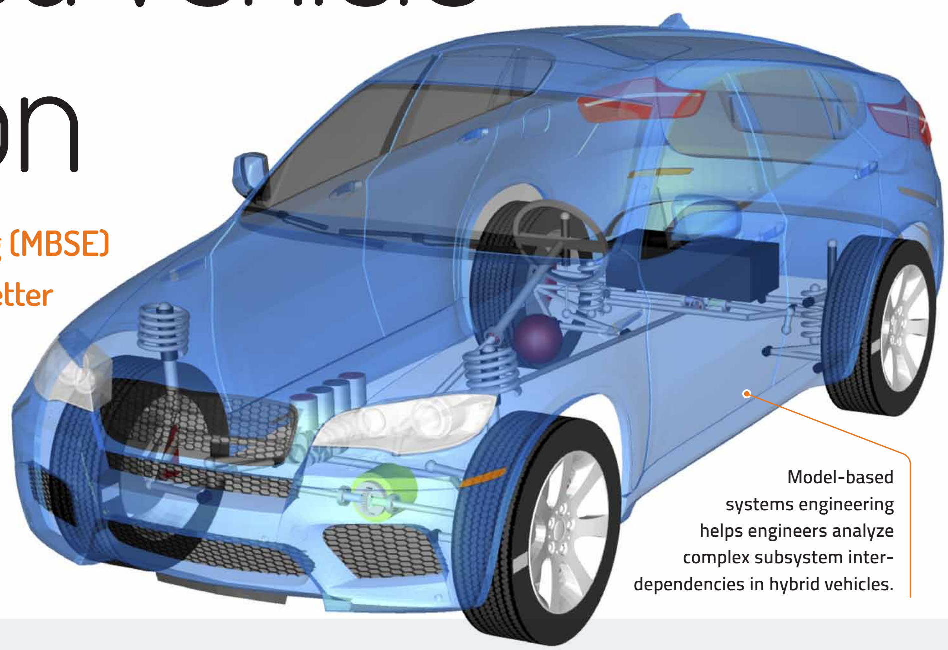
Integrated vehicle simulation

Model-based systems engineering (MBSE) using open standards provides a better understanding of the complex interactions at work in modern vehicle design.



Model-based systems engineering helps engineers analyze complex subsystem interdependencies in hybrid vehicles.

More than at any time in automotive history, performance factors are based on interdependencies that ripple throughout the vehicle, particularly for hybrids that combine combustion engines with electric propulsion systems

Modelon, a worldwide supplier of products and services for system design and optimization, used a *model-based systems engineering* (MBSE) approach to evaluate and balance multiple performance attributes for an e4WD hybrid car.

The key enablers in Modelon's study were *Dymola*, software from Dassault Systèmes that uses the open-standard *Modelica* language to model and simulate the behavior and performance of systems with complex interactions; and *FMI* (Functional Mockup Interface), an open-standard interface that enables models to be integrated into multiple simulation environments.

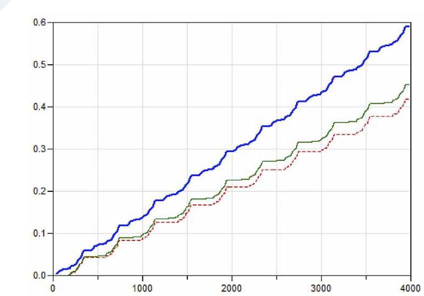
The vehicle models use *Modelica libraries from Modelon* that enable plug-and-play modeling with a variety of subsystem configurations at different fidelity levels *(see multi-fidelity sidebar).*

Maximizing fuel economy

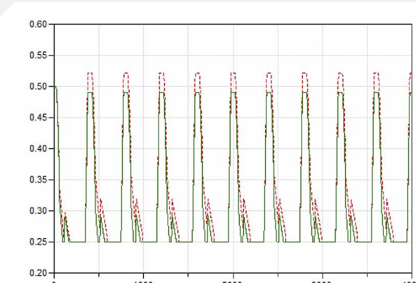
The central selling point of a hybrid vehicle is fuel economy. A hybrid achieves energy savings by synchronizing the engine, electric machines and battery for maximum efficiency. Further savings are gained from optimizing the use of parasitic power throughout the vehicle. The Modelon study compared three different powertrain architectures:

