



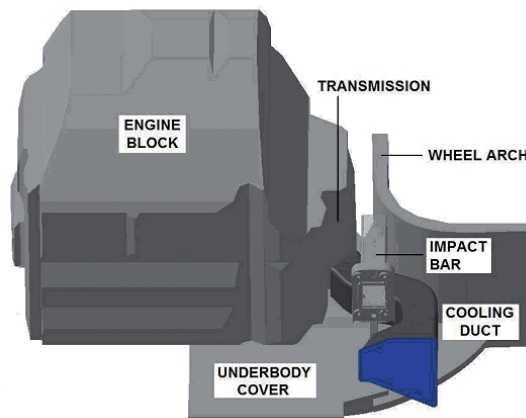
case history

Automatic Design Optimization at ICON using OpenFOAM and modeFRONTIER

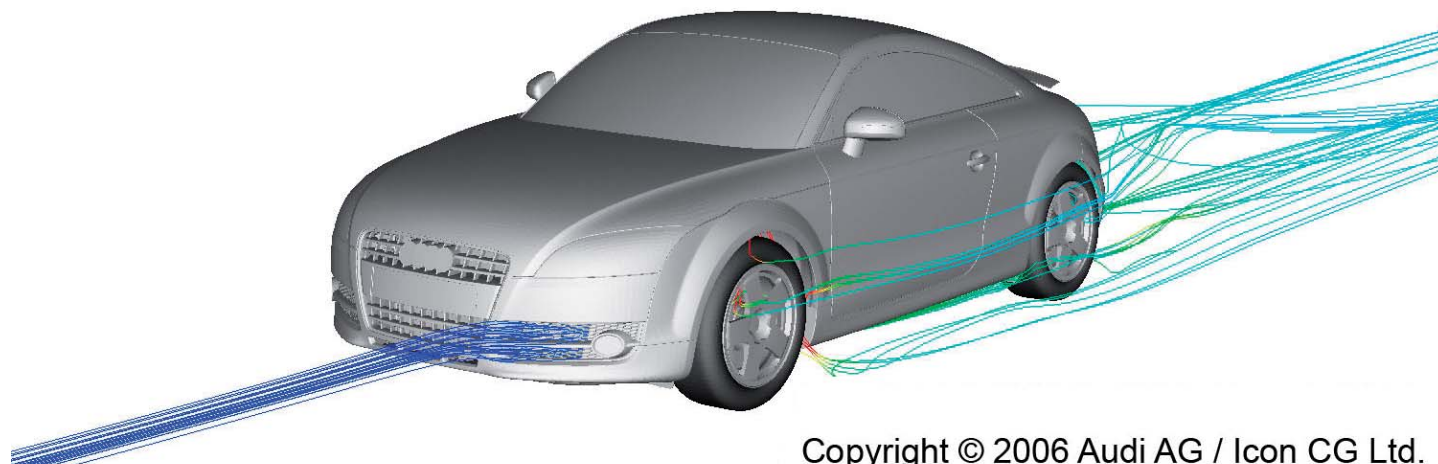
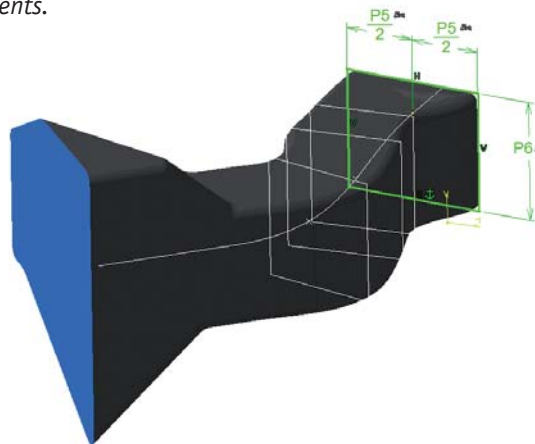
Advanced use of the optimization software modeFRONTIER has led EnginSoft to select ICON as a business partner for support and sales activities through Esteco-UK

Computational Fluid Dynamics (CFD) has reached high levels of acceptance in industry as a valid design tool thanks to the continuous improvements on the existing software and the rapid development in hardware. As lead times for solving fluid related problems have been drastically reduced, and more problems of a different nature can be solved, there is an increasing need to depart from the traditional "trial and error" design approach and take advantage of state-of-the-art optimization techniques to help to achieve the best possible design solution in the shortest time and with the minimum effort.

