

Comparison of HVE simulations to NHTSA full-frontal barrier testing: an analysis of 3D and 2D stiffness coefficients in SIMON and EDSMAC4

Jeffrey Suway

Biomechanical Research and Testing, LLC

Anthony Cornetto, Ronny Wahba, Fawzi Bayan

S-E-A, Ltd

ABSTRACT

Previous work by Cornetto, et al. [1] has shown a method for calculating three-dimensional (3D) stiffness coefficients for SIMON, based on existing crash test data. In the methods presented by Cornetto, et al., the resulting crash pulse and deflection-time history, as predicted by SIMON using the derived 3D stiffness coefficients, are compared to the data from NHTSA crash tests. This white paper will compare the SIMON simulations using A, B, C, and D stiffness coefficients from this method to SIMON simulations with the default HVE vehicle stiffness parameters as well as EDSMAC4 simulations with default stiffness parameters with the same vehicles. The three types of HVE simulations will be compared with the NHTSA crash test data with a focus on the crash pulse duration, shape, and peak, as well as the crush over time and maximum crush.

The same vehicles used in Cornetto, et al. will be used in this white paper. This includes vehicles in several different categories, including passenger vehicles, pickup trucks, minivans, and SUVs. The curves will be compared by applying the Object Rating Method (ORM).

INTRODUCTION

As stated, Cornetto, et al. presented a method for calculating the A, B, C, and D stiffness coefficients for SIMON, based on existing crash test data. This method uses acceleration-time data (crash pulse) from a vehicle crash test; data that is widely available through the National Highway Traffic Safety Administration (NHTSA) as well as the Insurance Institute for Highway Safety (IIHS). The crash pulse, along with vehicle mass and impact speed, are used to calculate the force acting on the vehicle and the associated vehicle deflection time history. An area-deflection function is created from a computer model of the vehicle. The calculated force divided by the associated area function (F/A) is plotted versus deflection, and a third-order polynomial is fit to the curve. The coefficients of this third-order polynomial are the A, B, C, and D stiffness coefficients.

Cornetto, et al. illustrated that in many of the cases presented, the simulated crash pulses were similar in shape, duration, and peak acceleration when compared to the NHTSA measured crash pulse. This white paper will compare simulation results from SIMON with 3-dimensional stiffness coefficients to well-established simulation techniques for accident reconstruction including SIMON with 2-dimensional stiffness coefficients and EDSMAC4.

RESULTS

The authors ran SIMON simulations for each selected vehicle with the 3D stiffness coefficients calculated using the method described and the default HVE 2D stiffness coefficients as well as EDSMAC4

simulations with the default HVE 2D stiffness coefficients. The simulations were set up to simulate the NHTSA test used to calculate the 3D stiffness coefficients. The simulated vehicle impacted a rigid barrier at the impact speed measured in the NHTSA test. The SIMON simulations were completed with DyMESH and both the vehicle and barrier meshes were tessellated with a 10-inch element size. The EDSMAC4 simulations were completed with all default settings.

Passenger Vehicles

2002-2006 Mini Cooper

The authors utilized the data from NHTSA test number 4273. This test used a 2002 Mini Cooper with a vehicle test weight of 1404 kg. This test was a full frontal impact into a rigid barrier at 56.16 kph for the New Car Assessment Program (NCAP). Using the data from the accelerometer mounted to floor, behind the driver's seat, the known test weight, and the known closing speed, the authors calculated A, B, C, and D stiffness coefficients of 40.616, 1.792, 0.913, and -0.00415, respectively.

Figure 1 shows the crash pulse for NHTSA test number 4273 (blue) and the SIMON simulation with the 3D stiffness coefficients (SIMON 3D in red), SIMON with 2D stiffness coefficients (SIMON 2D in purple), and EDSMAC4 (EDSMAC4 in green). Figure 2 shows the CG displacement for the same test and simulation series.

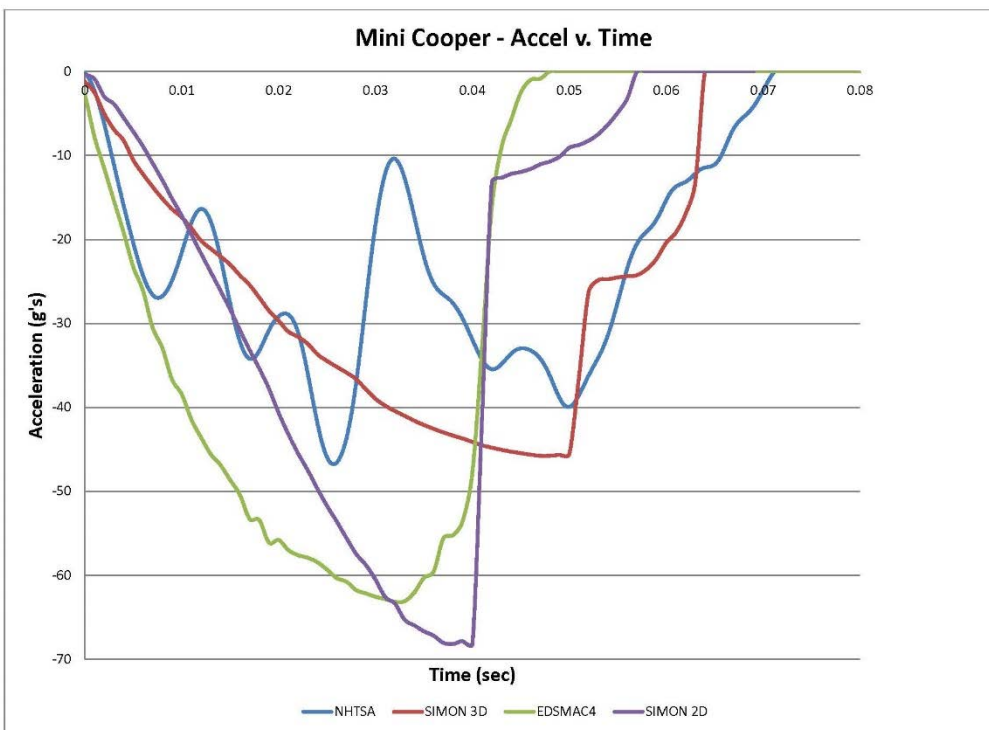


Figure 1. Mini Cooper crash pulse comparison

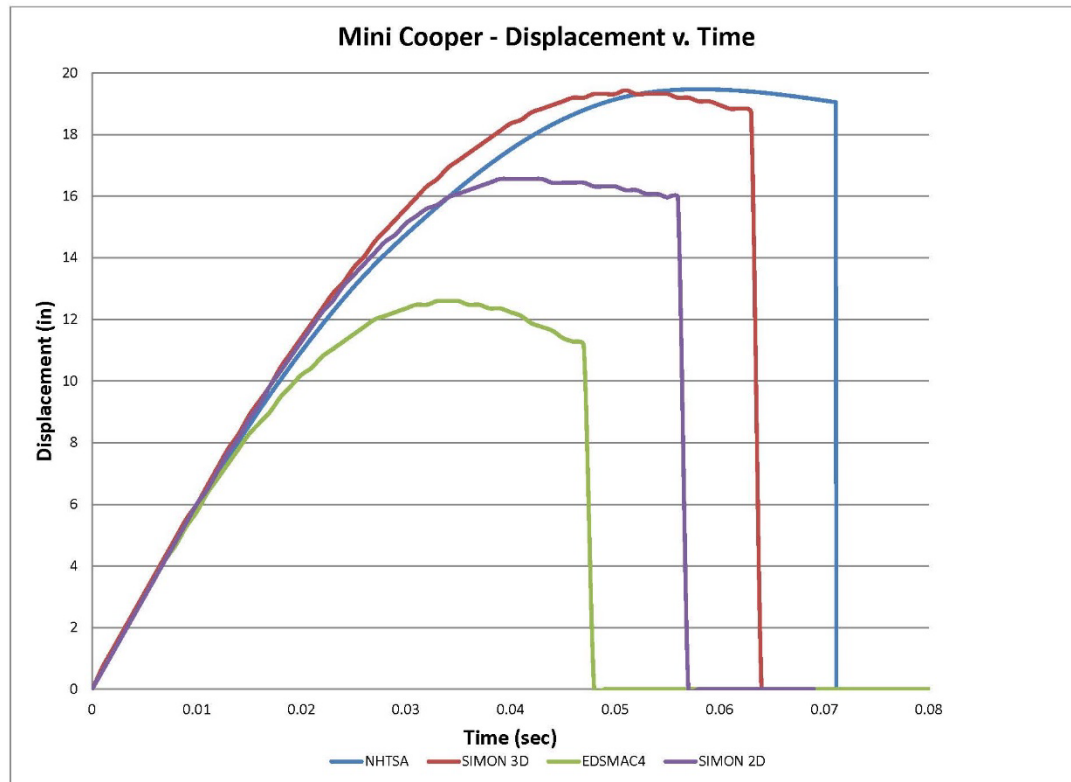


Figure 2. Mini Cooper CG displacement comparison

2000-2007 Ford Taurus

The authors utilized the data from NHTSA test number 4776. This test used a 2004 Ford Taurus with a vehicle test weight of 1785 kg. This test was a full frontal impact into a rigid barrier at 56.50 kph for NCAP. Using the data from the accelerometer mounted to the floor, behind the driver's seat, the known test weight, and the known closing speed, the authors calculated A, B, C, and D stiffness coefficients of 24.404, 1.089, 0.0467, -0.0015, respectively.

Figure 3 shows the crash pulse for NHTSA test number 4776 (blue) and the SIMON 3D (red), SIMON 2D (purple), and EDSMAC4 (green). Figure 4 shows the CG displacement for the same test and simulation series.

