Increasing passenger comfort and energy efficiency requires stringent development processes for the thermal management of an electric vehicle. Using the Thermal Lab tool, AVL has set up a smart development method for the analysis of the air conditioning system, which can also be applied to autonomous people movers and trucks.

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A sound understanding of thermodynamics is the basis for the successful development of vehicles with an efficient and consistent interaction of all systems and components. An innovative thermal management strategy for a Battery Electric Vehicle (BEV) balances the energy demand and extends the lifetime of the car components – particularly of the battery – at optimal levels of efficiency [1, 2]. At the same time, the best possible comfort for the occupants is ensured. At AVL, this smart approach is called Vehicle Thermal Management Strategy (VTMS).

TODAY'S EFFICIENCY CHALLENGES

Are efficiency and comfort conflicting objectives? Under extreme conditions, the range of a BEV is reduced by up to 50 % as soon as the system of Heating, Ventilation and Air Conditioning (HVAC) in the passenger compartment is activated. Eliminating the significant waste heat from the combustion engine in BEVs poses the challenge of handling the energy as efficiently as possible so that both the passenger compartment and the components can be kept at the right temperature with minimum energy demand.

Smart Approach for the Thermal Management of Electric Vehicles

Therefore, a VTMS can only be “smart” on the vehicle level (not on the component level alone), and only by using predictive controls, optimized passenger compartment models and cooling strategies as well as heat pump function and insulation of the passenger compartment.

How can this complexity in thermal management be mastered? Foremost through digitization: Within the next years, the aim is to make the steps from physical vehicle validation to pilot series production superfluous. This is because digital twins offer more flexibility. In-house tool chains, 3-D CFD analyses, **FIGURE 1**, and development environments from AVL enable the next technological leap to be completed reliably and quickly. As a consequence, the complexity is reduced. If this is taken a step further, it can be seen that the networking of co-simulations with testing can meet the market’s requirements and how the virtual prototype is integrated into the development process.

REDUCTION OF EFFORT

The automotive industry, and thus AVL, aims to reduce the simulation effort for modeling electrified vehicle drives by up to 40 %. Overall, AVL expects an

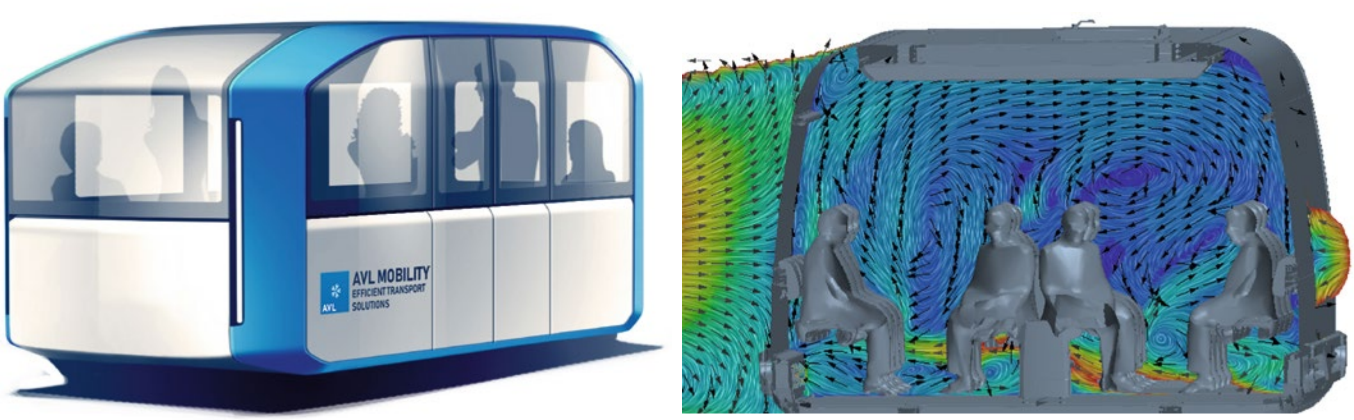

FIGURE 1 Air circulation in the passenger compartment of a people mover – view of the autonomous vehicle (left) and CFD analysis (right) (© AVL)

