\sin(\theta_2-\theta_3)\right] \tag{10}$$

$$\frac{\partial E_c}{\partial x_1}=0 \tag{11}$$

$$\frac{\partial E_c}{\partial \theta_2}=-\left(\frac{m_2 l_2}{2}+m_3 l_2\right)\dot{x}_1\dot{\theta}_2\sin\theta_2-\frac{m_3 l_2 l_3}{2}\dot{\theta}_2\dot{\theta}_3\sin(\theta_2-\theta_3) \tag{12}$$

$$\frac{\partial E_c}{\partial \theta_3}=-\frac{m_3 l_3}{2}\dot{x}_1\dot{\theta}_3\sin\theta_3+\frac{m_3 l_2 l_3}{2}\dot{\theta}_2\dot{\theta}_3\sin(\theta_2-\theta_3) \tag{13}$$

$$\frac{\partial V}{\partial x_1}=k_{01}x_1 \tag{14}$$

$$\frac{\partial V}{\partial \theta_2}=-\left(\frac{m_2 l_2 g}{2}+m_3 l_2 g\right)\sin\theta_2+k_{12}\theta_2-k_{23}(\theta_3-\theta_2) \tag{15}$$

$$\frac{\partial V}{\partial \theta_3}=-\frac{m_3 l_3 g}{2}\sin\theta_3+k_{23}(\theta_3-\theta_2) \tag{16}$$

By replacing the forms (8), (9),…, (16) in the relations (1), it is obtained the next system:

$$\begin{cases} (m_1+m_2+m_3)\ddot{x}_1+\left(\frac{m_2 l_2}{2}+m_3 l_2\right)\left(\ddot{\theta}_2\cos\theta_2-\dot{\theta}_2^2\sin\theta_2\right)+\frac{m_3 l_3}{2}\left(\ddot{\theta}_3\cos\theta_3-\dot{\theta}_3^2\sin\theta_3\right)+k_{01}x_1=0 \\ \left(\frac{m_2 l_2^2}{3}+m_3 l_2^2\right)\ddot{\theta}_2+\left(\frac{m_2 l_2}{2}+m_3 l_2\right)\left(\ddot{x}_1\cos\theta_2-\dot{x}_1\dot{\theta}_2\sin\theta_2\right)+\frac{m_3 l_2 l_3}{2}\begin{bmatrix}\ddot{\theta}_3\cos(\theta_2-\theta_3)+ \\ +\dot{\theta}_3\left(\dot{\theta}_3-\dot{\theta}_2\right)\sin(\theta_2-\theta_3)\end{bmatrix}+ \\ +\left(\frac{m_2 l_2}{2}+m_3 l_2\right)\dot{x}_1\dot{\theta}_2\sin\theta_2+\frac{m_3 l_2 l_3}{2}\dot{\theta}_2\dot{\theta}_3\sin(\theta_2-\theta_3)-\left(\frac{m_2 l_2 g}{2}+m_3 l_2 g\right)\sin\theta_2+k_{12}\theta_2-k_{23}(\theta_3-\theta_2)=0 \\ \frac{m_3 l_3^2}{3}\ddot{\theta}_3+\frac{m_3 l_3}{2}\left(\ddot{x}_1\cos\theta_3-\dot{x}_1\dot{\theta}_3\sin\theta_3\right)+\frac{m_3 l_2 l_3}{2}\left[\ddot{\theta}_2\cos(\theta_2-\theta_3)+\dot{\theta}_2\left(\dot{\theta}_3-\dot{\theta}_2\right)\sin(\theta_2-\theta_3)\right]+ \\ +\frac{m_3 l_3}{2}\dot{x}_1\dot{\theta}_3\sin\theta_3-\frac{m_3 l_2 l_3}{2}\dot{\theta}_2\dot{\theta}_3\sin(\theta_2-\theta_3)-\frac{m_3 l_3 g}{2}\sin\theta_3+k_{23}(\theta_3-\theta_2)=0 \end{cases} \tag{17}$$

