Universität Heidelberg • Interdisziplinäres Zentrum für Wissenschaftliches Rechnen

Group of Prof. Dr. H. G. Bock and Dr. J. P. Schlöder

Shape Optimization of Turbine and Compressor Blades

(cooperation with ABB Power Generation, Baden (CH) and MTU Motor and Turbine Systems, Munich)

Dr.Wolfgang Egartner, Dr. Volker H. Schulz

Project goal

We are developing and implementing *multiple setpoint optimization algorithms* by means of partially reduced SQP (PRSQP) methods. Overall aim is the reduction of turnaround times in turbomachinery design.

Problem description

The demand is to optimize the performance (e. g. minimize pressure loss, maximize efficiency, avoid flow separation) of the 3D blade (i. e. for a family of streamsurfaces) in its working range preserving solidness contraints, manufacturing constraints, heat engineering constraints and desired exit flow angle.

Why PRSQP?

The huge number of q3D flow problems involved leads to computation times of a couple of days or even weeks with standard optimization techniques. So we need an approach that allows *simultaneous* simulation and optimization of the multiple setpoint problem. PRSQP methods do that by directly attacking the optimality conditions, thus taking advantage of every available sensitivity information. On the other hand, they make it possible to define a relatively simple interface between the complex forward design system and the optimization modules as the multiple setpoint optimization step is split into projections towards optimum and flow solution. This is very important as it significantly reduces costs for software implementation and support. Finally, all streamsurfaces and operating point flow solutions can be computed in parallel.

Cascade flow solution for one streamsurface operating point

The equality constraints in the multiple setpoint optimization problem statement are the discretized S1-streamsurface-cascade flow equations, each of which is a coupled system of q3D freestream Euler equations (with Coriolis- and centripetal forces)

$$\int_{\partial A} \rho\,(\mathbf{v}^\top \boldsymbol{n})\; ds \;=\; 0\,,$$

$$\int_{\partial A} \big(\rho\,(\mathbf{v}^\top \boldsymbol{n})\,\mathbf{v} \,+\, p\,\boldsymbol{n}\big)\; ds \;=\; -\int_{A} \rho\,\boldsymbol{F}\, dV\,,$$

$$\int_{\partial A} \rho\, R\,(\mathbf{v}^\top \boldsymbol{n})\; ds \;=\; \mathbf{0}$$

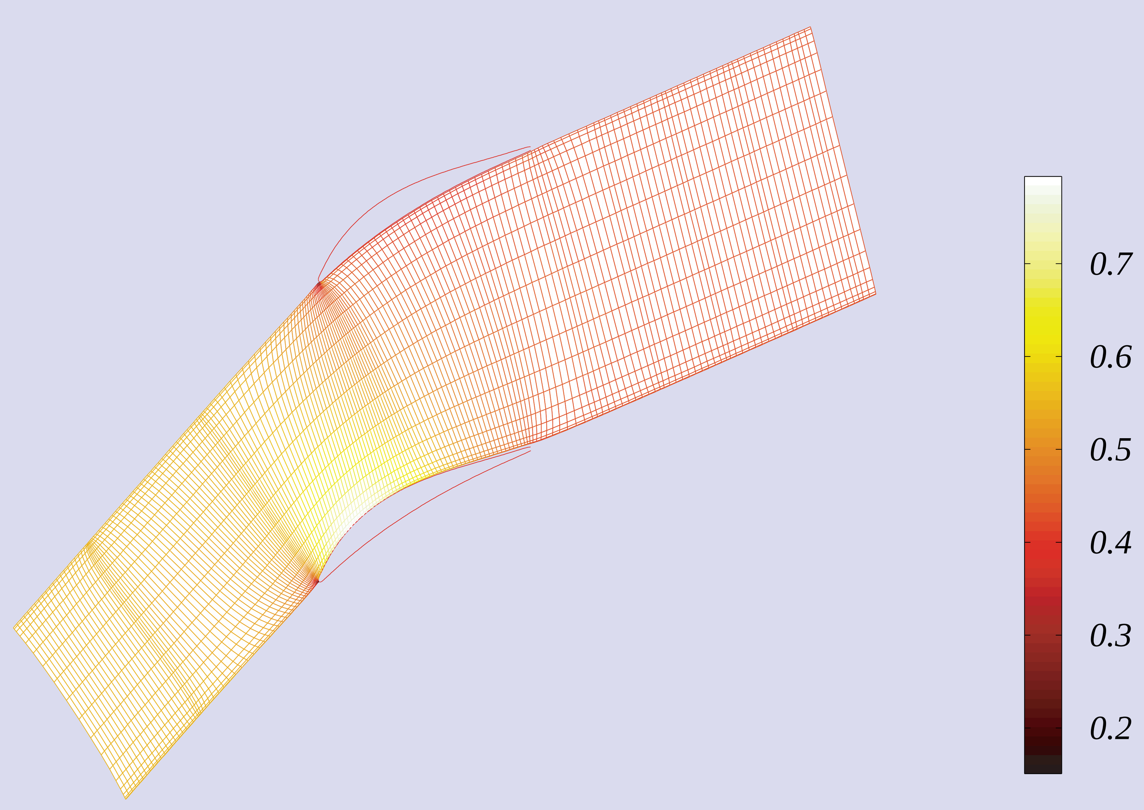
and integral boundary layer equations (laminar, transitional and turbulent models)

