

IIHS Side Impact Analysis Using LS-DYNA/Madymo Coupling

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Abstract

The LS-DYNA/Madymo coupling has a growing popularity in the field of vehicle crash analysis as it allows the users to merge an existing occupant simulation subsystem model and a full car structural model into one system. The extended coupling feature introduced in late 2002 has significantly enhanced this model fusion capability.

This paper demonstrates the application of such a coupling technique for the simulation of the IIHS (Insurance Institute for Highway Safety) side impact condition on one of General Motor's vehicle development programs. However, when this analytical work was originated, the test configuration was new and still not completely defined.

The baseline model consists of the vehicle structure and barrier model in LS-DYNA, and occupant and airbag models in Madymo. The baseline model was modified to demonstrate an enabler that helped improve side impact performance.

Introduction

The common simulation tools in crash analysis are full-vehicle FE models used primarily for structural analysis and sub-system models used primarily for occupant simulation. The sub-system modeling technique assumes that there are no structural modifications in the design and hence the structural behavior remains the same. Often, the sub-system model uses a prescribed structural motion taken from the full-vehicle modeling results and allows the user to modify the interior components and restraint systems to improve the occupant's performance. The advantage of using the sub-system technique is the quick turn-around time for computation. The timesaving is magnified when Madymo multi-body occupant models are used. However, in side impacts, because of the proximity of the occupant to the vehicle structure, sometimes it is difficult to decouple the occupant and structural performances. Hence there is a need for a coupling technique that combines the advantages of both full-vehicle analysis modeling and sub-system modeling techniques. When the two models are coupled, one could make changes to any component in the vehicle to understand its effect on occupant performance. Another reason for the coupling's growing popularity is that the multi-body dummy models remain robust tools for assessing injury values. When the IIHS first published its intention to develop a side impact test [1], there was a lack of relevant dummy models available and the Madymo multibody dummy was a ready-to-use model to start assessing the challenges connected with the new test.

The LS-DYNA/Madymo coupling is delivered in a program that contains both LS-DYNA and Madymo codes compiled into one binary. During the progress of model analysis, both codes exchange information relevant for contacts and supports between the LS-DYNA and Madymo entities.

This paper shows how this modeling technique was used for the IIHS side impact simulation. The baseline model discussed in this paper consists of the LS-DYNA barrier, vehicle structure;

and Madymo dummies and airbags. The baseline model was modified to demonstrate one of the basic side impact protection strategies. In addition to this simple demonstration, there has been a number of other design iterations performed on other vehicle programs within GM using the same modeling technique.

Application: IIHS side impact simulation

The increasing number of SUVs and trucks on the roads and the resulting increased potential of their involvement in traffic accidents with cars lead the IIHS to a definition of a new truck-to-side impact test configuration. In this test scenario, a moving deformable barrier with a truck-like front end and mass of 1500kg impacts the target vehicle perpendicularly with an initial velocity of 50 km/h.