2.3. The solving of equations of motion

The system (17) must be putted in a integrable form through the Runge-Kutta method of fourth order. To obtain this, we work on the system untill it becomes:

$$\begin{cases} (m_1+m_2+m_3)\ddot{x}_1+\left(\frac{m_2l_2}{2}+m_3l_2\right)\cos\theta_2\ddot{\theta}_2+\frac{m_3l_3}{2}\cos\theta_3\ddot{\theta}_3= \\ =\left(\frac{m_2l_2}{2}+m_3l_2\right)\dot{\theta}_2^2\sin\theta_2+\frac{m_3l_3}{2}\dot{\theta}_3^2\sin\theta_3-k_{01}x_1 \\ \left(\frac{m_2l_2}{2}+m_3l_2\right)\cos\theta_2\ddot{x}_1+\left(\frac{m_2l_2^2}{3}+m_3l_2^2\right)\ddot{\theta}_2+\frac{m_3l_2l_3}{2}\cos(\theta_2-\theta_3)\ddot{\theta}_3= \\ =\frac{m_3l_2l_3}{2}\dot{\theta}_3^2\sin(\theta_3-\theta_2)+\left(\frac{m_2l_2g}{2}+m_3l_2g\right)\sin\theta_2-k_{12}\theta_2+k_{23}(\theta_3-\theta_2) \\ \frac{m_3l_3}{2}\cos\theta_3\ddot{x}_1+\frac{m_3l_2l_3}{2}\cos(\theta_2-\theta_3)\ddot{\theta}_2+\frac{m_3l_3^2}{3}\ddot{\theta}_3= \\ =\frac{m_3l_2l_3}{2}\dot{\theta}_2^2\sin(\theta_2-\theta_3)+\frac{m_3l_3g}{2}\sin\theta_3-k_{23}(\theta_3-\theta_2) \end{cases} \quad (18)$$

The system (18) is one which has the following form:

$$\begin{cases} a_{11}\ddot{x}_1+a_{12}\ddot{\theta}_2+a_{13}\ddot{\theta}_3=f_{11}(x_1,\theta_2,\theta_3,\dot{x}_1,\dot{\theta}_2,\dot{\theta}_3) \\ a_{21}\ddot{x}_1+a_{22}\ddot{\theta}_2+a_{23}\ddot{\theta}_3=f_{21}(x_1,\theta_2,\theta_3,\dot{x}_1,\dot{\theta}_2,\dot{\theta}_3) \\ a_{31}\ddot{x}_1+a_{32}\ddot{\theta}_2+a_{33}\ddot{\theta}_3=f_{31}(x_1,\theta_2,\theta_3,\dot{x}_1,\dot{\theta}_2,\dot{\theta}_3) \end{cases} \quad (19)$$

The system (19) is one which has the following matricial form:

$$[A]\cdot[\ddot{Z}]=[F] \quad (20)$$

where:

$$[\ddot{Z}]=[\ddot{x}_1 \quad \ddot{\theta}_2 \quad \ddot{\theta}_3]^T \quad (21)$$

$$[A]=\begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix}=\begin{bmatrix} (m_1+m_2+m_3) & \left(\frac{m_2l_2}{2}+m_3l_2\right)\cos\theta_2 & \frac{m_3l_3}{2}\cos\theta_3 \\ \left(\frac{m_2l_2}{2}+m_3l_2\right)\cos\theta_2 & \left(\frac{m_2l_2^2}{3}+m_3l_2^2\right) & \frac{m_3l_2l_3}{2}\cos(\theta_2-\theta_3) \\ \frac{m_3l_3}{2}\cos\theta_3 & \frac{m_3l_2l_3}{2}\cos(\theta_2-\theta_3) & \frac{m_3l_3^2}{3} \end{bmatrix} \quad (22)$$

