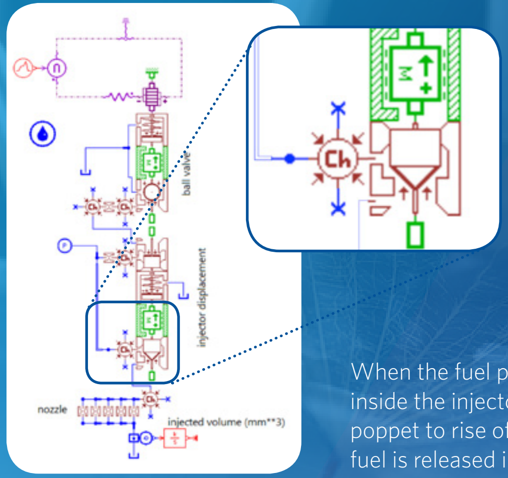
Design for real

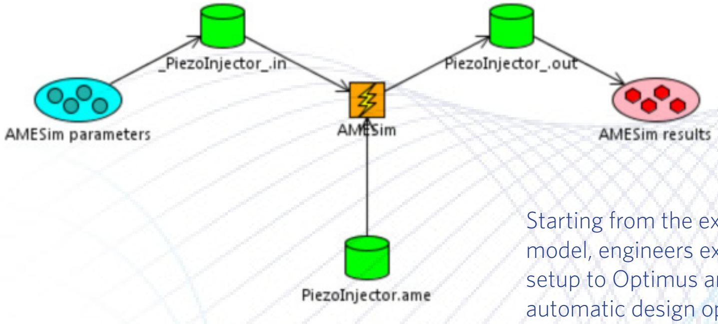
Optimus®

Case Study



When the fuel pressure builds up inside the injector, it causes the poppet to rise off its seat so that the fuel is released in the cylinder.

Optimizing fuel injector robustness through Optimus-driven system simulation



Starting from the existing AMESim injector model, engineers exported the parameter setup to Optimus and set up the software for automatic design optimization.

A leading automotive supplier used Optimus to successfully optimize the robustness of a new Diesel injector design. Engineers set up Optimus to orchestrate one-dimensional (1D) system simulations in LMS Imagine.Lab AMESim software. Optimus' fast design of experiment (DOE) and response surface modeling (RSM) identified the deterministic design optimum. Using the most suitable methods and algorithms, they optimized the robustness of the design with respect to injected fuel quantity, to make sure production variability has minimum impact on injector performance. The strategy is an important step in perfecting car engine performance, while delivering predictable operation and reducing fuel consumption and CO-emissions.

noesis
Empower your experience

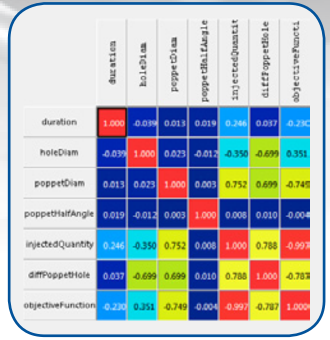
Quickly identifying the deterministic design optimum

The performance of injection systems inherently determines the operation and reliability of automotive engines. In a Diesel engine, the heat of compression is used to initiate ignition to burn the fuel that's injected into the combustion chamber. Premium electronic injection systems can sense engine revs, load, even boost and temperature to continuously alter the timing that matches the given situation.

Fuel injector engineers identified the input variables for the design optimization project at hand. They selected fuel injection duration and a number of mechanical injector parameters, including hole diameter, poppet diameter and poppet half angle. When the fuel pressure builds up inside the injector, it causes the poppet to rise off its seat so that the fuel is released in the cylinder. To meet specific design constraints, the input variations applied during optimization are restricted to stay between predefined boundaries.

