Comparison of Faceted Vs Ellipsoid Dummies In Frontal Crash Simulations

Authors:

Hovenga P.E., TNO Automotive Safety Solutions
Spit H.H., TNO Automotive Safety Solutions
Kant A.R., TNO Automotive Safety Solutions
Happee R., TNO Automotive Safety Solutions

Correspondence:

Kant A.R.
TNO Automotive Safety Solutions
T +31 15 2697435
Robert.Kant@Tass-Safe.com

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ABSTRACT

An improved Hybrid-III 50th %ile crash test dummy model has been developed in MADYMO. Advanced multibody techniques have been used to obtain fast computation times with the geometry and potential accuracy of CPU intensive finite element models. So-called facet surfaces have been used in combination with flexible bodies and rigid bodies. The MADYMO contact algorithm has been enhanced with options to separately describe the non-linear compliance of two contacting objects such as a dummy and a seat and orthotropic, penetration-dependent friction has been implemented to capture of 'belt pocketing' in the dummy flesh.
The available set of component and full dummy validations has been extended with load cases representing the latest restraint system designs and test procedures. A systematic validation has been performed using objective rating techniques to compare the enhanced facet model to the standard ellipsoid model. Objective rating showed that the enhanced facet model provides significant benefits in particular for chest deflections.

INTRODUCTION

FMVSS 208 and European legislation force OEM's to develop restraint systems to work under an increased number of conditions. Consumer tests demand injury values below regulated levels, and new injury criteria are being introduced for instance for the neck and for the extremities. Restraint system performance is to be evaluated for the mid size male and small female dummies, and the risk of airbag induced injury is to be evaluated with small female and child dummies. FMVSS 208 requires belted and unbelted evaluations and various speeds (16mph, 22mph, 25mph, 30mph, 35mph) and various level of deployment thresholds are generally considered for robust restraint performance in frontal impact. Numerical techniques such as DOE, optimisation and stochastics yield increasing numbers of simulations and this requires CPU efficient and robust solutions.
Predictive models of the regulated crash test dummies are a key component in restraint system optimisation. Multibody Hybrid III models with ellipsoid surfaces have proven to be highly effective in restraint system design. This paper presents a next level in multibody dummy modelling. An advanced facet model of the Hybrid III dummy is introduced as well as several recent MADYMO features which improve usability of this model. Finally objective rating is used to quantify the accuracy of both the new facet model and the standard ellipsoid model.

Figure 1: Ellipsoid (left) & facet (right) Hybrid III dummy models

FACET MODELLING

The development of the first generation of facet models is reported in [4,6,9] and evaluation can be found in [5]. Recently the MADYMO Hybrid-III 50th %ile facet model has been upgraded. The geometry was updated using 3D scans. The available set of component and full dummy validations has been extended with load cases representing the latest restraint system designs and test procedures. Using this extended dataset, the dynamic model parameters were recalibrated. Below the facet approach is summarised and recent enhancements are described which improve the user friendliness of facet models and enhance their predictive capability.

In facet dummy models rigid bodies and joints are used to define lumped parts and the connections of the dummy structure. The outer geometry is defined with a finite element surface mesh which is supported at the rigid bodies. These are the so-called facet surfaces. Deformable bodies are used to model the ribs and jacket [4].

GEOMETRY

The outer surface of the dummy is defined using facet surfaces (FE meshes) for all surfaces of the dummy that can have contact to the car interior, like the seat, instrument panel and restraint systems. This modelling technique combines the relatively fast solutions associated with multibody techniques with the detailed surface descriptions used in FE simulations. Benefits include better timing of contact interactions and more accurate environment/belt-dummy interactions.

CONTACT FUNCTIONALITY FOR FACET MODELLING

The compliance of the dummy foams is represented in validated contact characteristics. Non-linear stiffness & hysteresis functions are implemented for all dummy components, where local variations in foam thickness can be described using the thickness option. The contact characteristics are generally defined as stress/strain functions that are directly related to the applicable foam properties.