$$[F]=\begin{bmatrix} f_{11} \\ f_{21} \\ f_{31} \end{bmatrix}=\begin{bmatrix} \left(\frac{m_2l_2}{2}+m_3l_2\right)\dot{\theta}_2^2\sin\theta_2+\frac{m_3l_3}{2}\dot{\theta}_3^2\sin\theta_3-k_{01}x_1 \\ \frac{m_3l_2l_3}{2}\dot{\theta}_3^2\sin(\theta_3-\theta_2)+\left(\frac{m_2l_2g}{2}+m_3l_2g\right)\sin\theta_2-k_{12}\theta_2+k_{23}(\theta_3-\theta_2) \\ \frac{m_3l_2l_3}{2}\dot{\theta}_2^2\sin(\theta_2-\theta_3)+\frac{m_3l_3g}{2}\sin\theta_3-k_{23}(\theta_3-\theta_2) \end{bmatrix} \quad (23)$$

where: $f_{j1}=f_{j1}(x_1,\theta_2,\theta_3,\dot{x}_1,\dot{\theta}_2,\dot{\theta}_3)$, $j=1,2,3$.

The solution is: $[\ddot{Z}]=[A]^{-1}*[F]$, which is going to be obtained using *Symbolic Math Toolbox* of the *Matlab* software. Doing the notations: $x_1=y(1)$; $\theta_2=y(2)$; $\theta_3=y(3)$; $\dot{x}_1=y(4)$; $\dot{\theta}_2=y(5)$; $\dot{\theta}_3=y(6)$ and taking into consideration the expressions of $\ddot{x}_1$, $\ddot{\theta}_2$ and $\ddot{\theta}_3$ obtained as it was described above, it is formed the system of differential equations like below, which has a integrable form through the Runge-Kutta method of fourth order.

$$\begin{cases} dy(1) = y(4) = \dot{x}_1 \\ dy(2) = y(5) = \dot{\theta}_2 \\ dy(3) = y(6) = \dot{\theta}_3 \\ dy(4) = \ddot{x}_1 \\ dy(5) = \ddot{\theta}_2 \\ dy(6) = \ddot{\theta}_3 \end{cases} \tag{24}$$

Solving the system of equations above, between the integration limits [0; 0,1], considering the next values for the parameters whis are involved in the relations:
$m_1 = m_{automobile} + 2 \cdot (m_{upper\ leg} + m_{lower\ leg} + m_{foot}) = 1000 + 2 \cdot (7{,}4 + 4{,}16 + 1{,}78) = 1026{,}68\ kg$;
$m_2 = m_{abdomen} + m_{thorax} + 2 \cdot (m_{upper\ arm} + m_{lower\ arm} + m_{hand}) =$
$= 18{,}5 + 17{,}5 + 2 \cdot (2{,}76 + 1{,}67 + 0{,}6) = 46{,}06\ kg$; $m_3 = m_{head} + m_{neck} = 4{,}5 + 1{,}02 = 5{,}52\ kg$;
k_{01}=800000 N/m; k_{12}=380 Nm/rad; k_{23}=200 Nm/rad; l_2=0,427 m; l_3=0,240 m, g=9,81 m/s^2
and the initial conditions: $x_{10} = 0$; $\theta_{20} = 0$; $\theta_{30} = 0$; $\dot{x}_{10} = 15\ m/s$; (the initial velocity of the automobile just before the frontal impact (54 km/h)), $\dot{\theta}_{20} = 0$; $\dot{\theta}_{30} = 0$ are obtained the time history curves of the kinematic parameters of the bodies 1, 2 and 3. The masses's values of the human body's segments chosen in this example, are the ones which correspond to a Hybrid III 50th crash test dummy [3], [4], [5].

3. THE SIMMECHANICS OCCUPANT MODEL

SimMechanics is a *Matlab* toolbox dedicated to model dynamics of multibody systems. It is based on the graphical simulation environment *Simulink* and it provides a physical modeling blockset, and tools for visualization and analysis of mechanical systems. *SimMechanics* is a block diagram modeling environment for the engineering design and simulation of rigid body machines and their motions, using the standard Newtonian dynamics of forces and torques. Using *SimMechanics*, it can be modeled and simulated mechanical systems with a suite of tools to specify bodies and their mass properties, their possible motions, kinematic constraints, and coordinate systems, and to initiate and measure body motions. It can be represented a mechanical system by a connected block diagram, like other *Simulink* models, and it can incorporate hierarchical subsystems. The visualization tools of *SimMechanics* display and animate simplified representations of 3-D machines, before and during simulation [8].