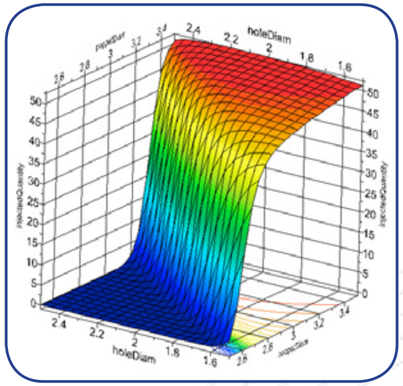
Engineers started from the existing AMESim injector model, and exported the parameter setup to Optimus in just a few clicks. They performed a nominal run to obtain the initial parameters configuration, which allows Optimus to select and execute a set of virtual experiments without human intervention. Following the Latin-Hypercube DOE method, Optimus automatically orchestrated the execution of 200 AMESim experiments. Design alternatives exhibiting too little difference between hole and poppet diameter resulted in zero injected quantity, defining the lower constraint for optimization. A Neural Network RSM is generated as a meta-model that visually reflects the injector behavior. Engineers use this interpolation technique to fully and rapidly understand the design space, revealing much more insight into product performance than can be possibly gathered manually.

A self-adaptive algorithm was used to run evolutionary optimization directly on the RSM. Using this method, the Optimus software managed to execute the hundreds of experiments in a matter of seconds. The optimal point identified served as the starting point for gradient-based optimization involving real full-system simulations in AMESim. The NLPQL algorithm ensures fast and accurate convergence when being close to the optimum. The algorithm overcomes any RSM inaccuracies and traces the deterministic injector design optimum using only 42 experiments.



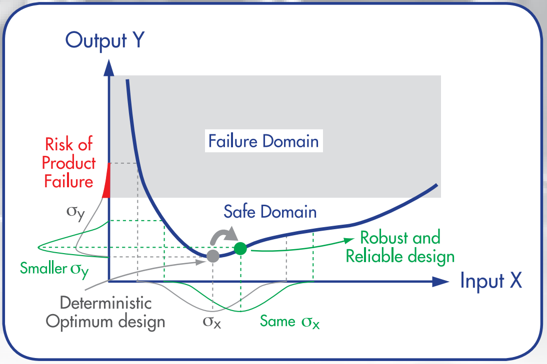
	duration	holeDiam	poppetDiam	poppetHalfAngle	injectedQuantit	diffPoppetHole	objectiveFuncti
duration	1.000	-0.039	0.013	0.019	0.246	0.037	-0.23
holeDiam	-0.039	1.000	0.023	-0.012	-0.350	-0.699	0.351
poppetDiam	0.013	0.023	1.000	0.003	0.752	0.699	-0.74
poppetHalfAngle	0.019	-0.012	0.003	1.000	0.008	0.010	-0.00
injectedQuantity	0.246	-0.350	0.752	0.008	1.000	0.788	-0.99
diffPoppetHole	0.037	-0.699	0.699	0.010	0.788	1.000	-0.78
objectiveFunction	-0.230	0.351	-0.749	-0.004	-0.997	-0.787	1.00

Optimus performed the Latin-Hypercube DOE method, illustrating that the poppet diameter has most influence on the injected fuel quantity.

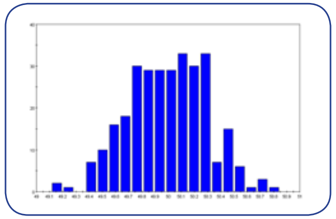


A Neural Network RSM clearly indicates the working and malfunctioning states of the fuel injector. Due to the steep gradient that separates the low and high regions, this is leading the designer to a typical robustness problem.

Improving the robustness of the deterministic design optimum



The targeted optimum is robust to small design changes, so that small perturbations of design parameters don't pull injector performance into the failure domain (see red area).



