Improvement of Occupant Restraint Systems using Enhanced Hybrid III Dummy Models in MADYMO-3D

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ABSTRACT

The MADYMO-3D standard HIII 5th%ile, 50th%ile & 95th%ile dummy models (Version 5.4.1) are able to provide the injury criteria, which occur during a crash. In order to have a better understanding of the injuries mechanisms, each interaction between the dummy and the interior parts including the restraint system should be studied. This requires additional dummy output and consequently a deep modification of the dummy structure is needed. By using some theoretical approaches it is ensured that the modified dummies provide the necessary additional output without changing the models' behaviour and their validity.

Based on the MADYMO-3D standard HIII dummy databases from TNO the new "force measuring" dummies were created at EASi-Engineering GmbH.

The paper deals with the description of a standard dummy, the development of an improved dummy, an example of results which can be provided by an improved dummy and an application of restraint system improvement using the enhanced dummy model.

INTRODUCTION

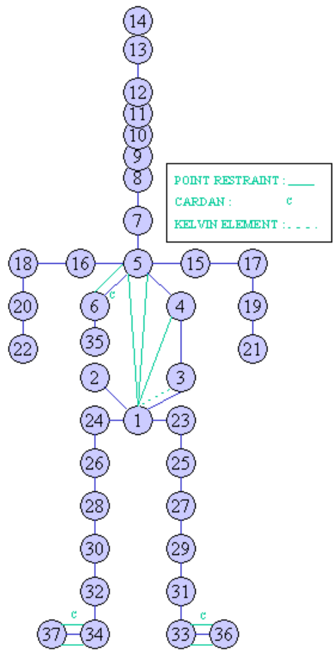
The MADYMO-3D standard HIII 5th%ile, 50th%ile & 95th%ile dummies (Version 5.4.1) are able to provide the injury criteria which occur during a crash. In order to have a better understanding of the injuries origin, each interaction between the dummy and the interior parts must be analysed. Therefore more output must be available: lots of sensors must be inserted in the standard dummy. This leads to modifications of the standard dummy structure.

An improved HIII 5th%ile female dummy and an improved HIII 95th%ile dummy are also built at this occasion. Due to the similarities between the dummies only the study for the HIII 50th%ile dummy is described below.

ORIGINAL HIII 50th%ile DUMMY

The present dummy is composed of :

- 7 chains: Picture 1.
- 37 joints.
- 69 shapes.
- 8 points restraints.
- 3 cardans.
- 1 Kelvin element.
- 3 accelerometers.
- …



Picture 1: Kinetic chains of the HIII 50th%ile dummy.

METHOD

The current section describes the results that are required for a better understanding of the performance of a restraint system: restraint forces, energy transfer and power analysis. Nevertheless one needs to ensure that the results are correct. That's why a verification process is necessary: Validity, Forces balance, constant energy level (energy transfer) and power equal to 0 (power analysis).

Validity

A comparison between the results coming from a model with the standard dummy and the same model with the improved dummy is realized. The output which was chosen for comparison of the standard dummy model and the enhanced dummy model is the standard LINACC output :

Lower Torso	x, y, z
Upper Torso	x, y, z
Head	x, y, z

If no significant difference appears in the signals then the improved dummy is assumed to have the same behaviour as the standard one.

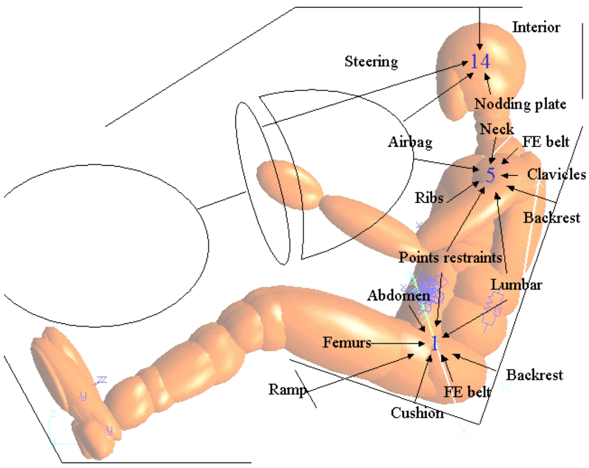
Forces balance

To ensure the performance of the new dummy the Newton's law is checked on a body :

$$\left(\sum \vec{F}_{external}\right)_{rigid\ system} = \left(m \bullet \vec{a}_{center\ of\ gravity}\right)_{rigid\ system}$$

If the sum of all the measured external forces on a rigid body equals the product of its mass and its acceleration at the center of gravity, this indicates that all external forces are taken into account.

The measurement of accelerations with this kind of dummy are made at 3 places: Lower torso, Upper torso and Head. So the forces balance should be realized on 3 bodies (Picture 2). Moreover the forces balance can be expressed with respect to either the global coordinate system (INERTIAL SPACE) or the local coordinate system (Body coordinate system).

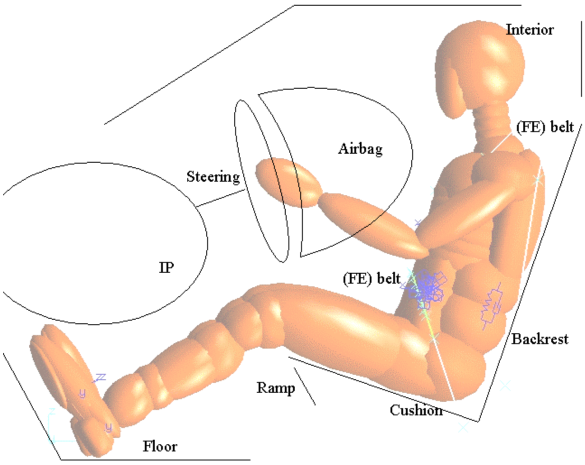


Picture 2: Forces working on the accelerometers.

