Truck Seat Modeling – A Methods Development Approach

Kevin Hix, International Trucks
Scott Ziemba, Mechanical Dynamics AA
Leslie Schoof, Mechanical Dynamics AA

1. BACKGROUND

The heavy trucking industry, like the automotive industry, is constantly on the drive to improve design methods and processes. The purpose of this project was to develop engineering methods and expertise in the area of truck seat modeling to capture the effects of seat dynamics on ride quality. The long-term goal of this project is to help support the selection and specification of seats for various vehicle applications.

For this project the desire was to not only improve the methodology behind ride evaluation but also further develop the techniques and applications of CAE simulation used by International. The project was better known as a "Methods Development" project.

Since the air suspension seats used in trucks isolate a significant amount of the road vibration, it is critical that the driver experiences a good ride from the seat. Previous ride simulations and evaluations only measured the ride response at the truck floor. For this project the goal was to develop methods for evaluating and predicting the ride response that the driver feels through the seat.

The long term business goal of the project was to implement this process into the "Systems Engineering Approach" where design targets can be cascaded from the OEM to the supplier base and, after processes such as modeling, testing, and validating, confirm that those targets were met. Below in **Figure 1**is a diagram of the Systems Engineering Approach.

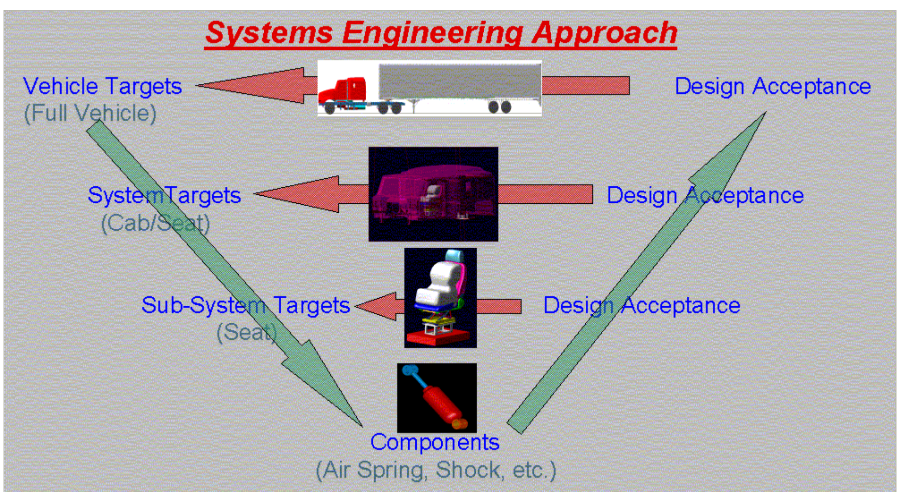

Figure 1 - Systems Engineering Approach

2. MODELING APPROACH

All modeling was performed using ADAMS 10.0

International chose to evaluate two different seats from two different suppliers. They also chose to evaluate the seat belt comfort as part of the project, but later found that the seat belts did not have any adverse effects on comfort for normal ride events.

The first seat evaluated was made by National Seating in Vonore, Tennessee. It is a typical North American air suspension truck seat in that it has thick-soft foam, a parallelogram vertical suspension, and a pendulum type fore/aft isolator.

The second seat evaluated was made by Grammer Ag. in Amberg, Germany and marketed in North America by Gra-Mag Truck Interior Systems. The Gra-Mag seat is a typical European seat in that it has thin-firm foam, a scissor type vertical suspension, and a spring type fore/aft isolator.

