CLEANING UP

Magneti Marelli reduces engine emissions and improves fuel efficiency by modeling the complete engine cycle.

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In 2009, the European Union ratified the Renewable Energy Directive (RED), which requires that 10 percent of motor vehicles run on renewable energy by 2020. Biofuels consisting of ethanol or an ethanol blend are one of the most practical renewal fuels for motor vehicles. In Brazil, the use of biofuel is already common; but most current vehicle engines do not deliver optimal performance, fuel economy or exhaust emissions with biofuels.

Magneti Marelli, a leading supplier of automotive components and systems around the world, is working to develop fuel injection systems that will improve the performance of existing engines running on biofuels. An Italian–Brazilian Magneti Marelli team is working with the support of ANSYS to use 3-D computational fluid dynamics (CFD) to simulate the complex operation of an internal combustion engine (ICE) to evaluate many virtual prototypes in the time that would be required to build a single physical prototype.

ADVANCED CFD TECHNOLOGY FOR PORT FUEL INJECTION ENGINES USING BIOFUELS

Simulation of an internal combustion engine analysis is time consuming and complex, and obtaining accurate results requires an appropriate simulation tool and engineering expertise. Increasingly complex control systems make it more difficult than ever to predict in-cylinder mixture formation, combustion and emission in these engines. Acceptable resolution of the engine flow and combustion requires large hybrid meshes for each configuration with associated computing overheads. Once the analysis has been set up, it takes many hours or days of computing to solve the model and evaluate the results. The results include large data sets that require considerable time and effort to evaluate and then generate useful information that can be fed back to the design process. In existing engines, the goal is to improve engine performance by optimizing the geometry and operating parameters of the air intake manifold and injectors. This requires comparing the analysis results of many different parametric configurations.

FUEL INJECTION SPRAY MODELING

Magneti Marelli engineers have overcome these challenges by combining automatic remeshing and parametric analysis methods using ANSYS CFX with a moving mesh to simulate the different states of the engine cycle, including fuel injection, spray formation and particle breakup. The most important part of engine simulation is modeling the fuel injection process. This requires accurately modeling the flow in the nozzle, including cavitation, spray motion, breakup and evaporation, and film formation and evaporation. The spray algorithm parameters are tuned with experimental data to obtain satisfactory quantitative prediction, especially when defining a new design or different operating conditions. In spray simulation, the most important characteristics are spray penetration depth and spray angle. The engineering team defines spray penetration depth as penetration depth in a specified direction. The spray cone angle is the radial expansion of the spray, measured at the end of the injection cycle. Predefined post-processing routines allow engineers to make decisions while the simulation is running.

Engineers use fluid dynamics to tune several aspects of fuel injection — the design of the injector, the spray targeting and the spray–wall interaction. This process is important during combustion mixture formation because wall spray growth and wall film dynamics influence combustion efficiency and pollutant formation, especially in port fuel injection engines using biofuel. Fuel deposited on the intake wall creates engine control difficulties because not all the injected fuel moves immediately into the combustion chamber. Fuel sediment is progressively transported to the combustion chamber, making it difficult to control the amount of fuel that is actually injected into the chamber, resulting in reduced engine performance and increased fuel consumption and emissions. Leading-edge fuel injectors spray fuel directly on a specific zone on the intake valve and its valve rod to reduce liquid film on the intake walls.

Simulation using software from ANSYS can accurately predict mixture formation, breakup phenomena, evaporation, and droplet–droplet and wall–droplet interactions, as well as enable the comparison of alternative engine designs with respect to all these different factors. The workflow within the ANSYS Workbench environment allows Magneti Marelli engineers to automatically investigate multiple parametric design variations. The company uses design of experiments (DOE) to reduce the number of simulation runs needed to explore the complete design space. DOE examines first-order, second-order and multple-factor effects simultaneously with relatively few simulation runs. It is possible to optimize the design with far fewer simulation runs — and with a higher level of certainty and in less time than the traditional one-factor-at-a-time approach.

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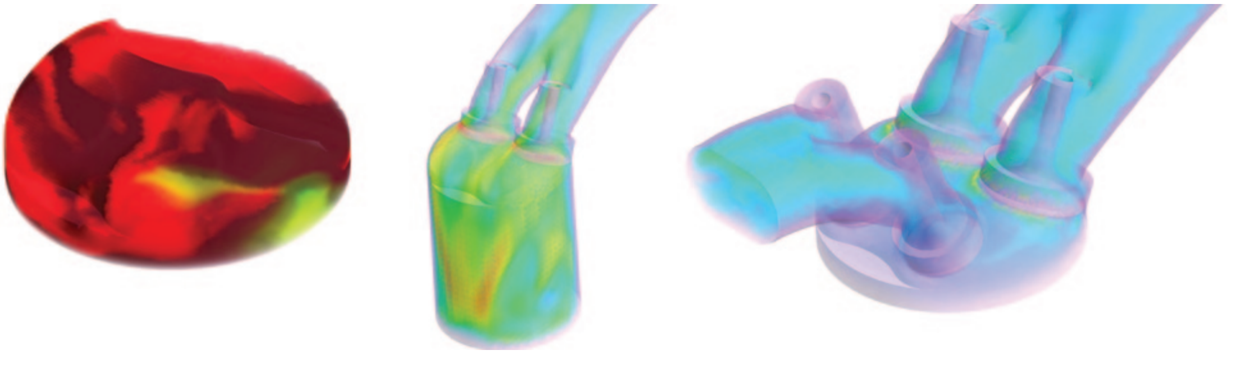
High turbulence levels facilitate fine mixing and atomization of fuel. One of the most valuable methods for evaluating the turbulence levels is the tumble