ICON has recognised the potential of integrating CFD and optimization software through involvement in various CFD design optimization projects with clients from the aerospace and automotive sectors. As an example of such work, a summary of a shape optimization study and robust analysis performed by ICON on a cooling duct located in the under-bonnet region of the new Audi TT is presented in this article.



Picture 2: Example of parametric duct geometry and under-bonnet components.



Picture 1: Audi TT under-bonnet cooling duct flow path

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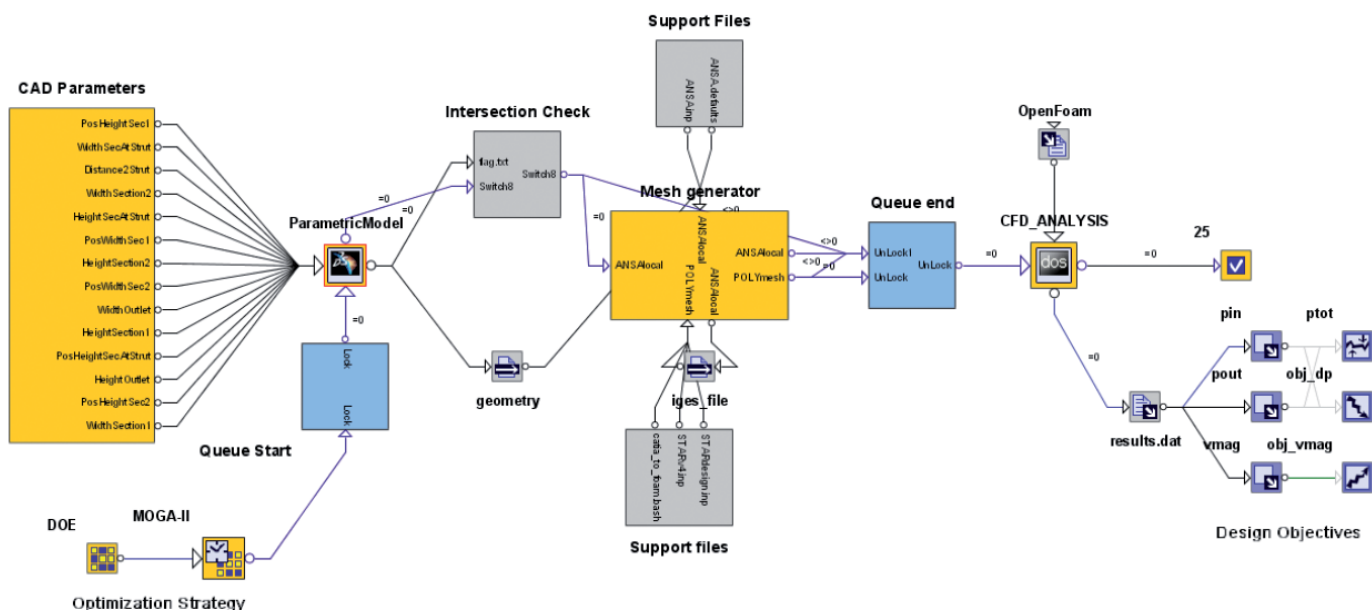
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CFD and Optimization: Integration and Methodology

The under-bonnet duct described here is responsible for channelling air from the side-grill (see Picture 1) towards the transmission for the purpose of cooling this component. Consequently, the main objective in this work was to improve the shape of the duct in order to minimize its pressure drop from inlet to outlet, to facilitate the flow of air, and to maximize the discharge

candidate solutions and select the final optimum configuration in terms of design objectives and sensitivity to minor changes in the input variables.

The first stage in the work was to generate a parametric CAD of the duct geometry in Catia V5, including a simplified version of the surrounding components to verify every duct design against collision with nearby



Picture 3: modeFRONTIER workflow for MOGA-II duct optimization

flow velocity, to enhance convective heat transfer. For any given design solution, the shape had to conform to the available space in the very compact and crowded compartment.