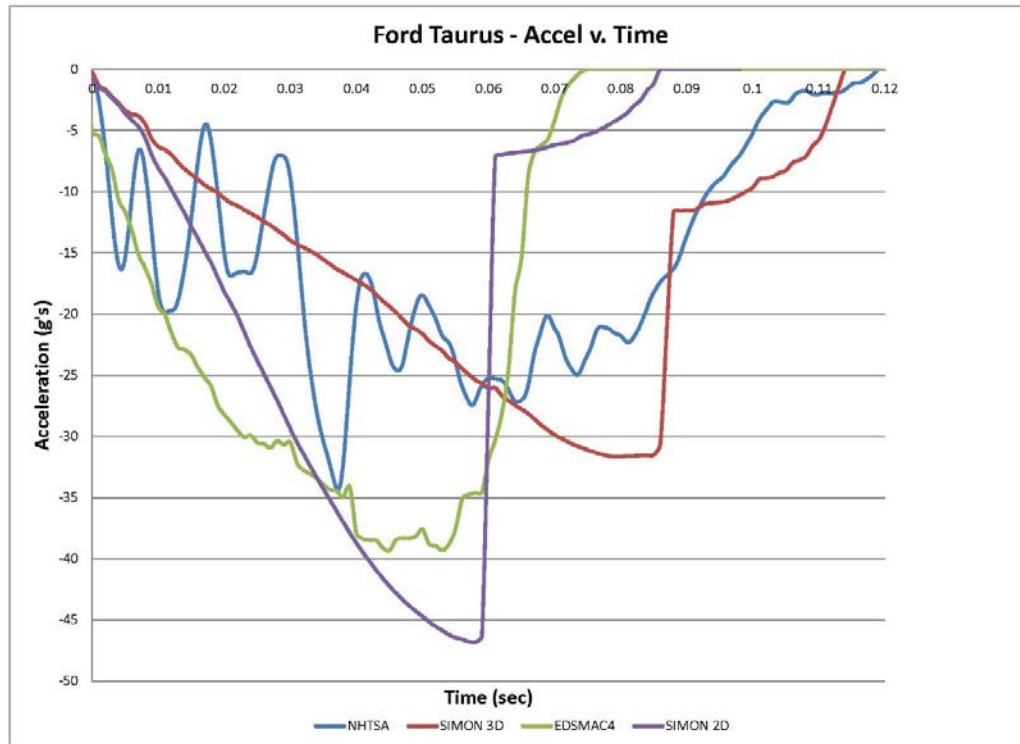


Figure 3. Ford Taurus crash pulse comparison

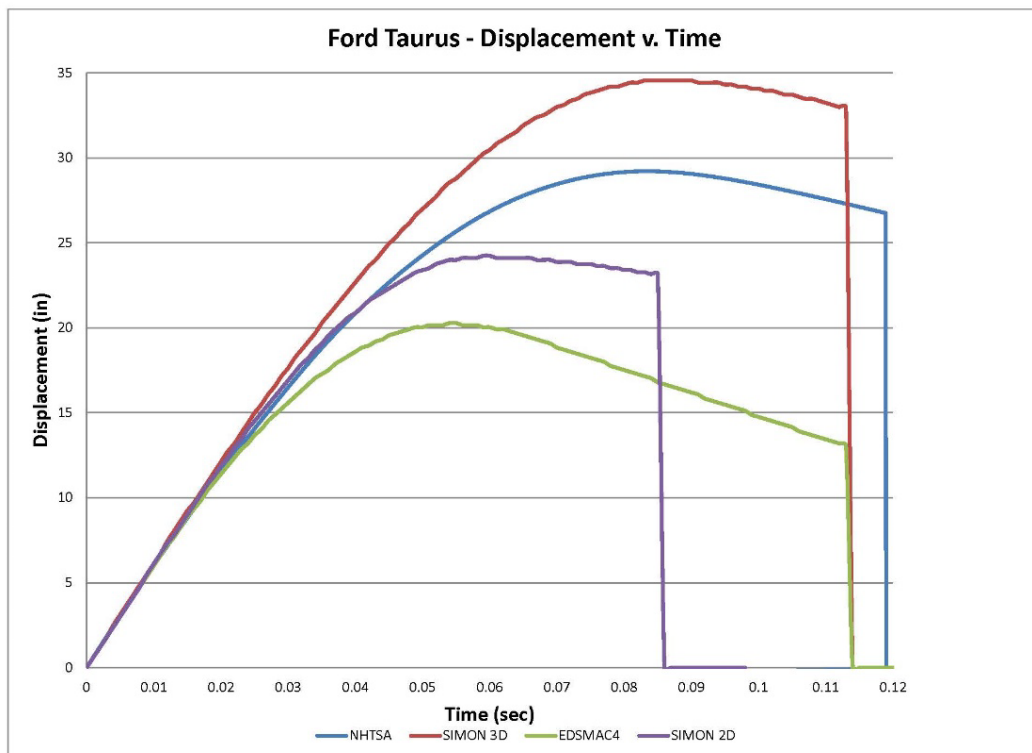


Figure 4. Ford Taurus CG displacement comparison

2005-2012 Audi A4

The authors utilized the data from NHTSA test number 6519. This test used a 2009 Audi A4 with a vehicle test weight of 1968 kg. This test was a full frontal impact into a rigid barrier at 56.20 kph for NCAP. Using the data from the accelerometer mounted to the floor, behind the driver's seat, the known test weight, and the known closing speed, the authors calculated A, B, C, and D stiffness coefficients of 25.376, 2.053, 0.0391, and -0.00221, respectively.

Figure 5 shows the crash pulse for NHTSA test number 6519 (blue) and the SIMON 3D (red), SIMON 2D (purple), and EDSMAC4 (green). Figure 6 shows the CG displacement for the same test and simulation series.

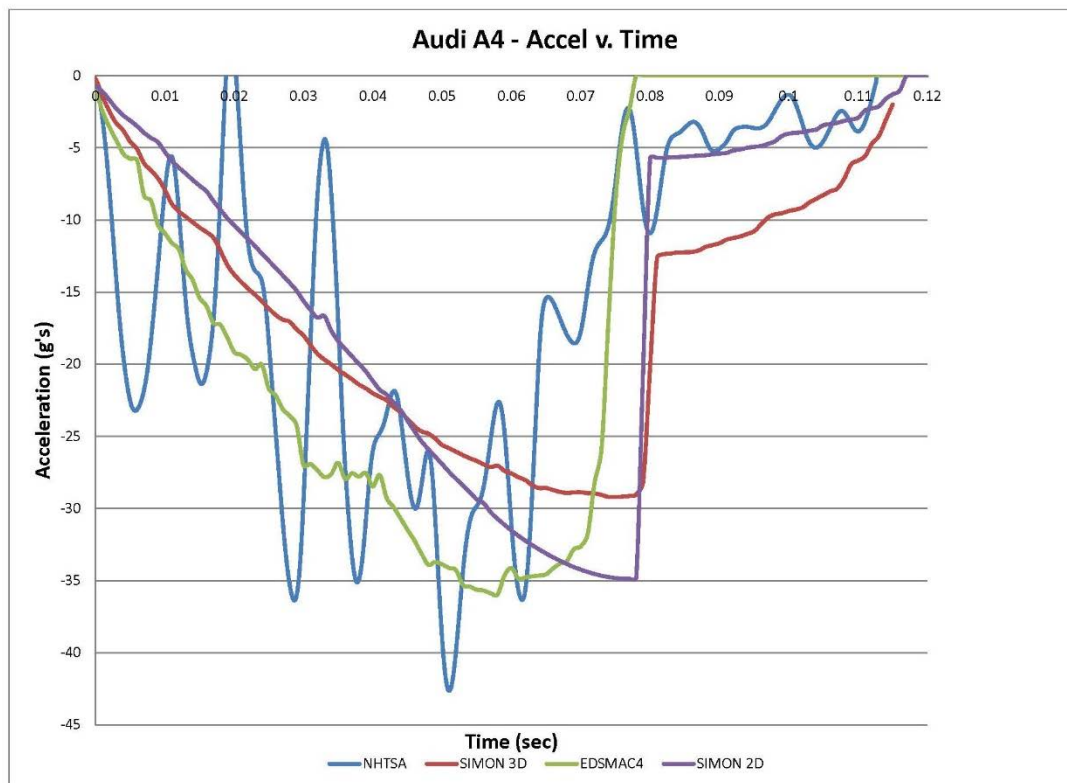


Figure 5. Audi A4 crash pulse comparison

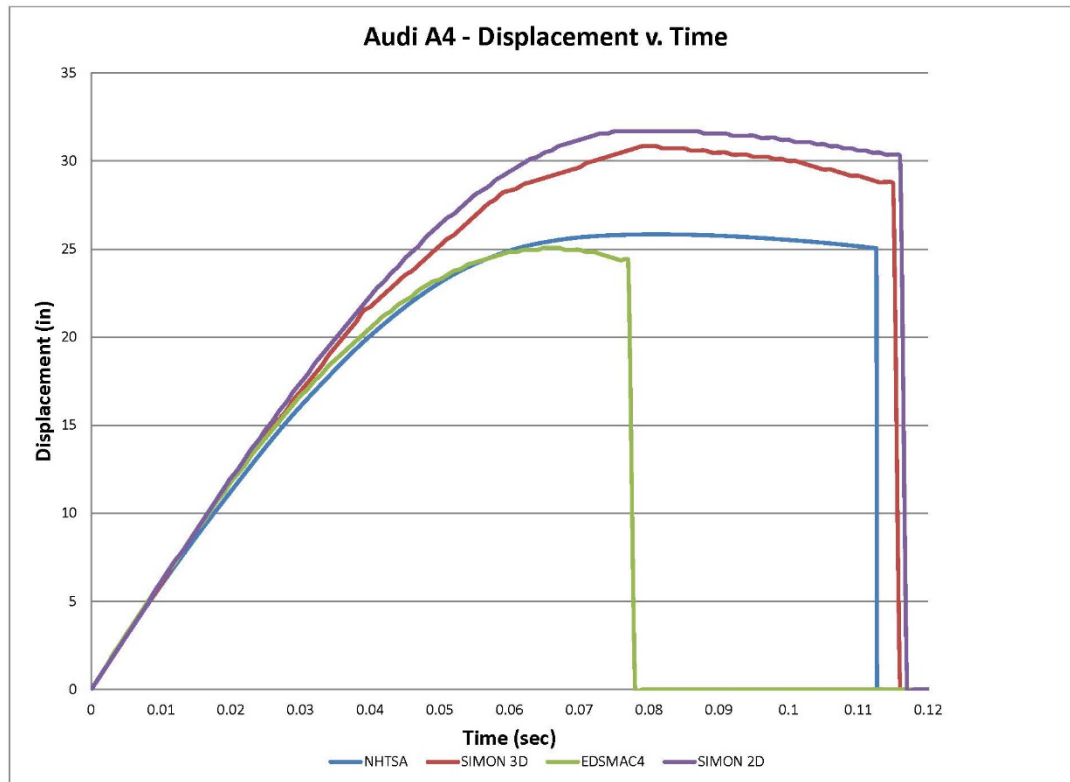


Figure 6. Audi A4 CG displacement comparison

Pickup Trucks

2004-2008 Ford F-150 Supercab

The authors utilized the data from NHTSA test number 4890. This test used a 2004 Ford F150 Supercab with a vehicle test weight of 2626 kg. This test was a full frontal impact into a rigid barrier at 56.50 kph for NCAP. Using the data from the accelerometer mounted to the left rear seat cross member, the known test weight, and the known closing speed, the authors calculated A, B, C, and D stiffness coefficients of 28.575, 0.274, 0.092, -0.00210, respectively.