3.1. The description of the model

The following *SimMechanics* model is similar with the analytical model presented above, having the same parameters (masses, lenghts, stiffnesses) and initial conditions. In figure 2 is presented the developed model's block diagram in which the elements have the following signification:

Body 1: represents the first body of the mathematical model with mass m_1, composed by the automobile's mass, the legs mass and the pelvian area mass. This body has a translational motion, along the Ox-axis, the link between the ground and *Body 1* is made through a prismatic type joint (*Prismatic* in figure 2, with the translation Ox-axis), with stiffness k_{01}=800000 N/m, which represents the stiffness of the frontal automobile structure which is deformed during the frontal impact. By *Body Sensor 1*, connected to *Body 1*, there are recorded three signals: the displacement *x1*, the velocity *v1* and the acceleration *a1* of *Body 1*, with respect to *World Coordinate System,* along Ox-axis, which are then displayed on *Scope 1*;

Body 2: represents the middle segment with mass m_2 in the mathematical model, composed by abdominal area mass, the thorax area mass and the arms mass. *Body 2* has a rotational motion with respect to *Body 1*, arround the connection point between the two of them (the gravity center of body 1 and the top-down point of body 2). The connection between *Body 1* and *Body 2* is made through a revolute type joint (*Revolute 1* in figure 2, with the rotation Oz-axis), with stiffness k_{12}=380 Nm/rad (which represents the stiffness of the joint between the pelvian area and the abdominal area). By *Joint Sensor 2*, connected to *Revolute 1* joint is recorded the angular displacement of *Body 2*, with respect to *World Coordinate System*, *teta2*, which is then displayed on *Scope 2',* after it was changed their sign with the help of *Dot Product 1* block, because in the model *SimMechanics*, the positive sense of rotation is considered to be the trigonometric one. By *Body Sensor 2*, connected to *Body 2* are recorded the signals angular velocity *omega2* and angular acceleration *epsilon2* of *Body 2* with respect to *World Coordinate System* then these are displayed on *Scope 2* with changed sign, by *Product 1* block.