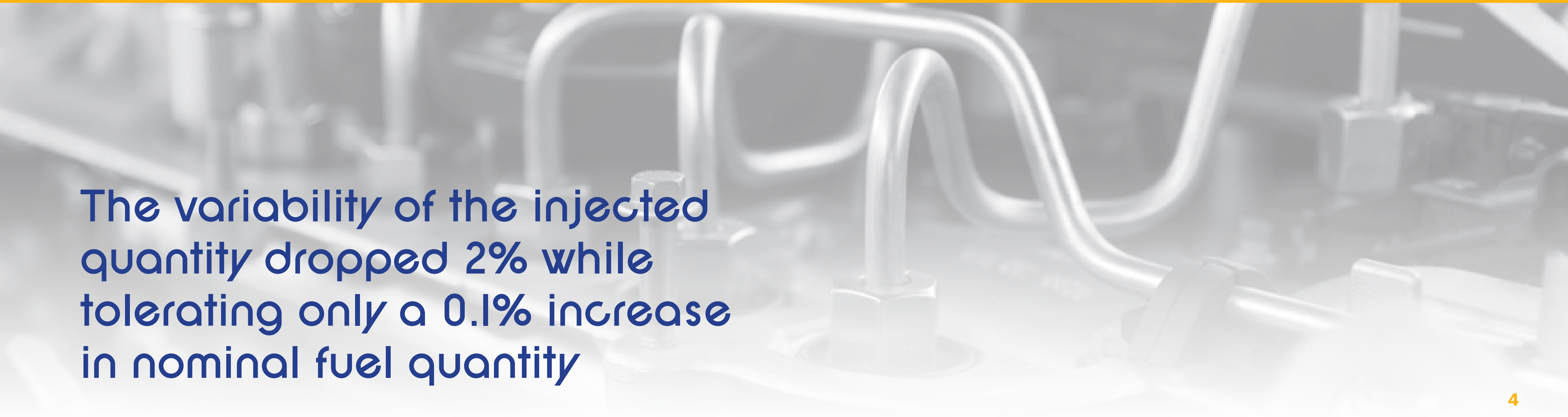
The innovative first order second moment (FOSM) method is much faster than the Monte Carlo method in determining the standard deviation of the injected fuel quantity.

In the real world, design input variables may slightly shift as a result of manufacturing tolerances and varying geometric properties. Although the accumulation of these variations might seem negligible, it's sometimes the source of unexpected and unintended product behavior. This means that a design that successfully passed the deterministic optimization stage and that is manufactured within specification, may fail.

Optimus performed the Latin-Hypercube DOE method, illustrating that the poppet diameter has most influence on the injected fuel quantity.
As Optimus ran evolutionary optimization directly on the RSM, the software managed the execution of the hundreds of experiments in a matter of seconds.
The strategy applied to maximize design robustness focused on minimizing the variability of the injected fuel quantity, while keeping the nominal value of this output variable on target. Monte Carlo sampling is a proven process to predict the standard deviation of the injected quantity, based on all specified input variable distributions. The method required 300 real AMESim system simulations, ultimately resulting in a standard deviation of approximately 0.30. A much faster alternative is the innovative First Order Second Moment (FOSM) method, which only needed 5 such real experiments to come to the same conclusion. FOSM accurately estimates the output variability based on input variability and first-order derivates of the system behavior.

The innovative first order second moment (FOSM) method is much faster than the Monte Carlo method in determining the standard deviation of the injected fuel quantity.

Thanks to robustness optimization, the variability of the injected quantity dropped 2% while tolerating only a 0.1% increase in nominal fuel quantity. The robust design optimum considerably reduces the probability of producing Diesel fuel injectors that inject out-of-spec fuel quantities. Developing Diesel injectors that guarantee precise injected fuel quantities help reconcile high engine performance with low fuel consumptions. In this way, Optimus supports the drive for designing cleaner and more environmental friendly fuel management systems.



The variability of the injected quantity dropped 2% while tolerating only a 0.1% increase in nominal fuel quantity

Project results - Return on investment

Process integration

- Straightforward export of the model parameter setup and the boundaries design task from AMESim to Optimus -> A few clicks to transfer critical information to Optimus
- Automatic driving of AMESim experiment simulations through Optimus -> Capturing the optimization process in order to orchestrate multiple simulation software applications in an automated fashion

Design optimization

- Tracing the design's deterministic optimum:
  - Latin-Hypercube DOE method -> Finding the most contributing factors
  - Global design optimization directly on neural network response surface -> Huge time savings because hundreds of experiments can be executed in seconds
  - Evolutionary design optimization directly on RSM to identify the design's optimal performance point -> Achieve fast and accurate convergence when being close to the optimum
- Robustness optimization
  - Assess the robustness of the deterministic optimum
  - Optimize the robustness using the First Order Second Moment (FOSM) method -> Huge time savings because only 5 experiments needed instead of 300 with the standard Monte Carlo method
  - Impressive results -> The variability of the injected quantity dropped 2% while tolerating only a 0.1% increase in nominal fuel quantity

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