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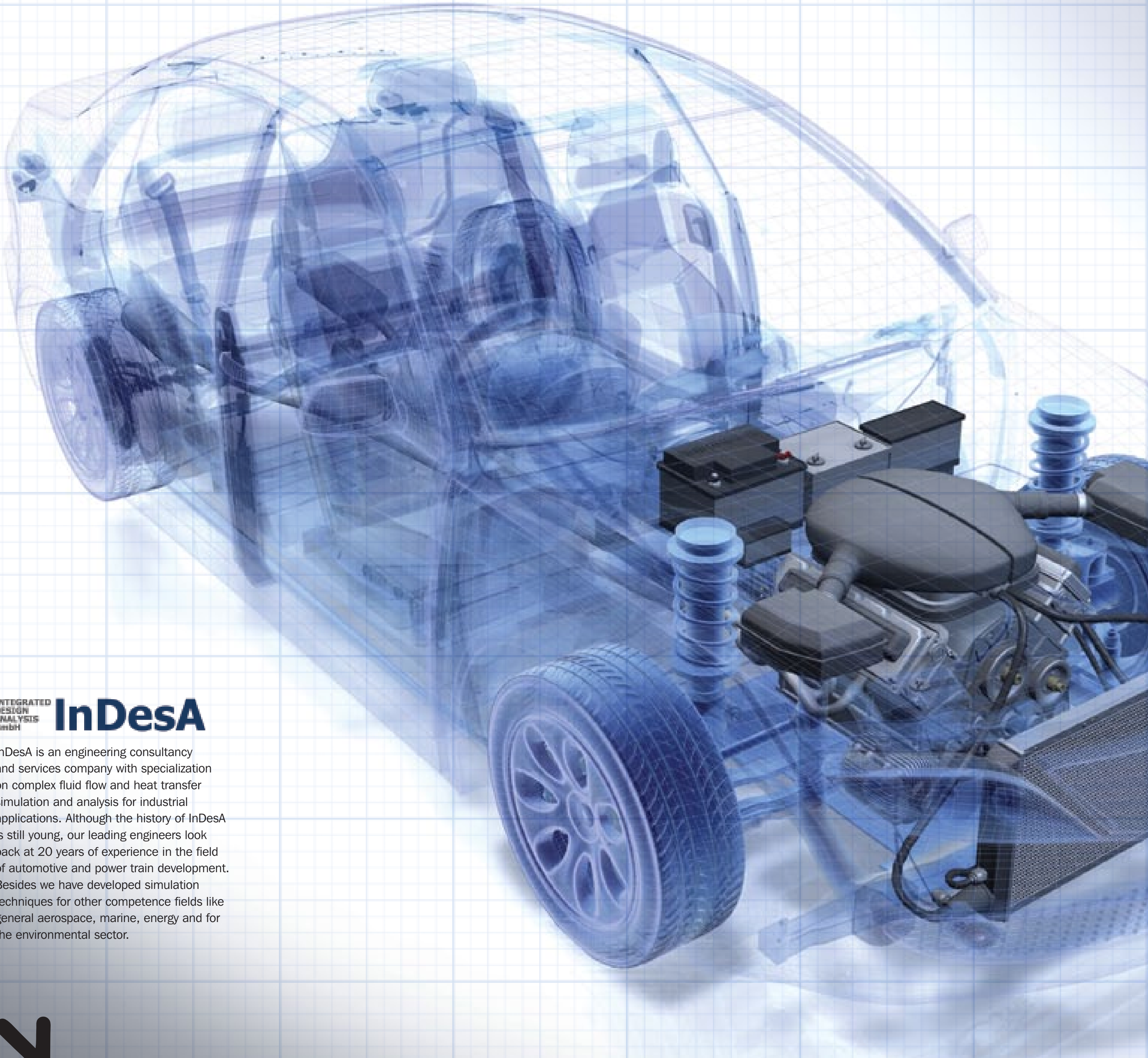
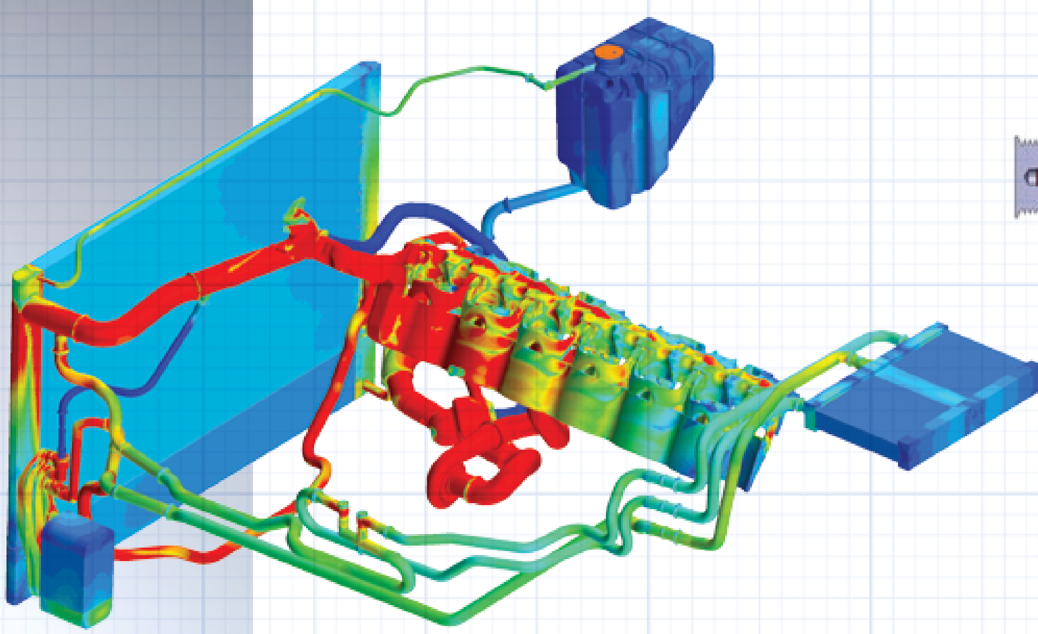


