

# The development of a virtual dummy for the vibrational comfort analysis of car drivers

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## **Abstract**

Most of human vibration models for seat-driver simulation are linear and do not take into account the real three-dimensional posture. Finite element models are also available, but they require a large amount of data. Moreover, these data are not readily adapted from anthropometric databases. A theoretical multibody model, where the human body is described in terms of rigid bodies, joints and lumped spring-dampers elements, is described in this paper. The model has been validated by comparing numerical results with experimental tests carried at Centro Ricerche Fiat and other research centers.

**Key words:** Vibrational comfort analysis, Car driver simulation, Human body model.

# 1 Introduction

With the purpose of analyzing vibrational behaviour of the man-seat system, a multibody model has been developed. Because of the reduced amount data required, linear models are almost a standard in this field [1]. However, they have limited capabilities in reproducing the change of posture and do not provide reliable results for certain types of excitation. Technical literature records also finite elements models, but the data from anthropometric databases are not readily available in a form suitable for this type of analysis.

Although virtual dummies developed with multibody techniques are widely used for crash simulation (e.g. [2]), there is little evidence on the use of these models for the analysis of the vibrational comfort of car drivers [3].

In our model, named with the acronym DAViD (Dynamic Automotive Virtual Dummy), the human body has been splitted into seventeen rigid parts with 3D motion. Standard kinematic pairs simulate the articulation of bones. The muscles and the elasticity of the body-seat contact have been lumped with traslational and rotational spring-damper elements. The model is completely parametric and can be scaled to simulate a significant portion of european population. The main geometric features of the subjects analyzed are taken from an existing anthropometric database.

The paper reports also a comparison between results of the proposed model and those experimentally obtained at Centro Ricerche Fiat and by other researchers.

## 2 Computational tools

The equations of motion were obtained with the help of SymDyn3D [4], a multibody dynamics software for the generation, in symbolic form, of the equations of motion.

SymDyn3D, developed at University of Rome Tor Vergata, has the following relevant features:

- use Euler-parameters for the description of body attitude;
- kinematic pairs are described through the method of constraints [5];
- use a lagrangian formulation, thus the DAE of motion are set in the

following index 3 form:

$$[M] \{\ddot{q}\} + [\Psi_q]^T \{\lambda\} = \{Q\} , \quad (1a)$$

$$\{\Psi(q, t)\} = \{0\} , \quad (1b)$$

where  $[M]$  is the mass matrix,  $\{q\}$  is the vector of generalized coordinates,  $\{Q\}$  is the vector of generalized forces,  $\{\lambda\}$  is the vector of Lagrange's multipliers,  $\{\Psi\}$  is the vector of constraints.

- the user has the possibility to formulate the DAE system (1) with a specified differentiation index (2 or 1);
- generate automatically the main Fortran source and accessory subroutines required to run the numerical simulation;
- in the present version the Fortran output is geared toward the use of RADAU5 [8], a Fortran subroutine for the integration of stiff DAE systems.

## 2.1 Graphical post-processing

SymDyn3D has been integrated with an *ad hoc* developed visualization software. This software, named ViR3D and written in Visual Basic, makes use of OPEN GL graphical libraries. In particular, after the numerical run, ViR3D loads all the output data files (one for each body of the model) and visualizes the motion of the bodies.

The software has also the capability to track trajectories and visualize vector velocities of prescribed reference points.

## 3 Outline of the human body model

The model, developed by means of a multibody dynamics approach, is composed of the following rigid parts: head, neck, chest, shoulders, arms, fore-arms, abdomen, pelvis, thighs, legs and feet [9, 10].

However, chest, arms, neck and head are constrained together to form a rigid body. The remaining parts are constrained by means of revolute or prismatic pairs.

The mass and its distribution on the different parts of the body depends on the percentile of population under analysis. Moreover, the upper part of the mannequin has always an ergonomically correct posture.

The posture parameters match the standards normally adopted at Centro Ricerche Fiat during the use of test rig **SEDYA**.

In particular, it is required that the subject under test has:

- a backrest inclination of  $23^\circ$ ;
- an angle leg-tigh of  $117^\circ$ ;
- a foot inclination w.r.t. the horizontal of  $20^\circ$ ;
- the hands laying down smoothly on top of the tighs

As an option, the computer model can handle also the posture of a driver with the hands on the steer wheel.