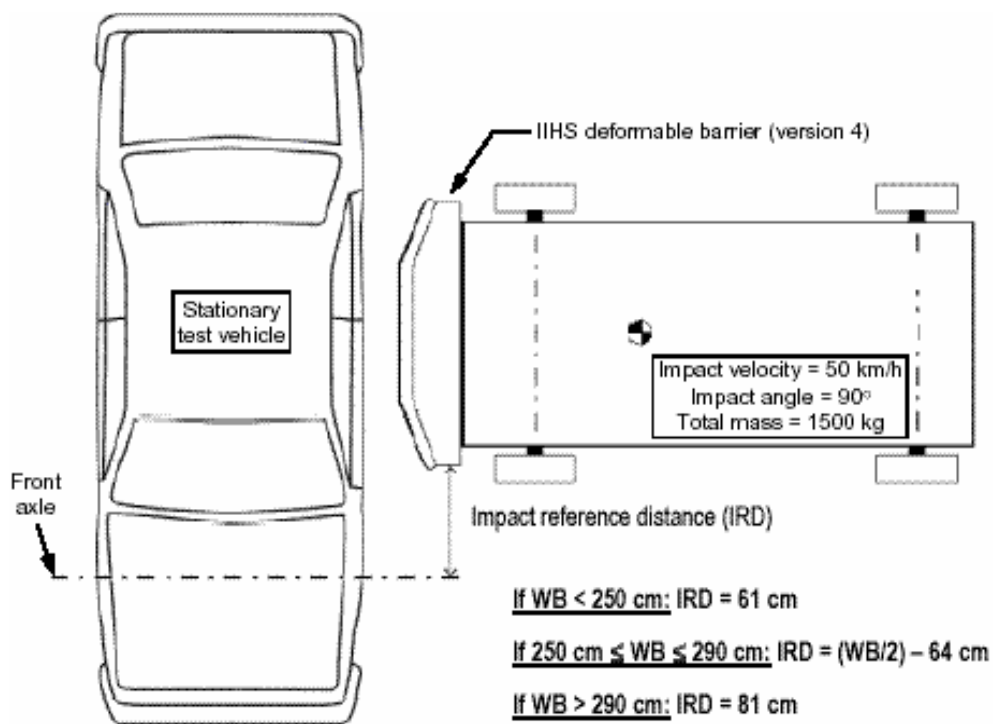


Figure 1: IIHS side impact test configuration.

The front and rear struck side seats of the target vehicle are occupied by SID2S dummies representing a 5th percentile female. Both dummy injury assessment values and vehicle structural performance assessment values are defined by the IIHS [2].

From the structural point of view, the major challenge of the test is that the barrier bumper misses the rocker area of most passenger cars. In other side impact scenarios, like LINCAP, the floor and its cross-car members absorb or transfer most of the impact energy. In the IIHS side impact, however, this load path gets involved much later in the event and it is the door and B-pillar that undergo a large deformation first (figure 2).

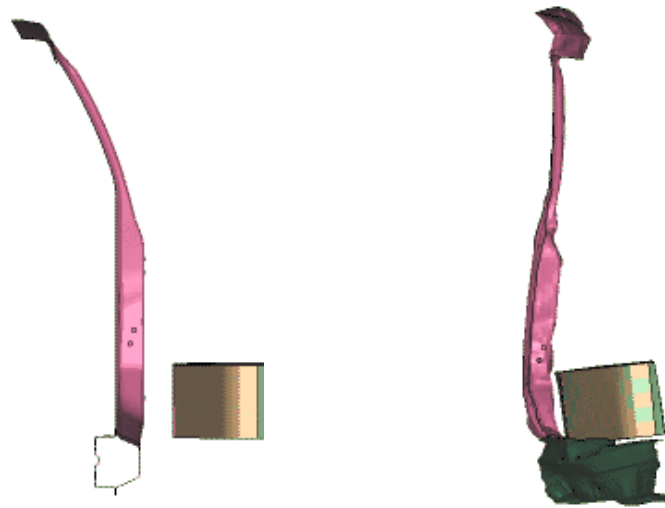


Figure 2: Barrier bumper to rocker overlap

The main challenges to occupant performance stem from the door intrusion velocity, the shape of the intrusion profile and the possible head contact with the barrier face intruding through side windows. The main enablers to improve the dummy loading in this test are the structural reinforcements, door trim design and thorax and curtain airbags.

Extended coupling model setup

This section will briefly describe how to set-up a coupling model of the IIHS side impact. The first step to create a coupling model is to create the two input files separately: the LS-DYNA input file and the Madymo input file. Often, the LS-DYNA input file will contain the vehicle and barrier FE structures, while the Madymo input file will contain dummy models and FE airbag models. Once these files are created and debugged, several relatively simple data cards need to be added to both of the files specifically for coupling.

To the LS-DYNA input file, this data card needs to be added (example, for a detailed syntax explanation please refer to [3, 4]):

```
*CONTROL_COUPLING
$ unit conversion between LS-DYNA and Madymo
$  UNLENG      UNTIME      UNFORC
   1000        1000        0.001
*CONTACT_COUPLING
  1
  3331
*SET_PART
$#      SID          DA1          DA2          DA3          DA4
      3331          0.          0.          0.          0.
$#      PID1 list of parts to be seen by Madymo
      900
      524
      525
```

The parts listed in this example (900, 524...) will be displayed in the Madymo KIN3 file and, also, the parts listed here can have a contact defined in the Madymo input file.