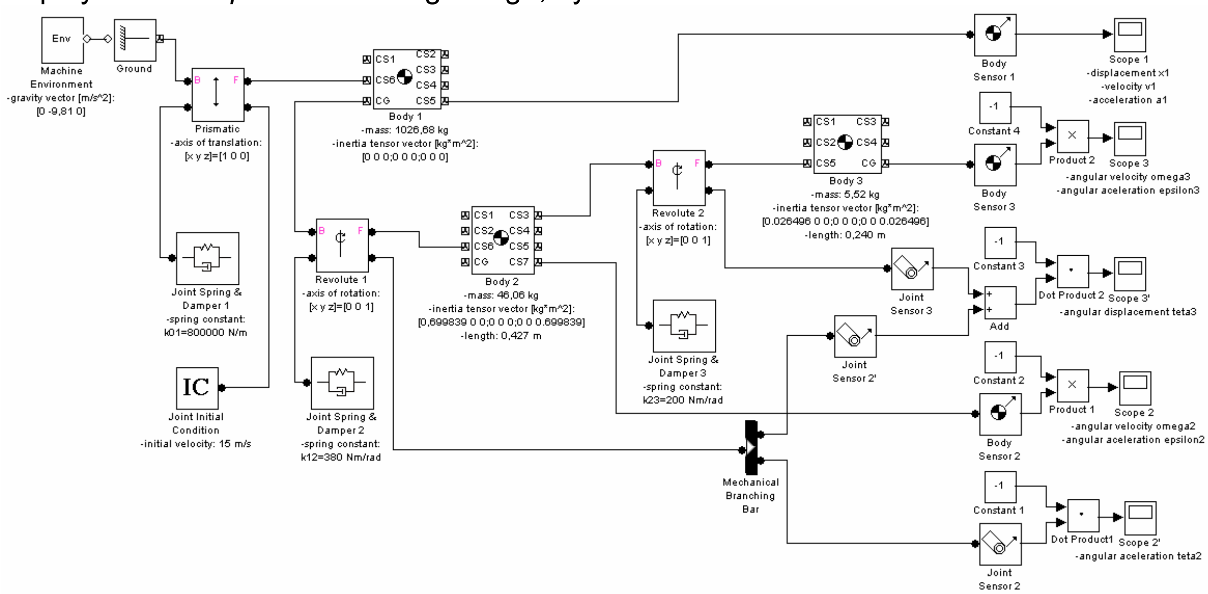


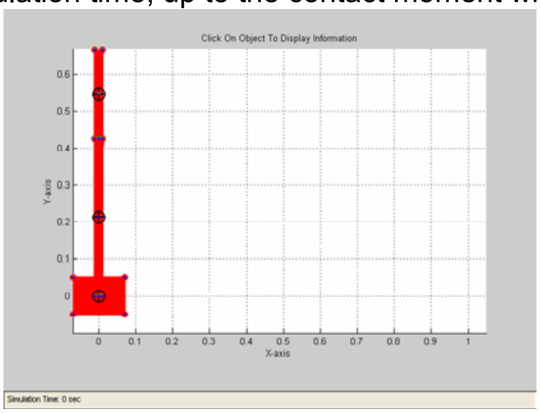
Figure 2. The block diagram of the SimMechanics model.

Body 3: represents the upper segment with mass m_3 in the mathematical model, composed by neck mass and head mass. *Body 3* has a rotational motion with respect to *Body 2*, arround the connection point between the two of them (the top point of *Body 2* and the top-down point of *Body 3*). The connection between *Body 2* and *Body 3* is made through a revolute type joint (*Revolute 2* in figure 2, with the rotation Oz-axis), with stiffness k_{23}=200 Nm/rad (which represents the stiffness of the joint between the thorax area the neck and head area). By *Joint Sensor 2'*, connected to *Revolute 1* joint is recorded the angular displacement of *Body 2*, with respect to *World Coordinate System*, which is then added (with *Add Block*, in figure 2) to signal recorded by *Joint Sensor 3*, connected to the joint *Revolute 2,* which records the angular displacement of *Body 3* with respect to *Body 2,* and the result of the adding operation, which represents the angular displacement of *Body 3* with respect to *World Coordinate System*, *teta3*, is then displayed on *Scope 3.',* with changed sign, by *Dot Product 2* block*. Body Sensor 3* records the angular velocity *omega3* and the angular acceleration *epsilon3* of *Body 3*, which are then dispayed on *Scope 3,* with changed sign, by *Product 2* block.

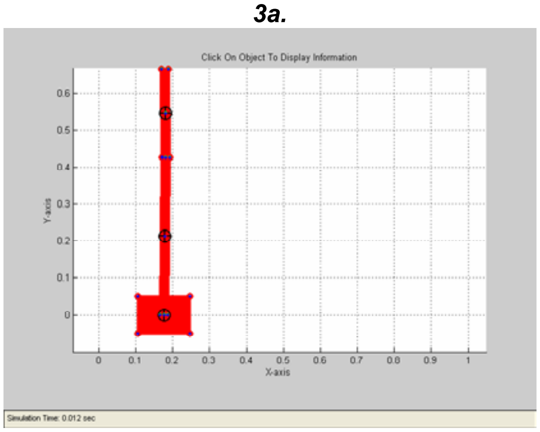
Machine Environment Block defines the mechanical environment for the machine, to which the block is connected gravity (g = 9,81 m/s^2). *Ground Block* grounds one side of *Prismatic Joint* to a fixed location in the *World Coordinate System*. *Joint Initial Condition Block IC* sets the initial linear velocity of the *Prismatic Joint* (with the translational Ox-axis), representing the initial velocity of translation of *Body 1* along Ox-axis (54 km/h = 15 m/s, before the frontal impact).