1. **Using a downsized, turbocharged engine.**
2. **Integrating a flywheel into the design.**
3. **Integrating an electric motor/generator with a battery.**

The simulation results to the right show that configurations two and three yield better fuel economy due to regenerative braking. Results also showed that energy management for hybrid vehicles is sensitive to battery characteristics, making it important to capture how battery configurations perform when interacting with mechanical, thermal and electrical subsystems. >>>



Fuel consumption



State of charge

Thermal interactions

Thermal system design also plays a major role in energy management and performance of hybrid vehicles. Modelon simulated the e4WD thermal system in conjunction with other vehicle dynamics to gain a complete picture of performance.

In the first case, a high-voltage battery was passively cooled through convective heat transfer from the vehicle's underbody. In the second case, the high-voltage battery was isolated from the underbody but included an active fluid coolant loop in the heat-exchanger stack.

The simulation results showed the benefits of using model-based systems engineering to reveal the complex multi-domain interactions among subsystems.

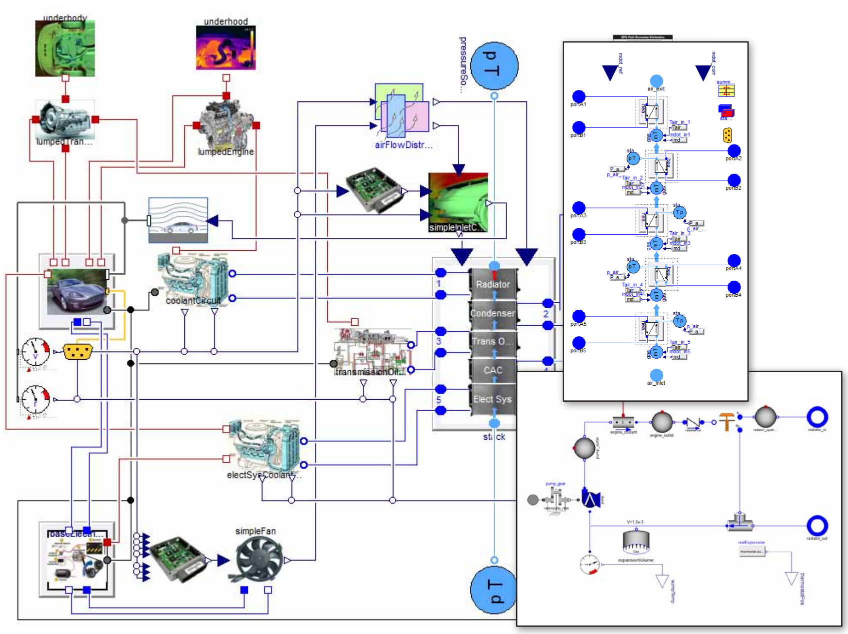
In the passive case, the battery recorded high internal temperatures due to limited heat dispersion to the surrounding air. Heat from the battery also increased the transmission oil temperature, since the transmission was connected to the car's underbody.

In the second case, active cooling of the battery reduced temperatures and allowed more efficient operation and charging.

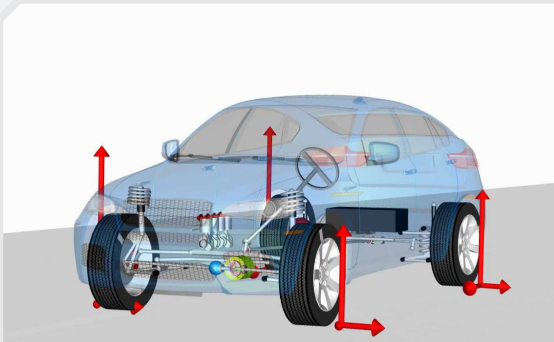
Driving performance

Partial electric propulsion in hybrid vehicles offers new opportunities to improve the driving experience, but it also introduces new complexities.

Acceleration must consider traction blending of the combustion engine and electric machines combined with front and rear torque distribution. Deceleration must take into account the split between mechanical friction brakes and electric machines. Both cases must fit into the energy management strategy and requirements for drivability, performance and safety.



Thermal system design plays a major role in energy management and performance of a hybrid vehicle.



Animation still image from the driving performance tests. Vectors indicate tire forces.

