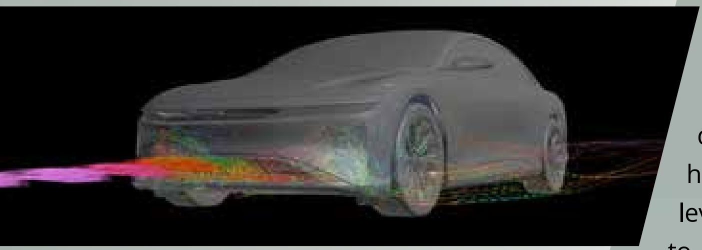
Electrifying VEHICLE

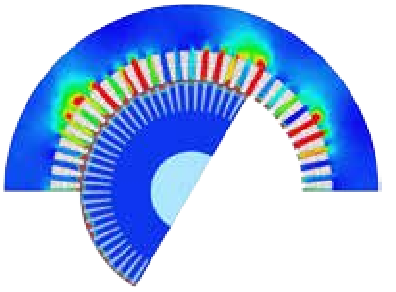


^ ANSYS Fluent was used to optimize vehicle aerodynamics.

Lucid's new luxury-class electric vehicle (EV) is designed to compete with the leaders in the high-end EV market. Lucid engineers extensively leveraged ANSYS multiphysics simulation software to improve the operation of most of the vehicle's subsystems by accounting for a wide range of performance factors to create a digital prototype. The use of a consolidated engineering simulation platform was critical to facilitate cooperation across the many different engineering disciplines on the design team, resulting in a wide range of performance improvements — both for the car and the engineering team.

By **Alberto Bassanese**, Manager, Multiphysics and Optimization, Lucid Motors, Menlo Park, USA

In developing a new high-end EV from scratch in just a couple of years, Lucid Motors faced enormous technical challenges, a complex regulatory environment and competitors with up to a century head start. However, being a new entrant also gave Lucid some key advantages as it was able to adopt best-in-class practices without being hindered by legacy methods. The company pioneered a unique approach, housing the teams working on each discipline involved in electric vehicle design — electromagnetics, thermal, structural, aerodynamic, etc. — in a single room to encourage collaboration from the beginning of the design process. Lucid further promoted teamwork and expedited the engineering process by equipping most of the engineering team with a common simulation platform: ANSYS multiphysics simulation software integrated in the ANSYS Workbench environment, which enables simultaneous optimization of all the different subsystems of the vehicle. This approach is making it possible for Lucid to address customer needs, solve engineering problems, optimize subsystems and components, meet regulatory requirements, and bring a world-class vehicle to market in a fraction of the time required by a conventional approach in which engineers work with different simulation tools in different and segregated disciplines.

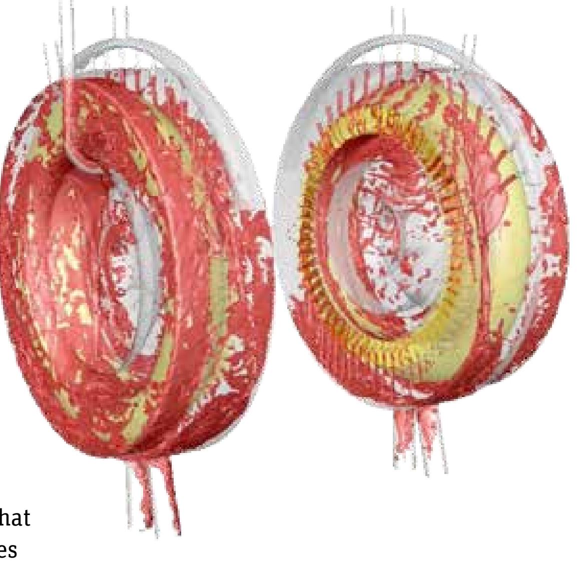


^ ANSYS Maxwell core losses were mapped into ANSYS Fluent to improve the motor design.

"ANSYS multiphysics simulation platform helps Lucid to address customer needs, solve engineering problems, optimize subsystems and components, meet regulatory requirements, and bring a world-class vehicle to market."

REDUCE DRAG

Lucid aerodynamics engineers used ANSYS Fluent — the key computational fluid dynamics (CFD) software within the ANSYS simulation platform — including the ANSYS Adjoint Solver to develop a vehicle body, and a new air intake and duct system to minimize the drag coefficient. The engineers leveraged ANSYS DesignXplorer, the advanced parametric analysis tool that is part of the integrated ANSYS platform, to drive the CFD software to simulate a broad range of vehicle shapes to determine aerodynamic performance. These simulations provided detailed guidance about the specific effects on drag of numerous shape parameters in the form of response surfaces, sensitivity charts, Pareto plots and trade-off plots. Armed with this information, stylists and aerodynamicists identified the vehicle shapes that yield the least possible drag while adhering to styling themes and other constraints.



