WORDS BY
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Engines are becoming evermore complex as manufacturers strive to improve efficiency within increasingly tight emissions standards. Fortunately, the capabilities of computer-aided engineering (CAE) are also growing. Digital simulations allow powertrains to be modeled in ever greater detail, helping engineers grapple with spiraling complication.

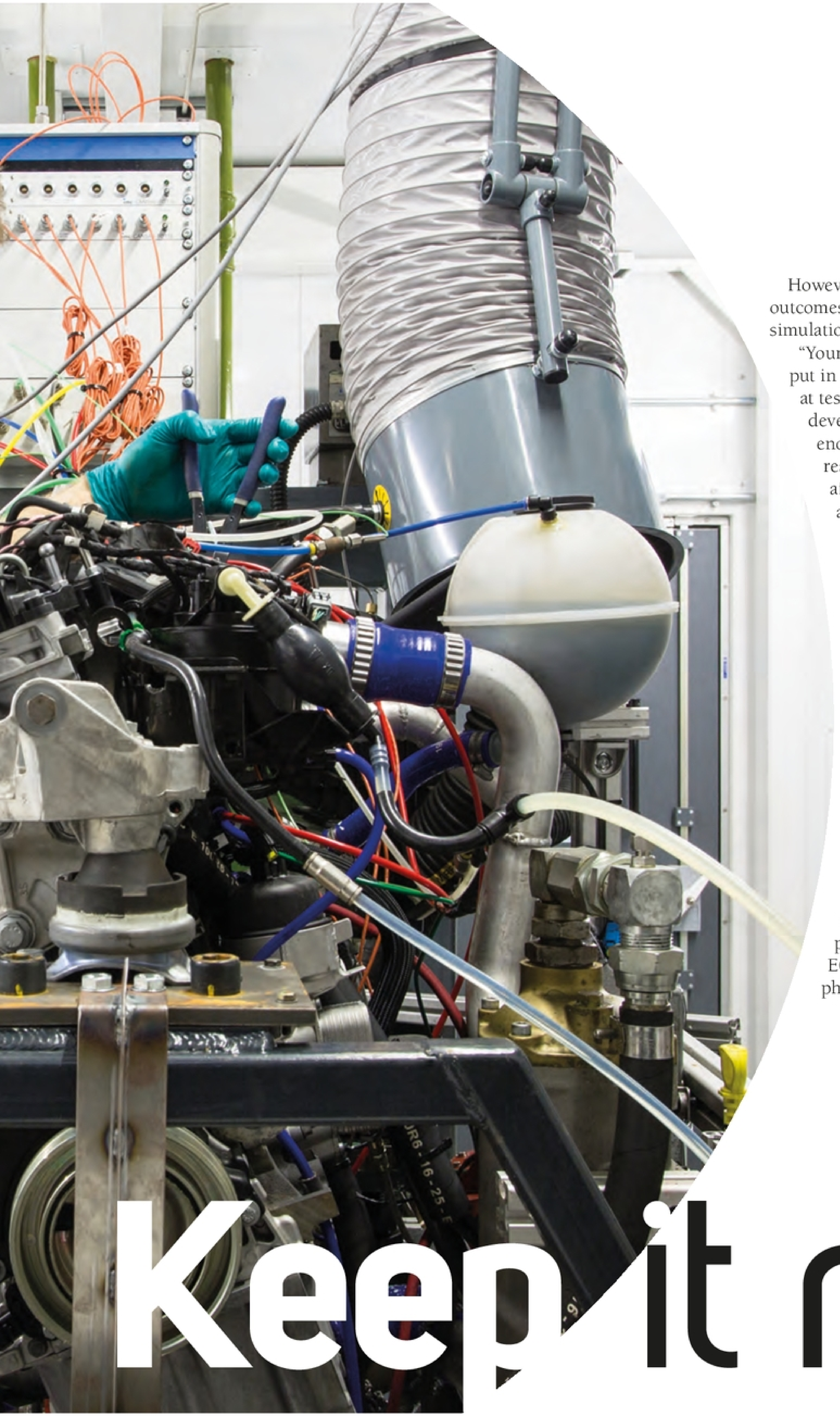
CAE doesn't yet dominate in this struggle, however. Any notion of moving to full digital development remains a far-off vision.

"The complexity of the physical world is still outstripping the virtual world," says Stephen Ratley, engine test leader at Horiba Mira. "If anything, I'd say physical testing is increasing, driven by the technology that's being put into vehicles. If something is really new, it has to be physically tested. By the time you've got confidence in your models, you've pretty much done the testing physically."

Nonetheless, CAE and other simulation technologies are playing an increasingly important role in engine development, even if they are not yet forcing mules and test rigs into retirement.