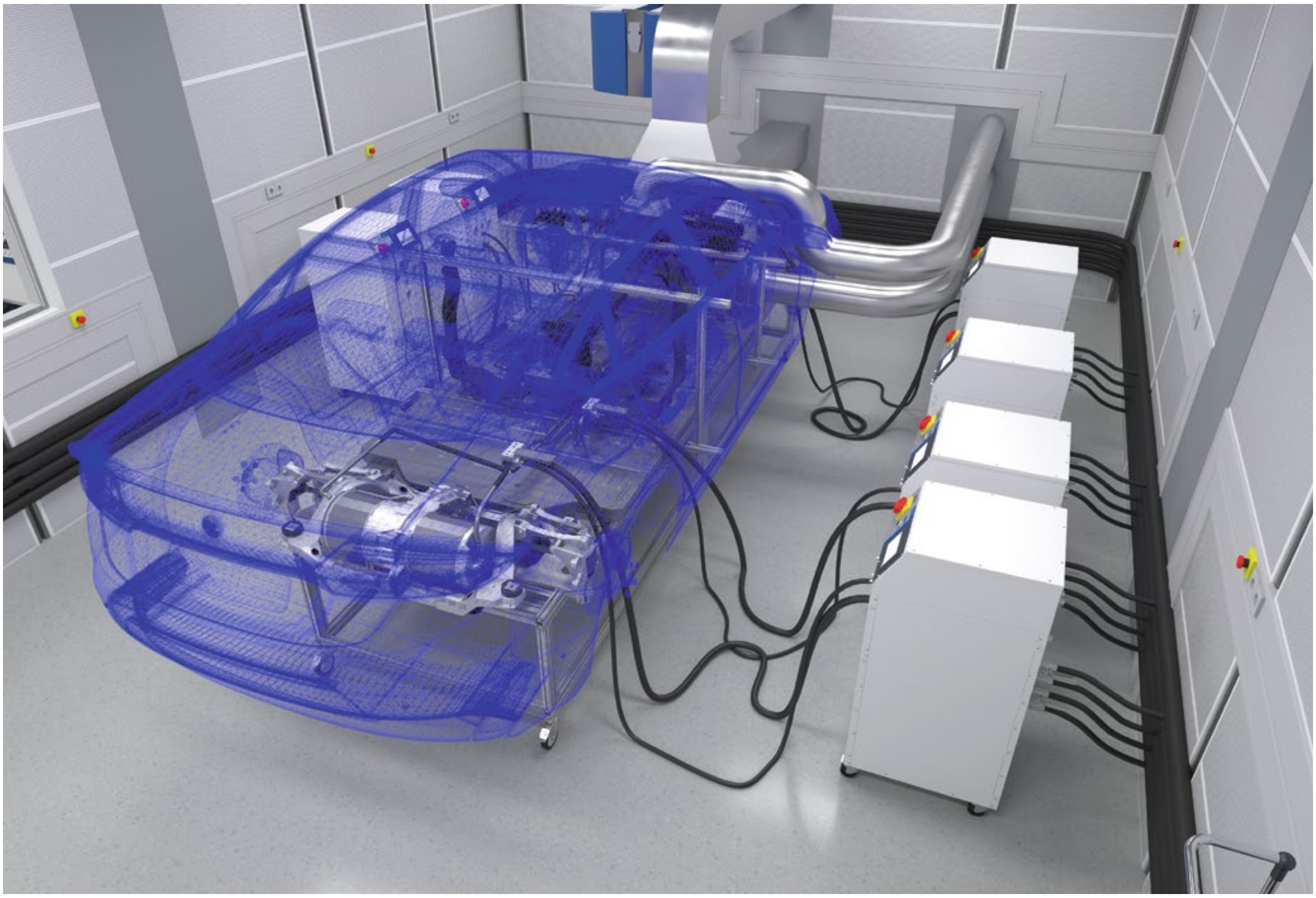

FIGURE 2 The Thermal Lab development environment is used to optimize the performance and calibration of the passenger compartment and drive components (© AVL)