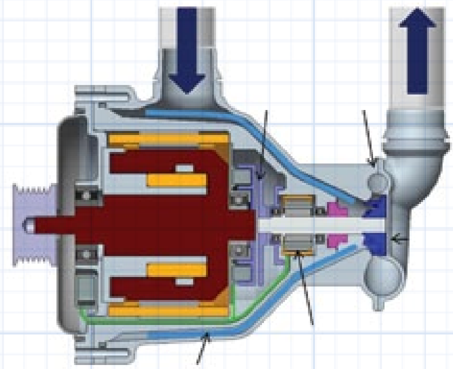
INTEGRATED DESIGN ANALYSIS GmbH InDesA

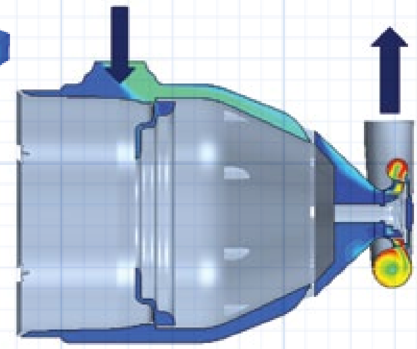
InDesA is an engineering consultancy and services company with specialization on complex fluid flow and heat transfer simulation and analysis for industrial applications. Although the history of InDesA is still young, our leading engineers look back at 20 years of experience in the field of automotive and power train development. Besides we have developed simulation techniques for other competence fields like general aerospace, marine, energy and for the environmental sector.