Pictures of each of the seats are shown below in and **Figure 2** and **Figure** 3**.**

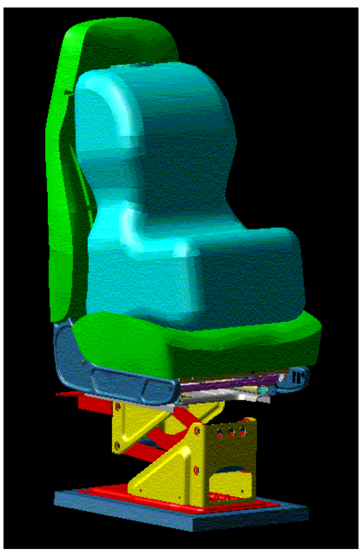

Figure 2 - National Seat

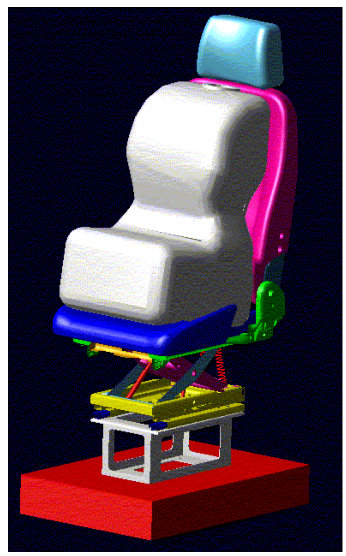

Figure 3 - GraMag Seat

Both seats are designed mainly to be vertical-performing seats along with some fore/aft compliance. Therefore, the initial intention in modeling the seats was to produce all-rigid models with special focus on the air springs, shocks, and fore/aft isolators. However, after analyzing the results, it was found that certain frequency content was not being captured, especially in the lateral direction. Therefore, flexible models were constructed of each seat.

Every component in each seat was modeled as a flexible body except the occupant, seat cushions, test fixtures, riser base (on GraMag), and miscellaneous components such as nuts and bolts and bearings.

The seat cushions were modeled using VFORCE functions that referenced force-deflection splines (stiffness) and constant damping coefficients. Four VFORCE's represented the seat bottom cushion and three represented the seat back cushion. For the damping component of the cushions, dynamic force-velocity data at various frequencies was provided from cushion suppliers. However, to simplify the application of the damping in the model, constant damping terms were estimated from the force-velocity curves which included some hysterisis effects.

The air springs for each seat were modeled using SFORCE functions. Each function referenced force-deflection splines provided by the seat suppliers. There were some minor damping characteristics in the air springs that were modeled using constant coefficients.

Due to a lack of appropriate force-deflection data for the GraMag air spring, a reverse engineering procedure was initiated. For this procedure, the air spring and shock were disabled. Three inputs were applied to the test fixture, replicating a .25g vertical sine sweep and one of the measured data channels on the seat frame was actually used to drive the upper seat frame. Therefore, with the upper and lower portions of the seat being driven by actual measured data, the displacement occurring between the upper and lower portions of the seat was measured and considered to be the same displacement that would be encountered by the air spring. This data was then used to help tune the model to achieve the desired force-deflection characterisitcs.

Shock absorbers for each seat were also modeled using SFORCE functions. These functions referenced force-velocity splines provided by seat suppliers. Hysterisis effects were simplified by averaging the jounce and rebound curves.

During initial testing of the GraMag seat, the fore/aft isolator, which dictates the controlled fore/aft motion of the seat, was locked out. Therefore it was not included in the full seat model. It was later modeled as an SFORCE and validated against test data acquired from additional testing. The fore/aft isolators on the National seat were pendulum-type mechanical isolators – four total. These were modeled using simple circle-curve contacts with friction parameters included.

Finally, the occupant was modeled as a rigid body which “floated” on the seat cushion VFORCE’s. In physical testing, this was actually a water test dummy weighing 170 lbs (77.1 kg). The dummy was “topped off” with water to prevent any “sloshing” from occurring during the tests. A water test dummy was chosen because International needed to evaluate the seat ride using an occupant that would be readily available and provide repeatable results. Additionally, it was easily modeled. In reality, however, the vibrational response of a human is significantly different from that of a water test dummy. For seat modeling and validation purposes, the water dummy was sufficient.

3. PHYSICAL TESTING

Physical testing of each seat was performed using a 5 DOF shaker table (no yaw). The table was driven using actual measured data taken from a full tractor-trailer ride event. The seats were instrumented with a total of 25 data channels using accelerometers, displacement transducers, and a force transduer. The seat belt and retractors were also included in the setup but were later found to have an insignificant contribution to the analysis in terms of ride quality.