MODELICA AND FMI BENEFITS

Modelica and FMI technologies enable engineering organizations to:

- Simulate all relevant physical domains and their interaction in the same system model.
- Create plug-and-play compatible component and system models.
- Use system architectures for rapid model configuration.
- Perform component-based evaluations.
- Work with different fidelity levels within the same framework.
- Export models to other tools and applications.

The Modelon study used a virtual skid-pad with a 50-meter radius and the friction lowered to 70 percent of nominal. The driver started from a standstill, released the brakes and then pressed the accelerator pedal.

Results from the acceleration and velocity profile showed the e4WD outperforming the original vehicle, mainly due to improved grip and greater torque from the standstill position. The feel of the e4WD would be much better as well, due to faster response time, smoother acceleration and lower jerk. The model-based systems engineering approach enables designers to balance physical systems with controls to reach the optimal blend of overall performance.

The benefits of integration and sharing

FMI-compliant tools allowed the models generated by the Modelon study to be easily exported to other programs such as Simulink to investigate controller design and optimization *(see deployment article).*

Model-based systems engineering using Modelica and FMI gives engineers a comprehensive picture of the complex interactions among different vehicle systems early in the design process. The result? Better designs, greater performance, and major cost savings by moving analysis forward in the product development process and reducing downstream physical prototypes. ■

Why multi-fidelity?

Say *low-fidelity* to many engineers and you're likely to get the same reaction you'd get from an audiophile: "What good is that? More fidelity is always better." But, it's not true in all cases.

An overly complex model early in the design process hurts engineering efficiency due to the time spent implementing and parameterizing the model. Superfluous modeling details can also impact simulation times. High-fidelity physics in thermo-mechanical systems can easily lead to orders-of-magnitude increases in simulation time.

A too-low fidelity model can cause problems as well, as it will not allow simulations to capture the key effects needed for adequate engineering analysis.

> **What would you rather do: 10 design iterations a day with multi-fidelity models or 10 a month using only a very high-fidelity model?**

Multi-fidelity, multi-perspective

Model-based systems engineering (MBSE) supports multi-fidelity: the ability to generate models at different fidelity levels that can be used throughout the product development process to support simulations involving multiple subsystems.

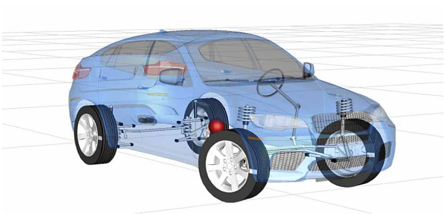
An electrical engineer might want detailed models of the electrical system and a simple representation of the rest of the vehicle, while a vehicle dynamics engineer is likely to have the exact opposite needs. That's called *multi-perspective.* While it is tempting to use high-fidelity models for all simulations, there is a price to pay for the detailed input data needed for these models and the increased development and simulation time. What would you rather do: 10 design iterations a day with multi-fidelity models or 10 a month using only a very high-fidelity model? ■

MBSE: THE FOUNDATION FOR ROBUST DESIGN

> In many cases, users of Modelica- and FMI-based tools could run thousands or tens of thousands of experiments in the time it takes to install a new prototype in a physical environment.

Despite the emphasis on inspection and on-line quality control in manufacturing, most product failures are related to design problems.[1] This understanding has driven the movement toward *robust design,* which can be defined as making a product or process insensitive to variation.

While much of CAD/CAM revolves around models, robust design is about the questions the models can answer. Model-based systems engineering (MBSE) based on open standards such as Modelica and FMI can provide answers in key areas of robust design such as sensitivity analysis, design optimization, and robustness verification.



Here's an example of a typical workflow for robust design:

1. Get component-level specs and tolerances from suppliers.
2. Build a detailed subsystem model in Modelica.
3. Run a batch of Monte-Carlo simulations using probability distributions that cover the tolerances of component specs. The output will be probability distributions on subsystem performance variables.
4. Build a simplified subsystem model in Modelica and plug it into a system-level model.
5. Use the probability distributions on subsystem performance from step 3 and run a batch of Monte-Carlo simulations on the system level. You now have a probability distribution on system-level performance variables.