InDesA Virtual Test Facility Center

Dr. Gerald Seider - InDesA







ABOVE
Flow through a complete coolant circuit

TOP Combined generator/coolant pump from IGEL AG
ABOVE Flow through the combined generator / coolant pump

The demands of modern vehicle design require that many components be designed and tested simultaneously. Almost all of these components need to be specifically optimized for their role in the particular vehicle design, and many utilize innovative technology. With little time for construction and testing of physical prototypes, along with the need for fast adaption of components due to changing module and system requirements, there is a compelling case for the introduction of more virtual testing at component level in vehicle development programs.

The need for simulation in the “V-Model” Development Process
The development of any vehicle takes several years, incorporating many thousands of hours of design and testing. To manage this process, most manufacturers of vehicles such as cars, buses and trucks have adopted the so-called “V-Model” development process.

The V-model process starts with the design of the overall vehicle system. Once the system has been fully specified, the vehicle is divided into a series of modules. Each of these modules is essentially considered as a separate sub-system for design purposes (although in practice the many interactions between different modules must be accounted for). The final and most detailed part of the design stage involves the design of the individual components that make up the modules such as heat exchangers, pumps and turbochargers. Having reached the bottom of the “V”, the verification branch becomes active and the individual stages are subjected to testing, starting with component level verification, then advancing to the module and finally to the vehicle level verification.

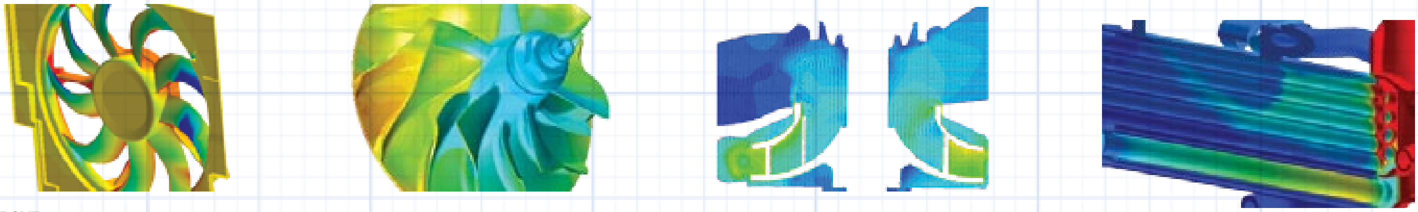
One of the most critical stages occurs as the process approaches the bottom of the “V”. Here, the vehicle components need to be designed and verified almost at the same time. While in the past it was often possible to select tried and tested “off-the-shelf” components, the complexity of modern vehicles requires that almost every component should be specifically designed and optimized for the overall system. Put simply, this means there is no time to build physical prototypes and measure performance on test rigs. The only practical solution to this problem is the adoption of a “virtual test rig” in which numerical simulation of virtual prototypes takes the place of physical testing and validation.

This becomes even more critical when dealing with innovative components that affect several parts of the system, such as the combined alternator/water pump unit described below. Such a unit influences both the cooling and electrical systems of the vehicle, creating an interdependence between them. Therefore, the system designer requires detailed operating characteristics of both the alternator and the water pump, while on the other hand it is very difficult for the unit supplier to build a prototype if the system designer has not completely defined his requirements. This creates an “iterative loop” that must be quickly resolved. Here again, we think that a virtual test rig would be helpful and beneficial for the development of innovative components.

The InDesA Virtual Test Rig
InDesA came to the conclusion that there is a demand for a highly optimized virtual test environment that is fast, flexible and cost efficient in comparison with traditional physical testing. Such a virtual test center would be useful for performance prediction of standard automotive accessory units, producing performance maps for fans, pumps, compressors and heat exchangers. The Virtual Test Center would also be beneficial for functional testing & confirmation of larger engine and vehicle thermal systems such as coolant circuits, heat exchanger packs in the front-end of a vehicle, electronics cooling, and the cooling of battery packs.

The figure above shows our main applications for accessory units such as cooling fans, compressors, coolant pumps and heat exchangers. For these, performance maps, e.g. pressure over volume flow rates for different fan or impeller speeds, are usually produced. Heat exchangers are slightly more complex as they feature two different fluids as well as heat transfer through the structure. For these, heat transfer and pressure loss maps are typically produced.