4. VALIDATION APPROACH

The test fixture input accelerations measured from physical testing were processed using nSoft. They were double integrated and applied to the model as displacement splines.

Characteristics measured during physical testing and used in the validation of the models included accelerations, displacements, and forces. Initially, the force results were intended to help validate a full occupant restraint system. However, it was later found that the forces were not only small, but the seat belt retractors never experienced “lock-up” during any of the test ride events. If lock-up had occurred it might have played a significant role in the overall ride quality results. The entire restraint system, including the retractors, was therefore not included in the full seat models.

In addition to using accelerations and displacements as ride evaluation tools, International chose to evaluate heavy truck seat ride in accordance with ISO2631-1 (Evaluation of Human Exposure to Whole-Body Vibration). For this purpose, an ADAMS/View macro was written. This method essentially takes RMS accelerations experienced by the occupant in three translational directions (three on the occupant’s back and three on the bottom) and weights them against pre-established weighting factor vs. frequency curves. Through various mathematical manipulations, the weighted accelerations are then combined to produce an overall ISO ride quality number.

Two models of each seat, all-rigid and flexible, were constructed and initially tested. The flexible models, however, were found to capture more of the frequency content in all three directions but more so in the lateral direction. This behavior was observed more on the National seat than on the GraMag. Therefore, the flexible models were used in the validation tuning process toward creating the baseline models, which would later be used in a design sensitivity study.

The frequency range of interest, for graphical evaluation, was concluded as being from 0 to 20Hz. This is the range most likely to be encountered during normal ride (can be higher) and is also the range weighted most heavily when calculating the ISO ride quality number.

Overall, the flexible models were configured with active normal modes between 50 and 1000 Hz for the Naional seat and between 50 and 500 Hz for the GraMag seat. Flexible body damping was set to 10% of critical for both models. A note should be made that although the active frequency content used in the model may seem rather large, considering we are only interested in a range between 0 and 20 Hz, proper flexible model behavior, such as deflections, is strongly dictated by the number of active modes in the model.

5. VALIDATION RESULTS

A note should be made that in the plots below, red is test data and blue is simulation data.

Figure 4 and **Figure 5** below show plots of accelerations of the National seat all-rigid model and flexible models, respectively.