Combined contact characteristics

By default in MADYMO facet contact it is assumed that one surface is rigid and the opposite surface is deformable. This means that the deformation stiffness has to be combined in one contact characteristic. The disadvantage of this approach is that for each contact where both surfaces deform a dedicated stiffness characteristic has to be derived by the user. An option for combined contact characteristics for facet surfaces is provided in MADYMO R6.2.1. Combined characteristics were already available for contact between ellipsoids and ellipsoid-to-plane contacts. The use of combined characteristics allows the user to define the characteristic of a component like the dummy, seat or IP without knowing the stiffness of the opposite surface. The contact is easier to define and therefore more user-friendly. It is no longer necessary to predict beforehand which structures will contact each other and define for every separate set a contact characteristic yourself. Using combined contact characteristics for facets it is possible to define a contact characteristic (stress-based) for every surface. The solver combines the two characteristics of the contact partners and calculates the contact forces. However, the big difference with the conventional method is that the forces no longer act in one point, but are divided over the contact area, which is more realistic (Figure 2).

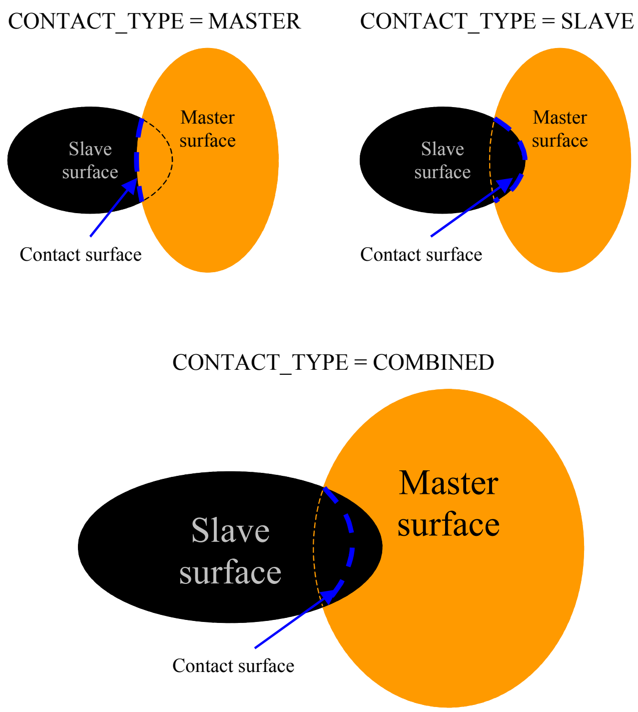

Figure 2: Facet surface contact types

<u>Advanced belt interaction modelling</u>
For a good description of the interaction between dummy and belt, not only a well-defined surface is important but also a physical description of the contact itself. The physical interaction of belts with crash dummies constitutes a complex combination of local deformations of the belt material and the dummy flesh combined with friction at the belt surface and the belt edge. Finite element techniques can potentially capture these phenomena in detail but CPU times increase dramatically compared to multibody approaches and therefore more efficient solutions are needed. MADYMO R6.2 offers two advanced options for modelling friction in MB_FE and FE_FE contacts:

1. Orthotropic contact friction
2. Penetration-dependent friction scaling

Orthotropic contact friction allows the user to define friction that is dependent on the direction of the relative surface motion (Figure 3). These directions are defined using the element connectivity of the slave surface. These tools provide the possibility to model complex friction phenomena such as "belt pocketing" where the belt cuts deeply into the more compliant dummy skin. Note that in this definition the element orientation is very important when using this functionality for the purpose of belt pocketing modelling.

Besides orthotropic friction also penetration-dependent friction is implemented. The friction coefficient depends on the level of penetration and can be used to describe the lateral forces of belt pocketing in a more realistic way. The penetration-dependent friction functionality can also be used to model the dummy - seat interaction.

