

DAViD - A MULTIBODY CODE TO SIMULATE A DYNAMIC VIRTUAL DUMMY FOR VIBRATIONAL COMFORT ANALYSIS OF CAR OCCUPANTS

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1. Introduction

The development of virtual simulators can avoid to set-up expensive test rigs, time-consuming tests, and is a winning strategy to be more competitive in road-vehicles market. Moreover vibrational comfort analysis is an important topic in vehicle design and the possibility to perform virtual vibrational tests on the effects of changing some parameters is useful tool for the designer. A literature search reveals that most of the simulation models in the field are based on elementary linear models. In some cases, finite elements are used, but this approach involves a large amount of parameters to be defined and managed. Thus the authors of this paper developed a virtual dummy model by means of multibody techniques. The formulation is the one described in Haugh's text book [4]. The code, named DAViD (the acronym of Dynamic Automotive Virtual Dummy), can mimic the non linear behaviour of a 3D human body model and requires a very small set of body data. The model is completely parametric and can be automatically scaled to simulate a significant portion of population. The code can be also linked to experimental results of accelerometers time histories to perform multi-input analysis based on seat input (translational and rotational), steer wheel input and pedals input. Driver and occupants can be both simulated. It is possible to introduce non linear viscoelastic parameters to match the actual behaviour of cushion foams used in the manufacturing of seats. The model provides also an assessment of vibrational comfort computed in compliance with international standards. The results of the code DAViD have been compared with experimental ones acquired on a vibrational test rig.

2. Multibody Model

The developed model is based on a multibody dynamics approach [4]. In particular the whole model is made of 15 rigid elements, 12 of which define the dummy, and the remaining 3 describe the car environment. The dummy is composed of two feet, two legs, two thighs, the pelvis, two arms, two forearms an upper part that is formed by head, neck, shoulders and chest rigidly connected together. The other bodies included in the model are seat, pedals and steering wheel. In

order to represent the human body articulations, kinematics constraints and viscoelastic elements are used to connect each part of the dummy. There are two spherical joints between pelvis and thighs, two revolute joints with transverse axes between thighs and legs, two revolute joints with transverse axes between legs and feet, one prismatic joint with longitudinal axis between pelvis and upper part, two spherical joints between upper part and arms, two revolute joints with transverse axes between arms and forearms. The viscoelastic elements used in the dummy are one translational, between pelvis and the upper part to represent the stiffness of torso, and two rotational elements, between arm and forearm to reproduce the muscular elasticity of the elbow. The dummy interacts with the car environment by means of seat, pedal and steering wheel contact simulated by other viscoelastic elements. The contact between hands and steering wheel and feet and platform car is simulated with four very stiff springs. The model can automatically scale geometric, mass properties and spring locations by means of changing few parameters (such as percentile). In fact the code is interlaced with an anthropometrical database. It is also possible to modify the backrest inclination and the hip-heel vertical position in order to change the configuration of the seat. The code can also manage several inputs at the same time. It can get input acceleration time histories acquired by experimental tests, as well as time histories on velocities and positions, filtering the signals in order to suppress noise. If necessary, forces and torques could be introduced as well as driving constraints.

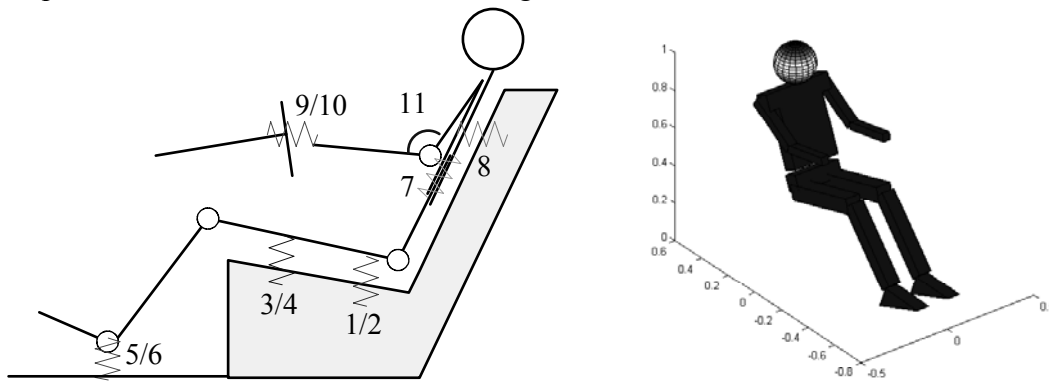


Figure 1. Viscoelastic elements (left) and complete 3-D dummy in Visualizer (right)