### **3.1 Bodies and constraints**

The joints between the bodies are shown in Figure 1. Each body articulation has been substituted by standard kinematic pairs. However, a more accurate model would require a careful analysis of the real relative motion between adjacent bodies [2].

In this version, the model has:

- two revolute joints, with transverse axes, between arms and forearms;
- one prismatic pair with longitudinal axis between abdomen and pelvis;
- two revolute pairs with transverse axes between pelvis and tighs;
- two revolute pairs with transverse axes between legs and feets;
- one prismatic pair with vertical or horizontal axis between the seat and the car chassis.

The following rheonomic constraints are also imposed:

- $20^\circ$  constant inclination of both feets w.r.t. the chassis plane;
- one driving constraint specifying the motion of the chair w.r.t.

The model has 11 degrees-of-freedom.

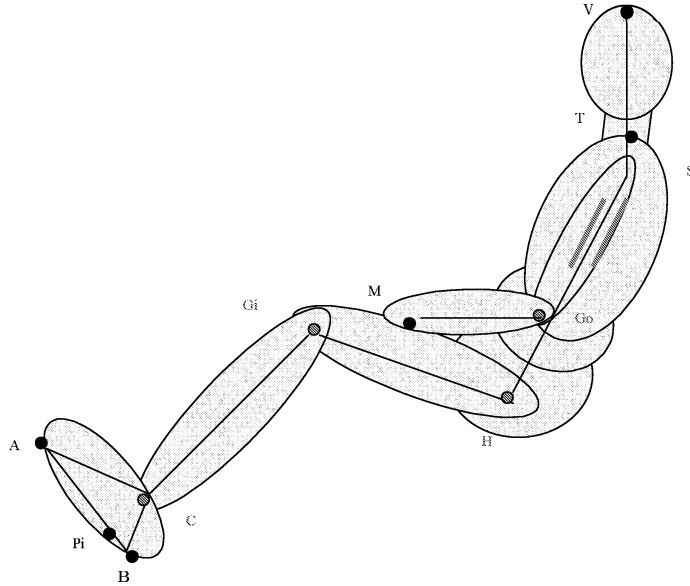


Figure 1: Lateral view of the virtual dummy

The interaction between the upper part of chest and the pelvis, is modeled by means of a linear spring-damper element.

### 3.2 Spring-damper elements

The contacts between body parts and the seat are modeled by means of spring-damper elements. The location of attachment points for such elements, stiffness and damping coefficients are obtained by interpreting the pressure maps experimentally obtained by means of mats manufactured by Tekscan (Figure 3).

The position of spring-dampers elements also depends on the population percentile under analysis.

Four spring-damper elements represent the distributed contact between body and cushion seat, whereas two spring-damper elements connect the backrest to the body (see Figure 2).

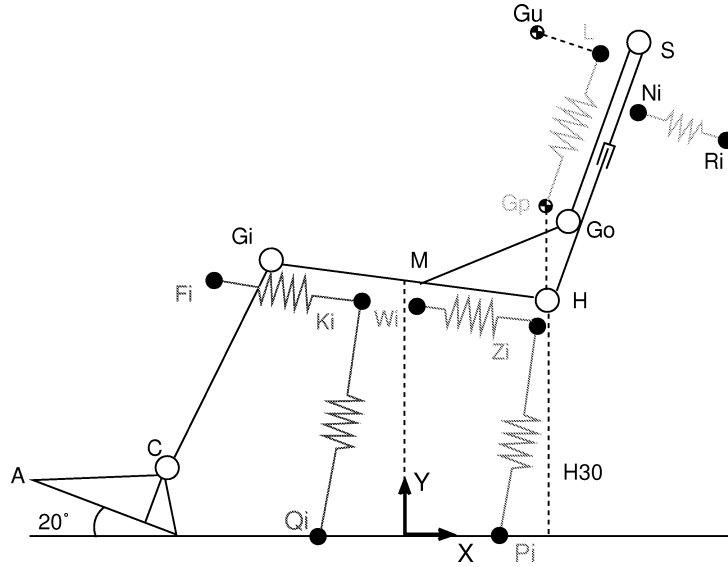


Figure 2: Position of spring-damper elements

There is another spring-damper element (not shown in the Figure 2) for the contact hand-tigh. The vertical stiffness of the torso is modeled by means of a spring-damper element connecting the pelvis with the chest.