Another important improvement regarding user-friendly modelling is the new possibility in MADYMO to make the deformable bodies rigid during the positioning of a finite element belt.

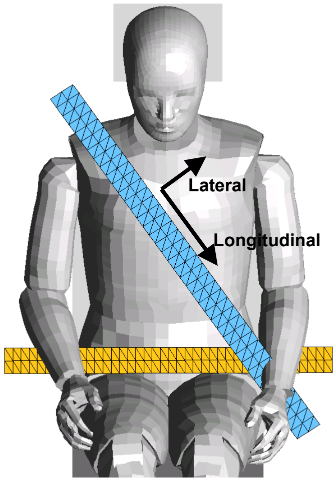

Figure 3: Facet dummy with FE belt

COMPARING ACCURACY OF ELLIPSOID & FACET MODELS USING OBJECTIVE RATING

Quality assessment on full dummy application level is a key application of objective rating methods. Full dummy application level is defined as simulations using multiple sub-systems (dummies, restraint systems, seats, car components, etc) that interact with each other. The quality values resulting from the rating procedure should give a good impression of the performance of the complete dummy model in its environment. In other words, the quality values should give a statement on how 'good' the simulation model is.

Quality assessment on dummy component or sub-system level will be done to get an impression of the performance of a particular part. The component applications are experiments with a well-defined environment. Those tests are used for calibrating the separate parts while the full dummy tests are used for the validation. Output used for the calculation of injury criteria and time signals involved in the regulations (FMVSS, USNCAP, EuroNCAP, JNCAP and ECE) will be the base of the selection of the signals used for the quality assessment. The quality assessment reported here is based on about 80 experiments. The experiments consist of full dummy, assembly and component tests with a variety of loading conditions. Outliers have not been removed. All simulations have been performed using MADYMO 6.2.1 with the latest released models:

1. The 50th percentile Hybrid III Ellipsoid model version 7.0
2. The 50th percentile Hybrid III Facet Quality model version 0.1

Three different criteria are chosen to evaluate the quality of the signals: the peak criterion, the peak timing criterion (both scalar criteria), and a signal trend criterion called the WIFac criterion. The peak criterion compares the absolute maxima of the experiment and simulation signals, the peak timing criterion the time where this maximum occurs and the WIFac judges the similarity of the total shape of the experimental and simulation curves. The WIFac criterion is therefore very sensitive to the time frame where the criterion is applied to. Here it is decided to apply it to the total time frame of the simulation. Note that for some signals noise can play a role, resulting in low quality values. As a next step the separate quality values resulting from the comparison of the signals are combined in lumped rating values using weighting factors. Here the weighting factors were chosen such that each experiment type was weighted equally. In line with methods for objective rating developed in the European projects VITES and ADVANCE [1], it is chosen to define the domain of score values as [0, 1] (x100%). The value of 0 corresponds to a very bad score whereas the value of 1 (100%) represents full correspondence of signals. The chosen domain is arbitrary, and has no impact on the quality of the rating method. For further details, and alternative formulations we refer to [3]. Table 1 shows the three rating criteria for chest deflection and Figure 5 shows rating for several other signals. For most signals the rating is presented separately in dummy component tests and in full dummy test. As could be expected the rating is generally best in the component tests.

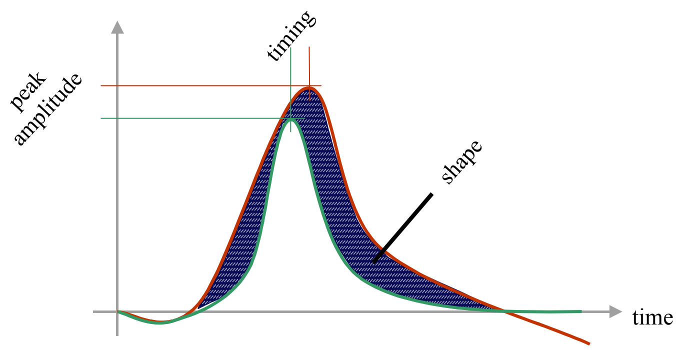

Figure 4: Three different criteria used for signal comparison.