To the Madymo input file, this card needs to be added (example):

```
<SYSTEM.REF_SPACE ID = "1"
  NAME = "INERTIAL_SPACE">
<FE_MODEL ID = "100">
<CONTROL_FE_MODEL />
<CONTROL_FE_TIME_STEP />
</FE_MODEL>
</SYSTEM.REF_SPACE>
<COUPLING FE_MODEL = "/1/100" >
</COUPLING>
```

By including these LS-DYNA and Madymo cards, the LS-DYNA/Madymo coupling program knows what LS-DYNA part information should be exchanged between LS-DYNA and Madymo during the progress of the job solution. Now the user can define contacts between the LS-DYNA and Madymo entities in the Madymo input file. Example:

```
<GROUP_FE ID = "10"
  NAME = "Vehicle_gfe"
  FE_MODEL = "/1/100"
  PART_LIST = "900 524"/>

<CONTACT.MB_FE ID = "1"
  MASTER_SURFACE = "/SID2sFront/Abdomen_gmb"
  SLAVE_SURFACE = "Vehicle">
<CONTACT_FORCE.CHAR
  CONTACT_TYPE = "MASTER"
  FRIC_FUNC = "friction_01"/>
</CONTACT.MB_FE>
```

Note that the LS-DYNA part 525 is not listed in this contact, still, it will be visible in the KIN3 file.

In our case, both curtain and thorax airbags were modeled in Madymo. Since these are Madymo FE structures that need to be attached to the LS-DYNA FE vehicle structure, some more cards need to be added. First we have to define a light-weight rigid body with an ellipsoid on it. This rigid body serves as a support body of the airbag. The ellipsoid information can be passed onto LS-DYNA while LS-DYNA will handle this ellipsoid as a rigid body. Using the *CONSTRAINED_EXTRA_NODES_NODE card this rigid body is attached to LS-DYNA vehicle structure. As an example, here is a set of cards that can be used to achieve this:

In Madymo:

```
<BODY.RIGID      ID = "1"   NAME = "att1"
  MASS           = "0.1"
  CENTRE_OF_GRAVITY = "0.0   0.0   0.0"
  INERTIA        = "0.01  0.01  0.01  0.0  0.0  0.0"
></BODY.RIGID>

<JOINT.FREE      ID = "1"   NAME = "joint_1" >
<CRDSYS_OBJECT_1
  POS            = "3.273  -0.600  1.115"/>

<CRDSYS_OBJECT_2
  BODY           = "att1"
  POS            = "0.000  0.000  0.000"/>
</JOINT.FREE>
```

```

<SURFACE.ELLIPSOID ID = "1"
NAME      = "ell_1"
SEMI_AXIS = " 0.0200    0.0200    0.0200  "
DEGREE    = "2.0">

<CRDSYS_OBJECT_1
BODY      = "att1"
POS       = " 0.000    0.000    0.000"/>
</SURFACE.ELLIPSOID>

<COUPLING      FE_MODEL="/1/100" NAME="Vehicle">
<COUPLING_SURFACE
EXTERNAL_REF   = "285"
SURFACE        = "/5/ell_1"
EXTERNAL_DATA  = "99911.0">
</COUPLING_SURFACE> </COUPLING>

```

In LS-DYNA:

```

*MAT_RIGID
$#  MID      RO      E      PR      N      COUPLE      M      ALIAS
    99911    7.8E-09  206800.  0.30001  1.      2.      1.      285.
$#  CMO      CON1    CON2
    0.      0.      0.
$#  A1      A2      A3      V1      V2      V3
    0.      0.      0.      0.      0.      0.
*SECTION_SHELL
$#  SECID    ELFORM    SHRF      NIP      PROPT      QR      ICOMP
    99911    2      0.83      0.      0.      0.      0
$#  T1      T2      T3      T4
    1.      1.      1.      1.
*PART
SUPPORT
$#  PID      SECID      MID      EOSID      HGID      GRAV      ADPOPT      TMID
    99911    99911      99911      0          0          0          0          0
*CONSTRAINED_EXTRA_NODES_NODE
    99911    275623

```

The coupling run generates both LS-DYNA and Madymo output files. The KIN3 file (Madymo animation file) contains all Madymo components and also the coupled LS-DYNA components. Figures 3 and 4 show the content of our model.