"There's no doubt that going digital is the right approach to get a better result," says Joseph Bakaj, vice president of product development at Ford of Europe. "It gives you the opportunity to try out more combinations than you could in the physical world and therefore squeeze the last 0.1% out of an engine."

Supercomputers may still struggle to accurately model the complexity of an entire engine under development, but a number of exciting new 'virtual' test tools are helping to slash the cost of building mules while reducing the risks of testing on public roads



Keep it real?

Though physical engine testing remains the dominant trend, advances in virtual simulation are becoming increasingly important to development engineers

However, the real world remains a cauldron of stochastic outcomes and teetering instabilities, making detailed simulation of some processes virtually impossible.

"Your model is only as good as the information you put in it," notes Phil Stones, chief powertrain engineer at testing specialist Millbrook. "When it comes to developing an entire engine, it really isn't good enough. When you start looking at the chemical reactions, how the engine heats up, how the aftertreatment heats up, how a hybrid system affects things, it gets very, very complicated."

Similarly, Phil Roberts, principal engineer at Horiba Mira, observes that simulation tools are better at modeling some components than others. "With the boosting system or valvetrains, it's quite easy to narrow down a large set of technologies into a smaller set that are more suited to your engine, but things like modeling combustion or the turbulence inside the cylinder are still hard to do even with supercomputers," he says. "You're always going to need an engine to be able to measure combustion data and turbulence inside the cylinder, to put feedback into your models."

Roberts adds that combustion stability with increased use of exhaust gas recirculation (EGR) is particularly tricky to model. "A lot of manufacturers are looking at dilute combustion with increased EGR," he notes. "You can't physically model the combustion stability and EGR's impact on flame propagation. You have to physically test that on an engine to get an idea of

"You'll get deposits forming, which is very difficult to simulate, because you don't know exactly where they're going to occur"

Phil Stones, chief powertrain engineer, Millbrook

where your combustion falls over and therefore how much dilution you can tolerate."

Millbrook's Stones, meanwhile, points to engine degradation as another area where modeling tends to fall short. "You'll get deposits forming, which is very difficult to simulate, because you don't know exactly where they're going to occur," he says. "It's also very difficult to simulate crankcase pressure and therefore blow-by of different oils and how they affect combustion as the engine wears."

Ford's Bakaj adds that switching between different operating states is yet another facet of engine operation that has proven tricky to simulate satisfactorily. "CAE has been capable for many years on steady-state assessments," he notes. "It's the transitions and driveability that have been hard to model, so for fine-tuning of calibration and driveability we still use mules. We can do a lot on dynamic rigs, and we're also close to the point where we could use advanced CAE to model dynamic transitions."

Main: Though many aspects of engine development continue to rely on real-world testing, virtual tools offer ways to reduce costs, and are playing a key role in OEMs' electrification strategies

Right: Digital methods were utilized during the development of Volvo's 1.5-liter petrol engine

Mules no more?

The role of mules is shrinking, however, helping to curtail the expense of building test vehicles and reducing the risks of testing on public roads. Bakaj adds that digital technology is also helping OEMs manage the move to electrified powertrains, which needs to be done without cutting back work on combustion engines. "We have to work on all of the technologies at the same time, which is obviously both a resource drain and a financial drain," Bakaj says.

According to Stones, many OEMs are also cutting costs by shifting some mule work onto advanced test rigs. "Engines, at a component level, can now be tested well before the vehicle exists, or even as a scoping exercise to see if a particular engine would be suitable for a vehicle you have in mind," he says.

Of the 28 test cells at Millbrook, three are able to emulate the presence of a full vehicle around a naked powertrain on test, in real time. "We take into account aerodynamics, gear ratios, tire rolling resistance – all the attributes of the vehicle that affect the powertrain and its performance," Stones says. "The engine then runs exactly as if it's in a vehicle, while still on a test stand."

Other specialists are responding to the same trends with their own advanced rig capabilities. "We tend to see more complex systems now, requiring a lot more electronic integration," says Dave Meek, engineering director at