Table 1: Chest deflection rating results for Hybrid-III 50th models.

		Ellipsoid model	Facet model
Component tests	Peak	0.854	0.902
	Peak Time	0.819	0.944
	WIFAC	0.605	0.836
Full dummy tests	Peak	0.795	0.894
	Peak Time	0.850	0.894
	WIFAC	0.613	0.668

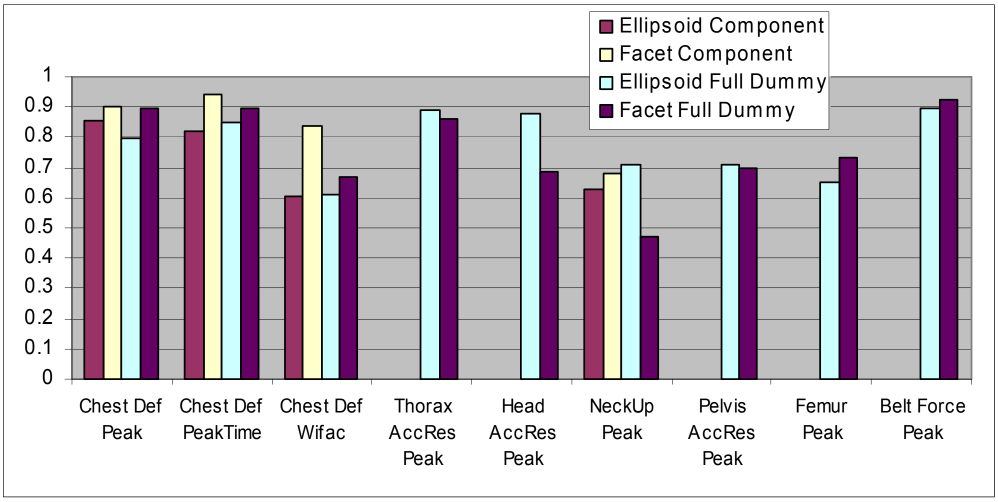

Figure 5: Objective rating of the ellipsoid and facet Hybrid III in component tests and full dummy tests

Several full dummy rating values seem to be rather low. To get more feeling about the absolute value of the rating outcome a correlation is done between repeated hardware experiments [3]. This correlation shows a rating outcome of 65% for experiments with a high repeatability. With this in mind it can be said that most rating values of the simulations are in the bandwidth of the repeated experiments. However for the head neck region, as well as the pelvis we feel that further improvement is possible. Here it shall also be remarked that the full dummy validations reported here have been developed for ellipsoid models. Full dummy validations which optimally benefit from facet technologies are now being prepared using recent features described in the previous section.

LS-DYNA TO MADYMO COUPLING

The LS-DYNA - MADYMO coupling has been introduced to effectively combine validated models in the two codes. Instead of converting component models such as airbag models, or substituting dummy models from different sources, the coupling enables to flexibly combine models in the preferred code. The "traditional LS-DYNA/MADYMO coupling" as released with MADYMO v5.0 enabled contact of MADYMO ellipsoids with LS-DYNA FE entities. The traditional coupling was successfully applied for frontal occupant safety analysis. One of the limitations of the traditional coupling was the linear contact stiffness of ellipsoids resulting from using the Penalty Based Contact Method. Furthermore the traditional coupling could not handle the latest MADYMO dummy technologies and, particular, FE dummy models for side impact and OOP.

Therefore LSTC and TNO have jointly developed the "extended coupling" which allows contact between almost all MADYMO & LS DYNA geometric entities. This gives LS-DYNA users access to the most advanced MADYMO dummy & human models, airbag functionality, etcetera. In the "extended coupling" the MADYMO contact algorithm is used to calculate loading between the two models (Figure 1). Thereby the validated contact properties of the MADYMO dummy models are now used by default in the coupling. In addition the thickness and bulk modulus of the LS-DYNA elements is taken into account.