Figure 7 shows the crash pulse for NHTSA test number 4890 (blue) and the SIMON 3D (red), SIMON 2D (purple), and EDSMAC4 (green). Figure 8 shows the CG displacement for the same test and simulation series.

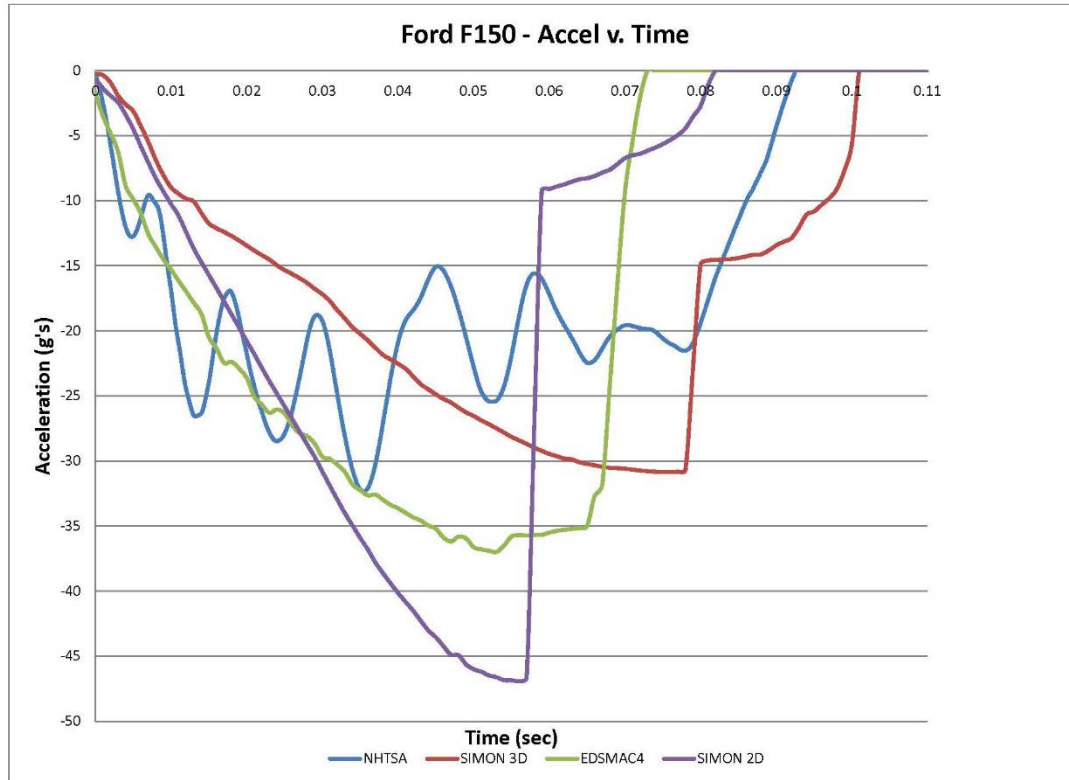


Figure 7. Ford F-150 crash pulse comparison

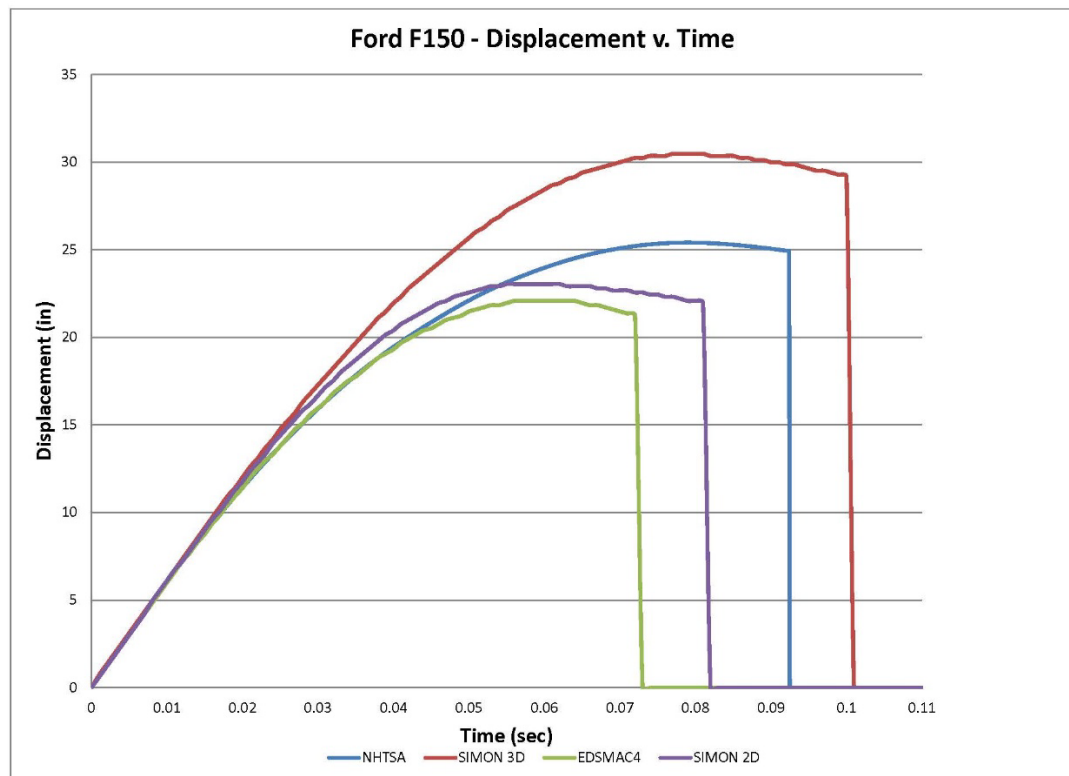


Figure 8. Ford F-150 CG displacement comparison

1994-2001 Dodge Ram 1500

The Authors utilized the data from NHTSA test number 2021. This test used a 1994 Dodge Ram 1500 with a vehicle test weight of 2305 kg. This test was a full frontal impact into a rigid barrier at 56.50 kph for NCAP. Using data from the accelerometer mounted to the left rear seat cross member, the known test weight, and the known closing speed, the authors calculating A, B, C, and D stiffness coefficients of 14.756, 0.252, 0.0608, -0.00119, respectively.

Figure 9 shows the crash pulse for NHTSA test number 2021 (blue) and the SIMON 3D (red), SIMON 2D (purple), and EDSMAC4 (green). Figure 10 shows the CG displacement for the same test and simulation series.

