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High-dimensional multi-fidelity optimisation of a 2.5 stage low pressure compressor

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The low pressure compressor (LPC) in modern jet engines has to meet high demands in performance and needs to operate in various conditions. Moreover, the low pressure compressor of an embedded engine has to deal with a distorted inflow, which makes it necessary to take a sufficient surge margin into account during design phase. These requirements become even more challenging, when weight restrictions lead to a narrow installation space.

In this paper the multi-disciplinary design optimisation of a highly loaded 2.5 stage low pressure compressor with more than 260 free parameters (mainly flow path, blade count, airfoil parameters of both rotors at five different radial heights and airfoil parameters of both stators at three different radial blade heights) under challenging constraints is presented. The automated optimiser AutoOpti ([1], [2] and [3]), developed in DLR's Institute of Propulsion Technology, is used to carry out the multi-fidelity optimisation. The aim of the optimisation is the improvement of isentropic efficiency and surge margin with the simultaneous fulfilment of geometric, aerodynamic and mechanical constraints. More than 30 constraints were taken into account.

Two fidelities are considered in this multi-fidelity optimisation approach. In general, the high-fidelity setup is more detailed and thus more reliable, but also more time-consuming. The low-fidelity setup is fast due to coarse meshes and downgraded mechanical analyses, so the data is used solely to improve the surrogate models. In both high- and low-fidelity process chains CFD simulations with the in-house flow solver TRACE and FEM calculations with the commercial software PERMAS are conducted.

In the CFD four operating points at two different rotational speeds are considered, one on the working line and one in near surge condition respectively. The operating points are marked in the performance map of the LPC in Figure 1. The aerodynamic demands in this optimisation are ambitious, but fulfilling them simultaneous with the mechanical constraints and within the restricted geometric design space is an even more severe challenge. Furthermore, the initial geometry does not fulfil the constraints. So the maximum static blade stresses and the Eigen frequencies need to be adjusted to comply with their limits for both rotors as well as the adjustable stator

1 and the fixed stator 2. Surge loads are taken into account by adding additional safety factors and also the bird impact scenario on Rotor 1 is considered by restraining leading edge stresses and geometric blade parameters.

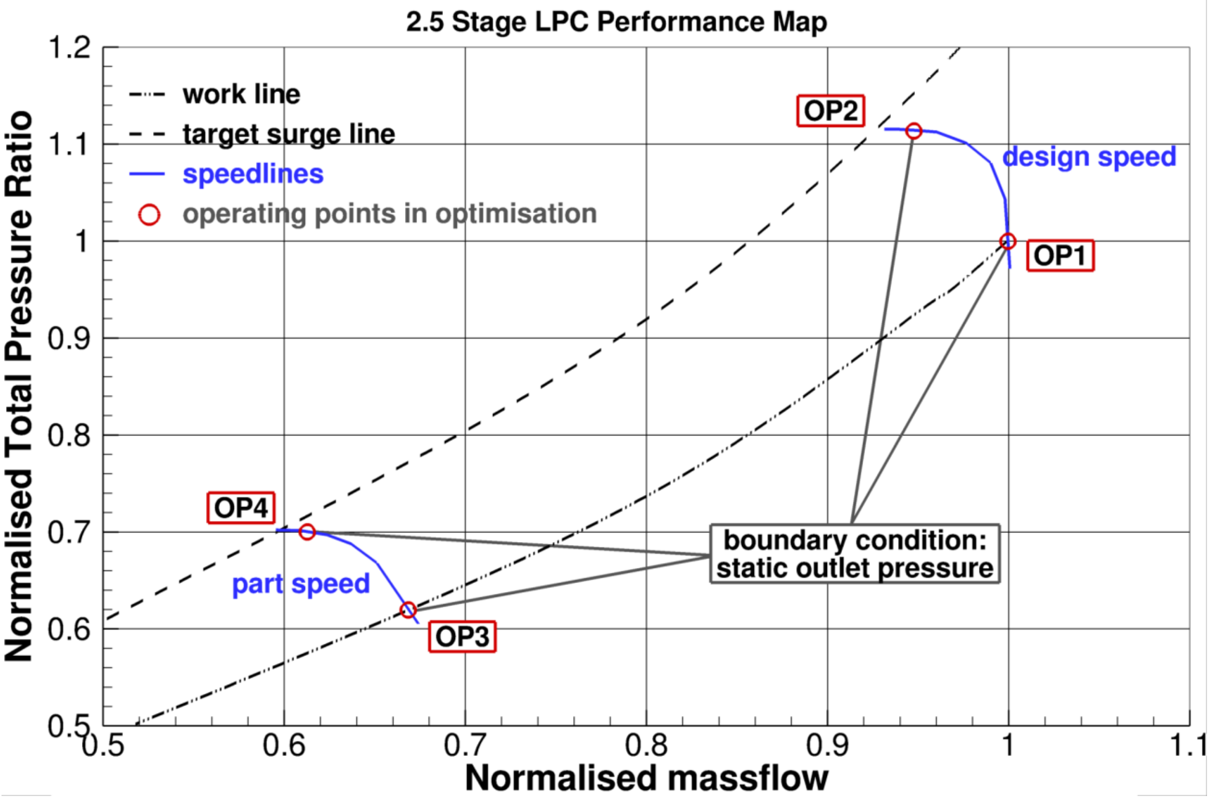

Figure 1 Performance map with the chosen operating points for the optimisation process