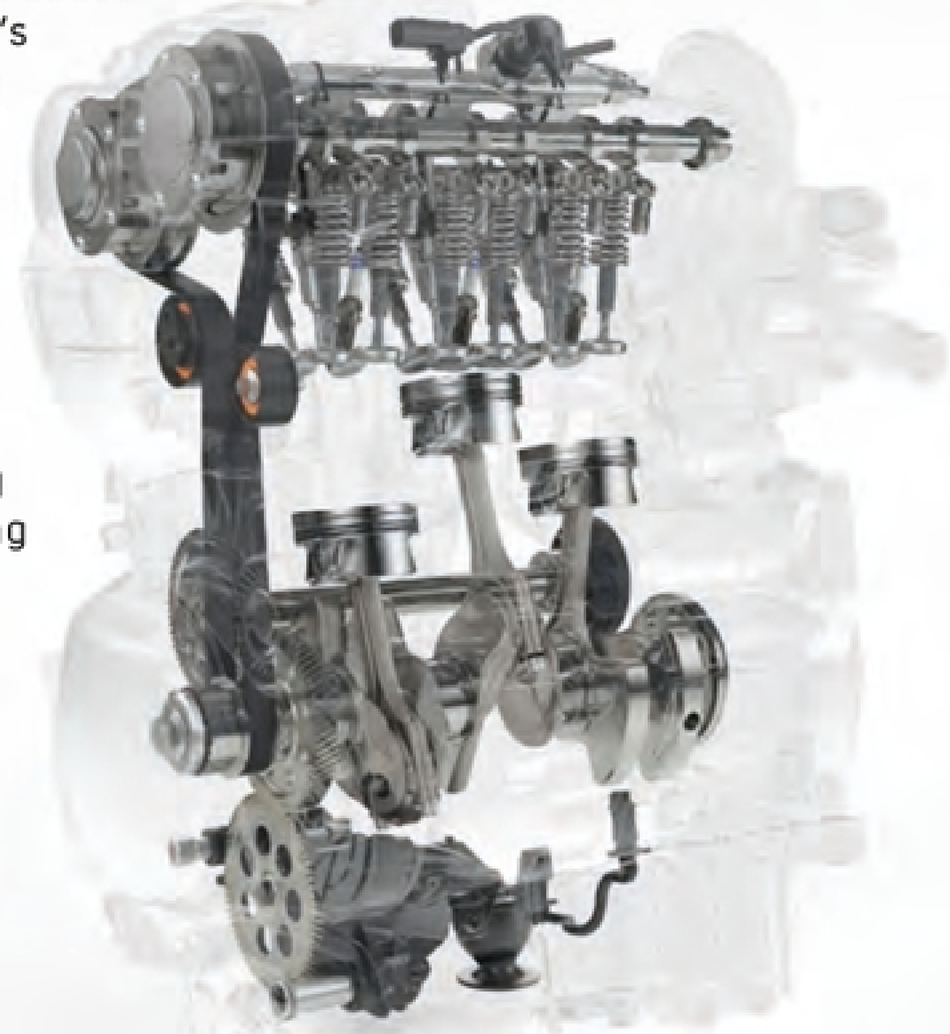
OEM VIEWPOINT: VOLVO

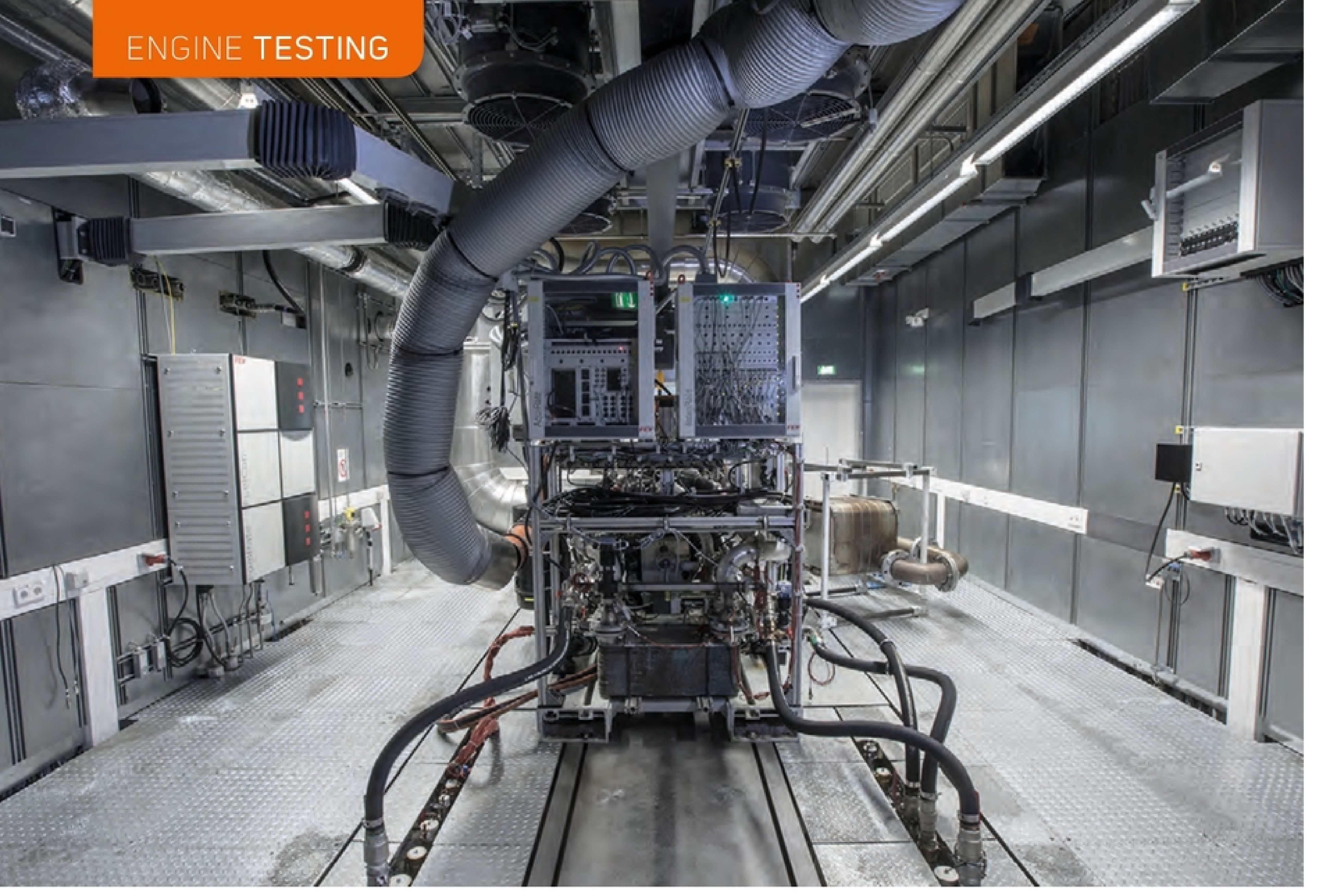
Fredrik Andersson, chief program engineer for powertrains at Volvo, says the Swedish company has considerably expanded its CAE capabilities over the past few years. He adds that digital methods were "fully used" in the development of Volvo's latest 1.5-liter, three-cylinder, direct-injection petrol engine.