The figure below shows more complex units, such as the water →



ABOVE
Fans, compressors, coolant pumps and heat exchangers are characterized by making a performance map.

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pump and heat exchanger being integrated with the coolant system, or different heat exchangers and a fan being grouped together into a front-end cooling pack. Those setups are used for functional testing and validation. Two more applications, which are similar to heat exchangers but with a more complicated heat flux path, deal with battery and electronics cooling.

All of these applications are obviously very computationally intensive: in order to produce performance maps, many operating points need to be calculated in parallel. InDesA has therefore invested in a computer cluster with 112 nodes, which uses a high speed communication switch. This hardware allows us to easily outperform conventional test rigs with respect to operating time.

At the heart of the virtual lab is STAR-CCM+, a comprehensive engineering physics simulation tool that provides an engineering process for solving problems involving fluid flow, heat transfer and solid stress. STAR-CCM+ is highly automated, which means that parametric design studies can be completed with little or no manual input.

An additional module, the Facility Supply, is represented by 1D system models for the engine, coolant or lubrication system, and aims to enhance the components integrated environment by including the whole system. The underlying motive is to eventually be able to reproduce the system characteristics of the coolant circuit, so the number of operating points needed to generate a performance map can be narrowed down to where the pump actually operates.

EGR Cooling Module Design

In this first example, we are looking at a typical EGR (Exhaust Gas Recirculation – a technique used to reduce nitrogen oxide emissions) cooling module. There is one inlet and one outlet, for the exhaust gas and the coolant each, where mass flow rates and temperatures are prescribed. Also, the environment is defined in terms of temperature and heat transfer coefficients. With a GT-SUITE engine model, the characteristic flow rates and temperatures, or the pressure difference between the exhaust inlet and outlet as the EGR cooler connects the exhaust with the intake manifold, can be retrieved. With a GT-POWER model, the highly fluctuating gas flow can also be captured, which is essential in the heat transfer analysis.

A few additional boundary conditions are needed for the positions of the bypass flap and the EGR valve integrated in the cooling module. The model setup can be done most efficiently in STAR-CCM+ where direct thermal fluid structure coupling (which includes all the details of the pipes or plates with fins or dimples, as well as details of flaps and hinges to account for flow leakage) can be used.

The simulation results were as follows: the outlet temperature and pressure loss of the coolant could be predicted, as well as the areas where boiling is likely to occur. We could also predict the volume flow rates for the valve seat cooling and assess the flow uniformity. For the exhaust gas, the most important result was the prediction of the outlet temperature and the pressure loss. We also predicted the forces on the bypass flap, as sometimes flow leakage is the reason why targets are not fully met. Structural temperatures were computed everywhere (and most importantly in the valve seat area), which enabled a structural stress/strain analysis to be conducted to gain some insight into fatigue problems. Finally, the heat flux was computed from the exhaust through the structure to the coolant.

By running enough operating points for the heat exchanger, we could calculate the Nusselt correlation for heat transfer and thus derive a full heat transfer map. Such correlations are usually needed for 1D system analyses. However, it should be stressed that a virtual test rig has more capabilities than just producing performance maps. The analysis of the results can highlight any weak points in the design and facilitate immediate remedial redesign.