After checking the results are correct a close look at the contacts should be taken to get the contribution of each external force.

Restraint forces

After having a detailed view of the forces on a body people do a zoom out to get now a global approach. The restraint forces we want to study are written in the Picture 3. Moreover the restraint forces can be expressed with respect to either the global coordinate system (INERTIAL SPACE) or the local coordinate system (Body coordinate system).



Picture 3: External forces working on the dummy.

Energy transfer

This study is meaningful only for a calculation with respect to the global coordinate system (INERTIAL SPACE).
Based on the restraint forces results each energy is calculated in order to know the "efficiency" of each force to restraint the dummy :

$$W = \int \vec{F}.d\vec{r}$$

$$W = \int \vec{F}.\vec{v}.dt \qquad \vec{v} = d\vec{r}/dt$$

$$W = \int_t F_x.v_x.dt + \int_t F_z.v_z.dt \qquad v_i = \int_t a_i.dt$$

The velocities are calculated from the LINACC output.

Power analysis

Based on the restraint forces results each power is calculated in order to know how aggressive is the restraint system :

$$P = \frac{dW}{dt}$$

$$P = F_x.v_x + F_z.v_z$$

The efficient working time of each force to restraint the dummy can be deduced easily.

IMPROVED HIII 50th%ile DUMMY

Based on the MADYMO-3D standard HIII 50th%ile dummy database from TNO the new "force measuring" dummy was developed at EASi Engineering GmbH.

For the validity check the standard LINACC output is used: no change of the dummy structure is required.

For the forces balance new accelerometers are needed and forces sensors are required. 2 cases of force are distinguished: internal forces (between joints) and external forces (dummy against an interior part).

For the restraint forces additional forces sensors are required: only external forces exist.

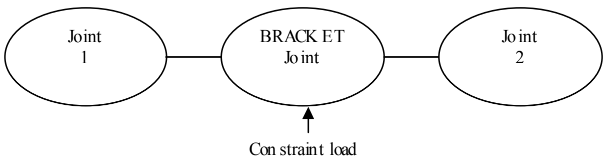
The energy and power calculation doesn't imply any additional modification of the dummy structure.

Accelerometer

New LINACC sensors are defined to perform the forces balance: attached to the Lower torso, the Upper torso and the Head, with the correct position and orientation, in local and global.

Internal force

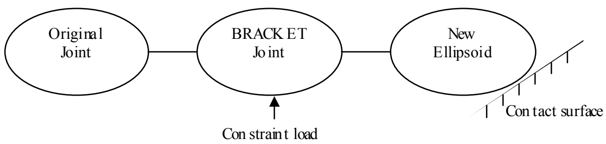
To have access to a force which is exchanged between 2 joints the main idea is to insert a BRACKET joint in between. This joint has got the position and the orientation of the joint where the forces balance is realized, low inertia properties, low mass which are subtracted from the joint of the forces balance. The 3 force components can be found in the RTF output file (Picture 4). So a new joint is defined but no additional kinetic chain is added.



Picture 4: Internal force sensor.

External force

To have access to a contact force which is applied on a joint the main idea is to attach a BRACKET joint on it with a copy of the original ellipsoids. Moreover the contact should be defined only with these new ellipsoids. This joint has got the position and the orientation of the original joint, low inertia properties, low mass which are subtracted from the original joint. The 3 force components can be found in the RTF output file (*Picture 10*). So a new joint is defined and an additional kinetic chain is created.



Picture 5: External force sensor.

Design

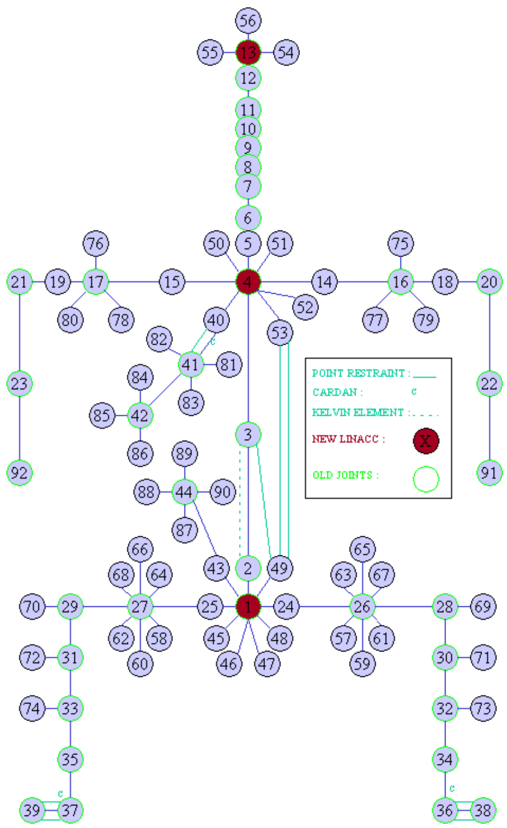
With all the requirements the improved dummy has got additionally :

43 chains.
55 joints.
111 shapes.
6 accelerometers.

and is now composed of :

50 chains: Picture 6.
92 joints.
180 shapes.
9 accelerometers.
…

Due to the condition imposed by MADYMO-3D under CONFIGURATION a complete new structure is developed including a renumbering of all joints.