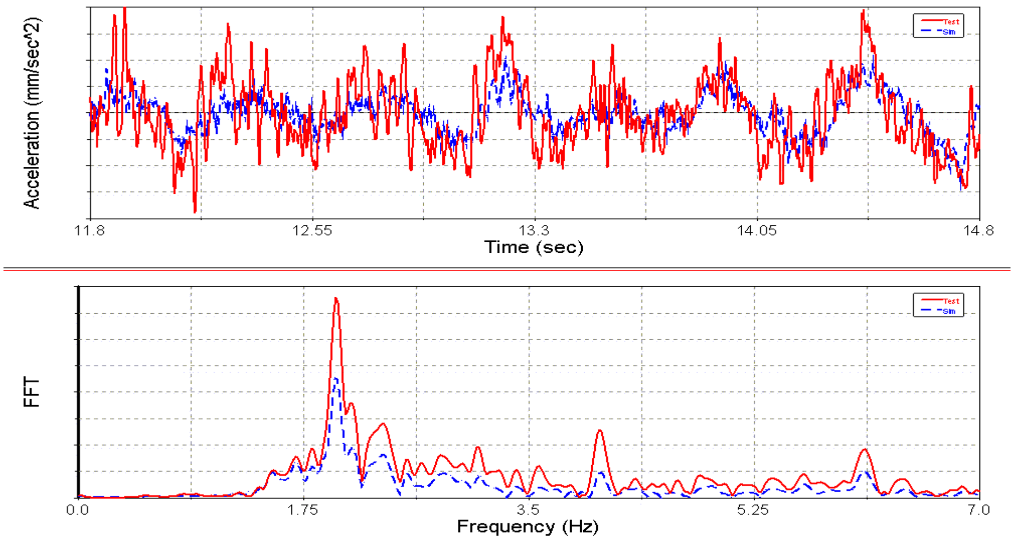

Figure 4 - National Seat All-Rigid Model - Vertical Direction

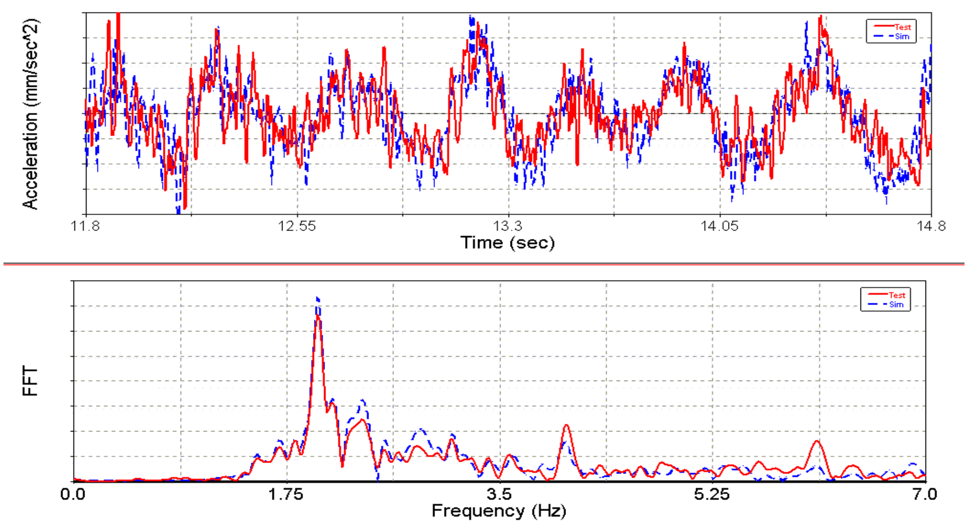

Figure 5 - National Seat Flexible Model - Vertical Direction

The seats are designed with the intent of the air springs and shocks absorbing the energy in the vertical direction. However, as seen in the plots above, flexibility does play a role in dictating some of the vertical behavior. The amplitudes as well as the FFT's for the flexible seat give indication of this behavior.

Although flexibility did play a role in the behavior in the fore/aft direction on the National, the fore/aft isolators showed to be greater dictators in the behavior in this direction. Specifically, tuning of the friction in the isolators allowed for better model correlation inside the flexible model. **Figure 6** and **Figure 7** below show plots of the FFT for a channel in the fore/aft direction.