$$\frac{d\theta}{ds} \;=\; \mathcal{F}_1(\theta,\delta^*,u_e)\,,$$

$$\frac{dH^*(\theta,\delta^*,u_e)}{ds} \;=\; \mathcal{F}_2(\theta,\delta^*,u_e,C_\tau)\,,$$

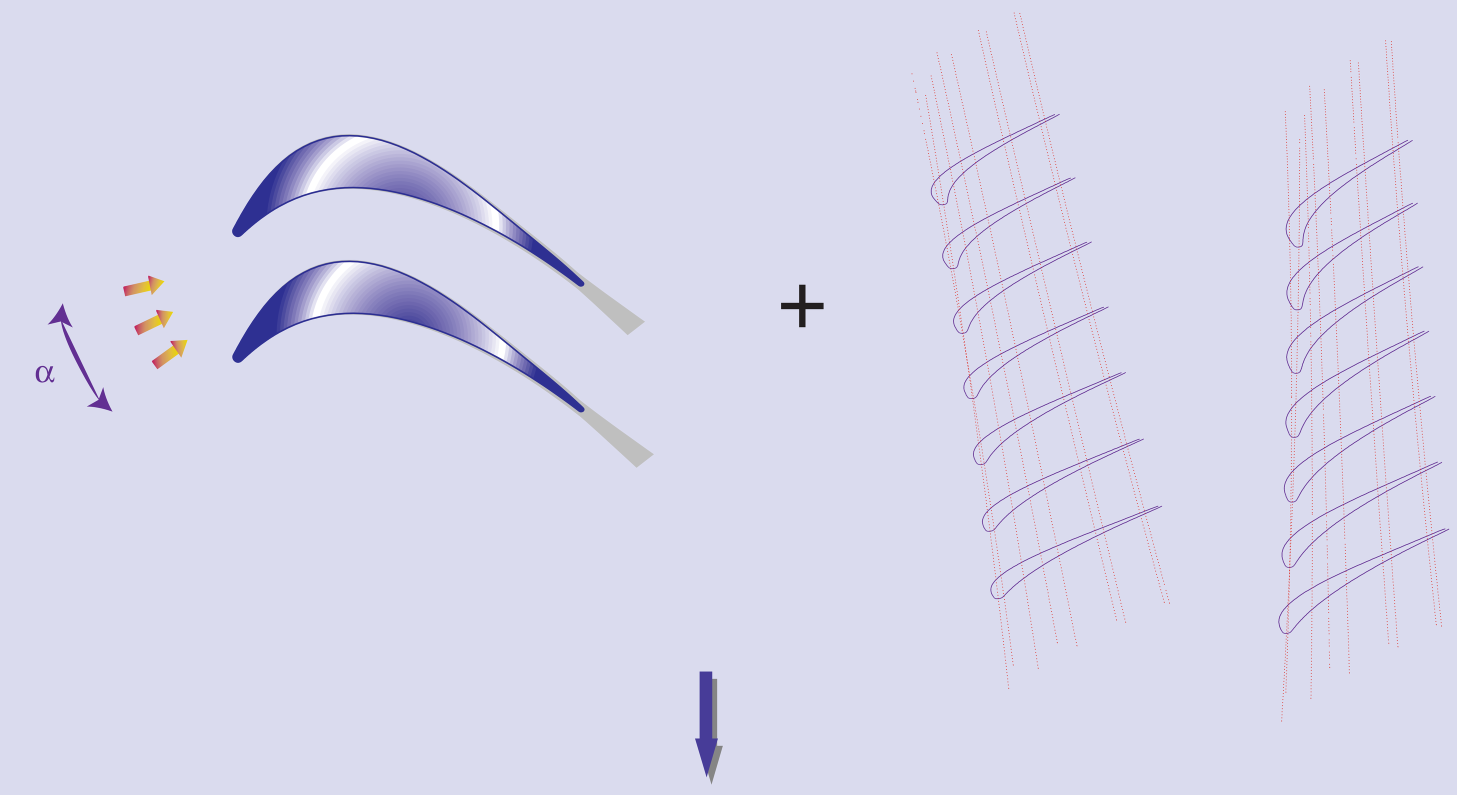
$$\frac{dC_\tau}{ds} \;=\; \mathcal{F}_3(\theta,\delta^*,u_e,C_\tau)\,.$$