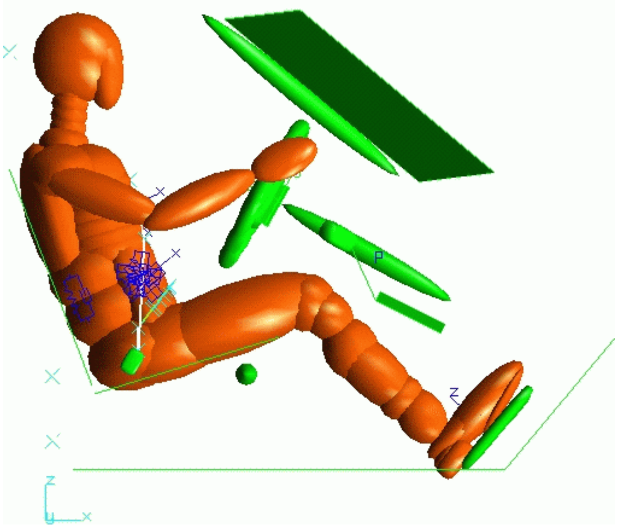
Picture 6: New structure of the HIII 50th%ile dummy.

RESULTS

At this occasion the desired performances are evaluated.

For this purpose 3 models whose components come from the TNO distribution were built. Due to the method similarities for each model only one example is shown here.

Frontal (Picture 7): This model is the TNO frontal application that came from the TNO distribution.



Picture 7: side view of the frontal model.

This model contains a dummy, a seat, a foot well, an analytical belt system (left side), a steering system, a windscreen, an IP, pedals and a driver airbag. Interior parts have a MOTION to simulate intrusions. An acceleration field is prescribed on the dummy: ***APPENDIX A***.

All the following work is performed automatically by using scripting languages.

All results concerning the improved dummy are available in 3 dimensions: x, y and z. In our case people look at the x direction only.

Validity

The validity is well preserved: **APPENDIX B**. So the improved dummy has the same behaviour as a standard one in this particular case.

Forces balance

The Newton's law is checked successfully at the 3 accelerometers locations: **APPENDIX C**. So all forces which are working on these particular bodies are properly measured and no force contribution is missing. It's now possible to know exactly how a part of a dummy/car influences the acceleration signals. The sign of results indicates if the force restraints or accelerates the body.

Lower Torso
The analytical lap belt is attached to the Abdomen (Body 2 - Translational) and so the lap belt is acting on the Lower Torso through the Abdomen. Thus the component of the "Abdomen" force is mainly responsible for the acceleration level.

Upper Torso
The analytical shoulder belt is attached to the Ribs (Body 6 - Free) and so the shoulder belt is acting on the Upper Torso through the Ribs. Therefore the component of the "Ribs" force is mainly responsible for the acceleration level.

Head
The head is only in contact with the airbag and the component of the "Airbag" force is monitoring the acceleration level.

Restraint forces

The next step is to study the results from a more global point of view: the measured forces are external forces which are working on the dummy i.e. the forces in which the user is interested: **APPENDIX D**.

The forces provide the load, which is working on the dummy.

The Newton's law isn't respected because the studied dummy parts aren't rigid and not all joints have the same orientation. But the deviation is still small.

Pelvis
The "Belt" force is the highest force. This confirms the previous explanations for the forces balance on the Lower Torso. Moreover the "Belt" restraint force is higher than the "Abdomen" force. This fact shows that the force is only partially transmitted to the Lower Torso. Additionally the dynamics of the "Abdomen" (Damping) body may affect the results.

Thorax
The "Belt" force and the "Airbag" force are the highest forces. This confirms the previous explanations for the forces balance on the Upper Torso. Moreover a contact with the steering wheel can be seen: "Steering" curve. With the detailed output one can see that the contact occurs with the Sternum at 68ms and the maximal force is nearly 675N.

Head
The remarks in the section "**Forces balance -** *Head*" are also valid here.

Energy transfer

The preservation of the total energy is checked successfully: **APPENDIX E**.

The energies give the use of the forces to restraint the dummy.

Pelvis
Most of the initial kinetic energy is converted into elastic-plastic deformation energy of belt.

Thorax
Most of the initial kinetic energy is converted into elastic-plastic deformation energy of belt and work of airbag.

Head
Most of the initial kinetic energy is converted into work of airbag.

Power analysis

Total power is equal to zero is checked successfully: **APPENDIX F**.

The powers give the agressivity of the forces to restraint the dummy. If results are divided by the respective mass then they are expressed in W/kg and can be compared easily: in this case the power acting on the thorax is smaller than those acting on the head and the pelvis.

Pelvis
The lap belt is working nearly for 40ms although the crash duration is approximately 100ms (see ***APPENDIX A***). So the pelvis was not coupled to the restraint system for 60ms.

Thorax
The shoulder belt is working nearly for 45ms and the airbag nearly for 40ms. So the thorax was not coupled to the restraint system for 55ms.

Head
The airbag is working nearly for 40ms. So the head was not coupled to the restraint system for 60ms.

APPLICATION

Energy management applied to the head

A brief look at the animation of the frontal application indicates the shortest distance between the head and the steering wheel is still important (**APPENDIX G**-a). So it is possible to decrease the injuries i.e. the maximal acceleration only by using this available space (a safety distance should be preserved nevertheless). To optimise the use of this space i.e. minimize the acceleration a constant level is required. A script (Reference: EASi TechSeminar) calculates this "ride-down" in the x-direction only by means of theory approaches: **APPENDIX G**-b.