Fluid dynamics can be used to model fuel injection — the most important element of engine modeling. Images illustrate simulation at different stages of the engine evolution: exhaust and intake valves both open (left); intake valve open (center); both exhaust and intake valves closed (right) with combustion.

index approach. The index quantifies the relative amount of tumbling or swirling flow in the engine. The tumble index is most important at low engine rpm speed, at which it can be difficult to ensure complete combustion and subsequent rapid flame propagation. The tumble index can also be used to confirm that turbulence levels at the end of the compression stage are adequate for combustion. Finally, the index provides an indirect indication of the injector positioning.

INTEGRATED ENGINE MODELING

To understand the impact of flow on engine performance, engineers couple CFX with GT-Power engine simulation software from Gamma Technologies. GT-Power predicts engine variables such as volumetric efficiency, torque and power based on combustion chamber architecture and various processes such as ignition, mixture formation and combustion. Fluid flow–driven predictions of the engine's maximum power correlate very closely to experimental measurements.

In addition, engineering staff use Workbench fluid–structure interaction (FSI) capabilities to automate the process of transferring temperature information from the fluids simulation into thermal analysis to determine the temperature distribution on a structure. The temperatures are, in turn, used in thermal analysis to identify thermal loads. These loads are applied to static structural analysis to ascertain stresses and deformations. Finally, prestressed modal analysis calculates mode shapes and frequencies of the fuel injector system components. Magneti Marelli also uses ANSYS electromagnetic simulation software to define the magnetic injector circuit; the company is beginning to use the tool for hybrid engine components.

Reliable simulation from ANSYS is helping Magneti Marelli to reduce the time required to develop innovative engine components that improve fuel efficiency and reduce emissions.

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Reference

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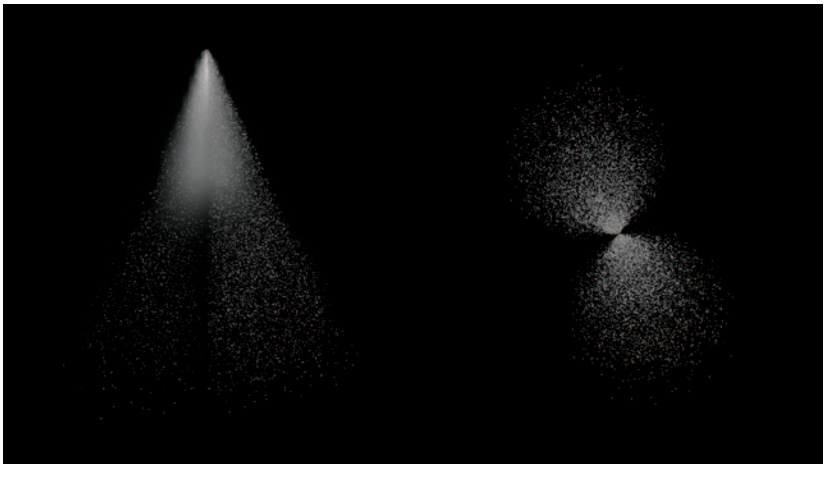
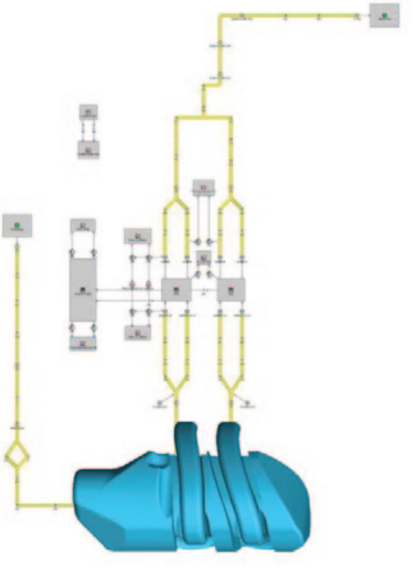


ANSYS CFX spray pattern evolution: front view (left) and top view (right)



Coupling fluid dynamics to GT-Power engine simulation provides accurate maximum power predictions.