3.3. Simulation results

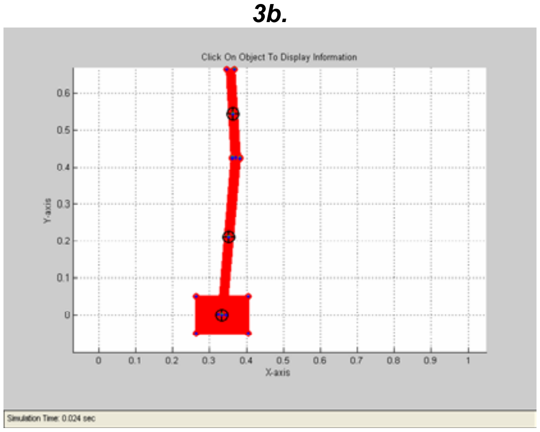
With the developed model it was simulated the motion of the bodies's system, during the period of time [0; 0,1] seconds. In figure 3, there are presented the succesive positions of the bodies at six different moments in time, at equal time intervals, durind the simulation time, up to the contact moment with the instrument panel (IP).



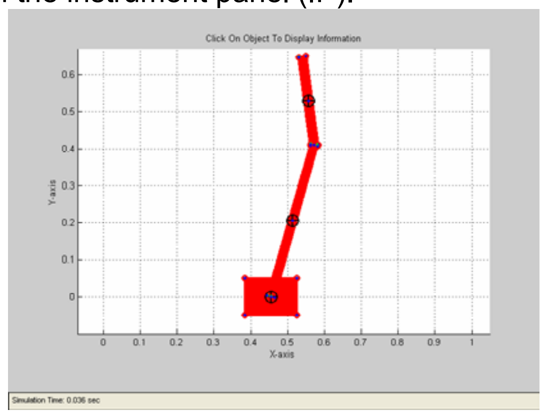
3a.



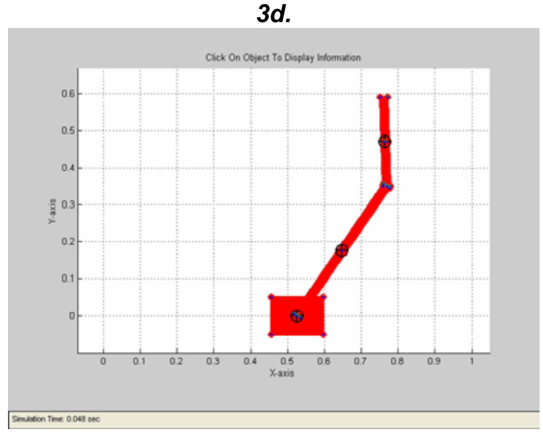
3b.



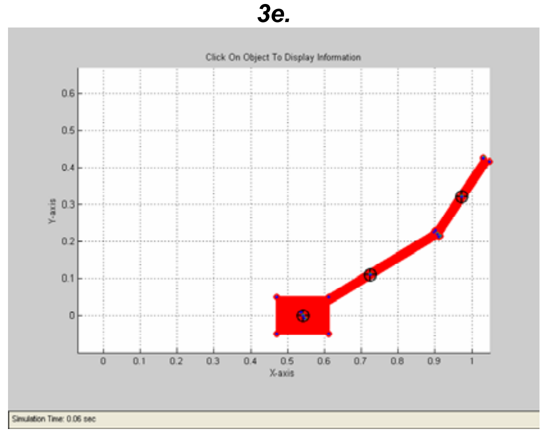
3c.



3d.



3e.

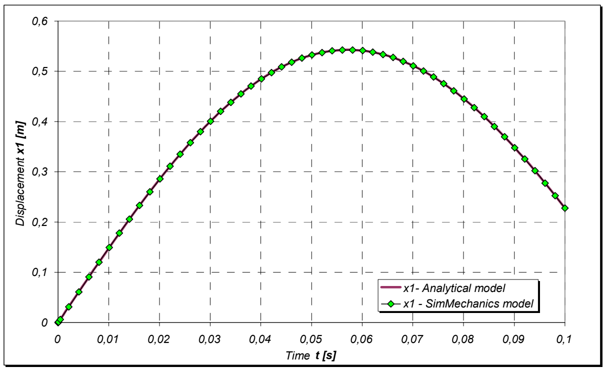


3f.