The outputs of the improved dummy identify the airbag as the main parameter to be tuned in order to reduce the acceleration level (**APPENDIX D**-*Head* and **APPENDIX E**-*Head*).Moreover the airbag force versus time can be calculated exactly from them in order to reach the wished acceleration level.

The power analysis show that the coupling between the head and the airbag begins at 40ms (**APPENDIX F**-*Head*). One way to reduce the head acceleration would be to achieve an earlier coupling of head and airbag by modifying the airbag deployment. This is, however, not the objective of this study.

The parameter that was chosen in this study is the leakage function of the airbag. By modifying the leakage over time (= active venting) a model was built with a significantly clearly reduced head acceleration: **APPENDIX G**-c.

REMARKS

Results concerning the improved dummy in appendices are given as example in the x-direction only, although all results are available in the 3 directions (local and global). Only the results from the script (theoretical optimisation) can be computed in the x direction.

In this paper the expression *"Belt" force* doesn't mean the belt tension but the force applied by the shoulder or lap belt on a dummy part.

A comparison of results with the original dummy is performed. This however doesn't imply a complete validity check.

CONCLUSION

The new enhanced dummy model is able to calculate interacting forces between the different parts of the dummy (internal forces) and interacting forces with the interior parts of the car (external forces). Forces coming from the restraint system and their effect on the dummy can be deduced exactly. This leads to a forces balance, which provides a better understanding of the forces acting on the dummy during a crash. It's also possible to know the energy transfer of each interaction to evaluate the efficiency of a force to restraint the dummy. The power analysis gives an idea about the effective working time and the aggressiveness of each force.

The performances of the "enhanced" and standard HIII dummies due to standard injury criteria measurement are identical for different load cases. Using the force balance and some analytical approaches the restraint system can be optimised to predefined levels for any occupant size, seating position and crash. The quality of existing restraint systems can be checked using the forces and energies balances and powers calculation.

3 improved dummies (5th%ile, 50th%ile and 95th%ile) are available and were checked with 3 models.

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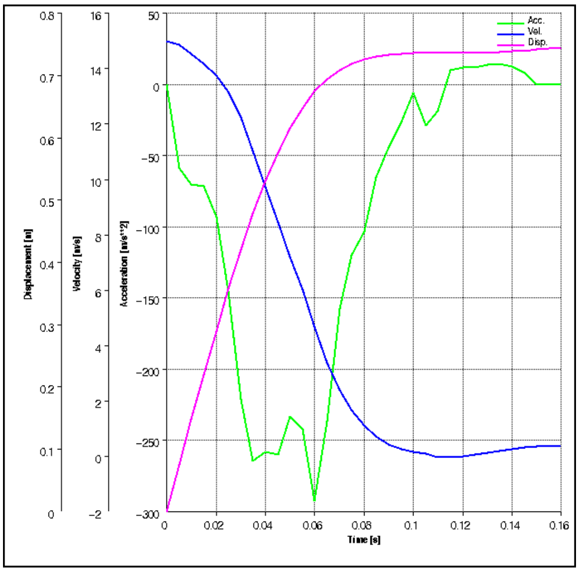
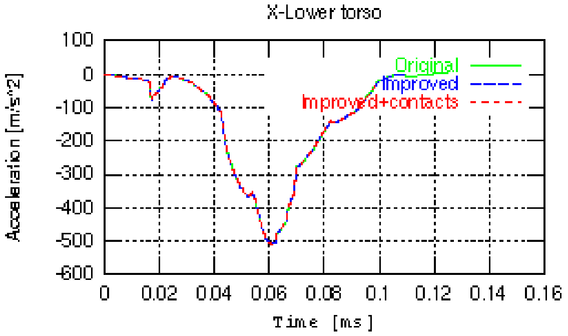
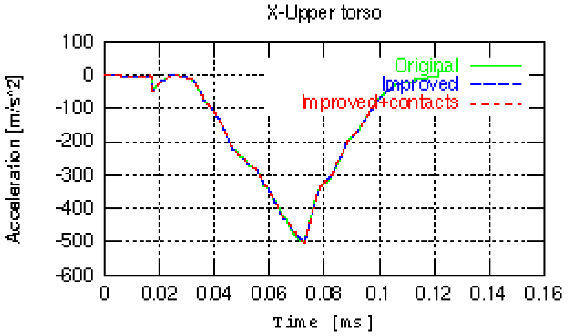
APPENDIX A Pulse in x-direction (Frontal application)