2.1 EQUATIONS OF THE MULTIBODY MODEL AND INTEGRATION

The equations of motion are deduced in the form of differential – algebraic system of index 3 [4] [5]:

$$\begin{cases} [M]\{\ddot{q}\} + [\Psi_q]^T \{\lambda\} = \{F_e\} \\ \{\Psi\} = \{0\} \end{cases} \quad (1)$$

where $[M]$ is the global mass matrix; $\{\Psi\}$ is the vector of constraint equation; $\{\lambda\}$ is the vector of Lagrangian multipliers; $\{F_e\}$ is the vector of external generalized forces; $\{q\}$ is the vector of generalized coordinates. In our model there are 15 bodies, and 105 generalized coordinates. The spatial location of the i -th body is described with seven parameters (i.e. three for the position of the

center of mass q_{7i-6} , q_{7i-5} , q_{7i-4} , and the four Euler's parameters q_{7i-3} , q_{7i-2} , q_{7i-1} , q_{7i} . The constraint equations used in the model can be divided into three groups:

- the first 15 equations (as many as the number of bodies in the model) are the normalization equations of the Euler's parameters (i.e. $q_{7i-3}^2 + q_{7i-2}^2 + q_{7i-1}^2 + q_{7i}^2 = 1$);
- the second group of equations is made up of the scleronomic constraints.
- the last group we include a driving constraint at inclination of pedals δ w.r.t. the horizontal plane (first two of (3)); regarding pelvis we impose no translation along z axis and rotation around the same axis (last three of (3)):

$$q_{39} = \cos\left(\frac{\delta}{2}\right); q_{46} = \cos\left(\frac{\delta}{2}\right); q_{17} = 0; q_{19} = 0; q_{20} = 0; \quad (3)$$

The complete model has 24 d.o.f. The integration of the DAE system, as it is shown in equations (1), has been performed rearranging the system as a first order one in the unique unknown y . Therefor the system to be integrated is in the following form:

$$[K]\{y'\} = \{\phi(y)\} \quad (4)$$

where:

$$[K] = \begin{bmatrix} I & 0 & 0 & 0 \\ 0 & I & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}; \{y\} = \begin{Bmatrix} q \\ \dot{q} \\ \ddot{q} \\ \lambda \end{Bmatrix} \text{ and } \{\phi(y)\} = \begin{Bmatrix} \{\dot{q}\} \\ \{\ddot{q}\} \\ \{[M]\{\ddot{q}\} + [\Psi_q]^T \{\lambda\} - \{F_e\}\} \\ \{\lambda\} \end{Bmatrix} \quad (5)$$

The system (5) is then solved by means of RADAU5.

3. Experimental set-up tests

A key point of simulation is the contact between seat and occupant that influences the vibrational response of the dummy. For this purpose an experimental procedure has been performed to find the seat force - deflection curve. Special mats, equipped with pressure transducers, are put on several seats and a jury made by people belonging to different physical groups has sat on the instrumented seat. Pressure maps have been acquired. Then spring elements have been introduced in the model and anchored to the points of high pressure concentration. For the computation of stiffness, appropriate tests have been performed on cushions using standard dynamometer. These have shown a non linear behaviour of polyurethane foams in their force/preload characteristic curves. A second kind of tests were performed to check the correct dynamic response of dummy. Some car have been tested on standard tracks and accelerometers signals have been acquired at measurement point (Figure 3). This signals have been replicated in a vibrational test rig, where the same seats have been mounted and the same driver has sat on. New signals have been acquired from SAE accelerometer pads placed on the cushion and on the backrest. The need for replicating these signals is due to obtain the repeatability, and a standardization of the test procedures.

