A new approach to durability road load simulations using Adams at Volvo Cars

By Joakim Zakrisson (Volvo Cars)
Thomas Nygård (Hexagon | MSC Software Sweden)
Hemanth Kolera (Hexagon | MSC Software)
Durability testing is a critical aspect of automotive product development. The ability to answer the question “Will it last?” can not only affect the design of a component but the entire system. Durability issues discovered late in the design cycle cost time and money to fix. If they are not addressed before product launch, they lead to warranty costs and lower customer satisfaction. Excellent durability characteristics often conflict with other attributes, such as ride and handling or NVH, and finding a way to balance competing requirements is necessary and difficult.

Since 1927, Volvo Cars is focused on providing its customers with a vehicle that is world-class in driveability, comfort, and durability. Vehicle endurance and strength are critical aspects of durability. Strength is the ability to remain functional when subjected to high loads, while endurance is the ability to remain useful over a prolonged period of usage. The durability department at Volvo Cars is responsible for ensuring vehicle strength and endurance. Volvo is invested in using Computer Aided Engineering (CAE) for product development and in using simulation methods to verify the vehicle performance instead of physical testing. Adams is the Multi-Body Dynamics simulation software of choice at the durability department at Volvo, with a group of seven simulation engineers using the software.

Simulating vehicle strength involves calculating the peak loads on the vehicle. Volvo uses a set of 14 vehicle events to set the dimensioning loads on the chassis components. These are categorized into vertical, lateral, and longitudinal events. Examples of such events include Drive Over Curb (vertical), Braking into a pothole (longitudinal), and skid against curb (lateral).

Simulating vehicle endurance involves calculating the fatigue loads on the vehicle. Like strength events, endurance events can be categorized in the vertical, longitudinal, and lateral directions. Some events may combine two directions. For SUV and Cross-Country cars, an off-road track is also simulated. Some of the 60 simulated endurance events include Cobblestone, Washboard, Potholes, Stop and Go, Off-road Track and Slalom.

Accurately simulating the road loads imposed during vehicle operation is critical to capturing the durability characteristics of the vehicle. Road loads are gathered from Adams simulations by using channels within Adams. Channels are like simulated instrumentation ports where you can measure system response and report the results directly in the frequency domain. To evaluate strength, the peak loads are extracted while for endurance evaluations damage and equivalent force are key factors. The gathered simulation data is then compared against a reference value, which can be another vehicle or the same vehicle with another chassis design.
Different groups use computed road loads within the organization. The output files are sent along with extensive documentation to teams working on component level Finite Element analysis within Volvo and shared with suppliers outside the organization. The road loads serve as input to Finite Element models for analyses of various vehicle components. Additionally, the simulated loads are used early in the design phases in the absence of test data to operate test rigs for both full system and component analysis.

In order to achieve a vehicle design that meets performance specifications, with respect to vehicle dynamics, across various road conditions, modern chassis systems have more and more elements of active/semi-active control. In active chassis systems, the suspension controls the vertical movement of the wheels relative to the vehicle body, using an onboard control system, unlike a passive suspension where the movement is dictated entirely by the road surface and constant suspension parameters. A semi-active suspension system is the middle case where the amount of energy that can be removed from the system is controllable in real-time. CAE methods for (semi-)actively controlled vehicle systems have to involve co-simulation of both the controller and the physical system. Since the computed road loads are influenced by the control system, co-simulation is key to capturing these loads accurately.

The vehicle systems simulated in this study contain semi-active dampers. The associated controls scheme is as shown in Figure 2. In the simulated control system inputs are vehicle parameters such as acceleration, suspension height, velocities etc. and the output response is a current level. This current level is then fed to a damper UDE in Adams which then uses the value along with the damper velocity to compute the damping force.

Volvo utilizes a highly automated process for execution of the simulation jobs. The Excel based set up is used to prepare the simulation job, execute it on a remote cluster and then post process the results. Process involves an Excel based interface for batch processing of Adams. This scripted batch process is used to run suites of Adams jobs with several different events and co-simulation runs. In Adams there exists several ways of connecting software together. Adams supports the FMI standard and enable FMU import and export as well as co-simulation. Additionally, Adams supports co-simulation outside of the FMI framework using a plant file. The process of co-simulation of Adams as plant model with Matlab involves the Adams Controls module. An m-file with plant settings and an Adams Controls acf file are generated. A solver routine receives and executes solver commands over the memory pipe or TCP/IP to run the simulation and communicate vehicle states.

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There are several limitations of this workflow that even open standards such as FMI do not solve. The target machine for the exported model cannot be specified, as the computing node is not known at the time of file generation. Also, the aspect of intellectual property comes in to play as the control system are developed and not available in its entirety to Volvo, hence it cannot be compiled into FMUs. The software being developed for a 32-bit vehicle operating system and then being simulated on 64-bit systems creates platform compatibility issues. Even though all of these can be worked around with the co-simulation, the process is manual with regards to file transfer and settings. Parallel execution of Simulink runs and keeping track of ports is hard. Also each analysis must be started manually from within Simulink, running Adams as the co-simulation slave.

To address these issues a new seamless approach (Figure 3) which, was developed by MSC Software Services, and installed at Volvo Cars which was in line with the current execution framework previously described. User generates Adams Car model files and customization outputs automatically. A scripted workflow sets up a TCP/IP connection to the Simulink server and initiates the Adams Car controls solver. Via this TCP/IP connection the co-simulation workflow is executed where the Adams/Car solver communicates with the Machine running the Simulink model. The process is initiated with the start of the Simulink server. The Adams solver files are generated as usual and then a run command submits the co-simulation to the Simulink server. The Adams solver communicates with the Machine for the exported model. This command starts the Adams daemon and communicates with the simlink server to exchange information and files, which in its turn starts the simulation during which Adams Controls will contact the daemon to start the actual co-simulation.

The co-simulation approach was compared and contrasted against a simplistic approach that did not involve any controls integration. Passive simulations were run at three different damping/current levels (Figure 4). This is an attempt to study the influence of a semi-active damper on road loads, by using passive dampers representing each of these current levels. Damper curves represent softest to hardest setting (lowest to highest current). For each of the drive modes (comfort, dynamic, off-road) a 60 event set was executed at each current level. This leads to additional post processing and added complexity while interpreting the processed results. Channels and their quotas are evaluated for peak, damage or equivalent force. Different damper settings are "worst case" for different channels. Based on the results, an engineering judgement has to be made to determine which damper setting to use as official data. There is the risk of over-dimensioning the components if the wrong level is chosen.

Results with a comparison between the co-simulated active simulation results and the passive simulations with the static current/damping levels are shown. For the potholes simulation, significant difference in topmount load for the low current passive damper (Figure 9) compared to semi-active simulation (Figure 7). Besides the significant difference in the topmount load, a lack of rebound damping and large bumpstop engagement is also seen in the passive simulation (Figure 8 and Figure 9).

For the drop off and rebound simulations, notice the max level current for the three modes (Figure 10). Compare topmount force from the semi-active simulations to its passive equivalent. With the controller feeding the maximum current independent of drive mode, running the passive low and mid alternative is unrealistic for some drive cases.

In conclusion Volvo Cars has opted to use the developed process which to the Adams user is barely noticeable and reduces the amount of manual interpretation, comparison and engineering judgement. Together with the service organization of MSC Software the process is being developed to support even more complex co-simulation scenarios involving additional tools in the simulation chain.