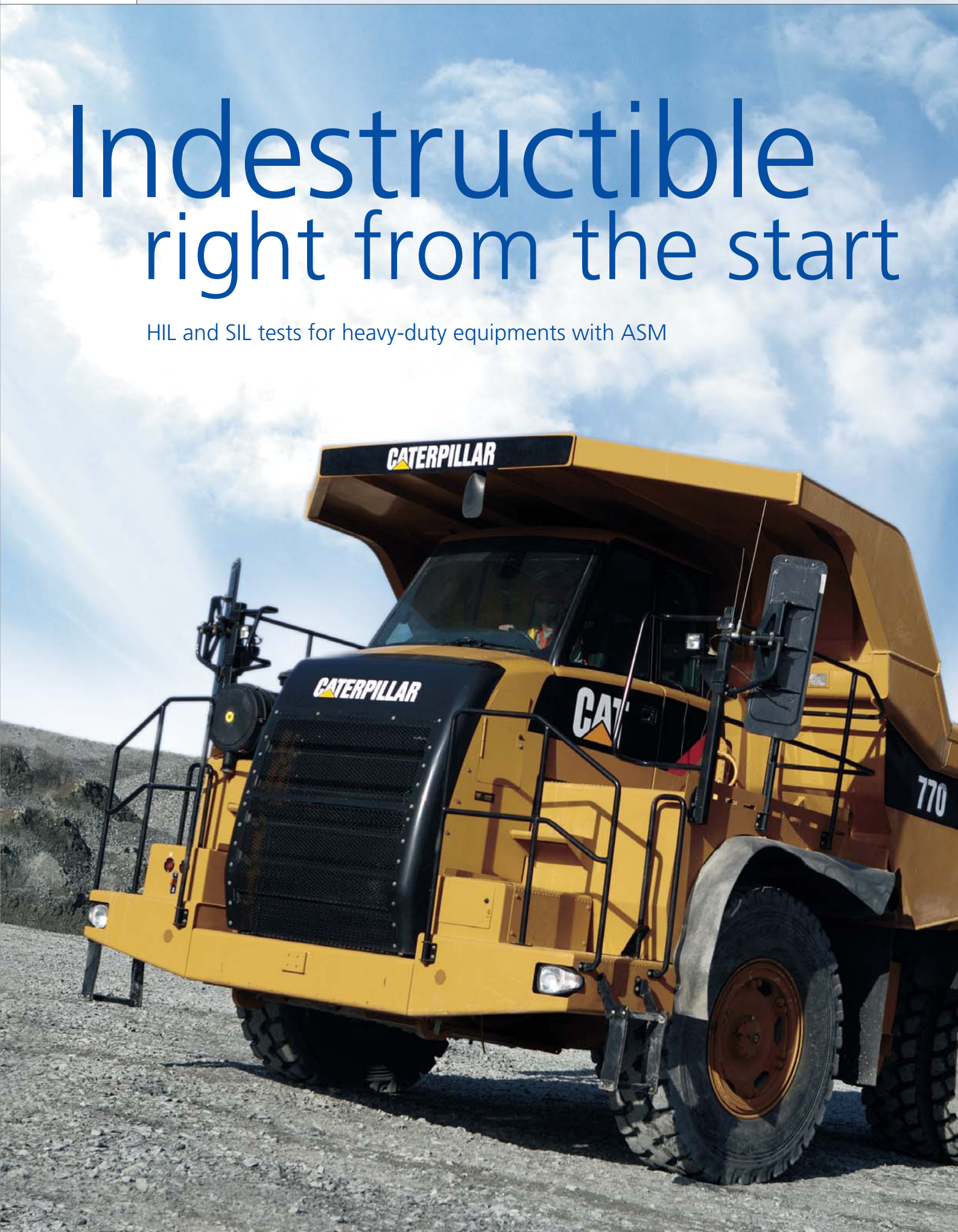
Indestructible right from the start

HIL and SIL tests for heavy-duty equipments with ASM



Construction, mining, demolition and forestry in the modern age are dynamic, increasingly complex tasks, and the heavy-duty equipment involved has a lot more intelligence inside than one would guess from the outside. The release tests on the electronic systems for the brand-new machinery illustrate how development processes are conducted at Caterpillar. From function design with custom-built high-fidelity models to the validation of control software, Caterpillar has efficient processes in place.