The overall optimization procedure consisted of generating parametric CAD models of the duct geometry, creating the corresponding computational meshes, performing the CFD analyses in batch mode, and applying the multi-objective robust design optimization product modeFRONTIER to find the optimal design layouts. Robust design analysis was then performed to screen the

parts (see Picture 2). The latter was achieved with an additional Catia v5 macro. A total of 16 input parameters were identified and employed to define a wide range of duct shapes.

The cooling duct geometry was then imported from Catia into the chosen mesh generator, i.e. STAR-Design. The resulting grids were all polyhedral and included wall extrusion layers. The meshing process was recorded in a batch script to be employed in the optimization procedure.

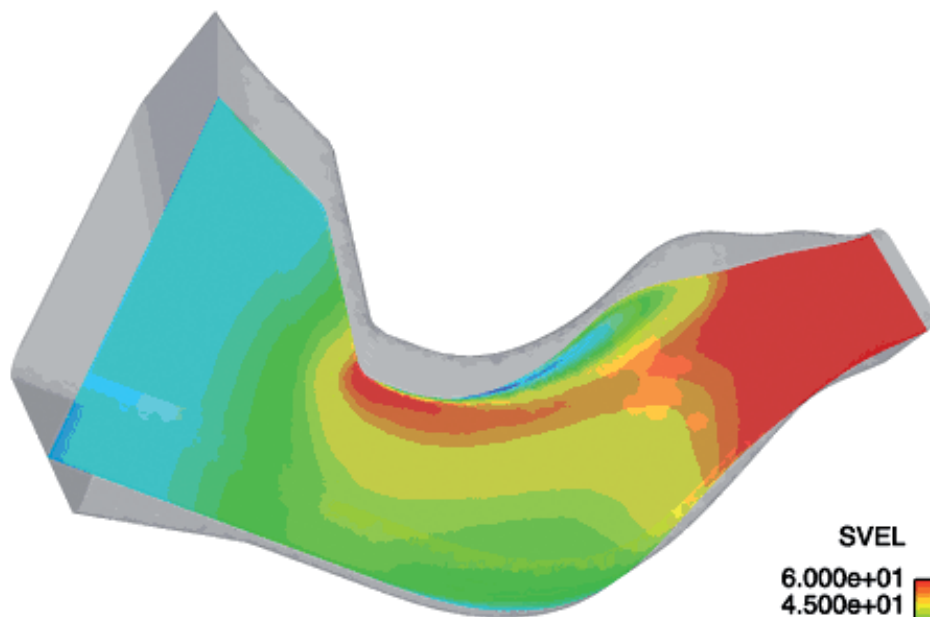
The polyhedral mesh created in the previous stage was then imported into the CFD code. The CFD solver selected



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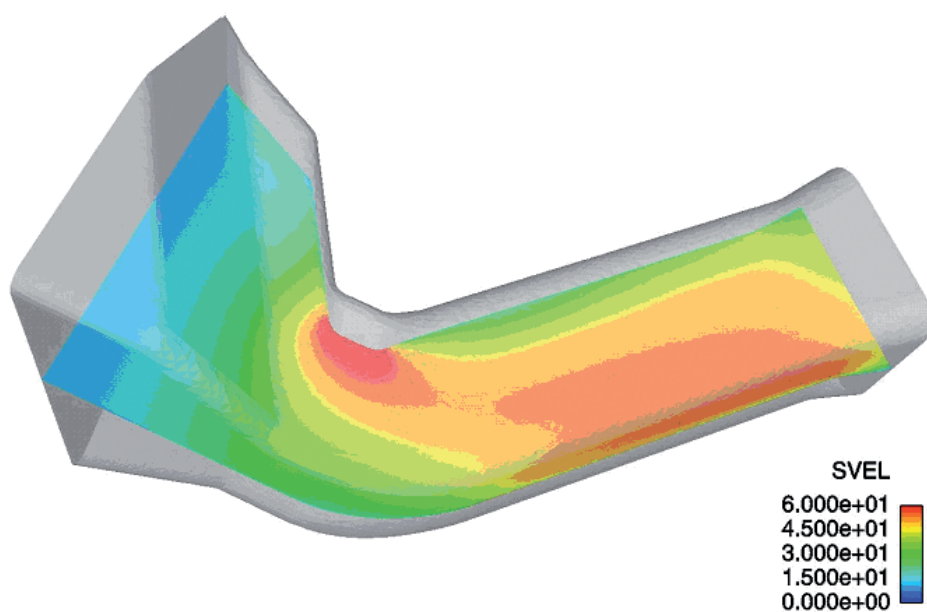
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suite. Automatic design optimization generally requires many CFD computations to converge towards the best design; consequently, an open source solution offers the freedom to exploit a large number of hardware resources without the cost limitations imposed by commercial licensing.