increase in development efficiency of more than 25 % and an increase in the accuracy of model prediction by 30 %. For all xEV configurations, a holistic simulation environment is developed in order to take into account key performance indicators of thermal management and external effects on vehicle level. The submodels – electrical components, inverters, electric machines, batteries, coolant and refrigerant circuits, passenger compartment models and control actuators – are integrated and interconnected via the AVL Model.Connect co-simulation platform. Subsequently, thermal management experts set up example coolant and refrigerant circuits and an element pool for the straightforward exchange of circuit components. On the way to achieving automation, generic test cases are then developed based on vehicle and powertrain targets, thus increasing standardization.

The submodels are specified to such an extent that a continuous adjustment and switching of the parameters and a holistic view of its effects are possible on the vehicle level. The knowledge acquired is used in the development of predictive models. The model is enhanced with additional target values, such as economy (cost-based solutions) and environmental protection (fuel-consumption-based solutions). In the end, this process will allow a transition from validation on component to system level – digitally. There is no one-fits-all solution, but with proven and established methods it is possible to find the right system design for each vehicle architecture and each characteristic, no matter if the focus is on high performance or on high comfort.

HVAC SYSTEMS AND THE CORONAVIRUS PANDEMIC

Alongside the requirements for temperature distribution, de-fogged windscreens and air draft, there is currently another subject of interest. In the wake of the Coronavirus pandemic, the quality of air inside the passenger compartment is often discussed at present, particularly the elimination of viruses. AVL's specialists have been occupied with the latter topic for many years. In this context, new partnerships are currently being established with companies that specialize in combatting viruses with ultraviolet (UV-C) light. This could also lead to smart applications in the passenger car segment. AVL helps to integrate these and similar technologies into the vehicle as efficiently as possible in order to ensure the best possible protection for the occupants.

Using 3-D CFD analyses, AVL can also simulate air circulation in order to design targeted air flows and to filter and extract the used air, if necessary. The team relies on tried and proven simulation techniques used in passenger cars and in the field of autonomous people movers, **FIGURE 1**, trains, buses and trucks.

OPTIMIZED PROCESSES DUE TO A MODEL-BASED DEVELOPMENT ENVIRONMENT

The logical consequence of a front-loading approach using simulation also requires hardware tests to provide accurate statements regarding performance and calibration of the thermal management system at the earliest possible development stage. In this context, AVL Thermal Lab is a novel development environment, **FIGURE 2**, and offers the possibility to optimize the energy efficiency of vehicles by investigating a range of HVAC systems without the need for expensive prototypes. A model-based Hardware-in-the-Loop (HiL) approach enables tests to be transferred from the road to the rig. This makes it possible to test the entire HVAC system (all coolant circuits including air conditioning of the passenger compartment) under realistic driving cycles and environmental conditions. The development environment thus closes the gap between steady state system tests, HiL test beds and vehicle tests using prototypes, which reduces both development times and costs while minimizing development risks.

The Thermal Lab has been specifically designed for testing and calibrating the HVAC system of vehicles. All coolant circuits including the refrigeration circuit can be tested under realistic dynamic conditions (for different driving cycles such as WLTP, RDE, etc. and for a range of environmental conditions). The unit under test is mounted in its geometrically correct orientation with real pumps, valves and pipework, etc. The powertrain components such as battery, electric motor and inverter are emulated using highly dynamic conditioning units employing simulation models. The CAE models from the virtual development stages are thus used in the hardware tests, which increases the quality of the results and facilitates networked development.

The highly dynamic conditioning units (thermal emulators) are able to run very high temperature gradients, both for the emulation of a heat sink (such as the main water cooler) or a heat source such as the battery. Thanks to the flexible and modular approach, it is possible to test a wide range of systems and architectures for many different powertrain types over a very large range of temperatures. Tests that are typically done using the Thermal Lab are the filling and venting of coolant circuits, level measurement and determination of oil concentration in refrigerant circuits, performance testing and the calibration of the entire VTMS, and the determination and optimization of the thermal management system energy efficiency.

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