Spring-damper element	Stiffness (N/m)	Damping coeff. (N·s/m)
Seat cushion-tigh $\perp$	11000	47
Seat cushion-tigh $\parallel$	10000	50
Seat cushion-buttock $\perp$	37000	140
Seat cushion-buttock $\parallel$	10000	50
Foot-chassis (horiz.)	50000	50
Foot-chassis (vert.)	10000	50
Chest-pelvis	48000	1000
Back-backrest	37000	140
Hand-tigh $\perp$	100000	50
Hand-tigh $\parallel$	25000	50

Table 1: Spring-damper elements coefficients

In Table 1 the main parameters of the spring-damper elements have been

summarized. These data have been obtained from different sources such as technical literature, experimental static and dynamic tests at CRF and seat manufacturers.

## 4 Experimental tests

The validation of the model was made by means of experimental tests at Centro Ricerche Fiat. These test can be classified as follows:

- static tests, required for the identification of body pressures on the seat cushioning of subjects with different anthropometric features.
- vibrational tests, for the acquisition of the dynamic response (indices S.E.A.T., FRF, RMS, etc.) along the vertical and longitudinal directions, under harmonic or road input

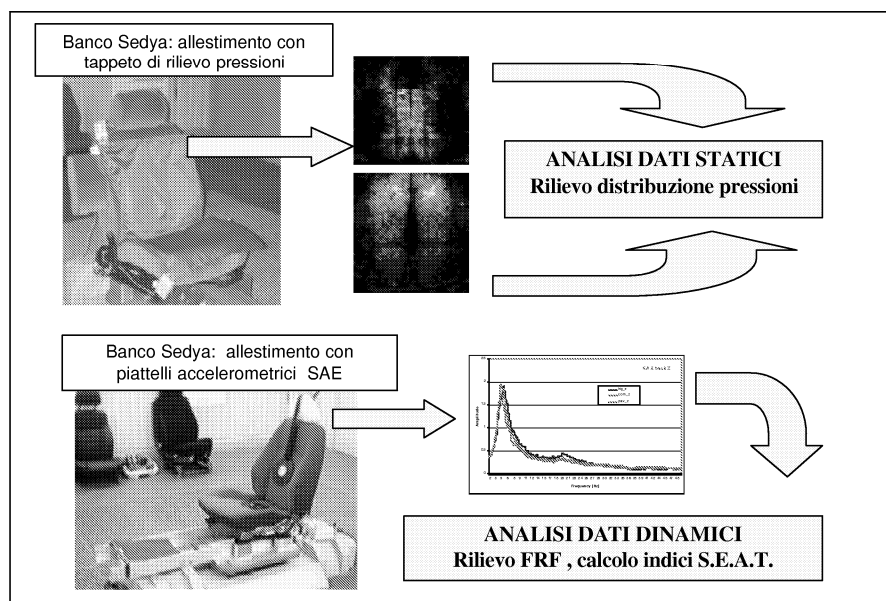


Figure 3: Experimental tests

## 5 Numerical results

The results herein reported are referred to a subject which belong to the 50<sup>th</sup> percentile and with the values of lumped viscoelastic parameters summarized in Table 1.

The model has been validated by comparing the plots of experimental and numerically computed longitudinal and vertical transmissibilities. Some of these plots have been experimentally obtained by means of the test rig *Sedya* of Centro Ricerche Fiat. Some others are taken from existing literature.

The seat has an harmonic law of displacement with an amplitude of 0.05 m, for the low frequencies (0.5, 1, 2, 3, 4 Hz), e 0.01 m for the high frequencies (5, 7, 10, 15 Hz).

For longitudinal displacements the amplitude is 0.03 m.

The transmissibilities have been obtained as a ratio between output and input amplitudes. The response has been experimentally measured, by means of accelerometers, at the tighs and at the chest

1. Vertical transmissibility of the tighs under a vertical input

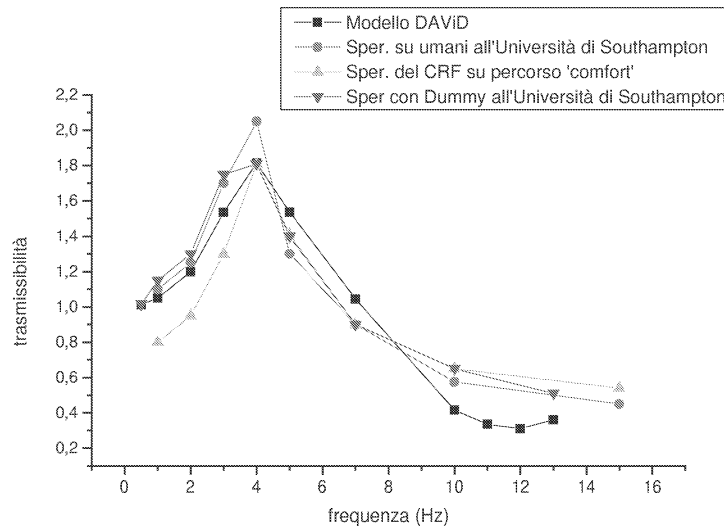


Figure 4: Comparison of DAViD and experimental tests: vertical transmissibilities of the tighs for a vertical input.

