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ABSTRACT

Under the Partnership for Next Generation Vehicles (PNGV) program instituted by the U.S. National Highway Traffic Safety Administration (NHTSA), a MADYMO articulated full vehicle model of the 1992 Ford Taurus for side impact has been developed and validated against test data. MADYMO (Mathematical Dynamic Model) is a computer package that is used to model rigid multibody kinematics and dynamics and finds application in simulating various crash situations and to assess occupant injuries. Input for the MADYMO model consisting of rigid body joint stiffnesses was obtained from an existing Finite Element (FE) model. Model validation was done by comparing the vehicle and dummy numbers with a series of side impact tests conducted by the Ford Motor Company. Model results correlated very well with both test and FE data. This model demonstrates the utility of rigid body based full car models for crashworthiness analysis. Such models result in significant saving in computational time and resources.

INTRODUCTION

The PNGV project is a collaborative effort between NHTSA and the U.S. car manufacturers. The goal is to develop a new set of passenger vehicles utilizing emerging technologies to produce a three-fold improvement in fuel efficiency. A major constraint on the PNGV designs is to ensure that the overall crash performance and safety attributes are not compromised by their lightweight and non-standard materials. With this objective, NHTSA proposes to develop a fleet of full vehicle crash models to study various impact scenarios.

Broadly speaking, the objective of crashworthiness analysis is to design the vehicle’s important structural members such that they behave predictably in the event of a crash while providing adequate protection for the occupants. By this definition, one must be able to predict not only the behavior of the structural members of the vehicle, but also the responses of the occupants. In Computer Aided Engineering (CAE) of crashworthiness, the structural analyses are usually performed using Finite Element (FE) analysis, and occupant simulation is done using rigid body dynamics.

FE analyses of full car crashes require a significant outlay of time and computing resources. On a SGI Origin 2000 machine using 2 processors, a typical full vehicle FE analysis consisting of approximately 100,000 elements requires around 48 CPU hours to complete successfully. This is in addition to time required for preprocessing and debugging.

Occupant simulation involves representing the occupants as a system of rigid bodies connected by mechanical joints, that interact with the interior of the vehicle represented by simple shapes (e.g. planes, cylinders, ellipsoids, etc). The analysis involves studying the behavior of the occupant system to an applied input, which is usually a acceleration pulse obtained from an actual crash test. These analyses typically require very limited computational resources. In many instances it becomes necessary to couple the occupant models with structural models and currently the techniques that are available for performing coupled analyses require almost double the time necessary for structural analysis alone. This effort is not entirely justified if the main focus is on determining the occupant responses to various crash situations.

A major portion of computational time is spent in analyzing the structural aspect of a full vehicle model. One way to reduce this overhead is to represent the major load bearing structures also as rigid bodies connected by properly defined joints. Thus in these models, both the vehicle structure and the occupants are analyzed using rigid body dynamics. Such models run in a fraction of the time required by full vehicle FE models. These models allow analysis of a variety of impact situations (for example: different dummy sizes, occupant positions, modes of impact and speeds). The current paper describes the development and validation of a full vehicle model of the 1992 Ford Taurus in side impact. MADYMO3D[1] code was used for developing the rigid body models.

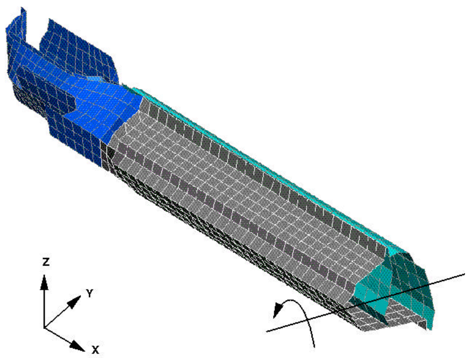

Figure 1. Component FE model for extracting joint stiffness.