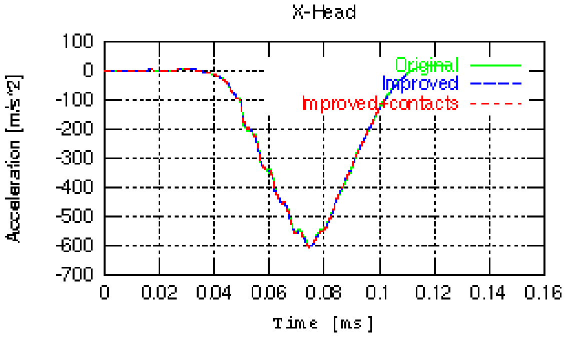


APPENDIX B Validity

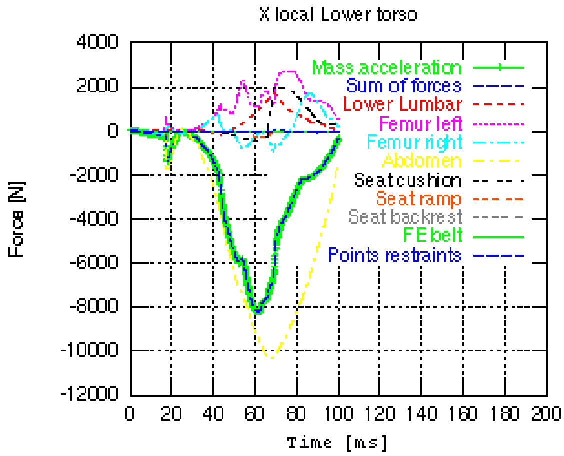
The curve "Improved" is an intermediate step during the development. The starting model is called "Original" and the final one is "Improved+contacts".

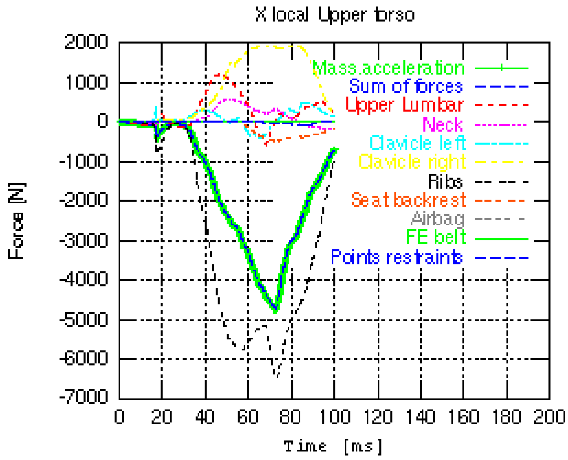


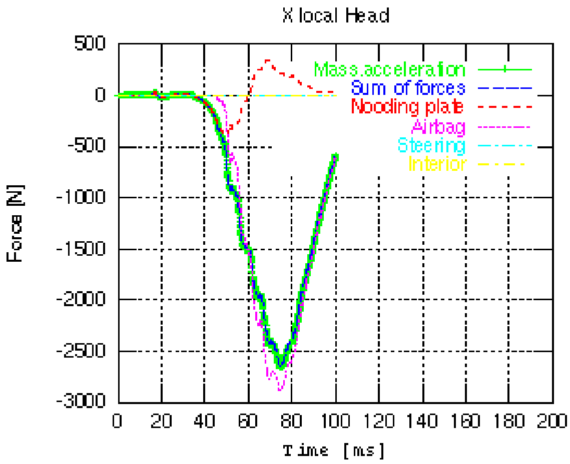




APPENDIX C Forces balance



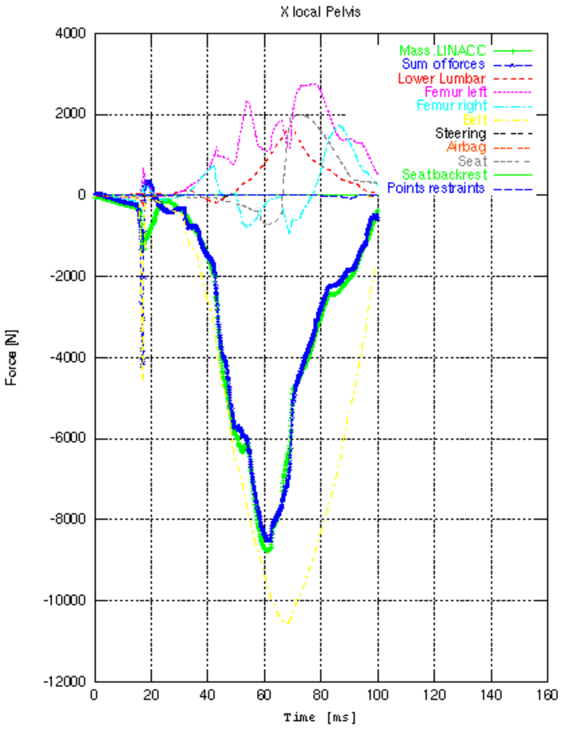




APPENDIX D Restraint forces

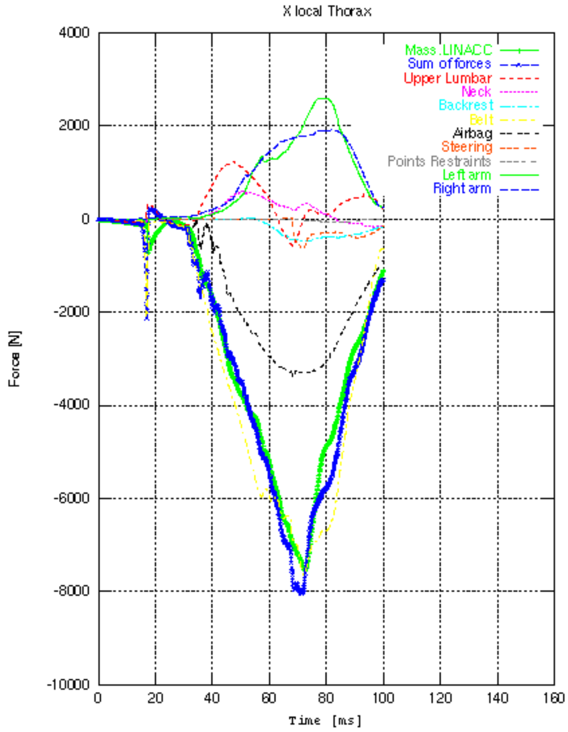
Pelvis

The “Seat” curve summarizes the both forces acting on the pelvis coming from the seat cushion and the ramp of the seat. The “Belt” curve would summarize the both actions of the lap and shoulder belt on the pelvis in case of an FE belt.