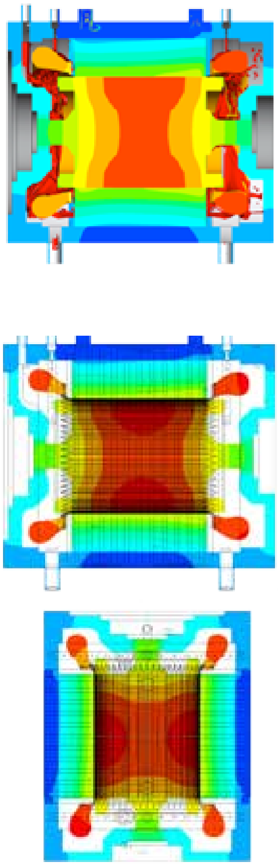
^ ANSYS Fluent multiphase volume of fluid oil-cooling transient simulation

OPTIMIZE THE MOTOR

The Lucid team utilized ANSYS Maxwell — the electromagnetic field simulation software within the ANSYS platform — for the design and analysis of electric motors, actuators, sensors, transformers, and other electromagnetic and electromechanical devices. Maxwell determined electromagnetic losses in the motor and, through ANSYS Workbench — the host environment and data exchange backbone of the ANSYS simulation platform — integrated these losses with an ANSYS Fluent simulation to determine temperatures throughout the motor. Two separate systems cool the motor. The first is a water jacket molded into the motor case. In the second system, transmission oil is injected into the hottest areas — the end windings and rotor. Engineers used two coupled models, an oil model and a water model, to simulate these two cooling systems. Multiphase transient analysis with the volume of fluids model was used to solve the domain cooled by oil in the oil model. This model produced heat transfer coefficients of the surface wetted by the oil and the local oil temperatures. Engineers modeled the water cooling system with a water model in ANSYS Fluent that used steady-state conjugate heat transfer to predict temperatures of the solid components of the motor.

The temperatures predicted by the water model were then used with the oil model and the simulation was run again. The resulting heat transfer values were mapped to the water model. This iterative process continued until the two models converged on the same temperatures. After the models converged, ANSYS Workbench enabled the engineers to easily incorporate the temperatures of the solid objects into an ANSYS Mechanical structural model to calculate thermal stresses and, finally, to perform fatigue analysis to ensure that the motor will deliver its promised life. Using simulation, Lucid engineers increased the power density and energy efficiency of the motor by 12 percent. The temperature predictions matched physical measurements within a 3 percent margin of error.

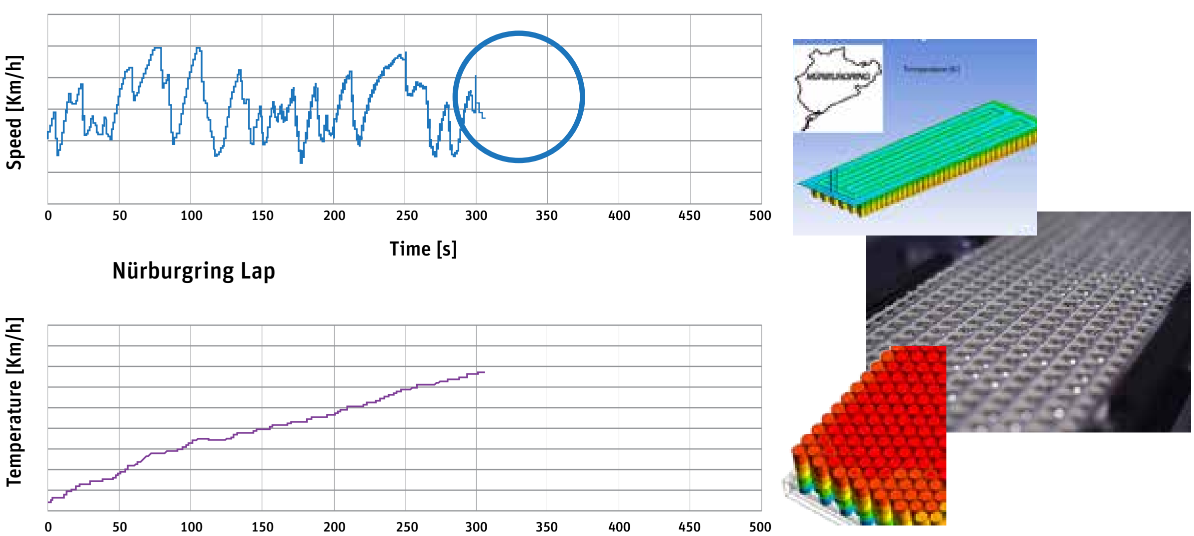
Another important aspect of motor design was to create the rotor flux map, which is embedded into the control algorithm and used to minimize motor losses under different operating conditions. Engineers employed ANSYS Maxwell and the ANSYS Electric Machine Design Toolkit, which computes torque speed curves, efficiency maps and other performance curves for electrical machines. They varied parameters such as frequency, slip and input current to calculate the rotor flux map and embedded it into the control algorithm as a lookup table. The fluxes are translated to pulse width modulation (PWM) voltages during operation of the vehicle. Compared to the normal approach of generating the rotor flux map with experiments on a dynamometer, this approach cut calibration dynamometer time by 80 percent.