Caterpillar (Cat, for short) is an international company that manufactures heavy-duty equipment for the worldwide markets of construction, mining, agriculture, and power generation. The products are equipped with electronic control units (ECUs) ranging from engine and transmission management to dedicated control devices for specific system features. At Caterpillar, software-in-the-loop (SIL) and hardware-in-the-loop (HIL) testing are the standard methods for productive development and to efficiently ensure the quality and reliability of these ECUs.
To test the engine ECU of its heavy-duty equipment, Caterpillar chose the diesel engine model and physical turbocharger model from dSPACE's Automotive Simulation Models (ASM). A customized drive train model from Caterpillar was used to meet the requirements of the equipment drive train. Due to the openness of the ASM, it was quite easy to integrate the custom drive train models with ASM.

High-Fidelity Models for Combustion Control

The development of new control functions begins with using high-fidelity engine models created by Caterpillar that simulate the combustion process in great detail – but not in real time of course. The result of many years of development, these "Enterprise" models are ideal for function design, where precise control of the fuel and air systems and of combustion is essential. The models use a one-dimensional approach. The combustion models also take cylinder pressure into account. During simulation with Enterprise, development focuses on optimized torque output, minimized fuel consumption, etc., but not on diagnostics and inter-ECU communication yet.

Early Controller Software Validation

In the next step, more ECU functions are integrated with the combustion control functions. SIL testing is a common procedure at Caterpillar to

Caterpillar's machinery produces unmistakable results.

test and validate the entire controller software under development at an early stage. In an ideal process, the same model is used for SIL and HIL testing, since the parameterization can be reused and signals can be compared directly. After Caterpillar chose the ASM Diesel Simulation Package from dSPACE to perform HIL tests, the goal was to run real-time simulations with the package during function design. The company's in-house simulation environment, Dynasty, was extended to execute not only Caterpillar's high-fidelity models but also the mean value models from dSPACE. Caterpillar and dSPACE worked together closely to integrate the simulation models. To transfer the parameters from Enterprise to the ASM, a solution based on a table with one-to-one variable referencing was implemented. Measurement data either from the real engine or from the simulation is required to complete the parameterization.

Co-simulation

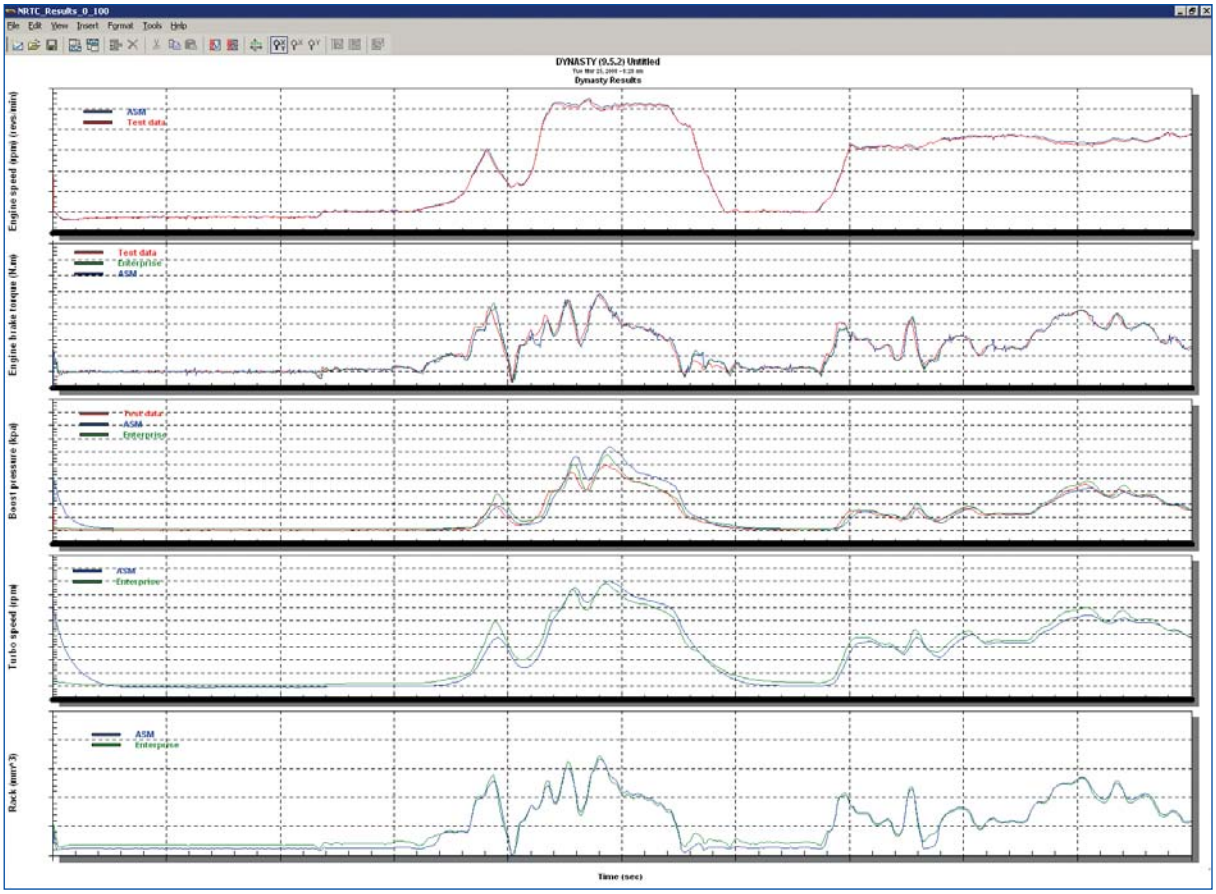
To evaluate the ASM diesel and turbocharger models and check that their quality and performance is sufficient, they were co-simulated with the Enterprise model in Dynasty and the results were compared. During co-simulation the ECU code was connected to the inputs and outputs of the ASM diesel engine model. The model was parameterized with ASMPara. Steady-state simulation results were checked against measurement data. Dynamic simulation results were compared with transient measurement data and with the Enterprise simulation results based on test cycles like the EPA Non-Road-Transient-Cycle. The simulation results of the ASM models matched the reference signals with excellent agreement in every case. As a result the ASM Diesel Engine Simulation Package is now used for controller validation during offline simulation and for ECU validation during HIL simulation.