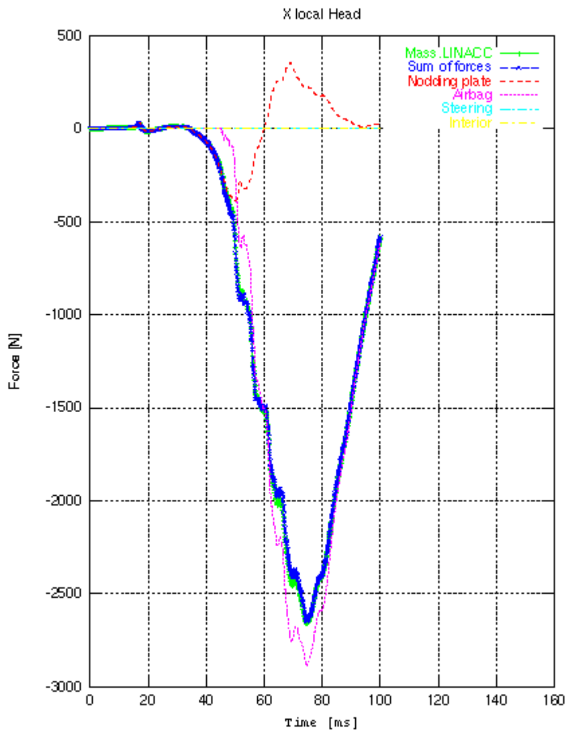


Thorax

The “Backrest” curve summarizes the forces coming from the Upper Torso Back, the Collar and both Clavicles due to a contact with the Back rest. The “Belt” curve signifies the sum of forces due to the shoulder belt and which are working on one of both Clavicles, the Ribs, the Sternum (FE belt) and the Collar (FE belt). The “Airbag” curve means the sum of airbag forces which are working on both Clavicles, the Ribs, the Sternum and the Collar. The “Steering” curve summarizes the forces coming from a possible contact between the steering system and the Ribs and/or the Sternum.