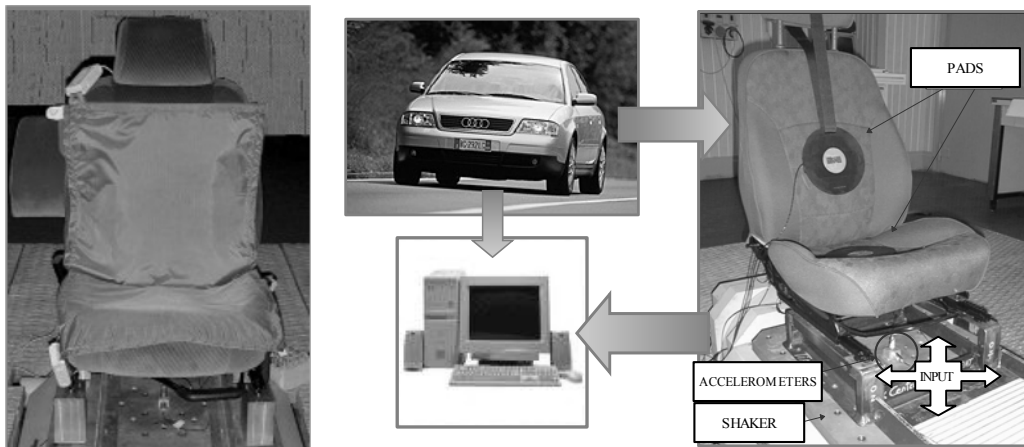


Figure 2. Experimental test rigs. Pressure mats (left) and vibrational shaker (right)

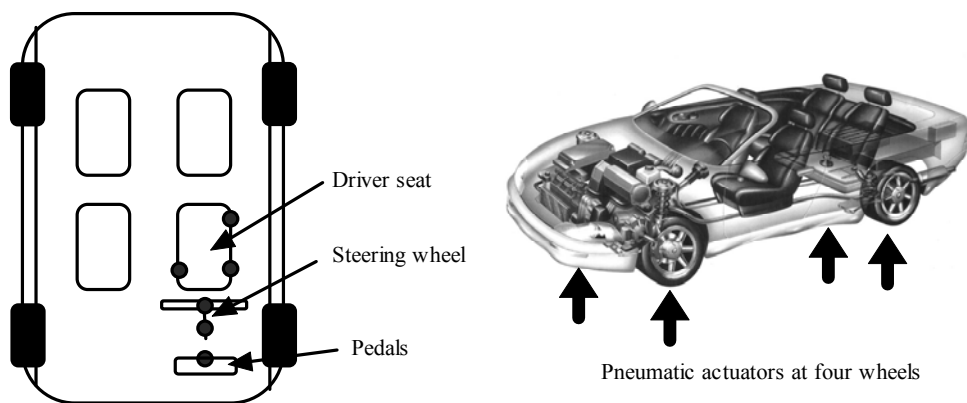


Figure 3. Layout of the experimental multi-input tests

4. Experimental multi-input tests

The DAViD code can take directly accelerometers data files to simulate a multi-input configurations. The user can impose input at the seat (6 d.o.f.), at steer wheel (4 d.o.f.) and at pedals (3 d.o.f.). The signals can be pre-processed by filtering. It is possible to run analysis directly acquiring data from a four axis shaker experimental test rig on which a car has been placed. The pneumatic actuators reproduce the track profiles and give vibrational inputs to the tires, and the response signals at six accelerometers has been collected. The accelerometers, all with three axes of sensitivity have been placed as shown in Figure 3 three between the seat and the chassis, one on the steer column, one on the steer wheel, and one at the pedals.

5. Graphical User interface and 3-D Visualizer

The code DAViD is provided with a graphical user interface to simplify input phase. All the window interfaces have been developed using Visual Fortran. Many dialogs contain figures and

drawings that directly refer to model's parameters. The user can select percentile of occupant being simulated, parameters of posture, parameters for all spring – damper elements, kind of occupant (driver or passenger), input type, analysis parameters (format of files, simulation time, visualization steps) and external forces. Specific databases that contain information about anthropometrics of the subjects and elastic characterizations of the seats have been implemented in the model. The 3-D visualizer is an external code developed in Matlab language (Figure 1) that can be run after every analysis. The human body is represented using simple geometrical shapes. The visualizer is interlaced with the same percentile rescaling database of the DAViD code.