Once the mesh was available in OpenFOAM, a series of scripts were employed to: (i) set up the CFD problem, e.g.: to apply boundary conditions, thermophysical properties, turbulence models, solver controls, etc.; (ii) to solve the CFD problems to convergence; and (iii) to post-process the CFD solutions to extract the values of the flow field variables corresponding to the objectives functions of the optimization problem, namely: pressure drop and discharge velocity. As before, each of these actions was automatically handled by modeFRONTIER.



The different stages of the automated CFD process described above were assembled together in modeFRONTIER through the Workflow (see Picture 3). In addition to this, the input variables, objectives and the optimization loop settings, including the DOE and the optimization algorithm, were also defined. For this example, the MOGA-II algorithm was selected with an initial population provided by a SOBOL-DOE, for a total number of 1,500 high fidelity design

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evaluations over a period of time of 72 hours.

In order to facilitate the selection of the “best” compromise between objectives from the Pareto frontier obtained from the MOGA-II investigation, the Multi Criteria Decision Making (MCDM) tool featured in modeFRONTIER was employed. Three designs were selected this way based on a utility function for pressure drop in a range of discharge velocities from 90 m/s to 120 m/s. The highest velocity limit was imposed to avoid excessive Mach numbers that could lead to sources of aeroacoustic noise.

Finally, in order to select the final design from the candidate solutions filtered out with the MCDM tool, a robust design analysis was performed. For this, all the original deterministic input CAD variables were re-defined as normal stochastic distributions, with a 10% standard deviation, using the Monte Carlo Latin Hypercube Sampling (LHS). A total of 130 samples were tested for each configuration in order to ensure the best possible approximation of the normal stochastic distributions. As a result, 390 additional design evaluations were performed.

Results and Conclusions

The results from the sensitivity analysis described earlier allowed the selection of the best robust design from the three layouts selected from the Pareto frontier. The final configuration was chosen by considering the lowest standard deviation of the objectives as main criterion, in addition to the standard optimization of the design objectives (i.e. minimize pressure drop and maximize discharge velocity). The CFD results for velocity magnitude are compared in Picture 4 for both the baseline design and the final optimized configuration. Overall, the pressure drop was reduced from 357 Pa to 330 Pa, while the discharge velocity was increased from 39.4 m/s to 107.8 m/s.

By using the optimization software modeFRONTIER in conjunction with the open source CFD code OpenFOAM, the traditional trial and error design approach was substituted by a fully automatic and logical procedure. The final design was achieved in less than 4 days with no user intervention, while results are supported by almost 1,900 CFD design evaluations.

ICON would like to thank Dr. Moni Islam (AUDI AG) and Mr. Paolo Geremia (Esteco UK, www.esteco-uk.com).

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ICON is an independent provider of confidential CAE simulation services and has had a long association with

industry by delivering CFD related projects at both OEM and supplier level since 1992. Close links with academic institutions, and continuous involvement with clients in various industries, has allowed ICON to establish a wide base of knowledge and offer technology transfer to its clients. Advanced use of the optimization software modeFRONTIER has led EnginSoft to select ICON as a business partner for support and sales activities through Esteco UK. The ICON engineering team also includes members of the original OpenFOAM development team that trained at Imperial College. Full details of comprehensive OpenFOAM and other CAE/CFD support packages are available upon request.

For further information: www.IconCFD.com