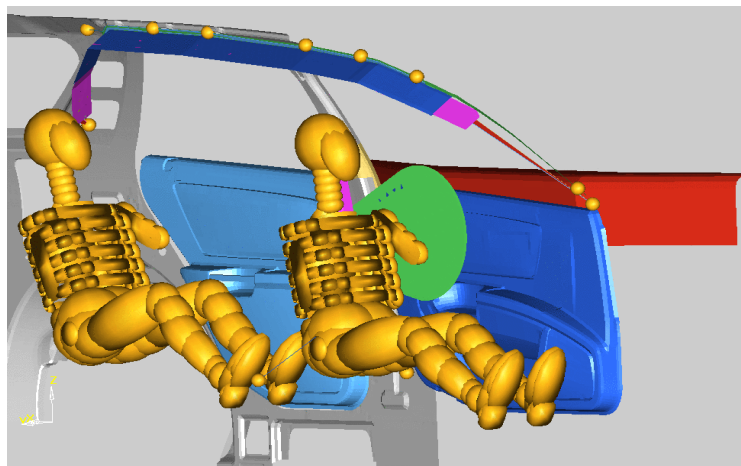


Figure 3: Madymo model setup with coupled LS-DYNA components (KIN3)

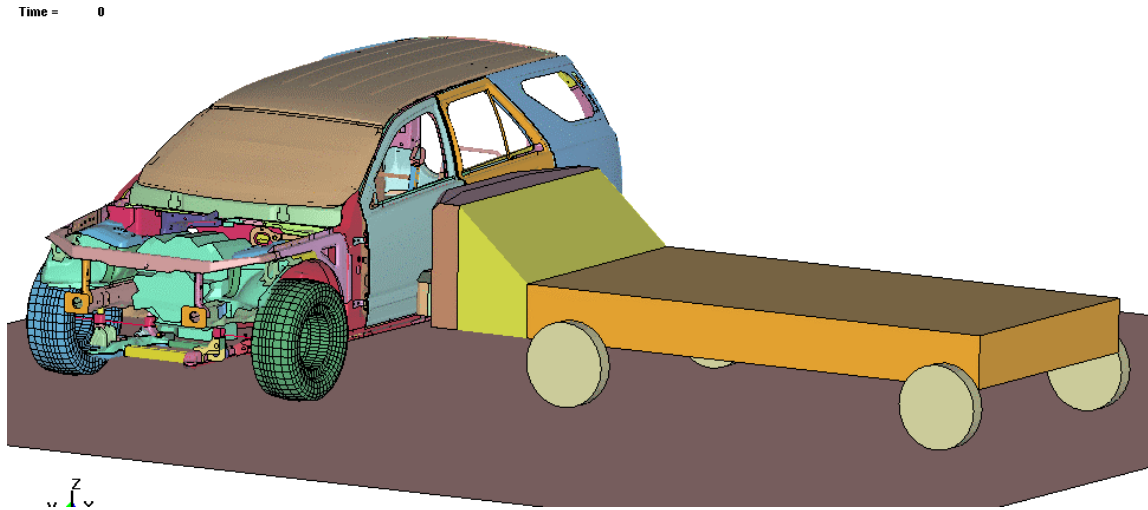


Figure 4: LS-DYNA model setup (d3plot)

Design modification and results

There have been a large number of papers published on how to optimize the structural and interior padding properties of the vehicle for the benefit of the occupant in the event of a side impact (for example [5]). Even though these papers mostly explore the test environments of FMVSS214, LINCAP and Euro-NCAP, it can be expected that conclusions coming from these works will be to some extent valid in the new IIHS side impact test environment.

Similarly, based on our experience from other side impact load cases, a set of modifications was performed on the vehicle FE model to achieve an improvement of the dummy response. These modifications were focused on a better load distribution throughout the dummy torso. Figure 5 shows a significant change in the rib deflection for both the thoracic and abdominal areas. Since the rib deflection limits are a major challenge [6] in this test condition, the use of the coupling model helped the GM safety integration team provide design directions to meet the desired occupant performance.