^ **ANSYS Fluent conjugate heat transfer simulation temperature contour plot**

COOL INVERTERS

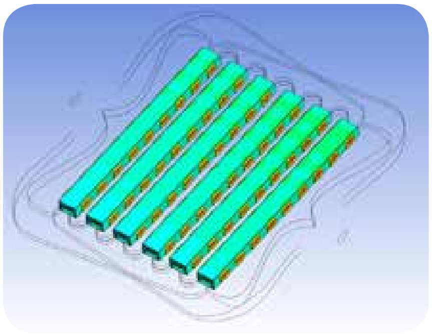
The inverters convert low voltage DC to high voltage AC to power the vehicle; this generates huge amounts of heat that needs to be removed to avoid exceeding the



^ **Engineers modeled the transient thermal performance of the battery using ANSYS Fluent and ANSYS Simplorer over a lap of the Nürburgring Grand Prix race track.**

> “Simulation enabled Lucid engineers to increase the power density and energy efficiency of the motor by 12 percent.”

junction temperatures of the inverters and destroying them. Engineers created a fully parameterized model of the inverters and used modeFRONTIER, a third-party optimization software that interfaces with the flexible ANSYS platform, to optimize key design parameters such as the fins’ topology and the cross-sections of the channels that move water through the inverter housing. They then leveraged the ANSYS Adjoint Solver to optimize by mesh morphing the shape of the manifolds connecting with the upstream and downstream piping. This process reduced peak temperatures by 18 C while maintaining the temperature of the different power transistors within 4 C of each other. At the same time, the pressure drop in the cooling system was reduced by one-third, and the volume and weight of the inverter housing was reduced by 15 percent.



^ ANSYS CFD shows that inverter temperature distribution is even across different IGBTs.

INCREASE BATTERY LIFE

Lucid engineers also created electrical and thermal models of the battery pack using ANSYS Mechanical — the structural mechanics solver in the ANSYS simulation platform — and ANSYS Fluent coupled within ANSYS Workbench to simulate electrode degradation during charging and discharging of the battery. By understanding the potential conditions that could degrade the electrodes during different drive cycles, engineers substantially increased the life of the battery. The simulation results were condensed into reduced-order models that are used to simulate battery performance under drive cycles, such as a lap at the Nürburgring race track.

Powering Lucid Motors with ANSYS
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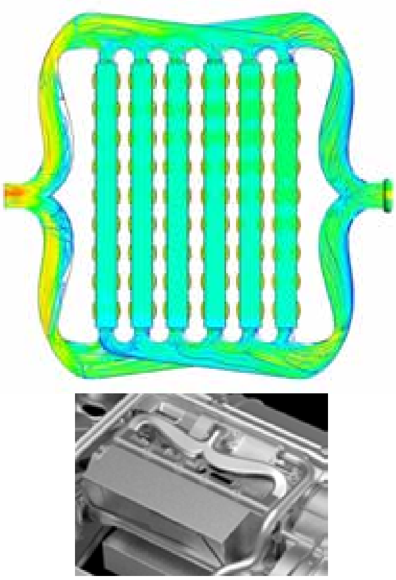
Using a sculpted battery pack allowed for a roomier interior.

> *"Lucid's pervasive use of simulation throughout the design cycle along with their dedication to upfront simulation has positioned the company for success."*



Simulating the inverter cooling system with ANSYS CFD

Simulation enables engineers to improve key vehicle attributes. For example, the conventional approach is to configure the batteries in a flat panel stacked under the car. This increases torsional stiffness and lowers the center of gravity, but it has a negative impact on legroom. Lucid engineers used simulation to reduce the size of the front inverter-motor and heating ventilation air conditioning (HVAC) units, freeing up space so that battery pack height could be increased in this area. This made it possible to sculpt the battery pack to reduce its profile beneath the passenger cabin, providing more legroom inside the cabin for greater passenger comfort.

Lucid's pervasive use of simulation with the ANSYS common simulation platform throughout the design cycle, along with their dedication to upfront simulation, has positioned the company for success against established EV competitors. Engineers from different disciplines employ ANSYS tools within the ANSYS simulation platform to perform digital exploration that takes the complex, multiphysics nature of the design into account. As an example of the results, the exterior of the new Lucid Air is only a little larger than a Mercedes E-class vehicle, yet the new vehicle has the interior space of a larger Mercedes S-Class. Lucid is taking reservations for the Lucid Air, which is scheduled to go into production in a new $700 million factory in Arizona during 2019, positioning the company to deliver a best-in-class automobile in a fraction of the time required by its competitors.

Advanced Design of Electric Machines Using the ANSYS Electric Machine Design Toolkit
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