"All testing related to engines is always very costly and it's very difficult to build engines at an early stage," he says. "However, we are still in the process of making sure our models are actually correct. So we're still doing the testing and we're comparing the results to what we get from our CAE models."

Refinement is still needed in modeling heat transfer, for example. "Our predictions are not yet 100% accurate, so that is an area where we need to bring more from experience back into the model," Andersson notes.

Simulation also struggles to predict failure modes arising from abuse and neglect. "That's very hard to do via CAE," Andersson explains. "And you probably still need to test the whole range of fuel that is available worldwide, making sure that everything works together with everything."





FEV's testing benches are connected to enable parallel testing of separate components, even when they are not mounted on the same virtual vehicle

"We have a dedicated test bench for batteries, another for e-motors and another for transmission or ICE testing. We can test all the components simultaneously, as if they were bolted together"

Stefan Trampert, group vice president of operations, FEV Group

testing provider Intertek. "A lot more computing hardware is needed to control and integrate the tests."

By emulating the whole vehicle around a powertrain, rig testing can spot the kind of system integration problems that have become an increasing risk. "We start to pick up a lot of early communications issues that would take time to flush out later on," Meek notes. "We're ahead of the game when it comes to debugging communications protocols that would keep vehicle engineers scratching their heads for ages."

As well as emulating parasitic loads and comms chatter, some test cells also fill in blanks by emulating missing parts of the powertrain. This allows physical testing to begin while some components are still on the drawing board.

"If you used traditional methods to test today's systems, you'd really struggle," says Meek. "We have powertrain rigs that include technology from dSpace, a German company that supplies emulation hardware and software. That enables us to run Simulink models of items that are missing from the critical hardware."

Virtual worlds

Another testing provider, FEV, has developed virtual shaft technology – a digital network that connects different test benches, allowing parallel tests of separate components as if they were mounted on the same virtual vehicle.

Stefan Trampert, group vice president of operations at FEV Group, explains: "We have a dedicated test bench for batteries, another for e-motors, and another for transmission or ICE testing. We can combine them with the virtual shaft controller in a real-time closed loop. We can test all the components simultaneously, as if they were bolted together."

This digital link enables integration testing of components that aren't yet adapted to each other. Any engine can be virtually attached to any transmission, for example.

Horiba Mira's Ratley says many OEMs are keen to employ these kinds of digital methods to unite different development silos: "The engine guys are doing their bit, the vehicle guys are doing their bit, the electric guys are doing theirs," he notes. "I think there will be more of a move toward whole powertrain, developing everything together on the same test bench."

Even as digital testing capabilities mature, Intertek's Meek predicts that physical testing will always remain vital. "You can only simulate what you know, so it's rare for simulations to throw up the unexpected," he observes. "It does happen – and will happen more as simulations get more complicated – but physical testing will always have the ability to surprise you."