

# Creating an accurate digital twin of a human user for realistic modeling and simulation

Multibody system simulation using biomechanical human body models in RecurDyn



## Biomechanical models of the human body

Human dummies have successfully been used for automotive crash testing since active movements by the hardware dummy are neither necessary nor technically feasible. Likewise, in computer simulation of automotive crashes, digital versions of the passive hardware dummy are used as a state-of-the-art solution. Crash simulation allows the influence of the external forces and accelerations acting on the human driver to be analyzed. Since the mass of the human body and the forces it applies to the car are small in comparison to the car, the man-machine interaction is neglected in most cases. On the other hand, however, it has surprisingly been shown that the results of a physical coupling between an F-16 pilot and his fighter plane are too strong to be ignored. So-called “roll ratcheting” is caused by the amplification of the fighter pilot’s steering commands to the aircraft which is fly-by-wire controlled. Pilot-induced oscillations have been described in the literature[2] and it has been shown that the dynamics of a 17-ton jet plane can sometimes only be understood if the human-vehicle interaction is taken into account in the simulation process. Biomechanical models of a human operator are applicable in a broad variety of fields. It is often more appropriate to use (re)active human body models that include the interaction between the human operator/user and the technical system. For instance, to predict key



By Dr. Valentin Keppler  
Biomotion Solutions

factors like safety, performance or comfort, realistic user models have to be incorporated in the CAE process.

Some simulation packages available on the market provide complex human musculo-skeletal models, but these packages lack the specific technical elements necessary for engineers to build complex technical simulation models that include bearings and technical gear, for example. On the other hand, industrial grade multibody systems (MBS) simulation allows for complex mechanical models of products (e.g. vehicles), but often neglects the human operators or only models them in low detail because the manual modeling and

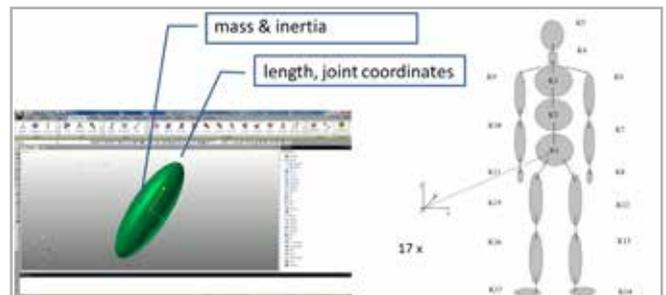


Fig. 1 - The human body can be modelled as a marionette consisting of 17 rigid bodies for MBS simulations

parametrization of individualized biomechanical human body models (HBM) is a complex and error-prone task.

Biomotion Solutions specializes in the simulation of human body models inside industrial grade multibody simulation software. Using VariBody, the HBM wizard for RecurDyn (part of Biomotion Workbench), body weight, stature and gender input will automatically generate HBM models that can then be imported as sub-models in an MBS model.

### Model generation

The mechanical principles of human motion have long been the subject of scientific research. For instance, in his book *De motu animalium* [3], Giovanni Alfonso Borelli, who lived in Italy from 1608 to 1678, described mechanically as systems of lever arms, deflection pulleys and ropes, the interplay between muscles and bones to generate the motions that can be observed in animals and nature. Since then, much research has been done in the field of biomechanics as it became known. With the development of computer simulation techniques, biomechanical models of humans have been developed to better analyze human motion.

For MBS simulations, the human body can be modelled as a marionette consisting of 17 rigid bodies. For the MBS model, it is necessary to provide the mass and inertia tensor for each of these 17 segments. Along with these, some geometric properties have to be specified to define the location of the joints. There are two principal ways to parametrize these body properties for each segment: determine the parameters like the mass, inertia and geometric properties for one specific subject for individual computer-aided simulation, such as for surgical planning or to analyze an athlete's performance; or, which is more common, build human body models on statistical bases using some established data sets (see examples in the references [4,5,6]). To better understand this statistical concept, Da Vinci's famous image of the Vitruvian man very nicely illustrates how the human body features some basic symmetries or proportions that make it possible to deduce the different segment lengths based on the subject's height. The use of statistical data and regression equations represents one approach to modeling the human body. Another is to calculate the mass properties of the segments based on the calculated volumes (cylinders, truncated cones and ellipsoids) and the mean densities. One such prominent HBM is the Hanavan model [7], but this method requires many segment lengths and radii to be measured and therefore more effort during the modeling process.