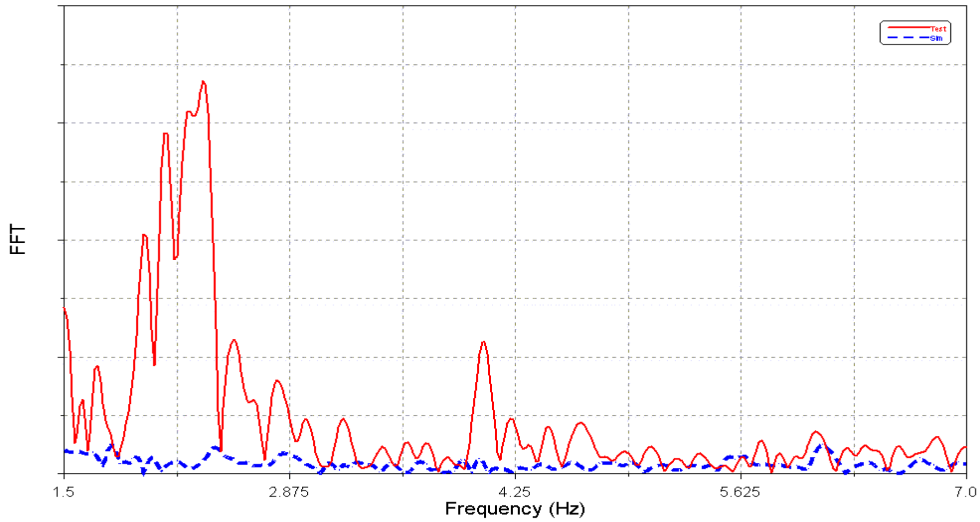

Figure 6 - National Seat All-Rigid Model - Fore/Aft Direction

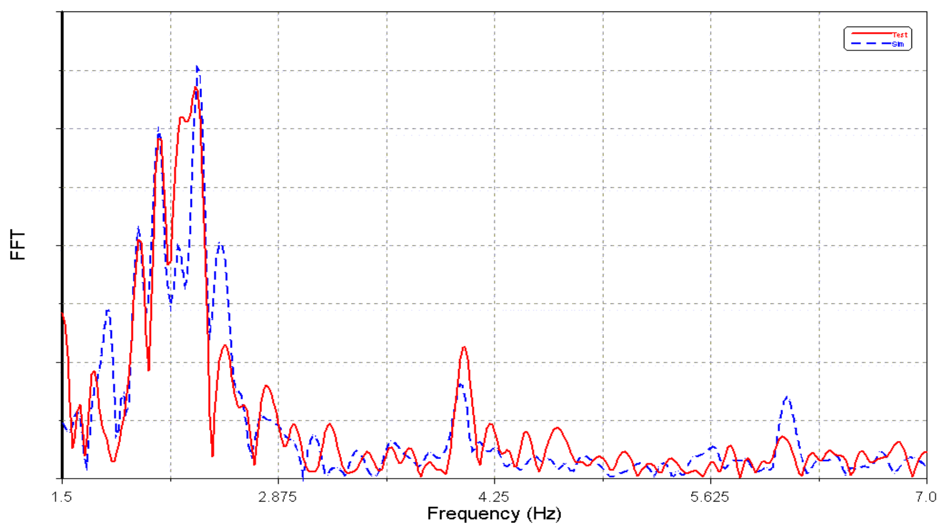

Figure 7 - National Seat Flexible Model - Fore/Aft Direction

Finally, the results of the National seat in the lateral direction were probably the most significant as far as comparing the all-rigid model vs. the flexible model. The flexible model correlated much better with test data, especially in the frequency range between 5 and 15 Hz. One can see that the suspension is essentially a cantilevered beam design subject to minor deflections. **Figure 8** and **Figure 9** below show this behavior.

