Ford Motor Company

Reduce Need for **Physical Prototyping** using Adams Real Time

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The Automotive industry is under constant pressure to address market demands in resource-constrained engineering environments. Stiff development timelines are compounded by shrinking physical prototyping budgets. The Ford Motor Company is focused on providing its customers with a vehicle that is world-class in both drivability and comfort, which are critical attributes that impact a customer's perception of the vehicle. These critical attributes are in turn impacted by the transmission shift strategy.

The traditional approach to transmission calibration at Ford involved physical testing of full vehicle prototypes with extensive test schedules which was both time consuming and expensive. In collaboration with MSC software and its services group, Ford developed a Hardware-in-the-loop testing process to reduce the need for physical prototyping.

Hardware-in The Loop Testing (HIL)

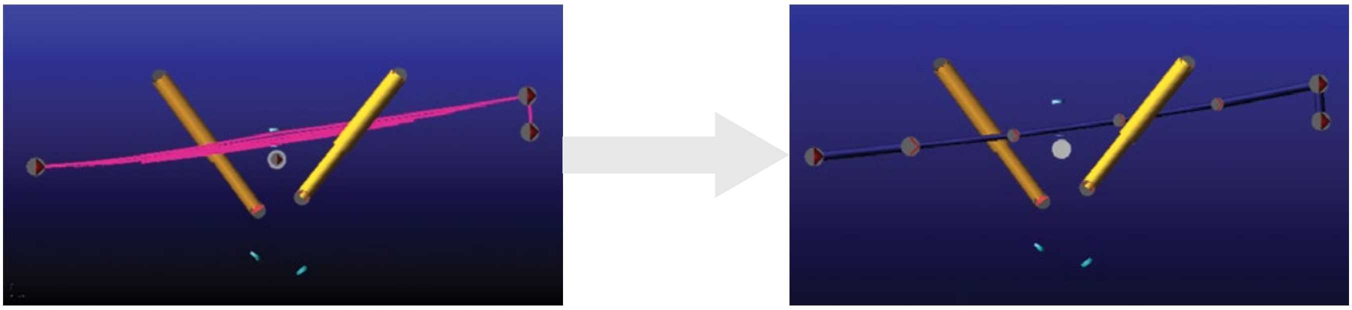
Ford has been a longstanding user of Adams vehicle dynamics models and with the release of Adams Real Time (RT) in 2017, Ford identified an opportunity to leverage its existing Adams knowledge base further downstream in the development cycle for vehicle testing and calibration.

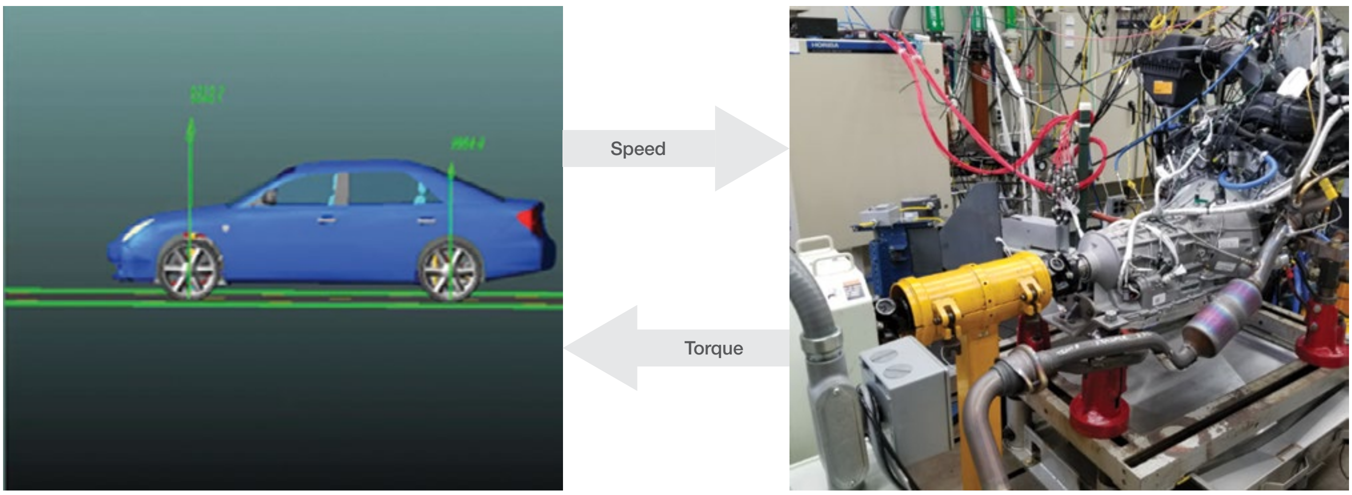
Together, MSC and Ford have implemented a combination of physical components and Adams Real Time models in a HIL test environment to evaluate the shift quality of multiple vehicle platforms. For each test set-up, a physical engine and transmission prototype was connected to a virtual Adams model of the vehicle. The implementation consisted of three phases:

- Model conversion for real time analysis. Existing Adams vehicle models were used to create corresponding Adams Real Time models that met the real time platform/hardware requirements platform/hardware requirements
- Model setup. The model was prepped for integration into the test bed. This involved creation of I/O channels, tuning of the RT solver settings and generation of the FMU, the model representation that conforms to the FMI co-simulation standard
- Integration with HIL test bed. The FMU was then ported onto the HIL platform and the model was calibrated to test data prior to performing hardware tuning.