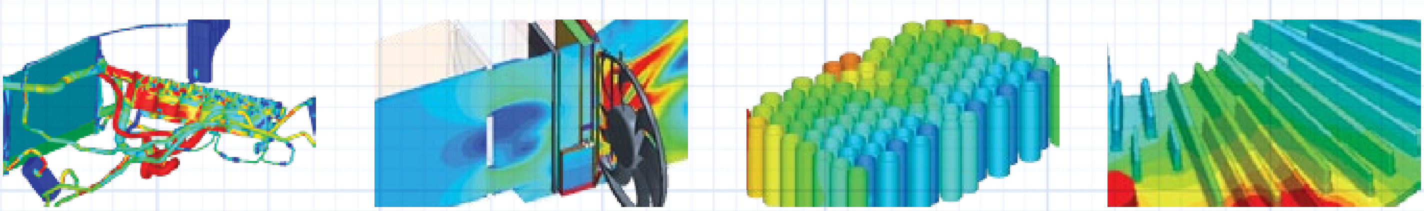
Innovative Pump Design

Our second example deals with a combined generator/coolant pump designed by one of our partner companies, IGEL AG. This design has recently won the “award of innovation” granted by the Würzburger Automobil Gipfel 2010. It consists of a belt driven generator, a clutch, and an electric motor with a coolant pump at the end. The generator is water cooled with the help of a water jacket. The water pump can be driven directly by the generator shaft if the clutch is closed, in which case the electric motor is disengaged. If the clutch is open, the e-motor can drive the impeller independently, even if the engine is switched off. So, in the first case, we have a mechanical water pump, and in the second, an electric water pump. This is particularly useful for turbocharger cooling, which must continue after the engine has been switched off.

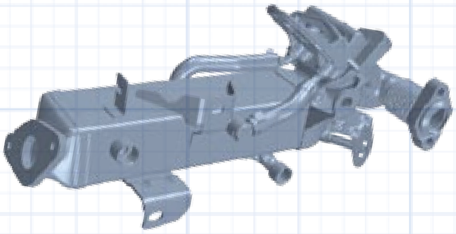
For the design of this innovative pump, we had specific fluid mechanical design goals. We had targets for generator cooling, pump performance, and efficiency. We had to keep the pressure loss of the water jacket low to avoid degrading the pump efficiency. To achieve the performance target, we had to design a new high speed impeller as the gear of the belt transmission for generators is much higher than for conventional water pumps. For this particular case, we took over not only the task of predicting the pump performance, but also the design of the impeller, the volute, and the generator coolant jacket. This is a clear example of how the virtual test rig approach enables the direct interaction of design and verification.

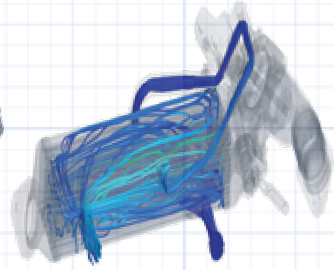
The challenge with marketing such a concept is that, as you approach different OEMs, each specifies a list of different wishes, requirements, and targets. This means that the generator/pump unit must be repeatedly adapted and redesigned in a very short time, before finally proving to the OEM that the component meets the required specifications. Cost efficiently, this can only be achieved within a virtual process where design and verification interact directly.

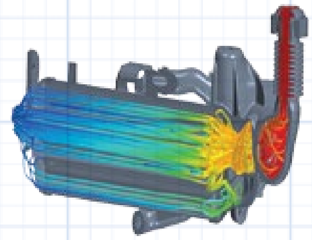
With just a single fluid stream, the model is not too complicated, using a single inlet and a single outlet. For this purpose, the movement of the impeller does not need to be modeled explicitly and it is sufficient to use the computationally less expensive method of Multiple Reference Frames (MRF). The simulation results predicted the volume flow rate and the pressure rise for different pump speeds,

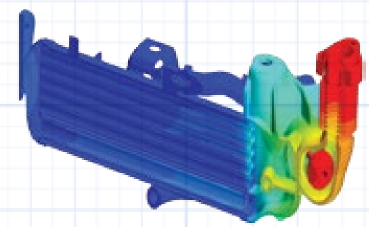


ABOVE
More complex arrangements, where multiple components are combined, require more computer intensive treatment.