Conclusions

The LS-DYNA/Madymo coupling allows the user to merge sub-system, Madymo occupant and airbag models with the LS-DYNA full vehicle structural model. The coupling technique was proved feasible and reliable for the IIHS side impact test condition in this paper. The robustness and consistency of the multi-body dummy models are the primary motivation for using this modeling technique.

Even though the first model setup requires a certain attention and basic experience in both LS-DYNA and Madymo, once the model is set up, it is very easy to analyze numerous design iterations. It would be very convenient to have a graphical interface that would help the user prepare the data cards specific for coupling. Since the coupling software is undergoing a rapid development, it is expected that the definition of supports of Madymo FE structures to the LS-DYNA structures will soon be made more straightforward.

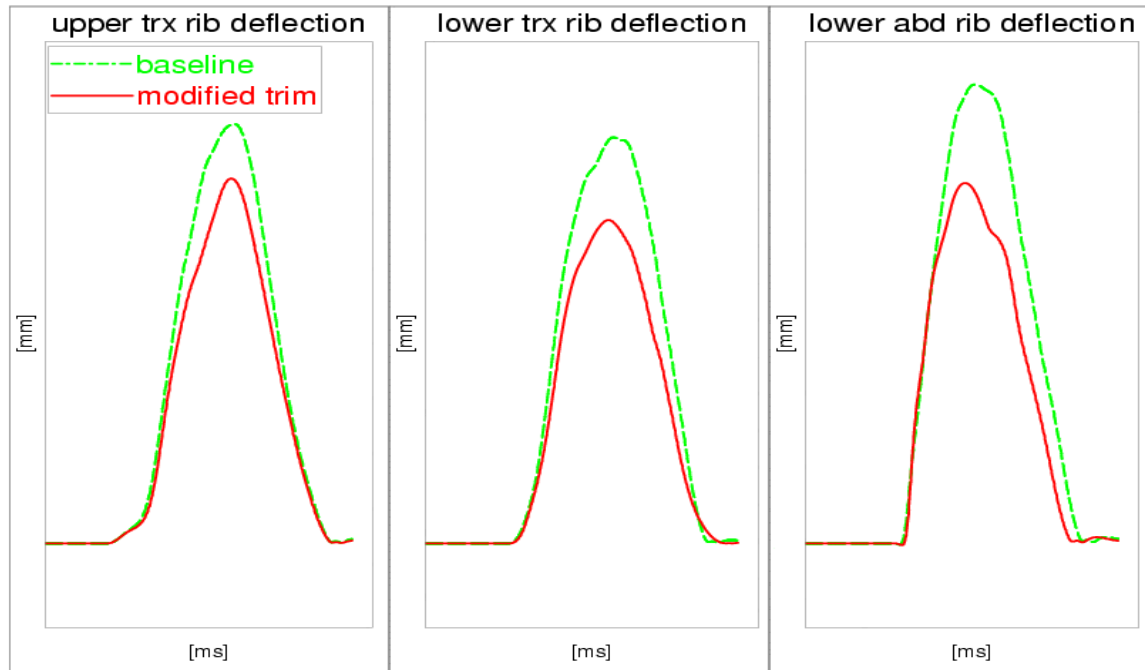


Figure 5: Example of an effect of the design modification on the dummy response.

References

- [1] Side Impact Crashworthiness Evaluation Program Development – Status Report, IIHS, Washington DC, October 2000
available at: <http://www.highwaysafety.org/presentations/sice.htm>
- [2] IIHS Side Impact Test Program Rating Guidelines, IIHS, Washington DC, June 5, 2003
available at: <http://www.highwaysafety.org/presentations/sice.htm>
- [3] Madymo 6.0.1 Reference Manual
- [4] LS-DYNA 960 User's Manual
- [5] Di Leo, Marcello: *Structure and padding optimization for side impact protection*, 16th ESV Conference, Windsor, Ontario, 1998
- [6] Arbelaez, Raul A.: *IIHS Side Impact Test Procedure Development*, SAE Government/Industry Meeting, May 14, 2003,
available at: <http://www.highwaysafety.org/presentations/sice.htm>