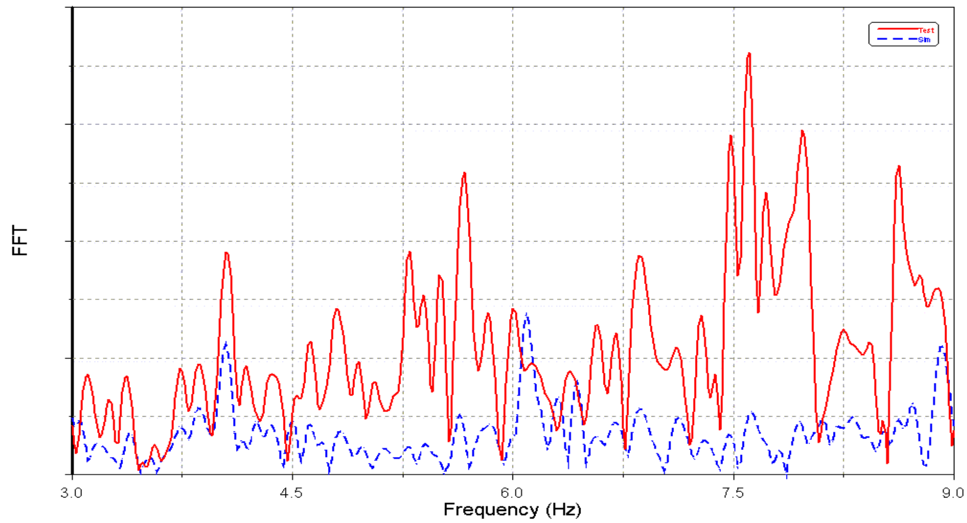

Figure 8 - National Seat All-Rigid Model - Lateral Direction

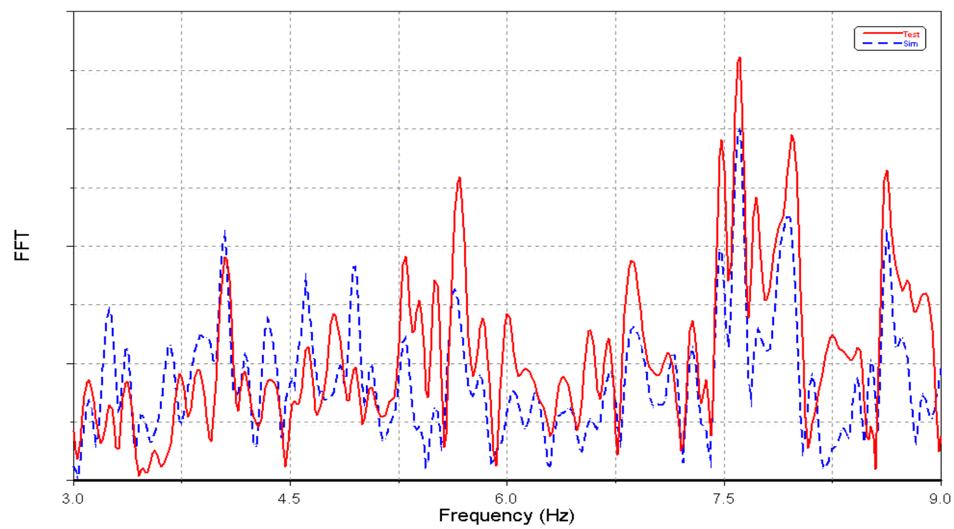

Figure 9 - National Seat Flexible Model - Lateral Direction

The ISO ride quality number used in the validation was significantly improved between the rigid and flexible models. Below in
Figure 10 is a chart showing the percent deviation from test data of the overall ride numbers as well as the numbers for the individual directions.

		RMS Seat Bottom			RMS Seat Back		
Model	Ride #	Vertical	Lateral	Longitudinal	Vertical	Lateral	Longitudinal
Rigid – % dev	**41.6**	**37.2**	**66.7**	**17.8**	**41.1**	**85.9**	**59.5**
Flexible - % dev	**12.8**	**18.6**	**23.3**	**15.5**	**2.7**	**28.1**	**1.3**

Figure 10 - National Seat Ride Quality Number Results

Results for the GraMag seat were slightly improved between the rigid and flexible models but the difference was not as significant as that found with the National seat models. The vertical direction exhibited some minor improvements, as shown in **Figure 11** and **Figure 12** below.