ECU Testing at Caterpillar

Caterpillar already equipped its testing laboratory with numerous HIL test benches from dSPACE, ranging from Mid-Size to Full-Size systems. These are used to test ECUs for the engine, transmission, and other parts of the equipment. Using ASM has made parameterization much easier, since parameters are available early in the development process when SIL is performed. Another advantage is that the open model design lets you easily couple custom transmission and drive train models with the ASM diesel models. Thus the HIL benches can be configured to match any project.

The Benefits of ASMs

Practical experience has shown that performing real-time HIL and SIL tests with the same model makes development much more efficient. Moreover, we have used ASM diesel engine and turbocharger blocks for a wide range of engines



The results of the Enterprise/ASM comparison.

(4 – 20 cylinder, VTG or wastegate turbo, CGI, …) and to streamline our development processes in many different projects. This is something that pays off quickly. We especially like the openness of the ASM. They are easy to understand and modify, and we can also easily integrate custom models.

Summary and Outlook

The ASM are installed as add-ons to Caterpillar's Enterprise model to support the development of new controller functions, where they are used for controller validation during function design and ECU testing. Caterpillar intends to use the ASM for most of its real-time engine models on HIL systems. Due to the advantages that the ASM bring, Caterpillar will expand its test lab with more systems from dSPACE. ■

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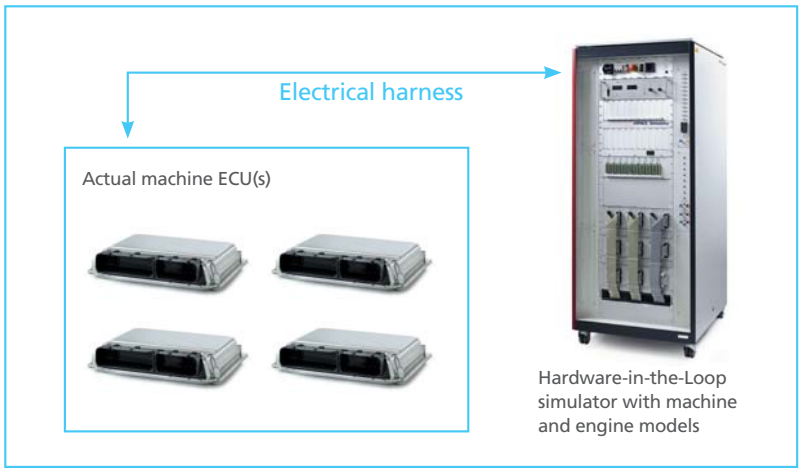
Setup of the HIL system.



Glossary

Dynasty – Caterpillar's multi-domain simulation environment

Enterprise – Caterpillar's high-fidelity engine simulation models

CGI – Clean Gas Induction, Caterpillar's solution for meeting emission regulation
EPA – Environment Protection Agency

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