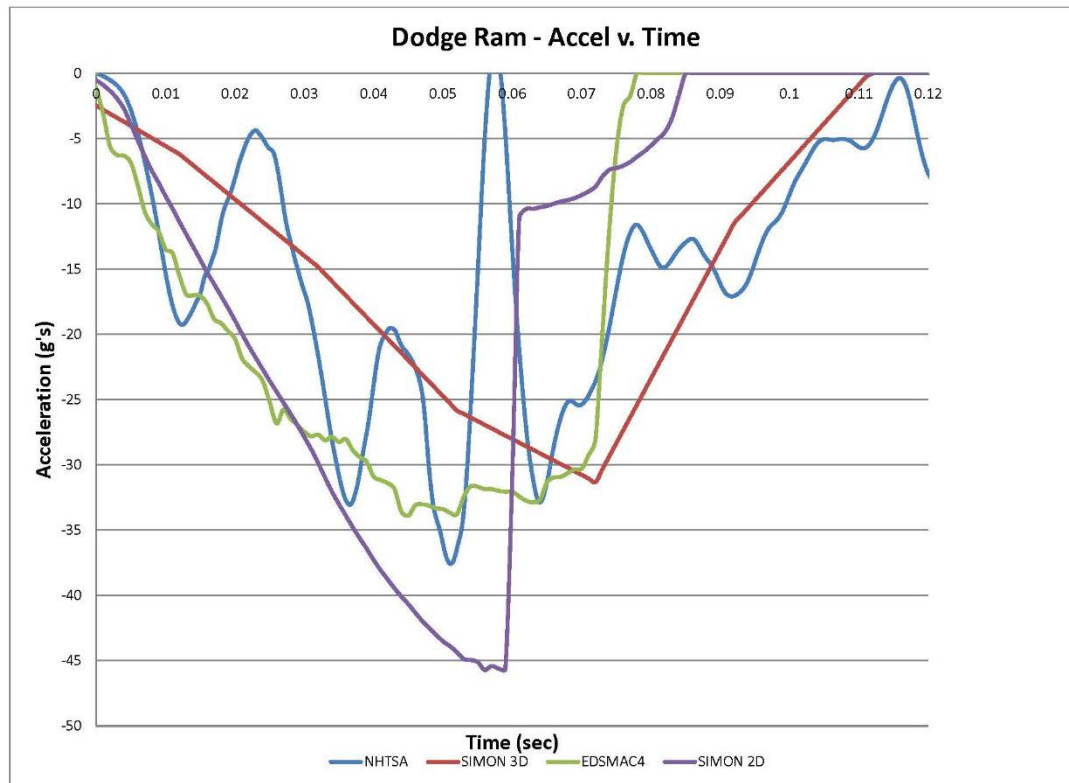


Figure 9. Dodge Ram crash pulse comparison

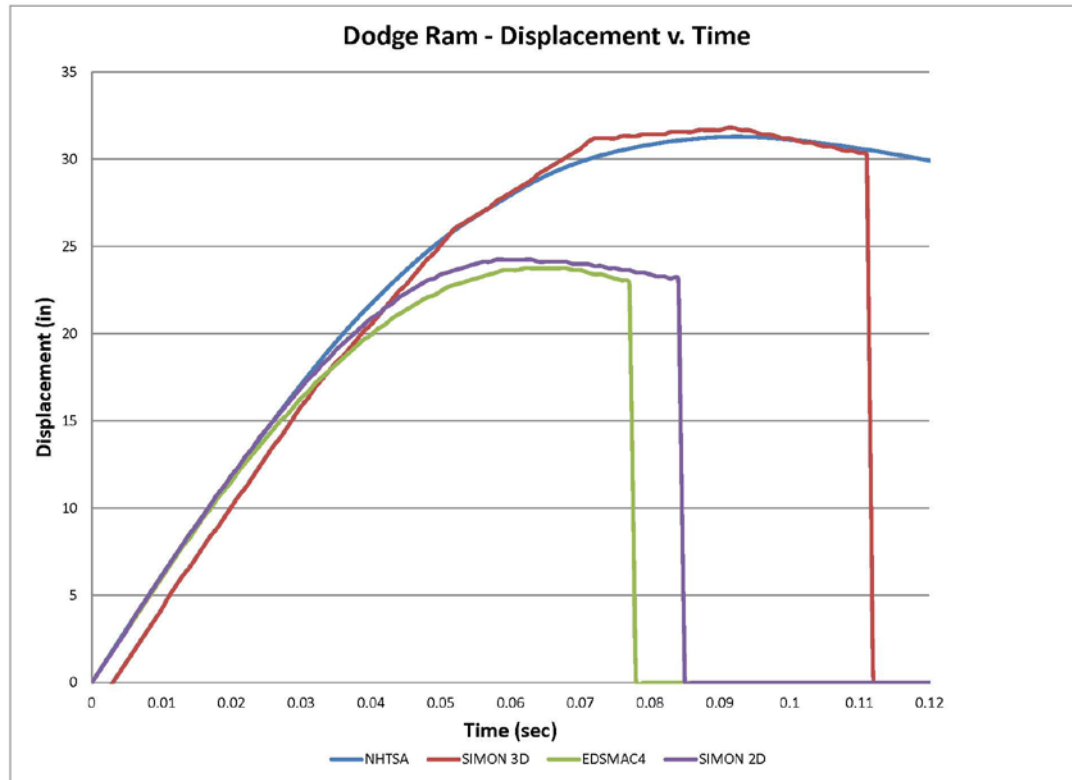


Figure 10. Dodge Ram CG displacement comparison

1999-2007 Chevrolet Silverado 1500

The authors utilized the data from NHTSA test number 4453. This test used a 2003 Chevrolet Silverado 1500 with a vehicle test weight of 2296 kg. This test was a full frontal impact into a rigid barrier at 39.20 kph for FMVSS No. 208 compliance testing. Using data from the accelerometer mounted to the left rear seat cross member, the known test weight, and the known closing speed, the authors calculated A, B, C, and D stiffness coefficients of 17.075, 0.309, 0.0552, -0.00124, respectively.

Figure 11 shows the crash pulse for NHTSA test number 4453 (blue) and the SIMON 3D (red), SIMON 2D (purple), and EDSMAC4 (green). Figure 12 shows the CG displacement for the same test and simulation series.

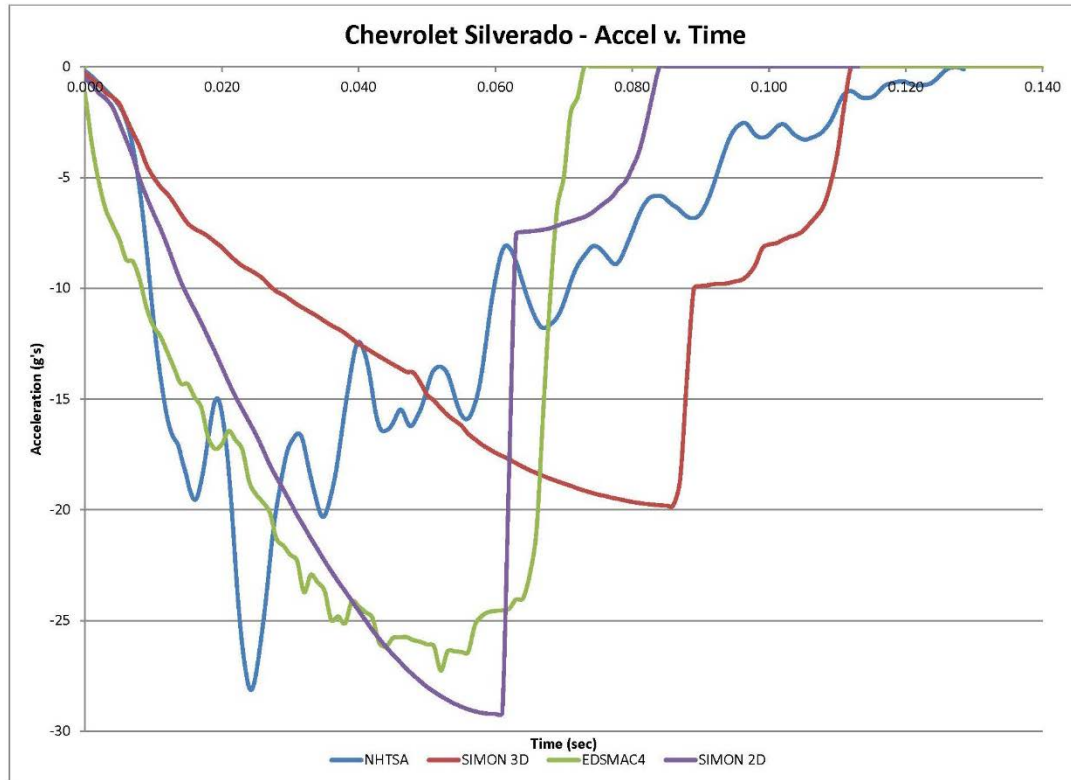


Figure 11. Chevrolet Silverado crash pulse comparison

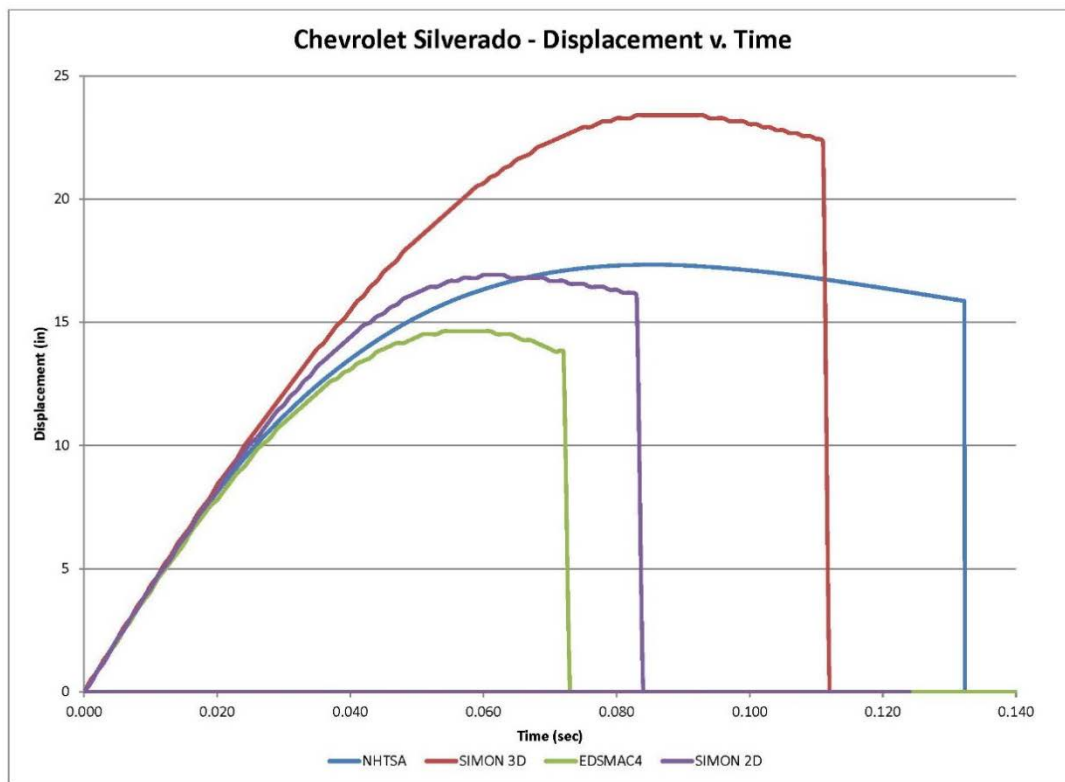


Figure 12. Chevrolet Silverado CG displacement comparison

SUVs

2002-2005 Ford Explorer

The authors utilized the data from NHTSA test number 3730. This test used a 2002 Ford Explorer XLT with a vehicle test weight of 2323 kg. This test was a full frontal impact into a rigid barrier at 55.33 kph for NCAP. Using data from the accelerometer mounted to left rear seat cross member, the known test weight, and the known closing speed, the authors calculated A, B, C, and D stiffness coefficients of 31.073, 0.673, 0.118, -0.00295, respectively.

Figure 13 shows the crash pulse for NHTSA test number 3730 (blue) and the SIMON 3D (red), SIMON 2D (purple), and EDSMAC4 (green). Figure 14 shows the CG displacement for the same test and simulation series.