METHODS

CAPTURING DATA FROM FE MODEL – An earlier task of the PNGV program involved the development and validation of a full car FE model of the 1991 Ford Taurus in side impact. Data for the structural components of the MADYMO model were extracted from this FE model. The first step in modeling was to locate the rigid points on the door-ring from the FE model. The door-ring consisting of the A-pillar, sill (or rocker), B-pillar, C-pillar and roof rail, is a predominant load bearing structure in side impact in addition to the cross-car beams that provide lateral stiffness. Rigid or hard points are those nodes about which the structure undergoes significant rotations. For the current model 25 hard points were identified from inspection of the FE model animation. These nodes determine the joint locations for the MADYMO model. The door-ring was broken up into smaller "components". Each component consisted of shell elements between two consecutive hard points and was analyzed in three modes of rotation (about x, y, and z –axes). The reaction torques at the hard points obtained from the nonlinear FE analyses were employed to characterize the joint stiffnesses for the MADYMO model (see figure 1.) The resulting joint stiffness curves appear like the ones shown in figure 2. The lateral stiffness of the car is represented by means of 9 nonlinear springs. The spring properties were obtained from the forces passing through several cross-sections defined for the full car FE model. All FE analyses were performed with LS-DYNA3D[2]. The essential structure of the impacted vehicle is shown in figure 3. The impacting vehicle is known as the moving deformable barrier (MDB), the properties of which are available in the MADYMO database. This is the barrier used in FMVSS 214 tests. The complete side impact configuration is shown is figure 4. Contacts between the barrier and the vehicle are then defined. An initial velocity of 13.5 m/s (in the lateral direction) and 6.5 m/s (in the axial direction) are applied to the barrier corresponding to the test conditions of 33.6 mph lateral impact at a crabbed angle of 27 degrees.

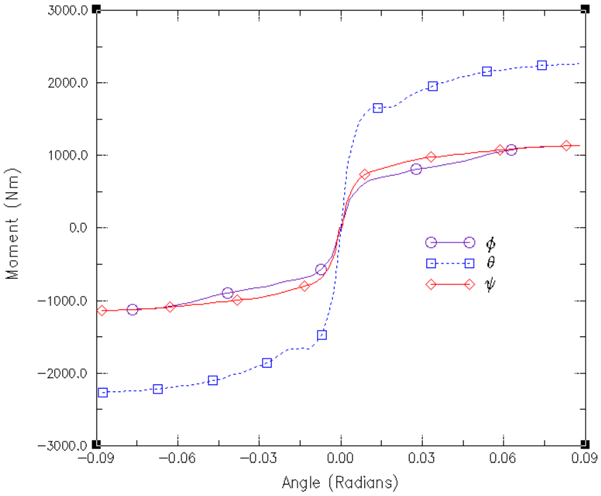

Figure 2. Typical joint stiffness curve from component FE runs.

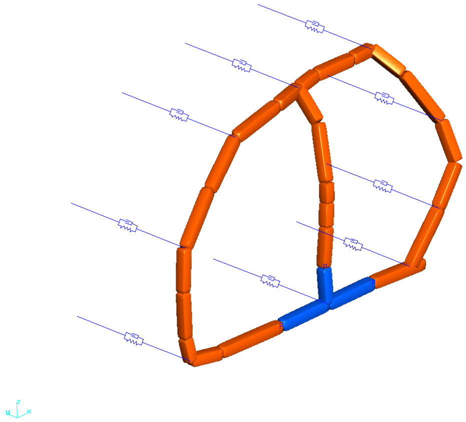

Figure 3. Door ring and cross car stiffness in MADYMO.

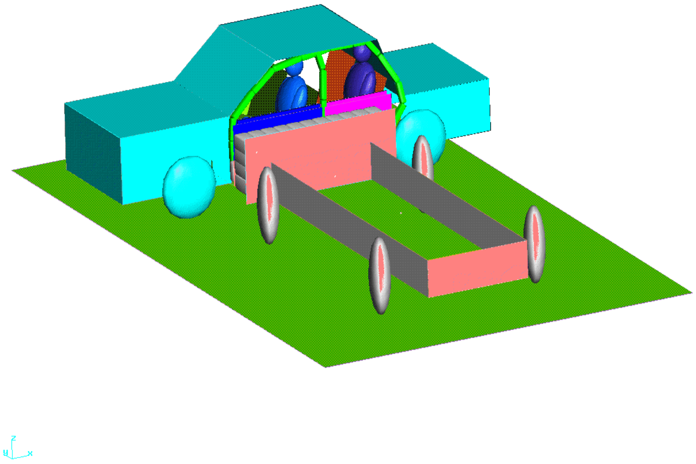

Figure 4. Complete configuration of the side impact model, including dummies and the MDB.