The coupling is performed directly via the displacement thickness δ^* by means of a q3D conservative streamtube discretization of the freestream equations.



Example S1-streamsurface Mach number distribution through compressor blades as computed by MISES. Problem size: ~ 12000 flow variables, 24 DOF (profile parameters)

Multiple-Setpoint problem structure



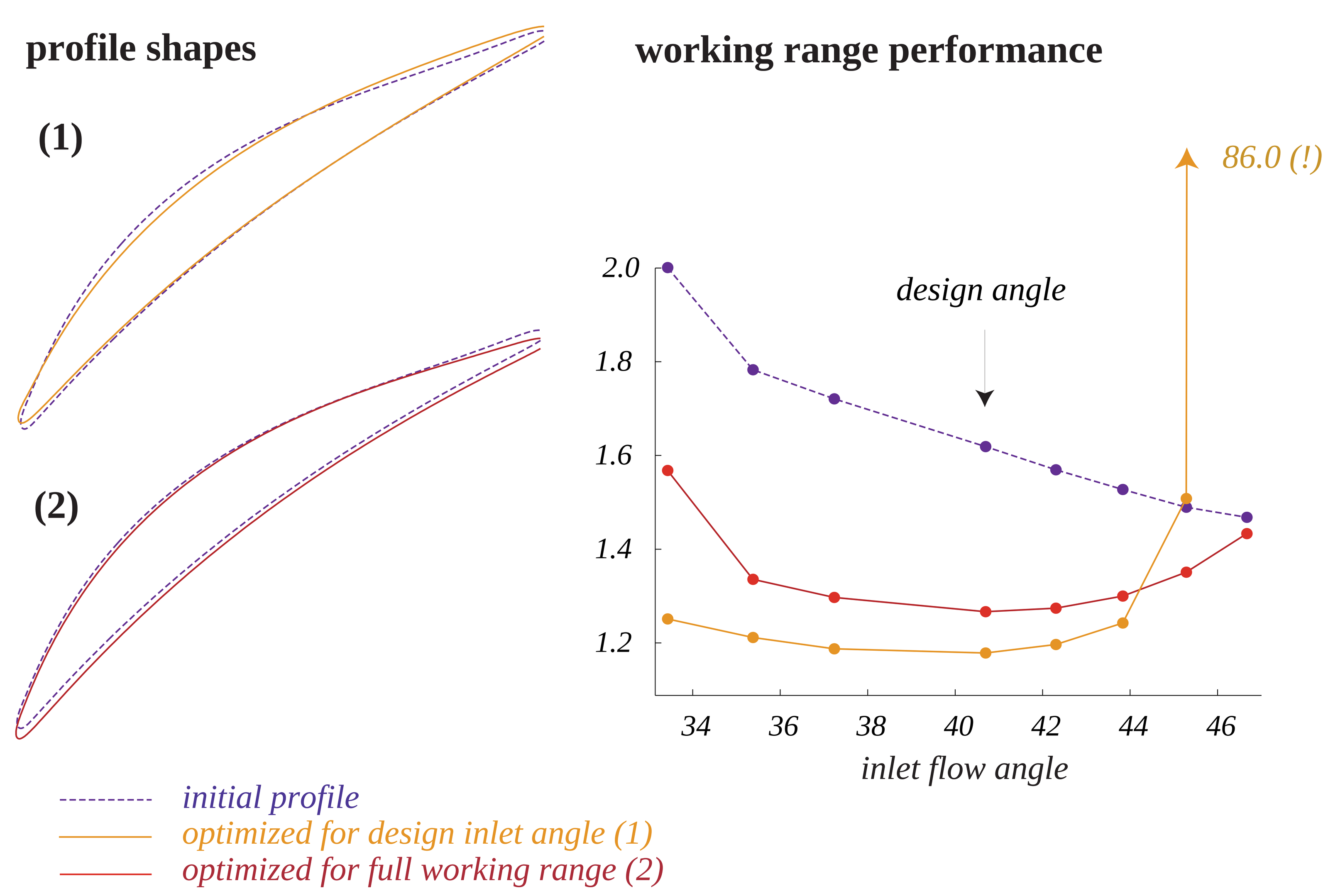
$$\min_{\boldsymbol{x}_{11},\dots,\boldsymbol{x}_{NM},\,\boldsymbol{p}_1,\dots,\boldsymbol{p}_M} \;\sum_{j=1}^{M}\sum_{i=1}^{N} \omega_{ij}\, \mathrm{f}\,(\boldsymbol{x}_{ij},\boldsymbol{p}_j,\alpha_i) \qquad \textit{overall performance}$$

$$\text{s. t.}\;\left\{\begin{array}{lll} \mathbf{c}(\boldsymbol{x}_{ij},\boldsymbol{p}_j,\alpha_i) = \mathbf{0} & \forall\, i,j & \textit{discretized flow equations} \\ \mathbf{g}_j(\boldsymbol{p}_j) \le \mathbf{0} & \forall\, j & \textit{streamsurface profile geometry constraints} \\ \mathbf{h}\,(\boldsymbol{p}_1,\dots,\boldsymbol{p}_M) \le \mathbf{0} & & \textit{3D-blade geometry constraints} \end{array}\right.$$

The *multiple setpoint structure* of the problem arises from two sources. Firstly, the blade must be optimal for a number of operating points characterizing the presumed working range. Secondly, a whole family of profiles has to be optimized at the same time.

Example

Below, two optimization results *for a single streamsurface* are shown. The first one (yellow line) is optimized for the design angle only, while the second one (red line) is the optimum for the prescribed working range. Both optimization runs have been started from the same initial blade (blue lines).



The design angle optimum (about 12 000 flow variables) has been computed in about 4 minutes on an Intel PII/400 Linux system.
This is only about three times of the computing time for a mere forward solution.
The working range optimization (8 operating points, about 96 000 flow variables) took about 40 minutes.