Since these two main methods to determine the parameters differ – one results in a more individual model but requires higher effort, and the other is quite easy but describes a “mean” body, we decided to use the method which is easier to deploy in engineering contexts for the model wizard. Consequently, the VariBody model wizard for RecurDyn builds a complete HBM using just three input parameters:



Fig. 2 - Input mask of the VariBody model wizard

body weight, body height and gender to calculate the segment parameters by means of regression equations.

### Using a wizard to generate the model

An HBM could be built up piece by piece in RecurDyn using the preprocessor where every anthropometric parameter like mass or inertia is calculated by means of regression equations. However, the large number of model parameters makes building many different HBMs with different anthropometrics, each of which has to be created manually for each model, an elaborate and error-prone task. It is, therefore, clearly beneficial to use a model wizard for this task. VariBody for RecurDyn generates the HBM in just a few steps based on user input of gender, stature and body weight.

After inputting the basic parameters, the user can choose between the available scenarios (sitting in a seat, standing, generic) and define some additional switches for the model generation. The

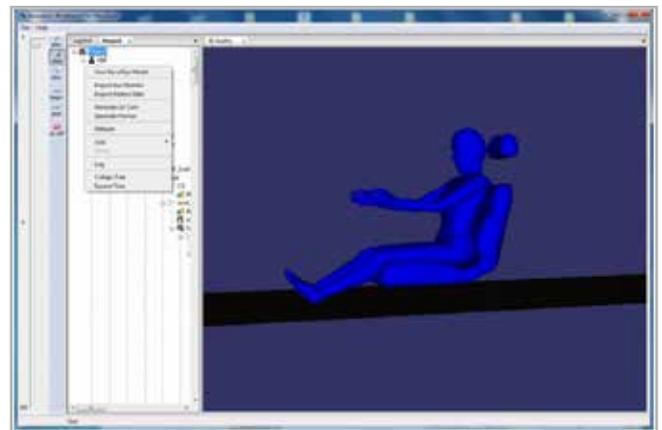


Fig. 3 - Save the model for export to RecurDyn



Fig. 4 - Model import into RecurDyn



Fig. 5 - Occupant models – different anthropometrics: 5% female (left) and 95% male (right) in the RecurDyn model

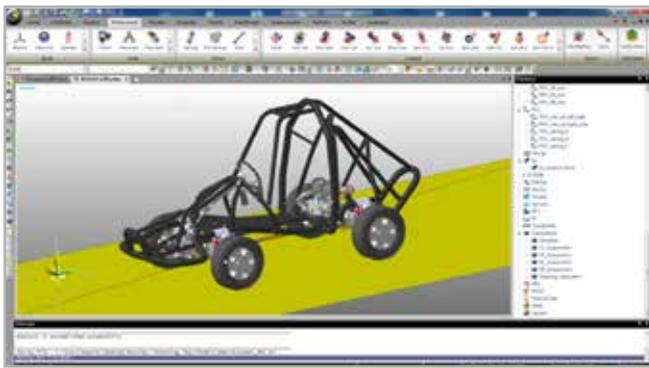


Fig. 6 - An existing vehicle model (e.g. the Buggy model - courtesy of Jacob Hustad) can be extended with an occupant model

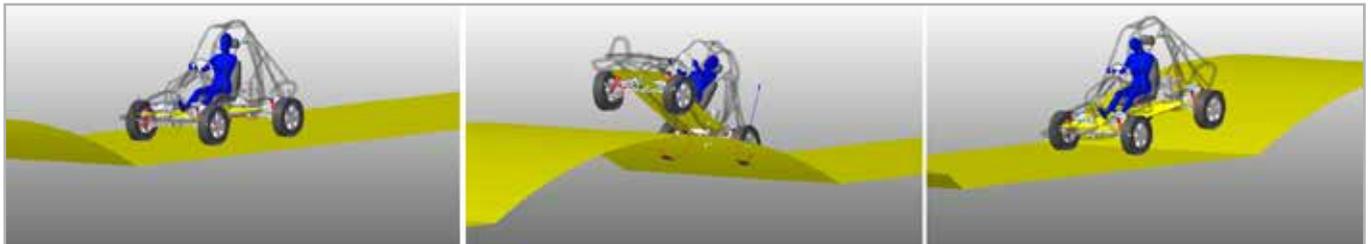


Fig. 7 - Simulation of the buggy model incorporating the HBM human occupant subsystem

wizard uses this input to generate a complete HBM including all joints, bodies and force elements. In addition to the HBM scenario of the “seated occupant”, a multi-segment model of a car seat is also included. The GUI allows the modification of the model’s pose using sliders for each degree of freedom. Once the desired pose is achieved, the model can be exported to an intermediate data file that can be parsed by the Biomotion model input parser in RecurDyn.

After the model has been imported into RecurDyn, the user can define the desired unit system and can modify or enhance the HBM using the RecurDyn preprocessor. In our “seated occupant” example, the model was extended with some contact elements between the human body and the seat.

**Example: Buggy occupant**

Using the model of a Buggy (courtesy of Jacob Hustad), the deployment of the HBM as the vehicle’s occupant is demonstrated in a car simulation. First, we modified the Buggy model provided by removing the simple, rigid rider structure. Then we loaded the prepared Biomotion HBM occupant subsystem into the model of the buggy. After adding some force elements (e.g. hands steering) and making a few adjustments (definition of the mother body, fixing the seat chassis to the buggy frame), the model was complete and could be integrated.

**Import data from motion capture**

The VariBody model wizard can also prepare an HBM for simulation of inverse dynamics with RecurDyn. Basically, inverse dynamics analysis is a process which reveals the inner forces and torques acting inside the human body, based on a motion that has been measured. At the beginning of the Twentieth Century, Eadward Muybridge used multiple cameras that had been trip-wired to perform the first biomechanical motion analysis [8]. Every measurement consisted of

a set of photo-plates. His image sequence of a galloping horse is a very prominent example of his work and, with it, Muybridge settled the question of whether all four hooves were ever off the ground at the same time during a horse’s gallop.

Technology has progressed substantially since then and today one can capture human motion in hundreds of frames per second, even in smaller labs. To enable the correct tracking of the joint angles, the test subject is prepared with reflecting markers, and infrared cameras are deployed to capture the motion. For example, the company Vicon is renowned for its technology and software in this field, but other

motion-capture technologies have also been developed, such as XSens, which uses a set of inertial measurement units worn on the body. C3D is a standard motion capture (mocap) output format.

The Biomotion Workbench allows this mocap data to be imported and exported to an MBS model for instance in RecurDyn afterwards. This requires the generation of an HBM based on the subject’s specific weight, stature and gender in VariBody. Then a specification of the



Fig. 8 - Two different motion capture systems: one based on visible light (left), one based on infrared cameras and reflective markers (right)

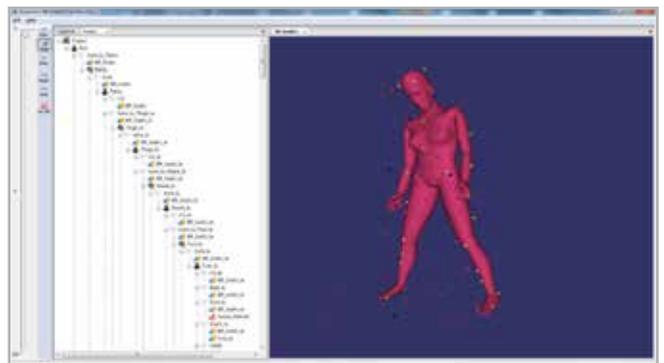


Fig. 9 - Motion data import in just a few steps: generate an HBM in Biomotion Workbench, load the marker-set definition and the motion data, and finally adjust the best initial pose before exporting the model to RecurDyn

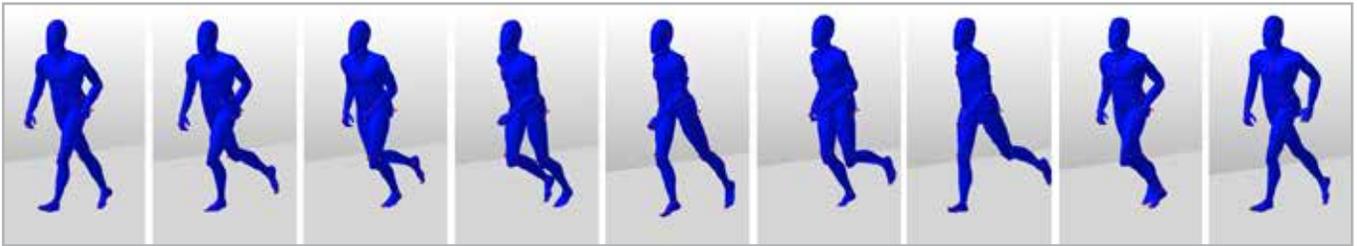


Fig. 10 - Import of motion capture data – gait sequence



Fig. 11 - Import of motion capture data – golf swing

marker set used must be applied to the model which can now import the C3D data. The export of this model to RecurDyn prepares it for the first step in the RecurDyn simulation: the calculation of the joint states that fit the 3D marker point cloud (motion filtering by body drag).

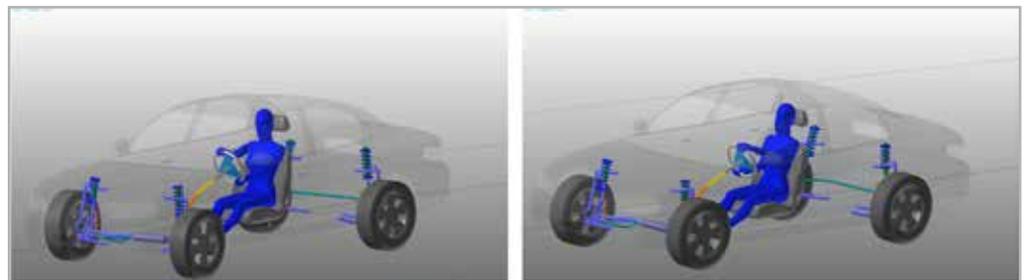


Fig. 12 - Using co-simulation, active HBMs can be used in closed-loop simulations.

**Motion filtering by body drag:** As the subject measured and the model differ slightly in geometry and degrees of freedom, it is necessary to perform a “body drag” to project the measured motion onto the model’s degree of freedom. By providing the 3D coordinates of every single marker on the subject, a set of joint states can be calculated which fit the measured motion.

These calculated joint states expressed as a function of time can now be used as accurate input data for an inverse dynamics analysis. In RecurDyn, this is done with the “c-motion” joint.

The inverse dynamics-driven HBM can now be used to calculate the forces and torques in the joints of the body (e.g. in the lumbar vertebrae). The model can also be extended by adding different passive or active mechanical structures so that, for instance, one can estimate the increased joint stress caused by the gear which a worker has to wear. This means, for example, that different backpack designs or orthotic devices may be compared in order to optimize these products. This last approach has recently been successfully deployed by a company that developed an exoskeleton using RecurDyn as their CAE tool.

### Active human body models

To model a realistic twin of a human interacting with products or vehicles, it is necessary to apply a simple yet realistic motion control to the HBM. This approach enables closed-loop simulation and the calculation of product variants. A communicator interface allows engineers to control the movement of the user model via the control input (for example, using a co-simulation in MATLAB/Simulink).

### References

- [1] EnginSoft Newsletter, Year 15 No. 4, Winter 2018
- [2] Smith J and Montgomery T July 1996 Biomechanically induced and controller coupled oscillations experienced on the f-16xl aircraft during rolling maneuvers. NASA Technical Memorandum 4752.
- [3] Borelli G 1680 De motu animalium.
- [4] Chandler R, Clauser R and McConville C 1975 Investigation of inertial properties of the human body. AMRL Technical Report, NASA Wright-Patterson Air Force Base.
- [5] Clauser C, McConville J and Young J 1969 Weight, volume and center of mass of segments of the human body. AMRL Technical Report, NASA Wright-Patterson Air Force Base.
- [6] NASA 1978 NASA Reference Publication 1024: The internal properties of the body and it's segments. NASA.
- [7] Hanavan, E. P. (1964). A mathematical model of the human body. AMRL-TR-64-102, AD-608-463. Aerospace Medical Research Laboratories, Wright-Patterson Air Force Base, Ohio.
- [8] Eadweard Muybridge, 1887 “Animal locomotion”, Images from “[https://commons.wikimedia.org/wiki/Category:Eadweard\\_Muybridge?uselang=de](https://commons.wikimedia.org/wiki/Category:Eadweard_Muybridge?uselang=de)”

For more information  
[info@enginsoftusa.com](mailto:info@enginsoftusa.com)  
 469-912-0504