RESULTS

STRUCTURAL MODEL VALIDATION – The structural model is completed by defining the inertia properties (mass, moments and products of inertia) obtained from the FE model. The model validation involves comparing the velocities of the MDB and the vehicle velocity at several locations such as the b-pillar, rocker, floor tunnel etc. to test and FE data. Ford Motor Company conducted a series of side impact tests on five Ford Taurus 1990 vehicles to study the variability of the structural test responses. These test results were used in our structural model validation. Test upper and lower corridors for comparing against the model results were obtained from these tests. In figure 5, the lateral component of MDB velocity (measured at the center of gravity of MDB) between the model and test is compared and shows good correlation. In figure 6 the lateral velocity of the upper b-pillar is shown. Model tends to overpredict the initial peak, but shows better agreement after 35 ms. This could be due to the simplified representation of the b-pillar structure. The lower b-pillar lateral velocity is shown in figure 7. The analysis signal corresponds well with the initial peak of the test in both timing and magnitude and lies well within the test corridor for times after the first 25 ms. Overall the kinematics of the simulation also demonstrated that the model was successful in capturing the essential features of a side impact crash.

OCCUPANT MODEL VALIDATION – Once the structural model was validated, the occupant dummies were positioned in the model. Calibrated dummy models were available from the MADYMO database. Contact interactions between the dummies and the vehicle interior (seats, door trim, floor, etc.) were defined in the model. The complete model validation then involves comparing the dummy accelerations (pelvis, upper torso, and spine) to corresponding results obtained from the same series of five tests that were employed for structural model validation. Mean curves were calculated from the five tests and the occupant dummy signals obtained from the analysis were compared to these mean curves.

A subset of the dummy numbers that were compared to test results are shown in figures 8 through 11. In figures 8 and 9 the pelvic accelerations of the front and rear dummies respectively are compared to corresponding mean test signals. In both cases, a small phase shift was observed between the test and analysis curves, with the analysis peak occurring later than the test peak by about 5-7 ms. The model represents the complex geometry of the interior door trim with a single plane, which could explain the slight offset in the timing of the peaks. Figure 10 shows the lower spine acceleration of the front dummy, which shows reasonably good correlation with the corresponding test both in magnitude as well as in timing. Figure 11 shows the upper left rib acceleration of the rear dummy. While the peak and its timing are in very good agreement with the test, the model shows a more sustained acceleration at the peak (the dummy reaches peak acceleration at around 37 ms and stays there until around 50 ms). In general, all the occupant numbers agreed reasonably well with mean test data, in the sense that the acceleration trends were very well captured by the model. In addition, visual inspection of the dummy kinematics revealed no major problems.

The present modeling technique has been extended to other vehicle models as well (1995 Chevrolet Lumina and 1994 Dodge Intrepid). Preliminary runs with these models have elicited very good responses and correlations with corresponding tests are underway.

CONCLUSION

A methodology for developing a full vehicle representation using MADYMO articulated rigid body formulation has been evolved. This model is useful for the prediction of both Occupant and the Structural responses in the Side Impact mode. The MADYMO Vehicle model's response matches well with the tests and the Finite Element results. Occupant injury criteria also compare well with the test results.

Compared to FE models of side impact, the current modeling technique presents a significant reduction in turnaround time. It is possible to study a variety of impact scenarios involving different speeds, different occupant sizes and positions. Such an undertaking would be extremely resource intensive if one were to use a full vehicle FE model or actual testing. With minimal enhancements, the model could be used in car to car impact simulations that would make it possible to study effects of vehicle compatibilities on crashworthiness.

These models were developed as a tool for studying occupant safety in varying crash environments involving different vehicles, speeds, occupants and modes of impact. More specifically, the models were developed under the behest of NHTSA for application in the PNGV program, and for vehicle compatibility studies. Other models being developed using similar techniques include models for studying full frontal, offset frontal and oblique impacts. Further models for the 1995 Chevrolet Lumina and the 1994 Dodge Intrepid are being developed using the same methodology. These models will be employed for predicting occupant & vehicle responses for a variety of different scenarios such as different dummy sizes, occupant positions, modes of impact and speeds.

ACKNOWLEDGEMENT

The Authors would like to thank the Ford Motor Company for the side impact test results (Nos. 1497-1501) that were used for validating the models.

REFERENCES

1. MADYMO User Manual Ver 5.3
2. LS-DYNA3D User Manual Ver. 940

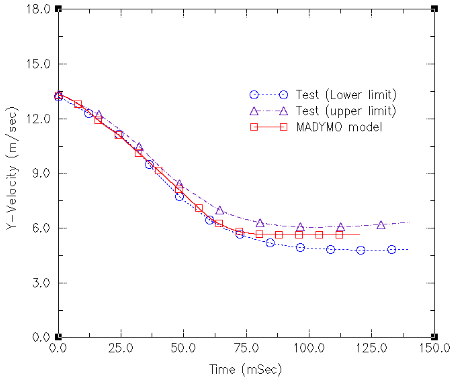

Figure 5. Velocity of the MDB.