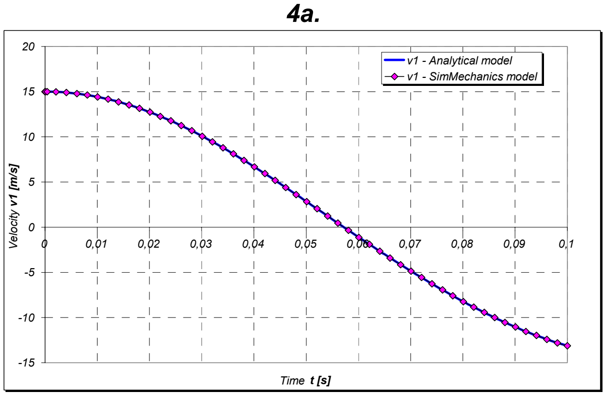
Figure 3. Six succesive positions of bodies's system up to the contact moment with the IP.

4. RESULTS AND CONCLUSIONS

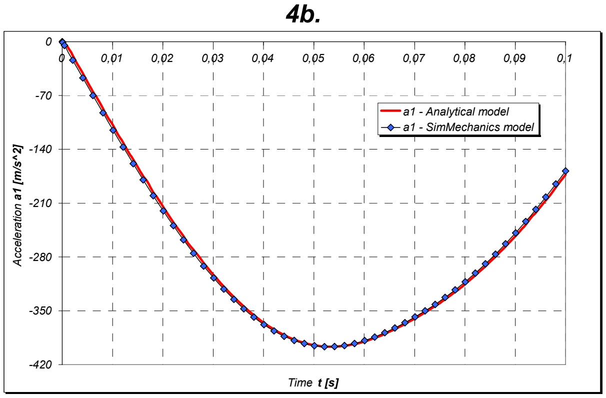
In figures 4 and 5 there are presented comparatively the time history curves of kinematic parameters of the three bodies's motions, developed with analytical model and with the *SimMechanics* model, both presented above. It is observed that all nine curves are one above the correspondent other one, fact that represents the validation of the *SimMechanics* model, which is based on the graphical simulation environment *Simulink*.



4a.



4b.



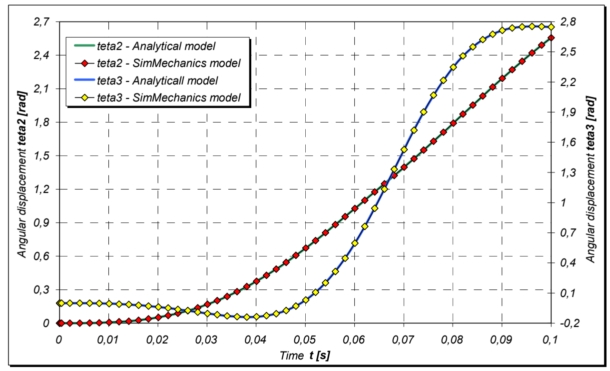
4c.

Figure 4. The time-history curves of the kinematic parameters of body 1.