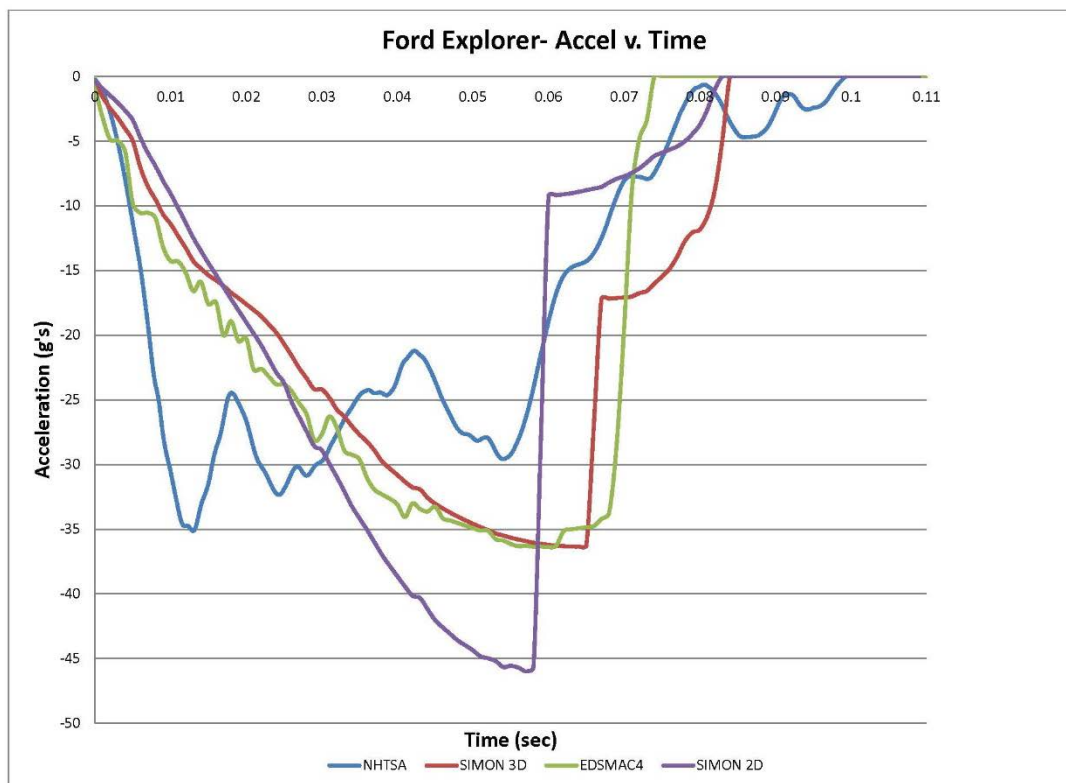


Figure 13. Ford Explorer crash pulse comparison

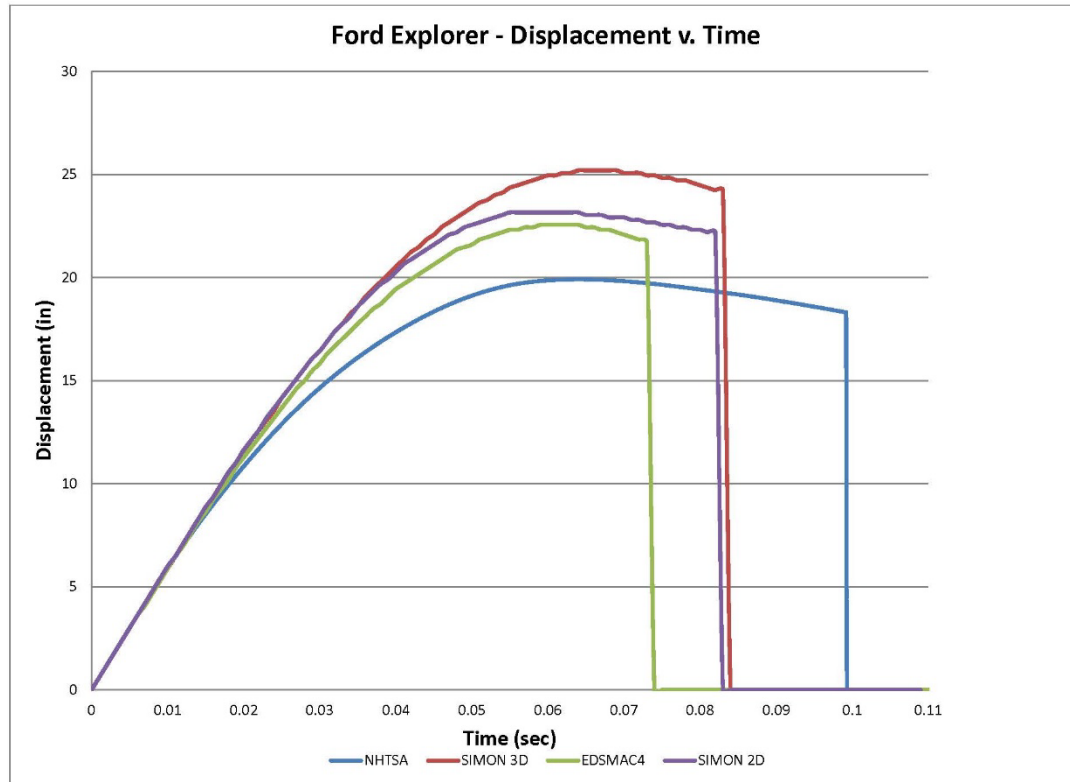


Figure 14. Ford Explorer CG displacement comparison

2004-2011 Nissan Pathfinder

The authors utilized the data from NHTSA test number 5278. This test used a 2005 Nissan Pathfinder SE-X4 with a vehicle test weight of 2393 kg. This test was a full frontal impact into a rigid barrier at 56.60 kph for NCAP. Using the data from the accelerometer mounted to the left rear seat cross member, the known test weight, and the known closing speed, the authors calculated A, B, C, and D stiffness coefficients of 34.274, 1.681, 0.0969, -0.00329, respectively.

Figure 15 shows the crash pulse for NHTSA test number 5278 (blue) and the SIMON 3D (red), SIMON 2D (purple), and EDSMAC4 (green). Figure 16 shows the CG displacement for the same test and simulation series.

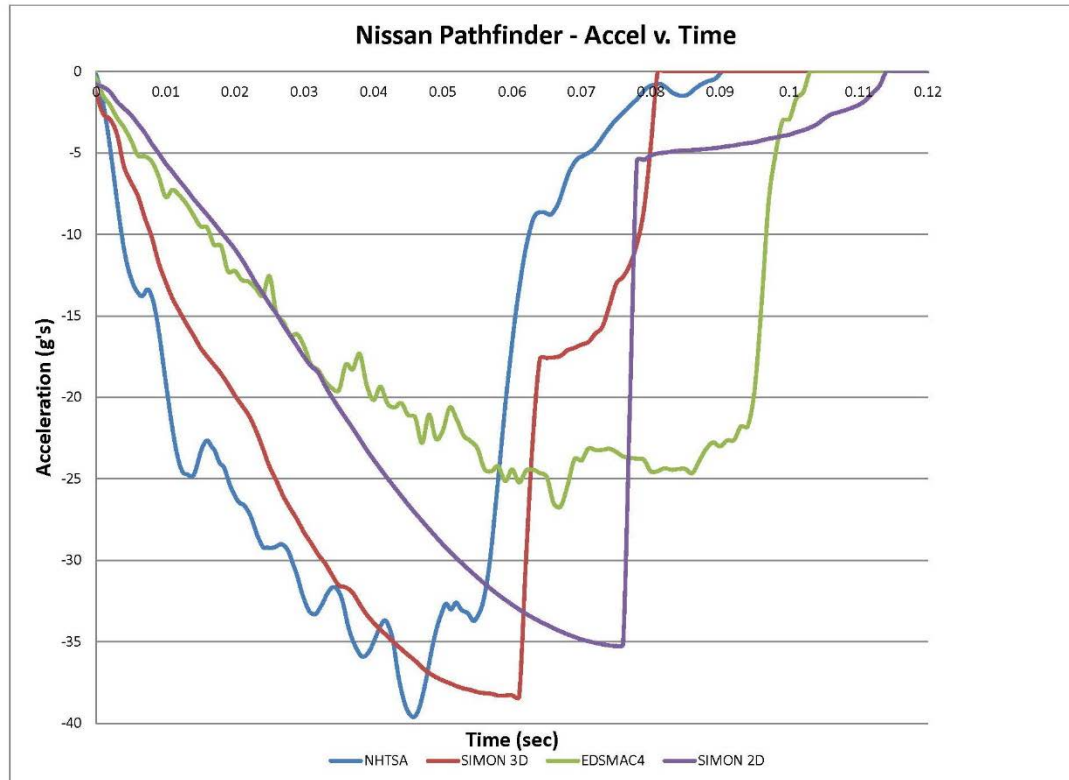


Figure 15. Nissan Pathfinder crash pulse comparison

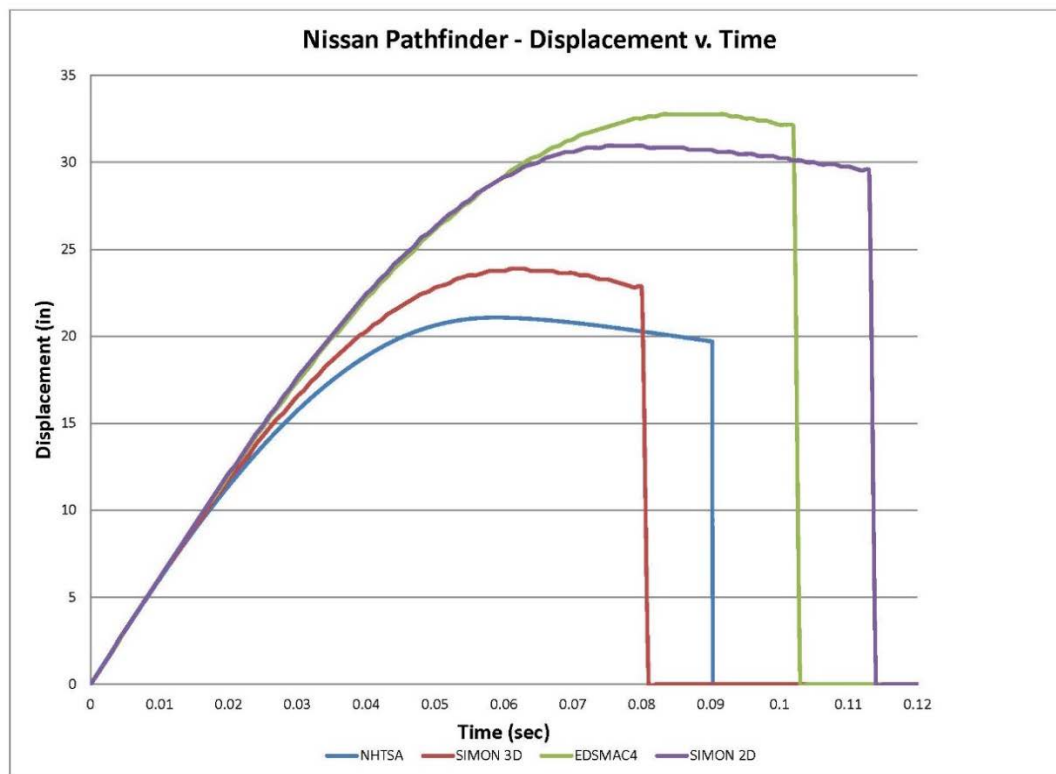


Figure 16. Nissan Pathfinder CG displacement comparison

2003-2011 Honda Element

The authors utilized the data from NHTSA test number 4555. This test used a 2003 Honda Element with a vehicle test weight of 1745 kg. This test was a full frontal impact into a rigid barrier at 56.01 kph for NCAP. Using data from the accelerometer mounted to the left rear seat cross member, the known test weight, and the known closing speed, the authors calculated A, B, C, and D stiffness coefficients of 20.657, 2.112, 0.0802, -0.00419, respectively.

Figure 17 shows the crash pulse for NHTSA test number 4555 (blue) and the SIMON 3D (red), SIMON 2D (purple), and EDSMAC4 (green). Figure 18 shows the CG displacement for the same test and simulation series.