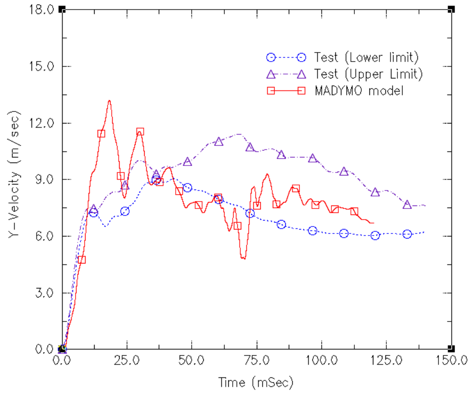

Figure 6. Velocity of the b-pillar (upper).

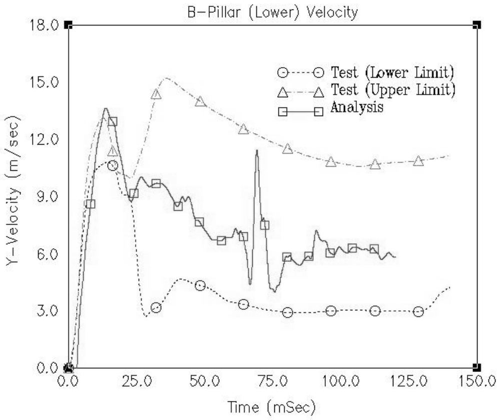

Figure 7. Velocity of the b-pillar (lower).

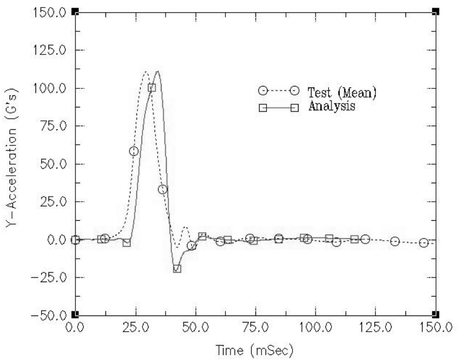

Figure 8. Front dummy pelvic acceleration

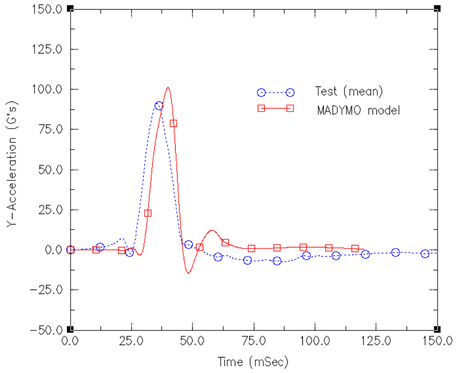

Figure 9. Rear dummy pelvic acceleration.

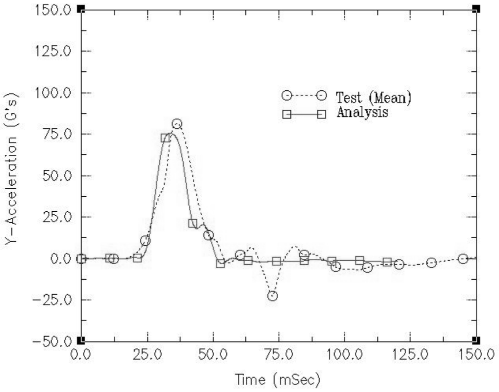

Figure 10. Front dummy lower spine acceleration.

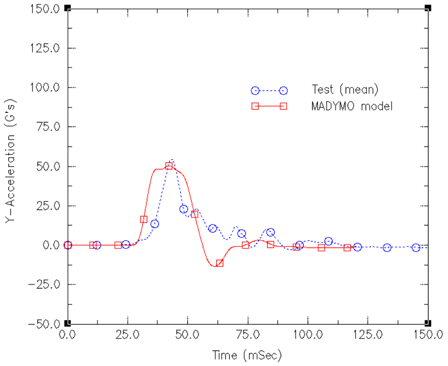

Figure 11. Rear dummy upper rib acceleration.