Recently MADYMO introduced optional d3plot output to facilitate joined post-processing of coupling results. Further coupling enhancements planned include:

1. Units synchronisation
2. Recommended memory setting
3. Improved error message handling
4. Improved functionality for including MADYMO airbags in coupling runs

Finally coupling performance is being improved aiming at full MPP scaleabilty. Here it is to be noted that coupling performance is a bottleneck only when many CPUs are used and FE MADYMO models are applied such as MADYMO FE side impact dummy models or human models. The ellipsoid and facet multibody dummy models as described in this paper are very efficient, and are generally not critical for CPU in the coupling. Also for side impact efficient multibody dummy models are effectively used in the coupling.

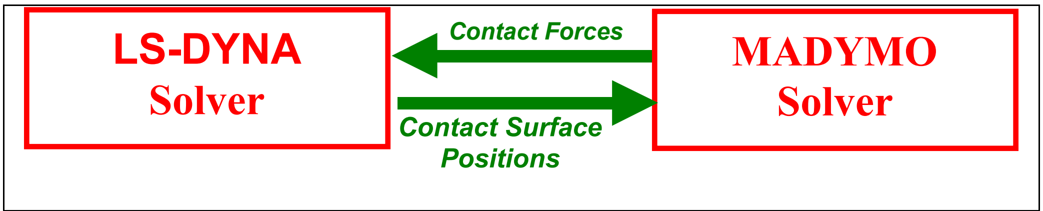

Figure 6: Extended coupling

DISCUSSION

OBJECTIVE RATING EVALUATED

Objective rating is definitely not as objective as the term suggests [3]. The quality values depend on the exact rating method and criteria, but also on the number of experiments and signals in a validation set and the simulation time frame considered. Therefore it is concluded that objective rating is particularly useful for comparing models, using the same rating conditions. This proved essential in the process of further improving both the ellipsoid and the facet model. Currently a quality report is offered for every major new MADYMO dummy model project. Not only the correlation improvement is being reported, but differences between dummy model, and software versions are being reported as well.

Tools like Adviser are helpful to create standard rating procedures [1,2]. In addition, high quality validation data is needed ranging from component tests to realistic applications. The PDB (Partnership for Dummy technology and Biomechanics) is creating a new validation set by doing extensive component and full dummy experiments with three different Hybrid-III 50th %ile hardware dummies. The experimental data, together with a clear description of the experiments, will be made available to the major numerical dummy model developers in the market. This validation set can then easily be used for comparing the quality of dummy models of different suppliers, as long as it is also agreed on the rating method to be used, since this will influence the rating numbers heavily as well.

FACET MODELLING

Facet models are more and more accepted as a valuable tool for crash safety simulations. They combine relatively low CPU usage - typically related to multibody approaches - with the possibility to model contact surfaces in detail using FE techniques. Especially for dummy/belt and dummy/airbag interactions a detailed contact surface description helps to make the model more accurate.

The latest developments in the field of facet modelling, combined contact for facets and the possibility to rigidise the flexible bodies during FE belt positioning, improve the user-friendliness significantly. Using the combined contact option for facets, in MADYMO R6.2.1 the solver combines the two characteristics of the contact partners and calculates the contact forces comparable with the conventional multibody method. However, the big difference is that the forces no longer act in one point, but are divided over the contact area, which is more realistic. The orthotropic friction introduced in MADYMO R6.2 offers a possibility to take the complex phenomenon of 'belt pocketing' during the belt loading into account. Together with a detailed description of the dummy skin (outer geometry), this can improve the model quality significantly.