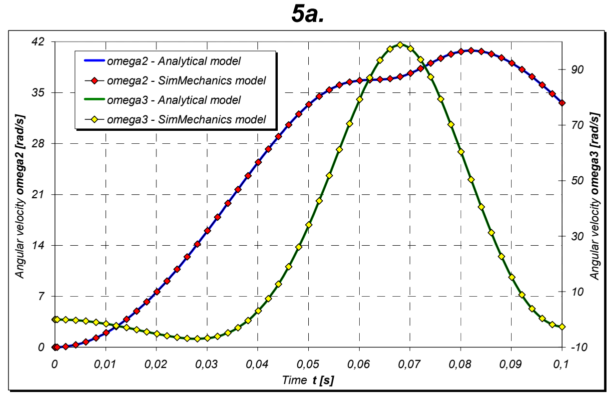
4a – displacement x_1***;***

4b – velocity v_1***;***

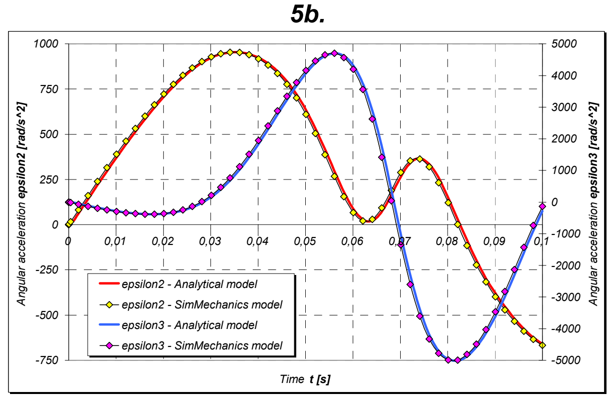
4c – acceleration a_1***.***



5a.



5b.



5c.

Figure 5. The time-history curves of the kinematic parameters of bodies 2 and 3.

5a – angular displacements θ_2 ***and*** θ_3***;***

5b – angular velocities ω_2 ***and*** ω_3***;***

5c – angular accelerations ε_2 ***and*** ε_3***.***

In a model of occupant's head impact with the instrument panel, developed by the authors, knowing the initial velocity of the head's center of gravity (in the local coordinate system, connected to the automobile) is indispensable. With the help of the models presented above, it is relatively easy to find the exact value of this parameter, in different conditions of simulations, related to the automobile's initial speed before impact, the impact energy dissipation automobile's characteristics, the passenger's anthropometric characteristics, the position of the occupant in the interior, in the absence of the restraint system(s), etc.

According to relation (5'), the velocity of the body 3's center of gravity in the local coordinate system connected to the body 1, which is the initial velocity of the head before the impact with the instrument panel, is obtained with the next relation:

$$v_{CG_3} = \sqrt{l_2^2\dot{\theta}_2^2 + \frac{l_3^2}{4}\dot{\theta}_3^2 + l_2 l_3 \dot{\theta}_2 \dot{\theta}_3 \cos(\theta_2 - \theta_3)} \quad (25)$$

and the time-history evolution of this velocity is presented in figure 6.

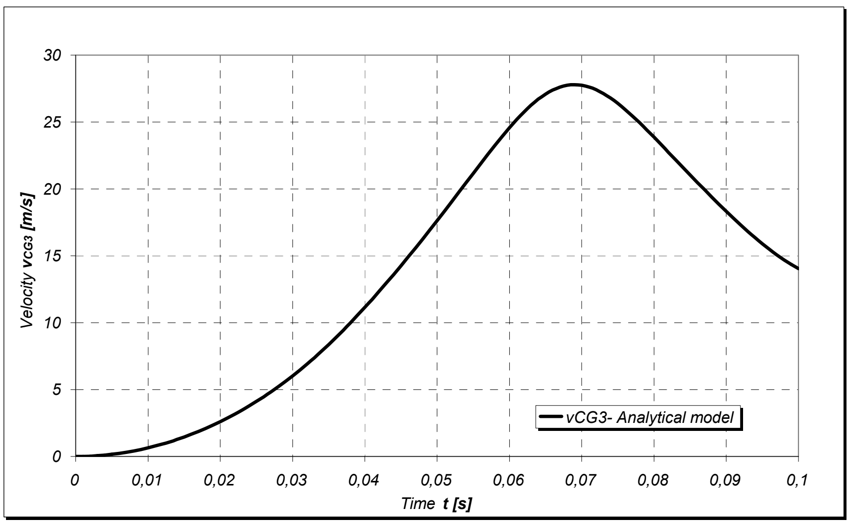


Figure 6. The time-history of the velocity of body's 3 center of gravity, with respect to local coordinate system, connected to the automobile.

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