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A logarithmic ω-equation formulation for tubulence models in harmonic balance solvers

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The harmonic balance (HB) method has been shown to be a capable tool to capture unsteady effects in turbomachinery with computational fluid dynamics [1]. The main advantage of this nonlinear frequency domain method is a significant speedup compared to a conventional unsteady time domain simulation. A frequently occurring problem are spurious oscillations resembling the Gibbs phenomenon. Particularly vulnerable to this is the ω-equation of turbulence models such as Wilcox $k-\omega$ or Menter SST $k-\omega$, due to the large values of ω close to the wall. This adversely affects both the obtained solution and the stability of the solver.

As a computationally efficient solution, we propose the use of a logarithmic version of the ω-equation. This approach was used by Bassi et al.[2] to address very similar problems in their discontinuous Galerkin solver. This is expected to have two beneficial effects: Firstly, a logarithmic ω-equation will smooth the strong peaks in the wake. Secondly, negative values for ω, which are entirely unphysical, can no longer be produced by the Gibbs phenomenon.

We implemented both a $k-log(\omega)$ model based on Wilcox $k-\omega$ and a SST $k-log(\omega)$ model based on Menter SST $k-\omega$ in TRACE, DLR's solver for turbomachinery flows. The models are validated with a flat plate and an infinite channel. Additionally a grid convergence study on a turbine airfoil is performed. The modified models show similar results to their base models. On the turbine airfoil differences arise on the suction site and in the wake especially for lower resolution grids. The impact of the Gibbs phenomenon on the flow is reduced, improving the transportation of the turbulent quantities through interfaces.

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