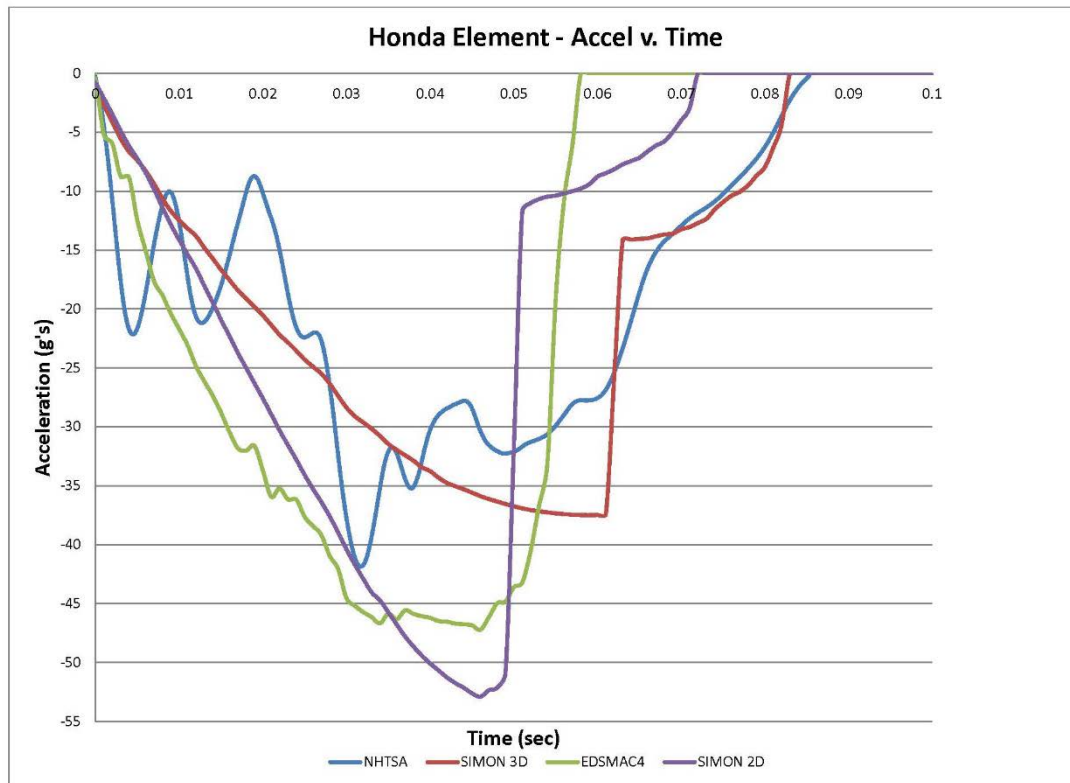


Figure 17. Honda Element crash pulse comparison

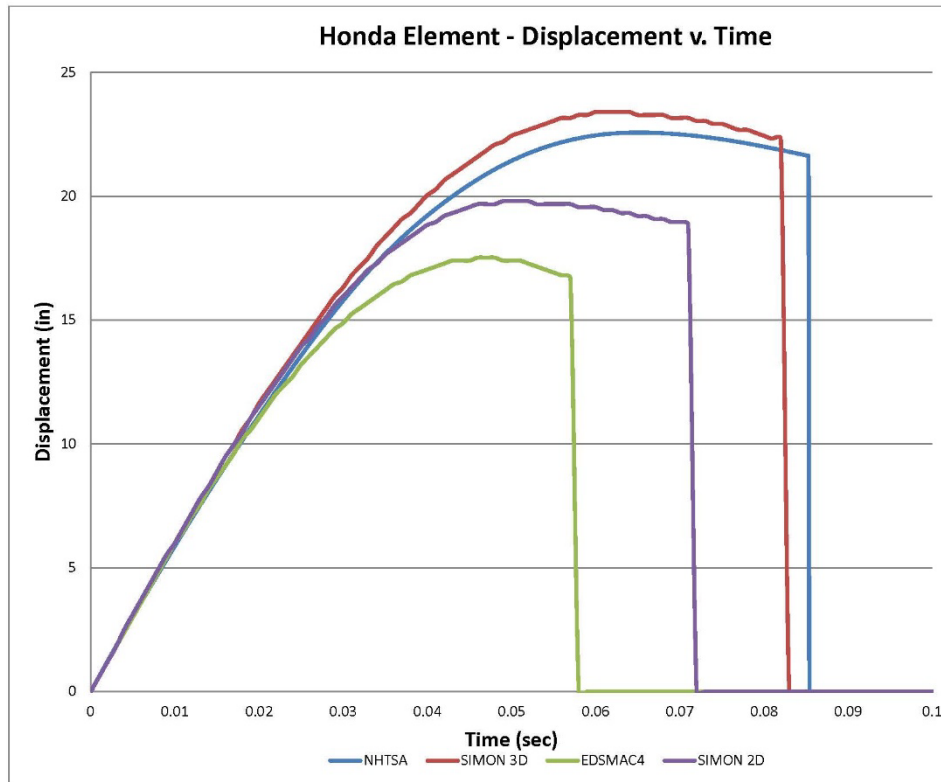


Figure 18. Honda Element CG displacement comparison

Minivans

1997-2005 Chevrolet Venture

The authors utilized the data from NHTSA test number 2750. This test used a 1998 Chevrolet Venture with a vehicle test weight of 2032 kg. This test was a full frontal impact into a rigid barrier at 56.50 kph for NCAP. Using data from the accelerometer mounted to the left rear floor pan, the known test weight, and the known closing speed, the authors calculated A, B, C, and D stiffness coefficients of 18.271, 0.454, 0.0349, -0.000735, respectively.

Figure 19 shows the crash pulse for NHTSA test number 2750 (blue) and the SIMON 3D (red), SIMON 2D (purple), and EDSMAC4 (green). Figure 20 shows the CG displacement for the same test and simulation series.

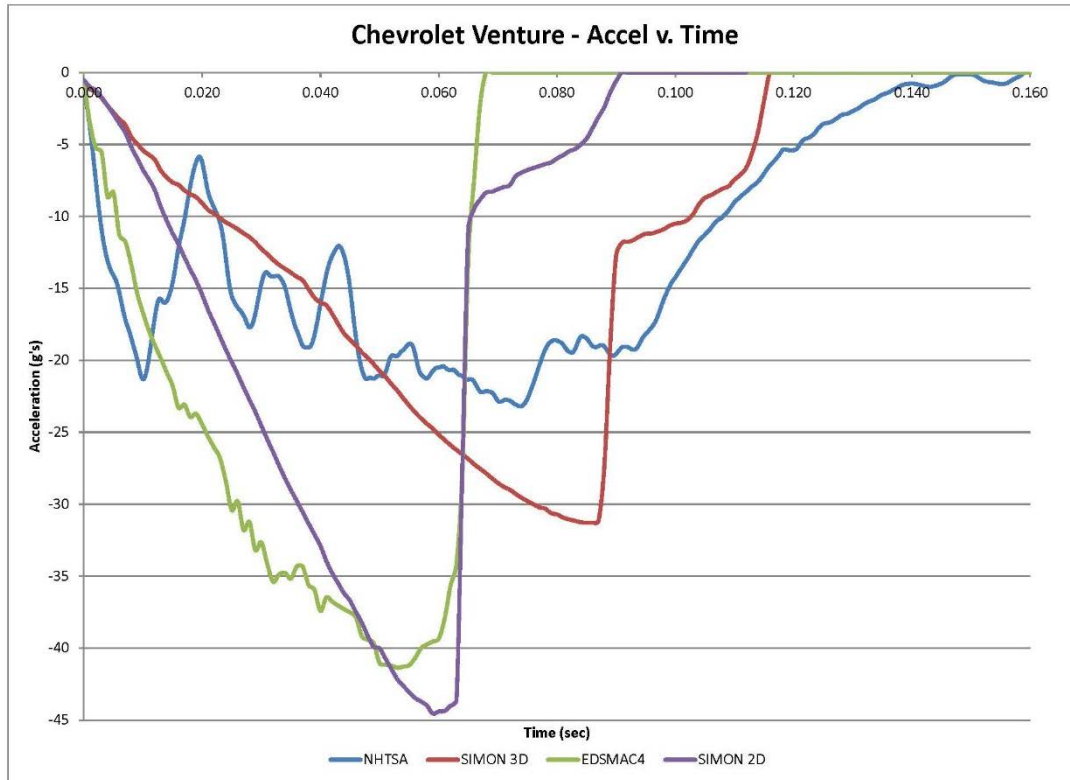


Figure 19. Chevrolet Venture crash pulse comparison

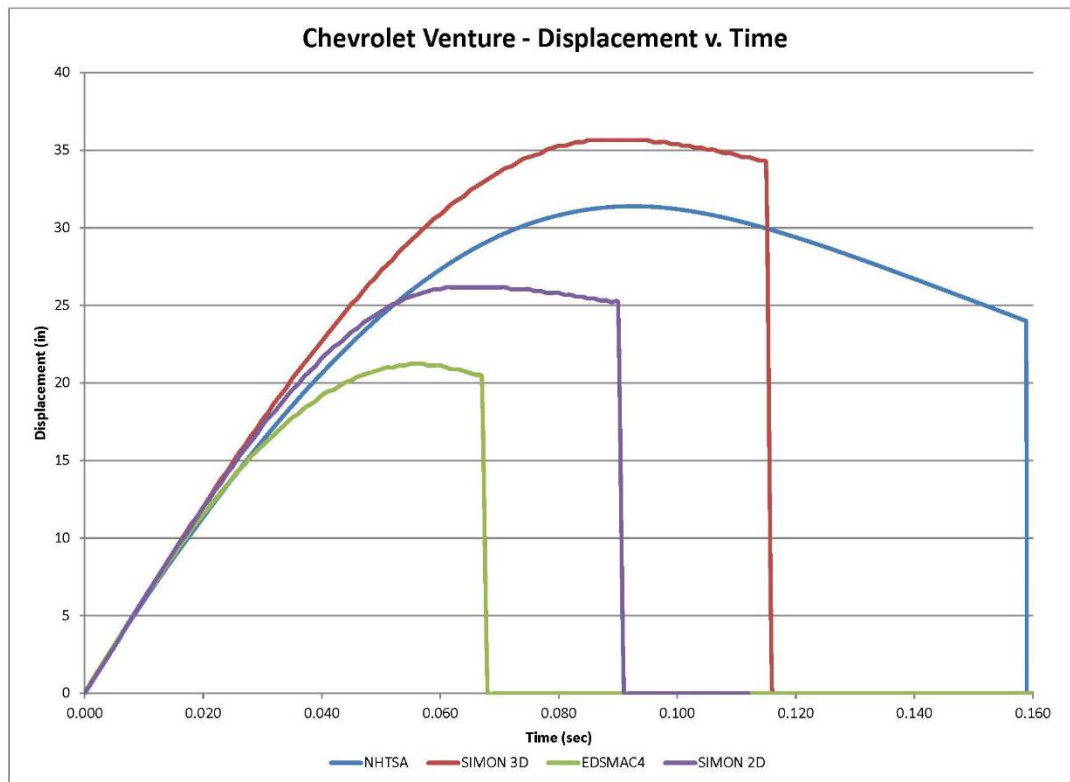


Figure 20. Chevrolet Venture CG displacement comparison

1996-2000 Dodge Caravan

The authors utilized the data from NHTSA test number 2279. This test used a 1996 Dodge Caravan with a vehicle test weight of 2054 kg. This test was a full frontal impact into a rigid barrier at 47.20 kph for FMVSS No. 208 compliance testing. Using data from the accelerometer mounted to the left rear floor pan, the known test weight, and the known closing speed, the authors calculated A, B, C, and D stiffness coefficients of 37.477, 1.474, -0.01047, -0.000547, respectively.