EGR Cooling Module Design


EGR Coolant flow


EGR Exhaust Gas Flow


EGR Structural Temperatures

as well as the hydraulic efficiency by determining the torque due to pressure and friction. We also predicted the onset of cavitation. For the water jacket of the generator, we calculated the pressure loss and heat transfer coefficient to assess the cooling capabilities. Finally, we extracted the pump performance map; affinity laws were helpful in completing this map. If a GT-SUITE model was added to the coolant system, we could derive the operating conditions under which the pump is balanced and establish where the pump would best operate. Accordingly, we could cut down the number of operating points, thereby saving a significant amount of computational effort and time.

More Complex Systems
Having investigated single accessory units, it can become informative to link them together. In this case, we combined a cooling fan with different heat exchangers to form a simplified underhood model for the investigation of a whole cooling module. For the fan, we can either use a 3D CFD model or derive a performance map and simplify the fan in the underhood model as a disc with a momentum source. As with the heat exchangers, we do not need to resolve the entire geometry but can use the Nu correlation derived by virtual testing or by conventional hardware testing.

We came up with a useful test rig set-up to investigate the mass flow and heat transfer rates of the cooling module of a car whose front-end geometry is not yet known or decided. By using a detailed CFD model for the fan, we could also account for the flow interaction between the fan and the engine and asses how it downgrades the fan performance. Needless to say, we could easily shift the positions of the heat exchangers and the engine to adapt the model to changes in the engine compartment.

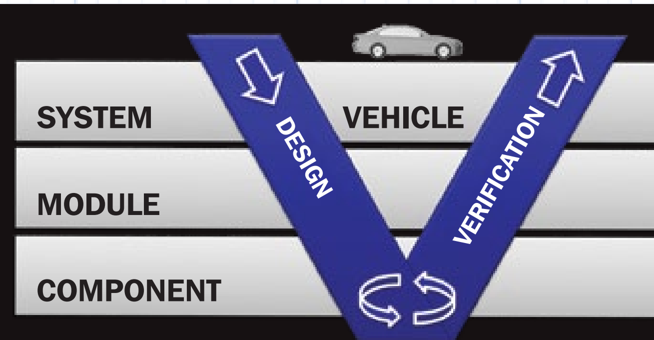
Coolant Circuit Design
Another example of a useful combination of accessory units is the coolant circuit, whose 3D CFD model is principally made of the CFD models of a water pump and heat exchangers (coolant side only). To complete the model, the geometries of the engine water jacket, thermostat, connecting pipes, and hoses are needed.

A 3D CFD model of a complete water jacket can be used to investigate the flow rates in the entire coolant system for different pump speeds and thermostat / valve settings. If the model is sufficiently detailed, it is also possible to investigate the filling procedure and de-gas behavior.

Conclusion
The InDesA Virtual Test Facility Center is an efficient and environmentally friendly concept.

It is efficient because we built a standardized procedure for a defined set of applications. The virtual world allows us to easily customize those procedures to the specific needs and wishes of our customers. This is made possible by our computational test facility center, which is powered by over 100 processors, linked with a high performance communication and storage system, and tuned for optimal performance of STAR-CCM+.

It is environmentally friendly because the cluster is cooled using only standard ventilation and no air conditioning. Considering that a single car radiator can discharge 100 to 150 kW into the environment, it is obvious that numerical simulation is far more energy efficient than the physical testing of prototypes. ■



ABOVE
The “V-Model” development process

DESIGN PROCESS

The InDesA Virtual Test Facility Center is based around the principles of High Fidelity, Repeatability, and Comparability

High Fidelity because we use high resolution CFD models to ensure the full detail of the geometry is captured (accounting for even the flow leakage in pumps, hinges, etc.). By exploiting the strength of the STAR-CCM+ physical model library, we are able to include radiation, two-phase for boiling, and, if needed, a kinematic module for pressure actuated flaps.

Repeatability because the CFD model of a test rig and the test object are packed and archived with all the results for reuse. Additional operating points can be run at request anytime in the future.

Comparability because we want to be able to compare results at different stages of the prototype, using the same boundary conditions, solution method, and mesh resolution.

❐ FACT

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