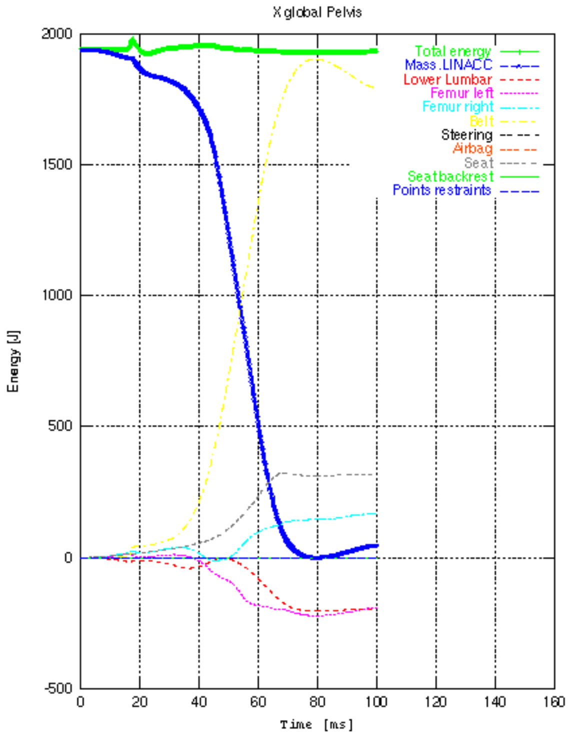
Head



APPENDIX E Energy transfer

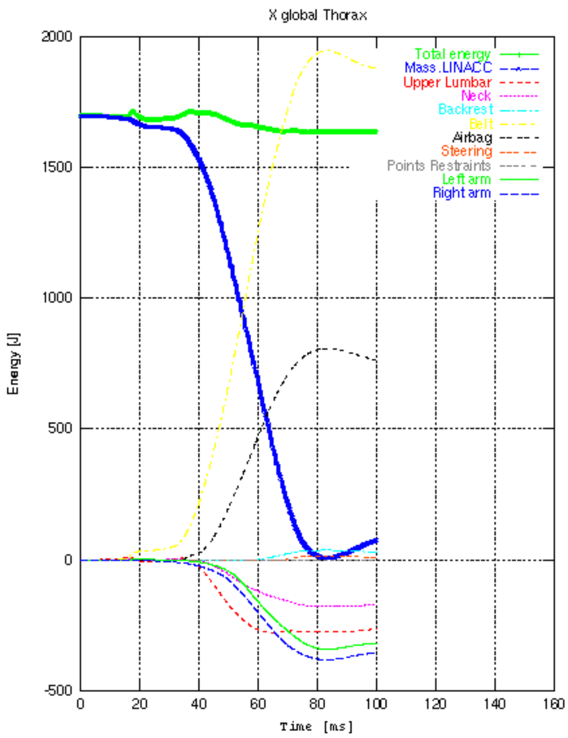
Pelvis

Same remarks as for the Restraint forces – *Pelvis.*

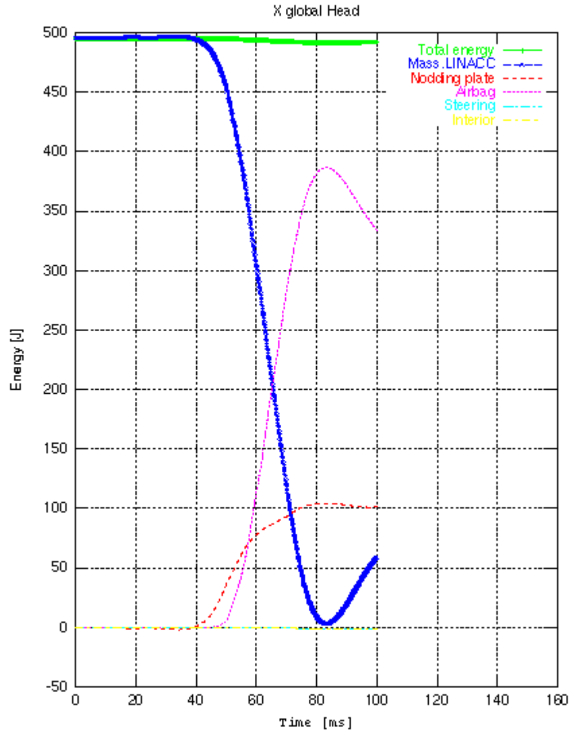


Thorax

Same remarks as for the Restraint forces – *Thorax.*



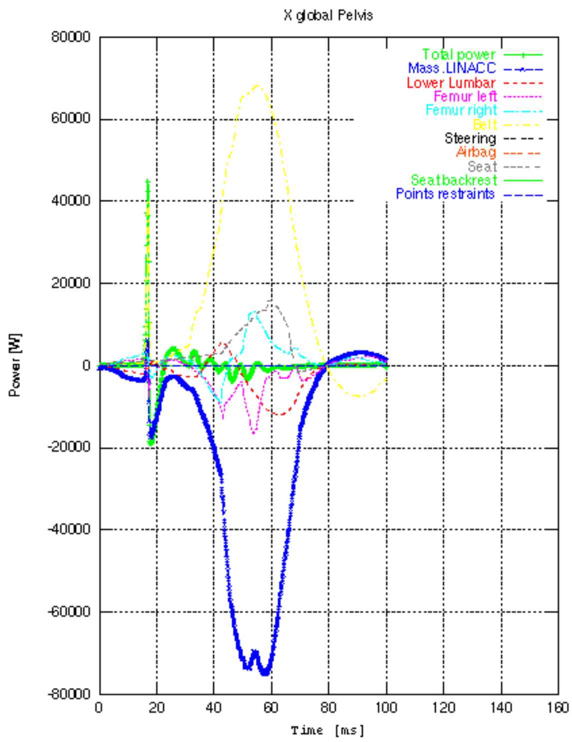
Head



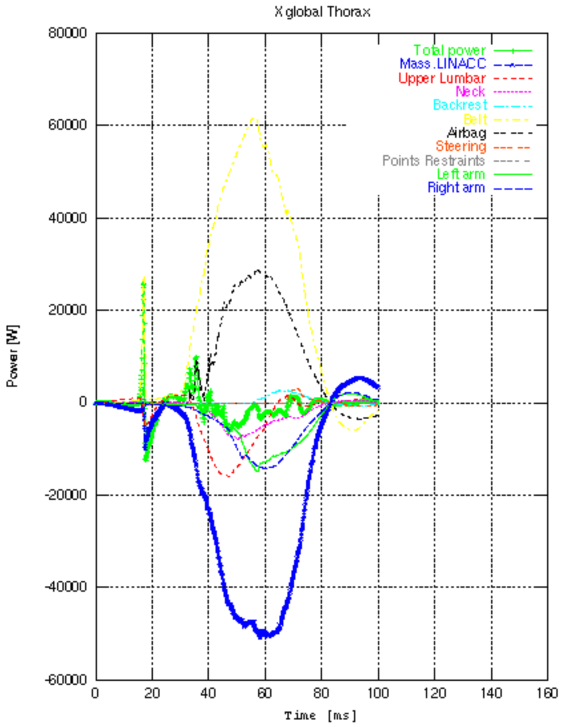
APPENDIX F Power analysis

Pelvis

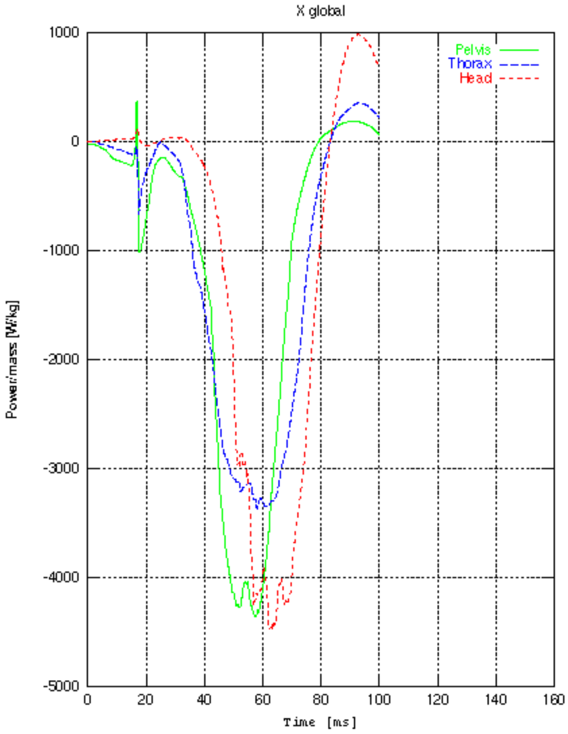
Same remarks as for the Restraint forces – *Pelvis.*