Figure 21 shows the crash pulse for NHTSA test number 2279 (blue) and the SIMON 3D (red), SIMON 2D (purple), and EDSMAC4 (green). Figure 22 shows the CG displacement for the same test and simulation series.

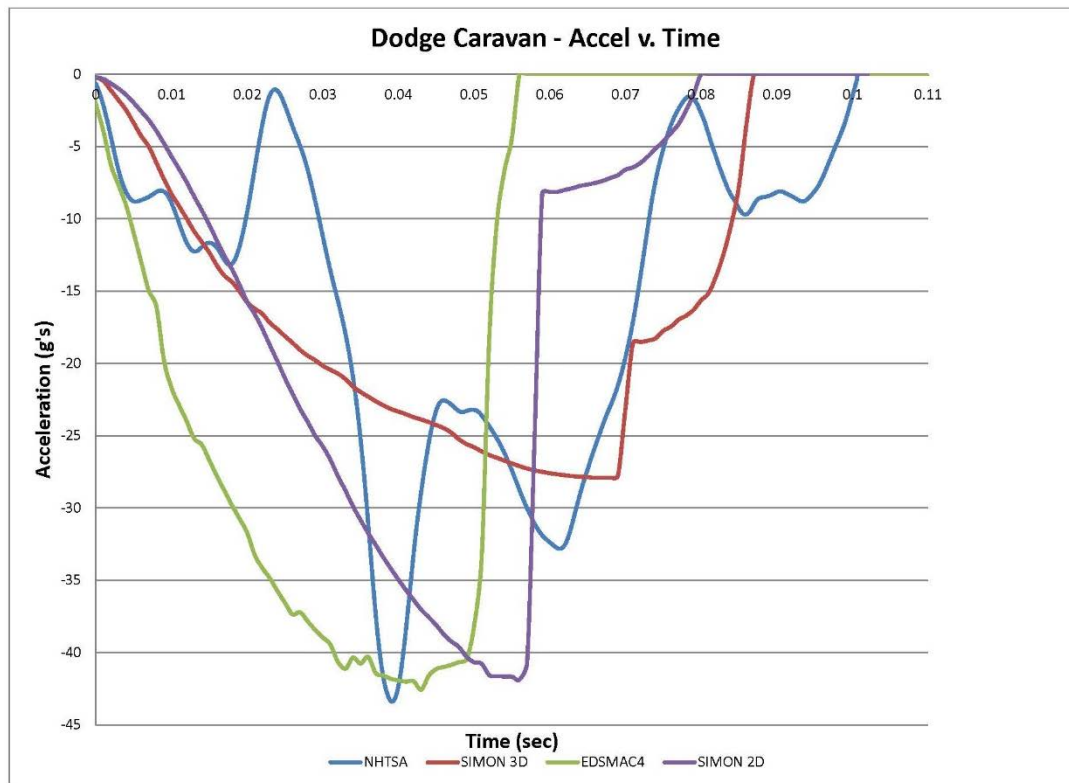


Figure 21. Dodge Caravan crash pulse comparison

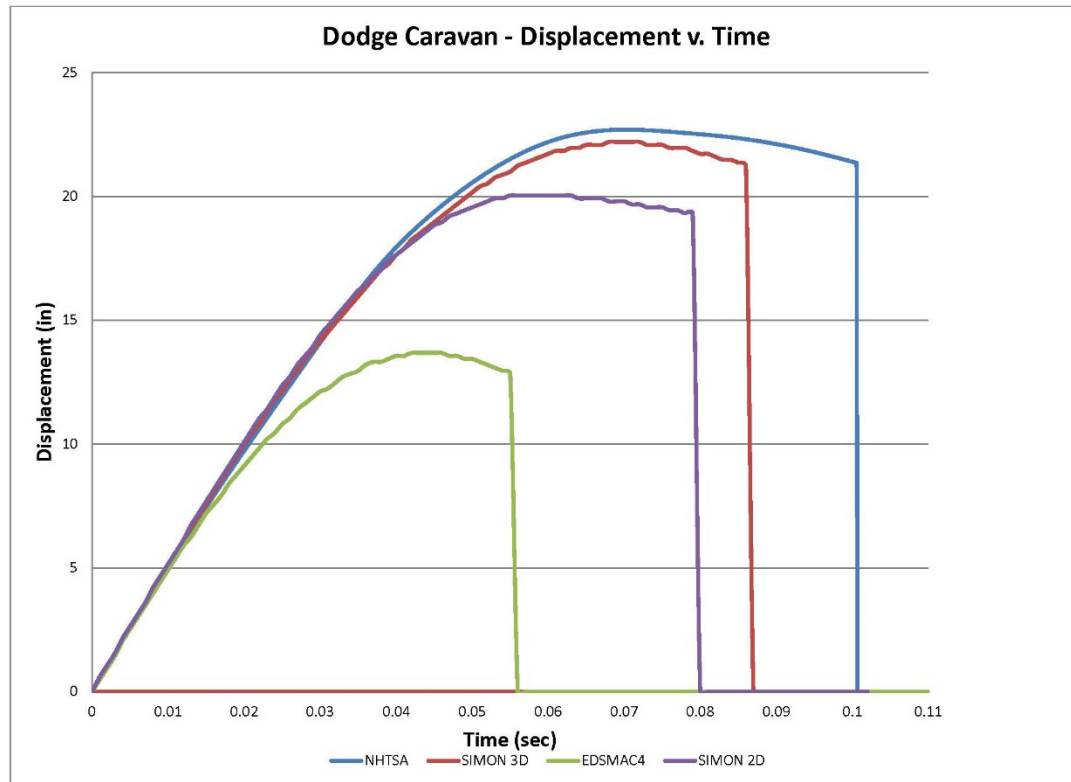


Figure 22. Dodge Caravan CG displacement comparison

1985-2005 Chevrolet Astro

The authors utilized the data from NHTSA test number 2071. This test used a 1994 Chevrolet Astro with a vehicle test weight of 1964 kg. This test was a full frontal impact into a rigid barrier at 47.30 kph for FMVSS No. 208 compliance testing. Using data from the accelerometer mounted to the left rear floor pan, the known test weight, and the known closing speed, the authors calculated A, B, C, and D stiffness coefficients of 54.0156, -3.184, 0.337, -0.00959, respectively.

Figure 23 shows the crash pulse for NHTSA test number 2071 (blue) and the SIMON 3D (red), SIMON 2D (purple), and EDSMAC4 (green). Figure 24 shows the CG displacement for the same test and simulation series.