The MADYMO Hybrid-III 50th %ile facet model has been upgraded. This model includes an updated geometry description based on 3D scans and improvements in the thorax and clavicle model, the knee region and the lumbar spine. Special attention was paid to a better prediction of the relevant signals when the dummy is applied to loading severities in the magnitude comparable to NCAP loading. Also the unloading phase of the thorax is significantly improved, allowing a more predictive study on belt retractor timings.

REFERENCES

1. *Hoof J van, Puppini R., Baldauf H., Oakley C., Kayvantash K. (2003). Adviser: A Software Tool for Evaluation and Rating of Numerical Models in Crash Safety Analyses, ESV Conference 2003, Paper Number 483.*
2. *JACOB C., F CHARRAS, X. TROSSEILLE, J. HAMON, M. PAJON, J. Y. LECOZ, Mathematical Models Integral Rating.*
3. *Hovenga P.E., Spit H.H., Uijldert M. , Dalenoort A.M (2005). Improved prediction of Hybrid-III injury values using advanced multibody techniques and objective rating. SAE 2005 Conference.*
4. *Koppens, W. P., Lupker, H., Rademaker, C. (1993). "Comparison of modelling techniques for flexible dummy parts", Proceedings of the 37th STAPP car crash conference, pp. 95-104, Paper No. 933116.*
5. *Krishnaraj Srikanth, Vikram Narayanasamy, Ravi Thyagarajan, Rohit Jategaonkar & Ana Barbir (2003) Comparison Of Facet and Ellipsoid Dummies In Frontal Crash Simulations. MADYMO Users Meeting, Detroit, 2003.*
6. *Made, Robin van der, Laurent Margerie, Eric Hovenga, Robert Kant (TNO Delft, The Netherlands), Juanito Co, Beibei Xu, N.S. Sriram, T. Laituri (Ford Motor Company Detroit, USA). Development of a Hybrid III 5th percentile Facet Dummy Model. SAE World Conference 2001, Paper 01PC-312.*
7. *TNO (2004), "MADYMO Database manual version 6.2.1", TNO Automotive, Delft, The Netherlands.*
8. *TNO (2004), "MADYMO Theory manual version 6.2.1", TNO Automotive, Delft, The Netherlands.*
9. *Verhoeve R., Kant R., Margerie L. (2001). ADVANCES IN NUMERICAL MODELLING OF CRASH DUMMIES, ESV Conference 2001, Paper Number 152.*

APPENDIX - MADYMO DUMMY MODELS, SUBSYSTEM MODELS, BARRIER MODELS AND HUMAN MODELS

Frontal / Rear Impact dummies	***Side Impact dummies***	***Child dummies***
Hybrid-III 5th female	EUROSID-I	Hybrid-III 3YO
Hybrid-III 50th	ES-2	Hybrid-III 6YO
Hybrid-III 95th	US DoT-SID	CRABI 12MO
Hybrid-III 50th standing	SID-H3	Q3
Hybrid-III 50th + THOR lower legs	SID-IIs	P3/4
THOR	SID-IIs + airbag interaction arm	P1 ½
Hybrid-II	BioSID	P3
Hybrid-III 50th FAA (aircraft)	WorldSID (in preparation)	P6
Hybrid-III 50th + TRID neck		P10
RID-II		
BioRID-II		
MATD (motorcycle dummy)		
Subsystems	***Barriers***	***Human models***
FMVSS 201 headform	Offset Deformable Barrier	Occupant 5th female, 50th & 95th male
Pedestrian child headform	FMVSS-214 MDB	FE occupant model
Pedestrian adult headform	EEVC-WG13 MDB	Pedestrian 3y/6y/5/50/95%
Pedestrian ACEA headform 3.5kg	IIHS-SUV MDB	Facet neck model
Pedestrian legform	FMVSS-201 impact pole	FE arm model
Pedestrian upper legform		FE buttocks model
ECE-R12 Bodyblock		Facet leg model
H-Point Machine		FE lower extremity model
		FE brain skull model (on request)