The computed plot of the vertical transmissibility shows a peak at 4 Hz and is in acceptable agreement with the transmissibilities measured

at Centro Ricerche Fiat and at University of Southampton. The differences may be due to the placement of accelerometers.

- Horizontal transmissibility of the chest for an horizontal input (See Figure 5)

Also in this case there is an agreement between computed and experimental transmissibility curves.

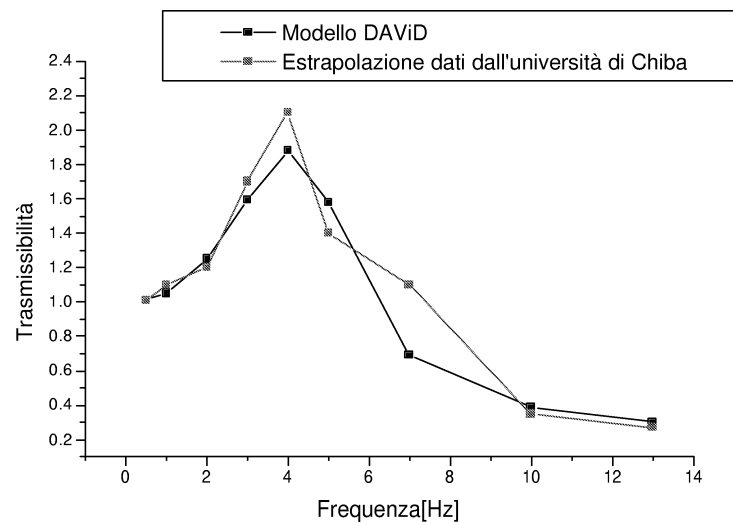


Figure 5: Comparison of DAViD and experimental tests at Chiba university [1]: Horizontal transmissibilities at the chest under an horizontal input

The influence of the geometric nonlinearity of the model on the numerical results can be appreciated from the analysis of Figure 6. In this Figure the it is shown the difference of transmissibility due to the variation of input amplitude.

## 6 Conclusions

It has been developed a multibody model for the vibrational analysis of the interface passenger-car seat.

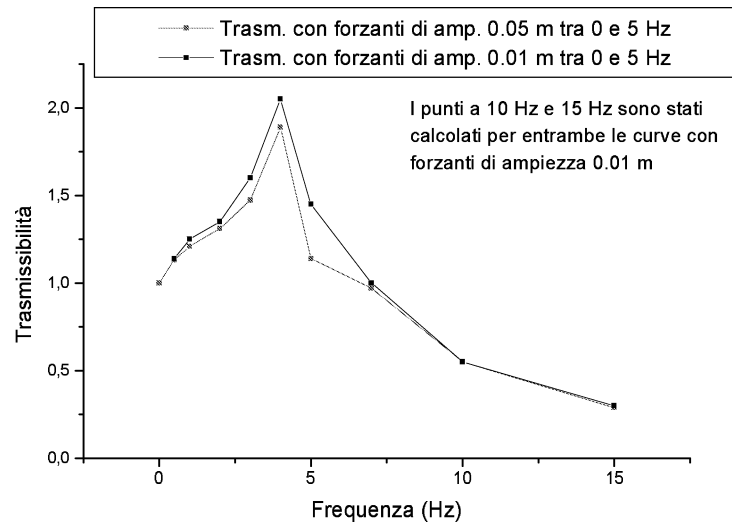


Figure 6: Vertical transmissibility of tighs for a vertical input

This model can be used for parametric analyses of the response of passengers with different anthropometric features and postures.

The multibody approach demonstrated its feasibility when simulating the vibrational response of passengers.

At this time the validation has been limited to the measurement of vertical and horizontal transmissibilities at the tigh and at the backrest. Geometric nonlinearities of the model match those experimentally measured.

These preliminary results demonstrate to robustness of the proposed model and are the base for further developments.

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