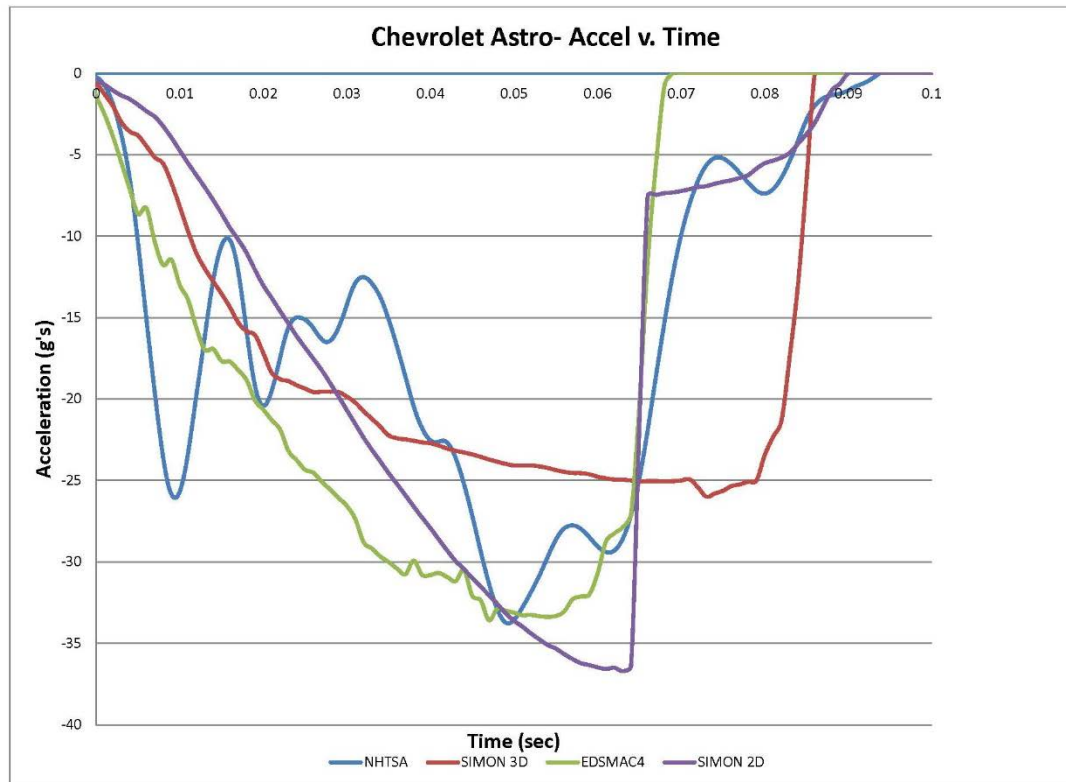


Figure 23. Chevrolet Astro crash pulse comparison

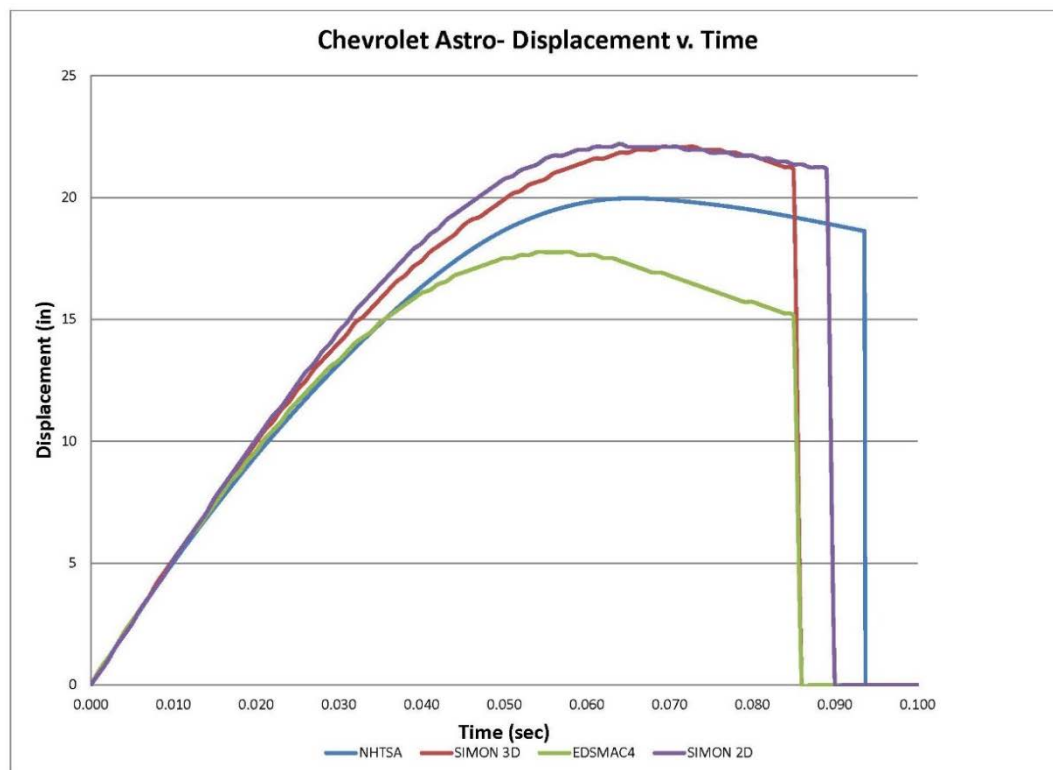


Figure 24. Chevrolet Astro crash pulse comparison

ANALYSIS

To analyze the various simulation methodologies, the Object Rating Method (ORM) [2, 3] was applied. This method compares the various simulations to the NHTSA tests in terms of correlation between the following criteria: peak values, peak value occurrence times, and curve shapes. Specifically, the ORM scalar compares the peak values and the ORM shape compares the peak value occurrence times and curve shape. The closer to 100%, the better the correlation.

The correlations were calculated for the acceleration time histories for each simulation versus the NHTSA test.

Passenger Vehicles

Table 1, 2, and 3 shows the results of the ORM analysis for the Ford Taurus, Mini Cooper, and Audi A4 respectively. The ORM analysis shows that the SIMON 3D simulations for the Ford Taurus and the Mini Cooper had the highest percentage match to the NHTSA test. The ORM analysis shows that the peak value occurrence times and curve shape for the three different simulations are similar to the results of the Audi A4 test; however, the peak acceleration value for the SIMON 3D simulation did not match the NHTSA test results nor did the peak values for the SIMON 2D simulation or the EDSMAC4 simulation.

Table 1. ORM Analysis for the Ford Taurus

	SIMON 3D	SIMON 2D	EDSMAC4
ORM scalar	92%	73%	87%
ORM shape	65%	39%	39%

Table 2. ORM Analysis for the Mini Cooper

	SIMON 3D	SIMON 2D	EDSMAC4
ORM scalar	98%	69%	74%
ORM shape	64%	39%	35%

Table 3. ORM Analysis for the Audi A4

	SIMON 3D	SIMON 2D	EDSMAC4
ORM scalar	68%	82%	84%
ORM shape	52%	52%	54%

Pickup Trucks

Table 4, 5, and 6 show the ORM analysis for the Chevrolet Silverado, the Dodge Ram, and the Ford F150, respectively. The ORM analysis shows that the SIMON 3D simulation for the Ford F-150 had the highest percentage match to the NHTSA test. The ORM analysis shows that the peak value occurrence times and curve shape in the SIMON 3D simulation for the Dodge Ram had the highest percentage match and the peak value was similar. The ORM analysis shows that the peak value occurrence times and curve shape for the three different simulations are similar to the results of the Chevrolet Silverado test; however, the peak acceleration value for the SIMON 3D simulation did not match the NHTSA test results nor the peak values for the SIMON 2D simulation or the EDSMAC4 simulation.

Table 4. ORM Analysis for the Chevrolet Silverado

	SIMON 3D	SIMON 2D	EDSMAC4
ORM scalar	70%	96%	97%
ORM shape	50%	52%	48%

Table 5. ORM Analysis for the Dodge Ram

	SIMON 3D	SIMON 2D	EDSMAC4
ORM scalar	85%	82%	90%
ORM shape	56%	37%	42%

Table 6. ORM Analysis for the Ford F150

	SIMON 3D	SIMON 2D	EDSMAC4
ORM scalar	95%	69%	87%
ORM shape	59%	47%	51%

SUVs

Table 7, 8, and 9 show the ORM analysis for the Ford Explorer, Honda Element, and Nissan Pathfinder, respectively. The ORM analysis shows that the SIMON 3D simulations for the Honda Element and the Nissan Pathfinder had the highest percentage match to the NHTSA test results. The ORM analysis shows that the SIMON 3D simulation for the Ford Explorer matched the NHTSA test results more closely than the SIMON 2D simulation and had a similar percentage match to the EDSMAC4 simulation.

Table 7. ORM Analysis for the Ford Explorer

	SIMON 3D	SIMON 2D	EDSMAC4
ORM scalar	97%	76%	97%
ORM shape	56%	57%	59%

Table 8. ORM Analysis for the Honda Element

	SIMON 3D	SIMON 2D	EDSMAC4
ORM scalar	90%	79%	89%
ORM shape	75%	50%	46%

Table 9. ORM Analysis for the Nissan Pathfinder

	SIMON 3D	SIMON 2D	EDSMAC4
ORM scalar	97%	89%	67%
ORM shape	66%	41%	36%

Mini Vans

Table 10, 11, and 12 show the ORM analyses for the Chevrolet Venture, Dodge Caravan, and Chevrolet Astro, respectively. The ORM analysis shows that the SIMON 3D simulation for the Chevrolet Venture had the highest percentage match to the NHTSA test. The ORM analysis shows that the peak value occurrence times and curve shape in the SIMON 3D simulation for the Dodge Caravan had the highest percentage match to the NHTSA test; however, the peak acceleration value of the SIMON 2D and the EDSMAC4 simulation matched the NHTSA test more closely than the SIMON 3D simulation. The ORM analysis shows that the SIMON 3D simulation test for the Chevrolet Astro had the lowest percentage match to the NHTSA test results. While the peak value occurrence times and curve shape is the lowest percentage match for the SIMON 3D simulation, the percentage is similar for the three different simulation methodologies. Additionally, it is believed that the unusual crash pulse of the Chevrolet Astro, compared to the other vehicles tested, could have been a contributing factor in the SIMON 3D simulation having the lowest percentage match.

Table 10. ORM Analysis for the Chevrolet Venture

	SIMON 3D	SIMON 2D	EDSMAC4
ORM scalar	74%	52%	56%
ORM shape	61%	35%	30%

Table 11. ORM Analysis for the Dodge Caravan

	SIMON 3D	SIMON 2D	EDSMAC4
ORM scalar	64%	96%	98%
ORM shape	55%	45%	29%

Table 12. ORM Analysis for the Chevrolet Astro

	SIMON 3D	SIMON 2D	EDSMAC4
ORM scalar	77%	92%	99%
ORM shape	58%	65%	60%

CONCLUSION

Reviewing the ORM analysis, the SIMON 3D simulations for 6 of the 12 vehicles tested (the Ford Taurus, Mini Cooper, Ford F150, Honda Element, Nissan Pathfinder, and Chevrolet Venture), had the highest percentage matches with the NHTSA test results for both the peak acceleration value and the peak occurrence time and curve shape.

The SIMON 3D simulation for the Ford Explorer had the highest percentage match for the peak acceleration value, and the percentage match for the peak occurrence time and curve shape was within 3% of the highest value.

The SIMON 3D simulation for the Dodge Ram had the highest percentage match for the peak occurrence time and curve shape, and the percentage match for the peak acceleration value was within 5% of the highest value.

The SIMON 3D simulation for the Dodge Caravan, had the highest percentage match for the peak occurrence time and curve shape; however, the peak acceleration value for this simulation was the lowest percentage match.

The SIMON 3D simulation for the Audi A4 and the Chevrolet Silverado had the lowest percentage matches for both the peak acceleration value and the peak occurrence time and curve shape; however, the peak occurrence time and curve shape was within 2% of the highest value.

The SIMON 3D simulation for the Chevrolet Astro also had the lowest percentage match for both the peak acceleration value and the peak occurrence time and curve shape. The authors believe that the unusual crash pulse of the Chevrolet Astro, compared to the other vehicles tested, could have been a contributing factor in this finding.

Based on this limited study, in 6 of the 12 cases the SIMON simulations, using 3D stiffness coefficients calculated with the method presented in Cornetto, et al., resulted in an overall better match to the crash pulse from the NHTSA crash test on which the stiffness values were based, when compared to SIMON simulations with 2D stiffness coefficients and EDSMAC4 simulations. In 3 of the 12 cases, the EDSMAC4 and/or SIMON 2D simulations resulted in a better match than the SIMON 3D simulations. In the remaining 3 cases, the SIMON 3D had the highest percentage match for either the peak acceleration or the peak occurrence time and curve shape, but SIMON 2D or EDSMAC4 simulations performed better in the other metric.

REFERENCES

1. Cornetto, A., Suway, J., Wahba, R., Bayan, F. "Calculating Three Dimensional Stiffness Coefficients for Use in Three Dimensional Simulation Modeling for Accident Reconstruction" Society of Automotive Engineers Paper 2014-01-0473
2. Hovenga, P. E., Spit, H. H., Uijldert, M., Dalenoort, A. M. "Improved Prediction of Hybrid-III Injury Values using Advanced Multibody Techniques and Objective Rating" Society of Automotive Engineers Paper 2005-01-1307
3. Eriksson, L., Zellmer, H., "Assessing the BioRID II Repeatability and Reproducibility by Applying the Object Rating Method (ORM) on Rear-End Sled Tests", Enhanced Safety of Vehicles (ESV) Paper Number 07-0201

CONTACT INFORMATION

Jeffrey Suway
Biomechanical Research and Testing, LLC
jsuway@brteng.com

Anthony Cornetto
S-E-A, Ltd
acornetto@sealimited.com

HVE-WP-2014-2

Ronny Wahba
S-E-A, Ltd
rwahba@sealimited.com

Fawzi Bayan
S-E-A, Ltd
fbayan@sealimited.com