Since the real time Adams model was derived from an existing vehicle model that was already being used within Ford for vehicle development, the model development overhead was minimal. Generation of the real time model from the existing full-fidelity Adams model involved multiple model reduction strategies.

For this use-case, it was necessary to include leaf springs in the real-time model. Since the pre-existing beam-based leaf spring model was too complex for real-time analysis, it was replaced with a 5-link model with equivalent behavior. A suspension subsystem simulation was run on a beam leaf spring model to obtain target values for the spring characteristics. The model tuning was assisted by executing a DOE that fine-tuned the hardpoints and bushings





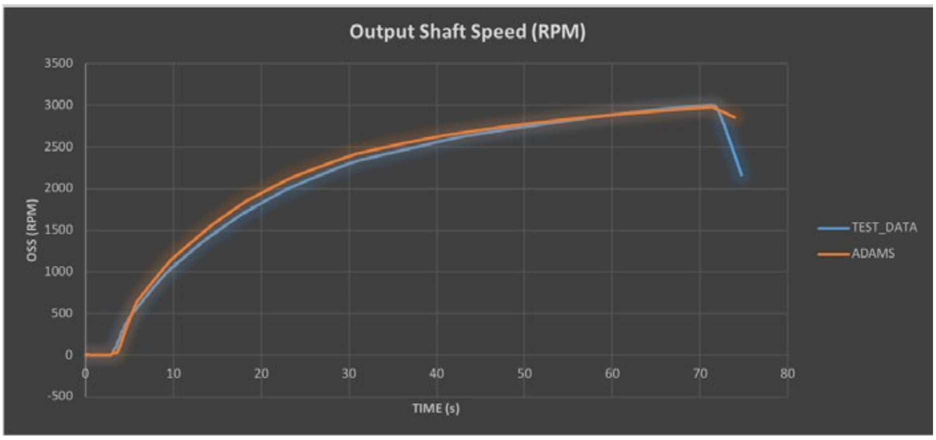


Figure 1: **Simulation Correlation with Test data at 50 % pedal input (VSPD Vehicle Speed, OSS-Output Shaft Speed)**

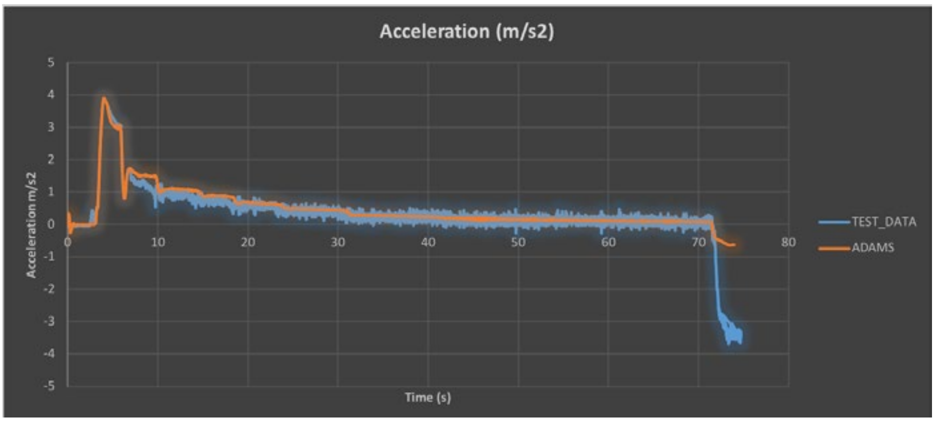


Figure 2: **Simulation Correlation with Test data at 75 % pedal input (VSPD-Vehicle Speed, OSS-Output Shaft Speed)**

to capture the right behavior in the 5-link model such as primary frequencies, static preloads, vertical rates and wind-up rates. The Adams Real Time model had 150 DOF and preserved the topology and parametrics of the original model. Elements such as hardpoints, joints, springs, dampers and bushings were maintained and could be modified. The benefit of this is that the model could capture higher frequency characteristics in the system responses and different configurations could be quickly explored.

The Adams-Real Time model was then exported as a Functional Mock-up Unit (FMU) and ported onto a HIL platform for execution. In future implementations, modeling parameters such as hard points, bushing characteristics etc. will be exposed in the FMU for run time tuning. This will allow Ford engineers to make changes to parameters and tune model response without having to make changes to the original Adams model and export a new FMU.

The physical torque at the output of the transmission was instrumented and applied to the Adams model as an input. Given this input torque, the Adams model reacted and provided a driveshaft speed response to the dynamometer which then enforced this speed on the engine and transmission. The model also provided the longitudinal vehicle acceleration as the vehicle changed gears, which could then be related to a ride comfort index. The ability to use a combination of vehicle dynamics models and hardware to simulate vehicle behavior provided Ford an opportunity to create both more efficient and more comprehensive testing programs while reducing vehicle prototypes.

The HIL realtime predictions were validated against vehicle test data to confirm correct vehicle response to known input torques. Figure 1 shows the velocities of the actual vehicle speed versus the model.

Figure 2 shows the output shaft speed and the longitudinal acceleration response. The vehicle response in between and during gear shifts showed good agreement. The agreement was consistent across all pedal positions pointing to the predictive nature of the Adams model. Calibration engineers then used the HIL setup to gauge and tune transmission parameters to attain the desired behavior.

The HIL dyno testing process has helped the Ford team meet its test objectives with fewer physical prototypes and in a lab environment that facilitates the tuning process. The same engine and transmission prototypes can be tested with multiple vehicles under multiple loading scenarios.