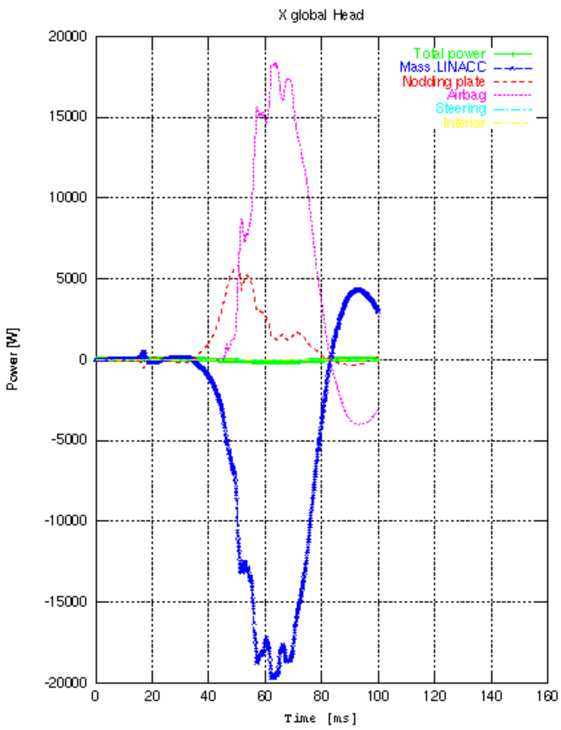
Thorax
Same remarks as for the Restraint forces – *Thorax.*



Comparison of powers

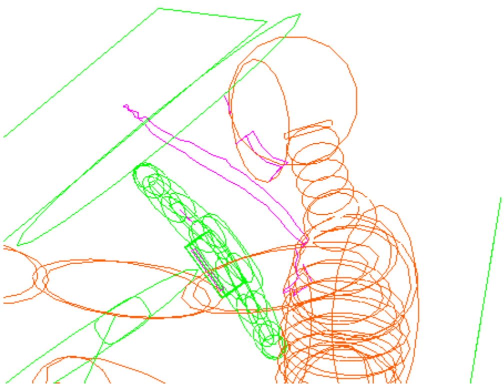


Head

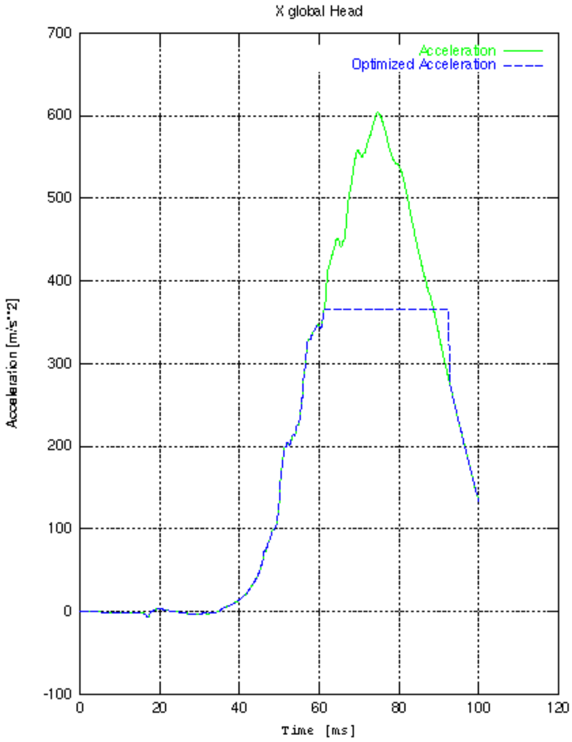


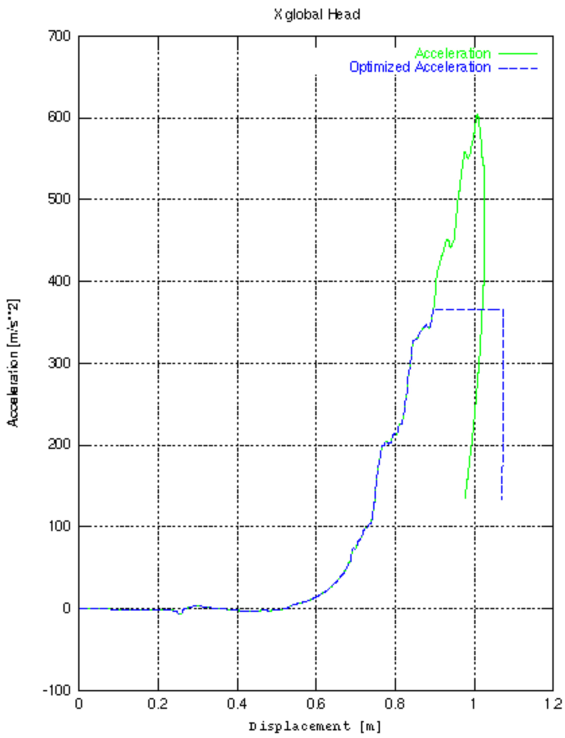
APPENDIX G Energy management

a) Picture of the animation of the frontal application model:



b) Results of the theoretical optimisation:





c) Results of the improved MADYMO-3D model: