An Overview of the HVE Human Model

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ABSTRACT

Developers of human dynamics simulation software inherently use a mathematical/physical model to represent the human. This paper describes a pre-programmed, object-oriented human model for use in human dynamics simulations. This human model is included as part of an integrated simulation environment, called HVE (Human-Vehicle-Environment), described in previous research. The current paper first provides a general overview of the HVE user and development environments, and then provides detailed specifications for the HVE Human Model. These specifications include definitions for model parameters (supported human types and human properties, such as dimensions, inertias, joints and injury tolerances). The paper also provides detailed specifications for the HVE time-dependent human output group parameters (kinematics, joints, contacts, belts and airbags).

HUMAN DYNAMICS SIMULATION models are useful in several types of research. Vehicle manufacturers use occupant simulation to assist in the design and development of vehicle interiors and energy absorption characteristics; pedestrian simulation assists in the design of less aggressive vehicle frontal shapes. Biomechanical researchers use human simulation to model the human body in an effort to gain a better understanding of how injury occurs. The U.S. Air Force uses human simulation to help design cockpits and ejection systems. Accident reconstructionists use simulation to study injury causation.

Developers of human dynamics simulation software inherently use a mathematical/physical model (i.e., an object described by properties such as dimensions, inertias and mechanical constants) to represent the human. The required complexity of the human model is dependent upon the complexity of the motion being simulated. For example, planar, two-dimensional (2-D) motion requires a relatively simple human model, while the simulation of three-dimensional (3-D) motion requires a model of significantly greater complexity. Historically, the use of occupant and pedestrian simulation has been limited because of the massive amounts of human and vehicle data required for execution.

This paper describes a 3-D human model available for use by developers of human dynamics simulation programs. The model, called the HVE Human Model, is included as part of an integrated simulation environment, called HVE (Human-Vehicle-Environment), described in previous research [1,2]. The purpose of this human model is to provide a standard, pre-programmed model available to researchers. It is hoped that by providing such a robust model in pre-programmed form, researchers will be inclined to produce more sophisticated simulators, thus, improving the state of the art in human occupant and pedestrian dynamics.

The purpose of this paper is to provide details of the HVE Human Model so that researchers may assess the applicability and suitability of the model to their human dynamics simulation programs.

OVERVIEW OF HVE

HVE is a computer environment for executing human and vehicle dynamics simulations. It may be viewed as a computer abstraction of the nine-cell matrix for accident reconstruction originally proposed by the late Dr. William Haddon, first Director of the National Highway Traffic Safety Administration [3]. The nine-cell matrix describes the possible interactions between humans, vehicles and their environment during the pre-crash, crash and post-crash phases of an accident.

HVE is not itself an accident reconstruction program. Rather, HVE is an interface for running accident reconstruction and simulation programs, much like Microsoft Windows™ is an interface for running PC programs.

* Numbers in brackets designate references found at the end of the paper.
The HVE interface is an integrated set of editors. The Human Editor, Vehicle Editor and Environment Editor are used for creating 3-D physical and visual models of humans, vehicles and environments. Once created, the interactions between these models may be simulated using any HVE-compatible human or vehicle simulation model in the HVE Event Editor. The simulation results may be displayed both numerically and visually by HVE. Using the HVE Playback Editor, simulations from several events may be edited into a single coherent sequence involving multiple humans and vehicles. The output may be routed to a display, printer, plotter or VCR. See reference 1 for further details.

**HVE Environment**

A block diagram for the HVE simulation environment is shown in Figure 1. Note that, conceptually, the HVE interface surrounds the simulation model. The interface is comprised of five modes: Human Mode, Vehicle Mode, Environment Mode, Event Mode and Playback Mode.

The HVE Developer’s Toolkit [2] is a library of functions and data structures that provide the developer of a human or vehicle dynamics model access to the HVE interface.

The HVE Human Model is the 3-D human created by the HVE Human Editor and used by HVE-compatible simulations. It is defined by the human data structure described in the HVE Developer’s Toolkit.

The remainder of this document describes the details of the HVE Human Model which is created using the HVE Human Editor. Although the information is provided in the form expected by the programmer/developer (refer to Appendix A for the actual data structures), it should also be useful to any technical person wishing to understand the basic parameters which define the human model.

**HUMAN MODEL**

The HVE Human Model is created, viewed and edited in the Human Editor, one of the five editing modes which comprise HVE’s graphical user interface (see figure 2). In general, the Human Editor allows the user to produce, from HVE’s human database, one or more humans to be included in the Active Humans List. One or more of the humans in this list may then be selected for study in a human dynamics (or vehicle dynamics) simulator.

This section of the paper describes the following details of the HVE Human Model:

- Human Database (General Parameters)
- Human Properties (Model Inputs)
- Event-related Parameters (In-use Inputs)
- Output Parameters (Model Outputs)

**Human Database**

The HVE Human Database is a user-extendable library of humans selectable according to the following keys:

- Sex (Male, Female)
- Age
- Weight Percentile
- Height Percentile

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*Figure 1 - Block Diagram for HVE application environment. The HVE Human Model is created and edited in the Human Editor (see heavy box). These humans may then be used in the Event Editor by any HVE-compatible simulation model.*
The event-related human parameters include the following:

- Position/Velocity
- Collision Pulse
- Contacts
- Restraint usage

The parameters for these three data groups are shown in Table 2.

**Position/Velocity**

Human simulations require initial positions and velocities for each degree of freedom. Linear and angular positions are supplied during event editing, either by direct manipulation of the segments in the event viewer or by data entry into the position/velocity dialog. Velocities are assigned using the position/velocity dialog.

The simulation code is responsible for telling HVE which degrees of freedom to make available in the dialog. For example, a 2-D simulator such as MVMA-2D [7] would not request entries for roll, yaw and y positions, whereas 3-D simulators [8,9,10] would request entries for all fields.

Additional positions may be assigned as visual targets. Targets are humans which are displayed at user-selected positions along the vehicle path, and allow the researcher to assess how closely the simulation matches the desired (actual) human path. The available human target positions are associated with vehicle positions, and are therefore named Begin Perception, Begin Braking, Impact, Separation, Point-on-curve, End-of-rotation and Final/Rest.

**Contacts**

Human simulators predict motion by calculating the force between ellipsoids attached to the human model and surface planes attached to the vehicle model. If it is known ahead of time that certain ellipsoid/surface pairs will not interact (e.g., occupants will not normally interact with exterior surfaces), force calculations for the pair may be ignored. The Contacts information allows the user to deselect pairs of contacts from consideration during execution.

**Restraints**

For each type of restraint device installed in the vehicle (availability of each device is determined by the vehicle), the Restraint parameters define how the restraint is being used (if at all) during a simulation.

**Collision Pulse**

Occupant simulations require a collision pulse (actually, an acceleration vs time curve). This pulse defines the inertial environment. HVE knows if any collision pulses are available as a result of executing other events (e.g., EDSMAC [11]), and supplies the pulse automatically, if
Table 3. HVE Human Model Output Parameters

<table>
<thead>
<tr>
<th>Variable Name</th>
<th>Pgm Units</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>SEGMENT KINEMATICS x,y,z or X,Y,Z coordinates</td>
<td>in</td>
<td></td>
</tr>
<tr>
<td>Roll, Pitch, Yaw angles</td>
<td>rad</td>
<td></td>
</tr>
<tr>
<td>Total Velocity x, y, z linear velocity roll, pitch, yaw ang vel</td>
<td>in/second</td>
<td></td>
</tr>
<tr>
<td>Total acceleration x, y, z linear accel roll, pitch, yaw ang accel</td>
<td>in/second^2</td>
<td></td>
</tr>
<tr>
<td>JOINTS</td>
<td>rad</td>
<td>segment-fixed</td>
</tr>
<tr>
<td>roll, pitch yaw articulation</td>
<td>in-lb</td>
<td></td>
</tr>
<tr>
<td>Mx, My, Mz (joint elasticity)</td>
<td>in-lb</td>
<td></td>
</tr>
<tr>
<td>Mx, My, Mz (joint damping)</td>
<td>in-lb</td>
<td></td>
</tr>
<tr>
<td>Mx, My, Mz (joint stop)</td>
<td>in-lb</td>
<td></td>
</tr>
<tr>
<td>ΣMx, ΣMy, ΣMz (total)</td>
<td>in-lb</td>
<td></td>
</tr>
<tr>
<td>CONTACTS</td>
<td>in</td>
<td></td>
</tr>
<tr>
<td>i,j,k ellipsoid location</td>
<td>in</td>
<td></td>
</tr>
<tr>
<td>contact deflection</td>
<td>lb</td>
<td></td>
</tr>
<tr>
<td>contact total force</td>
<td>lb</td>
<td></td>
</tr>
<tr>
<td>contact normal force</td>
<td>lb</td>
<td></td>
</tr>
<tr>
<td>contact friction force</td>
<td>lb</td>
<td></td>
</tr>
<tr>
<td>BELTS</td>
<td>in</td>
<td>segment-fixed</td>
</tr>
<tr>
<td>x,y,z anchor point</td>
<td>in</td>
<td></td>
</tr>
<tr>
<td>belt stretch</td>
<td>lb</td>
<td></td>
</tr>
<tr>
<td>belt tension</td>
<td>lb</td>
<td></td>
</tr>
<tr>
<td>AIRBAGS</td>
<td>psi</td>
<td></td>
</tr>
<tr>
<td>bag pressure</td>
<td>lb</td>
<td></td>
</tr>
<tr>
<td>bag radius</td>
<td>in</td>
<td></td>
</tr>
<tr>
<td>contact force</td>
<td>lb</td>
<td></td>
</tr>
<tr>
<td>for each contact vs ellipsoid pair</td>
<td></td>
<td></td>
</tr>
<tr>
<td>for each bag posn</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The results are presented in the vehicle-fixed reference frame for occupants and the earth-fixed reference frame for pedestrians.

Joints

The Joints output group contains joint articulation angles (segment-fixed) and torques for each of the 14 joints.

Contacts

The Contacts output group contains the parameters associated with interactions between occupant ellipsoids and vehicle contact surfaces. Segment-fixed contact locations, force and deflection results are included.

Belts

The Belts output group contains the parameters associated with interactions between the occupant and vehicle belt restraint systems, and includes belt stretch and tension.

Airbags

The Airbags output group contains the parameters associated with interactions between the occupant and the vehicle airbag system, and includes current levels of airbag pressure and force.

Static Reports

In addition to the time-dependent output track parameters described above, additional output information related to the HVE human is monitored. These results are displayed in the form of static reports and include:

- **Messages** - Textual information relevant to the simulation (e.g., execution warnings and diagnostics)
- **Accident History** - Time, simulated position and velocity for each segment for each of the specified positions (impact, separation, etc.)
- **Human Data** - A report containing a list of the HVE Human Model parameters which were actually used by the simulation (Note that, although the HVE Human Model may contain several hundred parameters, the simulation might use only ten or 20.)
- **Injury Data** - A report containing information about those forces and accelerations which exceeded the user-defined tolerance levels

Whereas the output track groups produce results at each simulation output interval, the above static reports are produced only once; this occurs at the end of the run.

**DISCUSSION**

The HVE Human Model may be used by relatively simple, 2-D simulators as well as sophisticated, 3-D simulators. Although the HVE Human Model contains literally hundreds of parameters per human, the programmer may select as many or as few of these parameters as are necessary to meet the needs of the simulation model.

The HVE Human Model is included as part of the HVE interface specification [1]. As an evolving standard, the desired. The pulse factors may be used to vary the amplitude of the individual pulses.

**Output Parameters**

Output parameters related to the HVE Human Model are called human output tracks. Note that a human's output tracks are also event-related, because it is the responsibility of the simulation to calculate them and send them back to HVE as output.

Output tracks contain time-dependent results calculated by the simulation code (the code tells HVE which parameters it calculates; HVE then makes these available as output).

The output tracks for the HVE Human Model are divided into five categories:

- Kinematics
- Joints
- Contacts
- Belts
- Airbags

Each of these output categories is described in detail below.

**Kinematics**

The Kinematics output group contains position, velocity and acceleration results for each segment.
The above keys provide inputs to the HVE human database which calculates the parameters for a 15 segment human using GEBOD [4]. In addition to these database keys, the user may specify the Location (the options are Pedestrian or one of nine seat positions in the HVE Vehicle Model [5]), and an image filename (the name of an editable, 3-D geometry file for the human; if none is supplied, the 15 segment ellipsoids are used to visualize the human).

The Human Editor creates a copy of the selected human for use in the current simulation. Therefore, changes to an individual human do not affect the human database. Any modified human may be added to the human database after modification.

**Human Properties**

The HVE Human Editor displays the current human in the Human Viewer (see Figure 2). The HVE Human Model has 15 segments and 14 joints, as provided by GEBOD. A schematic diagram is shown in figure 3.

Input data categories for the current human are selected by clicking the mouse on one of the 15 segment CGs to display the following input data categories:

- Inertias
- Contact Ellipsoids
- Injury Tolerance
- Joints

These input categories, and their associated parameters, are defined in the following sections.

**Inertias**

Inertial parameters are defined for each of the 15 segments. The individual parameters are shown in Table 1. Mass is actually entered as weight and divided by the current acceleration of gravity. For reference, the human's total weight is displayed. Product of inertia, $i_{ij}$, is not included in the parameters.

**Contact Ellipsoids**

Contact ellipsoids are the physical surfaces the simulation uses to determine the force on a human segment. The default ellipsoids for the selected segment are the same as the segment ellipsoids defined by GEBOD. Up to two additional ellipsoids may be created for each segment. Their location and orientation are defined relative to the segment's $i,j,k$ coordinate axis system.

**Injury Tolerance**

Injury tolerance parameters may be specified for the entire human (regardless of which segment is selected, the same injury tolerance dialog is displayed). Human tolerance levels for motor vehicle impacts are defined in SAE J885 [6]. The simulation code may compare these user-entered

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**Figure 2 - HVE Human Editor and Viewer.** The Human Editor is used for selecting and editing HVE Human Models.
Figure 3 - 15 Segment, 14 Joint HVE Human Model based on GEBOD [4].

tolerance levels with the current levels of simulated force and acceleration to predict injury. This, in turn, may be used by the simulation code to produce a message alerting the researcher that the specified tolerance levels have been exceeded. The individual tolerance parameters are shown in Table 1.

Joints

Each of the 14 joints is shown in the Human Viewer, and is selectable by clicking the mouse on the segment CG, and then selecting the desired joint from the joint list. Joint locations are editable and are defined relative to the segment's i,j,k coordinate axis system (see Figure 4).

HVE provides for ball-and-socket and hinge joint types. The individual parameters which define the joint properties are shown in Table 1.

Event-related Parameters

Event-related parameters are in-use factors which affect the human model during execution of the simulation. Because these parameters are not related to the human, but rather to the event, they are assigned to the human during event editing. Event editing is the process of setting up the simulation for execution.

Table 1. Human Model Parameters for 15 Segment Humans

<table>
<thead>
<tr>
<th>Variable Name</th>
<th>Pgm Units</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>INERTIAS:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>mass</td>
<td>lb·sec²/in</td>
<td></td>
</tr>
<tr>
<td>Roll, Pitch, Yaw inertia</td>
<td>lb·sec²/in</td>
<td></td>
</tr>
<tr>
<td>CONTACT ELLIPSOIDS:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ellipsoid Name</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Center Coords</td>
<td>in</td>
<td></td>
</tr>
<tr>
<td>Length</td>
<td>in</td>
<td></td>
</tr>
<tr>
<td>Principal Axes</td>
<td>rad</td>
<td></td>
</tr>
<tr>
<td>INJURY TOLERANCE:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HIC</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Head Pitch Concussion</td>
<td>rad/sec²</td>
<td>see reference 6 Head Injury Criterion</td>
</tr>
<tr>
<td>Head Side Accel</td>
<td>in/sec²</td>
<td></td>
</tr>
<tr>
<td>Chest Sl</td>
<td>in/sec²</td>
<td></td>
</tr>
<tr>
<td>Chest Force</td>
<td>lb</td>
<td></td>
</tr>
<tr>
<td>Chest Fwd Accel</td>
<td>lb</td>
<td>left and right belts</td>
</tr>
<tr>
<td>Max Axial Femur Load</td>
<td>lb</td>
<td>left and right belts</td>
</tr>
<tr>
<td>Max Torso Belt Force</td>
<td>lb</td>
<td>left and right belts</td>
</tr>
<tr>
<td>JOINTS:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Joint Name</td>
<td>in</td>
<td></td>
</tr>
<tr>
<td>Joint Coordinates</td>
<td></td>
<td>see figure 3 j,j,k relative to segment</td>
</tr>
<tr>
<td>Joint Properties:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Joint Type</td>
<td></td>
<td>Ball/Socket or Hinge</td>
</tr>
<tr>
<td>Stop Angle, + Rotation</td>
<td>rad</td>
<td>about i,j,k</td>
</tr>
<tr>
<td>Stop Angle, - Rotation</td>
<td>rad</td>
<td>about i,j,k</td>
</tr>
<tr>
<td>Stop Elasticity, + Rotn</td>
<td>in-lb/rad</td>
<td>about i,j,k</td>
</tr>
<tr>
<td>Stop Elasticity, - Rotn</td>
<td>in-lb/rad</td>
<td>about i,j,k</td>
</tr>
<tr>
<td>Stop Energy Dissipation</td>
<td>dimensionless</td>
<td>about i,j,k</td>
</tr>
<tr>
<td>Elastic Const, Linear</td>
<td>in-lb/rad</td>
<td>about i,j,k</td>
</tr>
<tr>
<td>Elastic Const, Quadratic</td>
<td>in-lb/rad²</td>
<td>about i,j,k</td>
</tr>
<tr>
<td>Elastic Const, Cubic</td>
<td>in-lb/rad²</td>
<td>about i,j,k</td>
</tr>
<tr>
<td>Damping Constant</td>
<td>in-lb/rad²</td>
<td>about i,j,k</td>
</tr>
<tr>
<td>Full Damping Ang Vel</td>
<td>rad/sec</td>
<td>about i,j,k</td>
</tr>
<tr>
<td>Max Angle, + Axis Rotn</td>
<td>rad</td>
<td>about i,j,k</td>
</tr>
<tr>
<td>Max Angle, - Axis Rotn</td>
<td>rad</td>
<td>about i,j,k</td>
</tr>
</tbody>
</table>

Table 2. Event-related Parameters

<table>
<thead>
<tr>
<th>Variable Name</th>
<th>Pgm Units</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>PositionName</td>
<td></td>
<td>Initial, Begin Perception, Begin Braking, etc.</td>
</tr>
<tr>
<td>x,y,z or X,Y,Z</td>
<td>in rad</td>
<td>Separation, Point on curve, End of rotation.</td>
</tr>
<tr>
<td>Roll, Pitch, Yaw</td>
<td></td>
<td>Final REST.</td>
</tr>
<tr>
<td>COLLISION PULSE:</td>
<td></td>
<td>Table vs time</td>
</tr>
<tr>
<td>f wd, lat, vert lin accel</td>
<td>in/sec²</td>
<td>Table vs time</td>
</tr>
<tr>
<td>roll, pitch, yaw accel</td>
<td>rad/sec²</td>
<td>Table multipliers</td>
</tr>
<tr>
<td>pulse factors</td>
<td>dimensionless</td>
<td></td>
</tr>
<tr>
<td>CONTACTS: Selected Contacts</td>
<td>boolean switch</td>
<td>Allow Interaction?</td>
</tr>
<tr>
<td>RERAINTS: Selected Restraint System</td>
<td>switch</td>
<td>Belts or Airbag</td>
</tr>
<tr>
<td>In Use</td>
<td></td>
<td>TRUE or FALSE segment name</td>
</tr>
<tr>
<td>BeltAttachedTo</td>
<td>boolean switch</td>
<td>i,j,k segment coords</td>
</tr>
<tr>
<td>AttactCoords</td>
<td>in</td>
<td>right, left sections</td>
</tr>
<tr>
<td>BeltStack</td>
<td>in</td>
<td></td>
</tr>
<tr>
<td>AirbagBeginFillColor</td>
<td>in sec</td>
<td></td>
</tr>
<tr>
<td>AirbagFillDuration</td>
<td>in sec</td>
<td></td>
</tr>
</tbody>
</table>
model and its associated database could be incorporated into any simulator using a relatively simple data translator.

Because it is an evolving standard, simulation developers are likely to develop simulations which require a few parameters not included in the HVE Human Model. Parameters not included in the model, the developer may hard-code the values (this is only reasonable for parameters which seldom change) or put the values in a separate file called by the simulation code. However, the developers of HVE are encouraging these simulation developers to participate and make suggestions for new human model parameters consistent with the needs of researchers.

A typical occupant or pedestrian simulation program using the HVE Human Model is built using the HVE Developer's Toolkit [2,12] and, thus, takes advantage of the HVE 3-dimensional interface for setting up, executing and viewing simulations.

The HVE Developer's Toolkit is written in C and assumes the simulation will be programmed in C or C++. FORTRAN programs have not yet been included. It is, however, possible that FORTRAN programs could be incorporated using C or C++ "wrappers" around the FORTRAN program. This requires further research.

The HIVE interface has been developed for use on Silicon Graphics (SGI) workstations. It is written in C++, and leverages off the SGI Open GL and video libraries. Open Inventor [13] is used to visualize all HVE objects (humans, vehicle and environments). HVE requires a level of graphics processing power not yet available on personal computers (see reference 1 for performance comparisons). The HVE executable program is approximately 10 megabytes, requires a minimum of 32 megabytes of random access memory, and at least 1 gigabyte of hard disk space. An individual human binary file is 6,852 bytes (without 3-D image geometry data).

SUMMARY

This paper has presented a detailed overview of the features of the HVE Human Model. Individual input and output parameters were presented and discussed.

The main purpose of the HVE Human Model is to provide a standard model available for use by the simulation community. The model may be used directly from within the HVE simulation environment or included as a standard for use in other simulation environments.

As a result of the availability of the HVE Human Model, it is hoped that researchers will consider enhancing their current simulations as well as developing new and more advanced occupant and pedestrian simulation applications.

TRADEMARKS

HVE and EDSMAC are trademarks of Engineering Dynamics Corporation. Windows is a trademark of Microsoft Corp. Open GL and Open Inventor are trademarks of Silicon Graphics, Inc.

REFERENCES

12. HVE Developer's Toolkit, Engineering Dynamics Corporation, Beaverton, OR, 1994 (currently under development).
Appendix A - HVE Human Model Data Structures

Review of this structure provides an overview of the HVE Human Model. Simulation programmers familiar with the C programming language may use this information to design human simulations; it is also useful for providing a basic understanding of the model's parameters.

/* human.h
 * Human Data Structure (7-5-94)
 */

struct HumanData {
  long Id;
  char Name[MAXNAMELENGTH];
  int Location;
  int Sex;
  int Age;
  int BodyType;
  int Percentile;
}

struct HumanSegment {
  struct HumanColor {
    float r;
    float g;
    float b;
  } Color;
  struct SegmentInertia {
    float Mass;
    float Inertia[3][3];
  } Inertia;
  int NumEllipsoids; /* on this segment */
  int CurrentEllipsoid; /* on this segment */

  struct SegmentEllipsoid {
    char EllipsoidName[MAXNAMELENGTH];
    float Coord[3][3];
    float PrincipalAxes[3];
  } Ellipsoid[MAXELLIPSOIDSPERSEGMENT]; /* define 3 */
  int NumJoint; /* on this segment */
  int CurrentJoint; /* on this segment */

  struct SegmentJoint {
    int Id; /* index of joint (up to MAXHVEJOINTS) */
    float Coord[3][3]; /* rel to selected seg CG */
  } Joint[MAXJOINTSPERSEGMENT]; /* define 4 */
}

} Segment[MAXHVESEMENTS]; /* define 15 */

struct HumanJoint {
  int Type; /* BALL_JOINT = 0, HINGE_JOINT = 1 */
  float StopAngPlus[3];
  float StopAngMinus[3];
  float StopElasticityPlus[3];
  float StopElasticityMinus[3];
  float EnergyDissipation[3];
  float ElasticQuadratic[3];
  float ElasticCubic[3];
  float DampingConst[3];
  float DampingVelocity[3];
  float ToleranceAnglePlus[3];
  float ToleranceAngleMinus[3];
}

} Joint[MAXHVEJOINTS]; /* define 14 */

struct HumanTolerance {
  float HO;
  float HeadPitch;
  float HeadSideAccel;
  float Chest;
  float ChestForce;
  float ChestAccel;
  float KneeForce;
  float LelRot;
  float LeftTorso;
  float RightLap;
  float RightTorso;
}

/* end of human.h */