6. Comfort assessment and virtual perceiving

The comfort assessment is important to predict the effect provoked by vibrations on the human body. Many car accidents happens because of tiredness, or disturbs to perception, that can be avoided decreasing the level of transmitted vibration. Three aspects of vibration are fundamentals: the *exposure time*, the *amplitude* and the *frequency* [5]. The consequences of vibration exposure are not simple: the perception of motion, the sensations it produces and the interference with health and activities are all complex phenomena. Various standards for assessing whole-body vibration have been promulgated. These standards attempt to define easy methods of quantifying complex vibration conditions, nevertheless no simple standard can offer evaluation procedure which can accurately predict all known effects of vibration on the body. However, to estimate the comfort of car occupants, the authors have followed the method prompted by BS 6841 norm. According to such norm the Vibration Dose Value VDV is defined as follows:

$$VDV = \left[\int_{t=0}^{t=T} a_w^4(t) dt \right]^{1/4} \quad (6)$$

where $a_w(t)$ is the frequency-weighted acceleration time-history and T is the period of time over which vibration is measured. The evaluation of (6) requires the weighting of acceleration time history, that can be approximated, as stated in the norm, with piecewise functions. To compute the overall VDV the vibrational signals have to be measured at three points: seat cushion-body interface, seat backrest-body interface and ground-feet interface. These time histories are then frequency weighted and scaled with a factor variable from 0 to 1.0. For each weighted signals, VDV are computed and then an overall VDV is computed using:

$$VDV = \left(\sum_i VDV_i \right)^{1/4} \quad (7)$$

7. Results

In this section some results obtained running DAViD simulation code are presented and compared with those experimentally acquired. The simulated test is a multi-input one. The input data have been automatically filtered with a pass-band filter at the beginning of the run. The simulation time is 10 seconds. In Figure 4 are compared the FFT of the experimental and

computed time histories of pelvis (vertical acceleration) and upper part (horizontal acceleration). For the simulation we chose a driver belonging to 50 percentile, posed with the angle between legs and thighs of 105 deg, the head inclination of 18 deg, the neck inclination of 8 deg, the angle between the arms and the forearms of 42 deg, the pedals are at 20 deg.

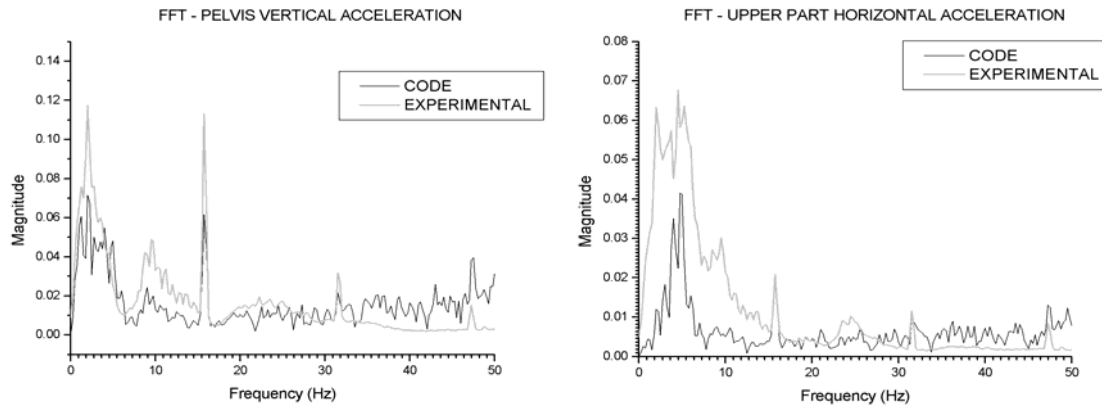


Figure 4. Comparison between computed and experimental FFTs

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