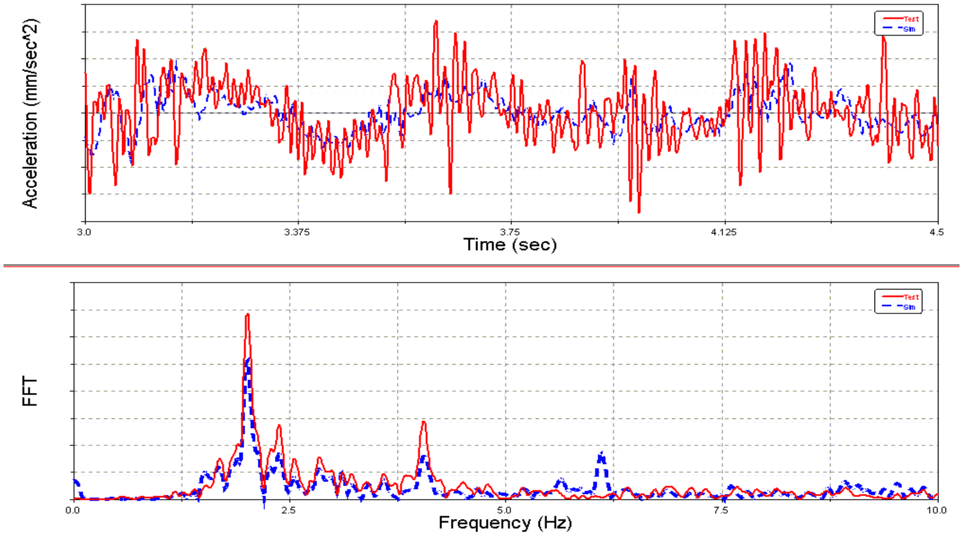

Figure 11 - GraMag Seat All-Rigid Model - Vertical Direction

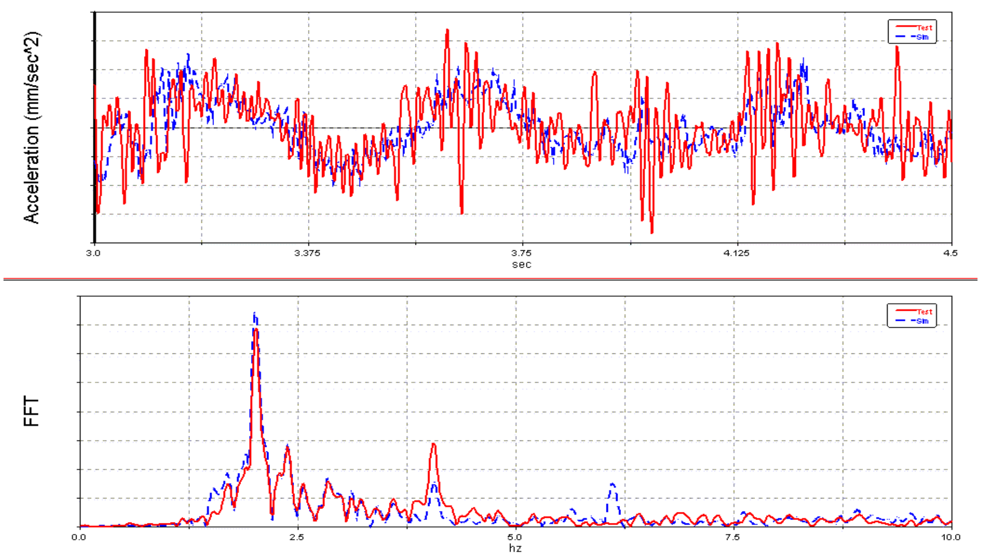

Figure 12 - GraMag Seat flexible Model - Vertical Direction

Graphically, the fore/aft and longitudinal directions did not exhibit significant improvements when going from the all-rigid model to the flexible model. Both models correlated reasonably well with test data. However, resulting frequency characteristics allowed the ride quality numbers for the tuned flexible model to achieve much better correlation to test data. Below in **Figure** 13 is a chart showing the percent deviation from test data of the overall ride numbers as well as the numbers for the individual directions.

		RMS Seat Bottom			RMS Seat Back		
Model	Ride #	Vertical	Lateral	Longitudinal	Vertical	Lateral	Longitudinal
Rigid – % dev	**21.8**	**1.9**	**11.5**	**32.1**	**32.4**	**20.5**	**27.4**
Flexible - % dev	**12.0**	**24.5**	**3.8**	**28.6**	**5.9**	**13.6**	**21.8**

Figure 13 - GraMag Seat Ride Quality Number Results

6. CONCLUSION

Overall, the use of flexible models over rigid models proved to be more representative of the actual seats. Not all the natural frequency normal modes were needed in the models and flexible body damping (modal damping) was accomplished with a constant 10% across all modes.

Modeling air spring and shock data using SFORCE functions and force-deflection and force-velocity splines provided relatively accurate correlation results for the sub-systems. Validating these sub-components in their own separate models provided a good de-bugging technique, rather than trying to resolve any issues in the full seat models.

Modeling of the seat cushions with VFORCE’s gave fairly accurate results but showed some room for improvement, as the loading on the cushions is more of an infinitely-distributed load rather than loading at selective points.

The ISO ride quality number was a valuable and easy-to-use tool for evaluating and quantifying overall ride quality. Lower frequencies, those likely to be encountered during normal ride as well as having the most effect on human comfort perception, are given the heaviest weighting. From the three directions evaluated inside the ISO macro, the vertical direction carried the heaviest weighting.

In all, the overall ride quality number for the National seat model was improved from a 41.6% deviation from test data on the all-rigid model to 12.8% on the flexible model. These numbers were also improved on the GraMag seat, going from 21.8% on the all-rigid model to 12% on the flexible model.