The variable inlet guide vane (VIGV) in front of the two LPC stages consists of two parts, a fixed strut and a variable flap. The flap, like the first stator, is adjustable to ensure high isentropic efficiencies and large surge margins at all rotational speeds. The work of Hieber [4] resulted in an aerodynamically well-performing VIGV that delivers the needed outflow angle distributions for the downstream rotor blade row. The VIGV blade geometry is fixed during the optimisation except for the adjustment angle at part speed.

The final design fulfils all aerodynamic and mechanical constraints. In Figure 2 the progress of the optimisation concerning the constraints can be seen. The blue dots represent the high-fidelity geometries that completed the process chain successfully. With the progression of the optimisation – and therefore increase of geometry numbers – the penalty value for constraint violation decreases continuously. The main part of the optimisation had to be spent on the fulfilment of the constraints, while in the end the objectives were optimised. Even though, the isentropic efficiency of the optimised geometry is slightly improved at design speed compared to an initial geometry (0.7 percentage points), but at part speed the increase is about 2.5 percentage points. The drawback is that the surge margin could not be conserved with a drop of 2.5 and 2.9 percentage points respectively at the two considered rotational speeds.

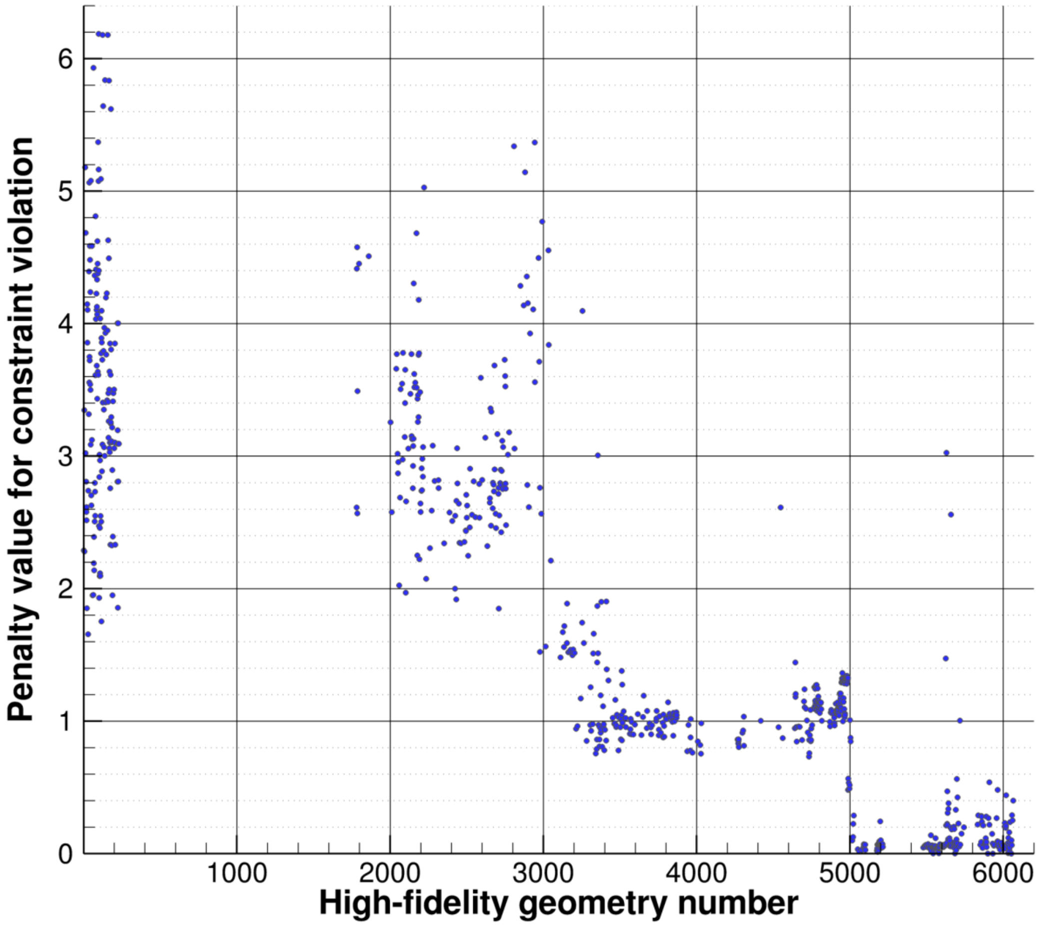

Figure 2 Progress of the optimisation concerning the fulfilment of the constraints

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