Better answers, more experiments

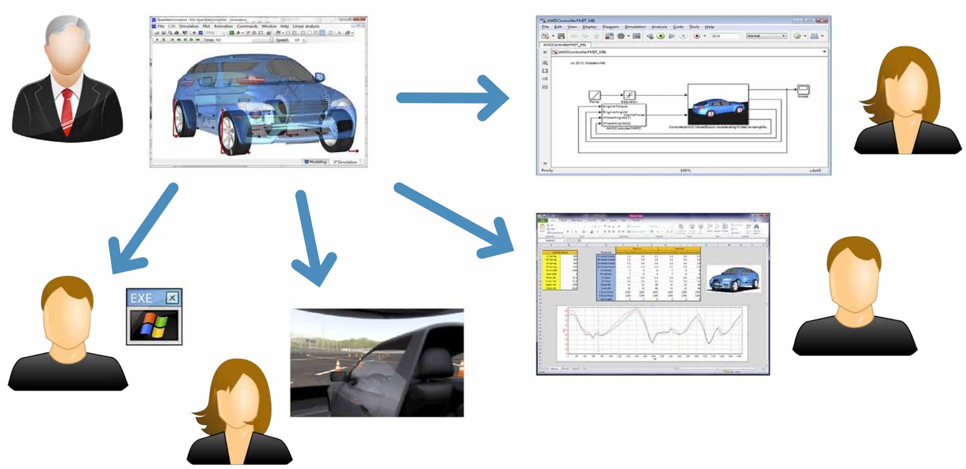
By applying these techniques across the design space, engineers can choose a design that is on target for the nominal component specs and will meet the required tolerances for variations due to noise factors.

The bonus is that tools based on Modelica and FMI can dramatically increase productivity over the traditional physical experiments used for robust design. In many cases, users of Modelica- and FMI-based tools could run thousands or tens of thousands of experiments in the time it takes to install a new prototype in a physical environment. ■

1) *Robust Quality* by Genichi Taguchi and Don Clausing, Harvard Business Review

To create is great, to deploy is divine

Almost everyone in the western world is taught this exercise early in their education: A message is whispered to a student in the front of the classroom and is spread person to person. By the time the message reaches the last person in the class, it is always altered irrevocably.



In some aspects, engineering organizations are enterprise-wide versions of that classroom. Great models can be created but often lose something in the translation during the deployment stages. Or they are recreated again and again as they move from discipline to discipline.

Standardizing the models

As more companies leverage the value of a variety of engineering analysis tools earlier in the product-development process, the need for standards becomes more acute.

In the case study of the e4WD hybrid car *(see integrated vehicle design story)*, the open-standard Modelica was used to define the models. FMI (Functional Mockup Interface) was used as a standardized interface to generate a model known as an *FMU*, which enables integrated simulation of models from different tools.

Wider model deployment

The ability to export models outside the original software used to develop them opens up the possibility of widespread model deployment throughout the enterprise.

The e4WD vehicle model with the driver, for example, was imported into *Simulink* using the *FMI Toolbox for MATLAB*. This allows control designers to test and evaluate their designs within their familiar working environment. And it goes both ways: The controller from *Simulink* can be exported as an FMU for import back into *Dymola*.

A standalone FMU enables engineers to use their familiar analysis tools to understand details of a subsystem or the effects of a design change. Different component sizes for the e4WD vehicle were evaluated, for example, in Excel using the *FMI Add-in for Excel*.

Finally, a full vehicle can be imported into a driver-in-the-loop (combining a model with virtual human interaction) environment using the *FMI Library*. Coupling a model exported with automated optimizations for fixed-step solvers with a program such as *rFactor Pro* allows complex, high-fidelity models to be run in real-time simulations.

Right models, right time

Think of Modelica and FMI as the technologies that help guarantee you always have models in the forms needed for analysis and decision-making. The result is workflow automation that delivers reduced modeling time, improved engineering efficiency, the flexibility to allow engineers to use the tools with which they are most comfortable, and improved collaboration among specialists in a range of engineering disciplines. ■

Modelon

This mini-zine is published by Modelon, the global expert in applying model-based systems engineering (MBSE) to system and control design for customers such as Audi, BMW, Daimler, Saab Aerospace, Siemens, Tetra Pak, Toyota, Volkswagen, Volvo and many more.

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