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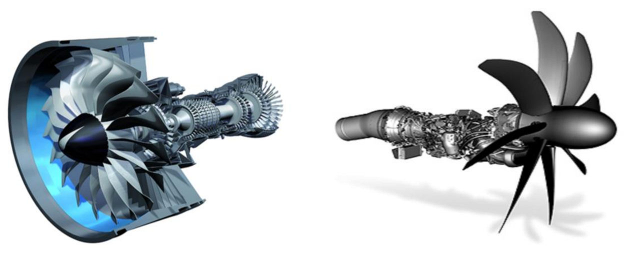

IMPROVE: Innovative Methoden der Profilgestaltung in Verdichtern

Introduction

Objectives

- Numerical optimization of high-lift airfoils under steady and unsteady inflow conditions, incorporating boundary layer (BL) stabilization.
- Experimental validation of numerically optimized airfoils in low-speed cascade tests, comparing single (SS) and tandem airfoil (TS) configurations.

Motivation

- Shift the transition point downstream to minimize BL losses and enhance aerodynamic efficiency.
- Stabilize the BL using surface structures to reduce the risk of flow separation.

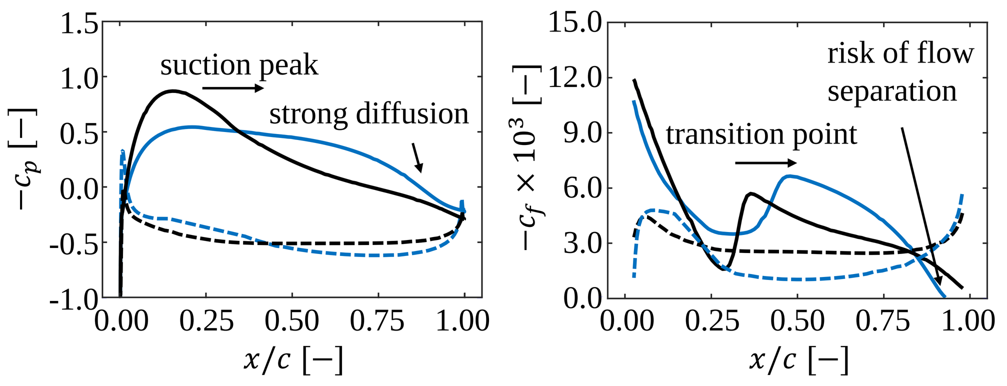

Fig. 1 Static pressure (left) and skin friction (right) coefficient for the SS reference (black) and a potential laminar (blue) airfoil.

Influence of Tu and Re on boundary layer behavior

- Reference SS and TS exhibit comparable operating behavior at different loading levels.
- Turbulence intensity (Tu) and Reynolds number (Re) influence transition behavior, BL loading, and entropy production.
- Total cascade losses scale linearly with BL losses.

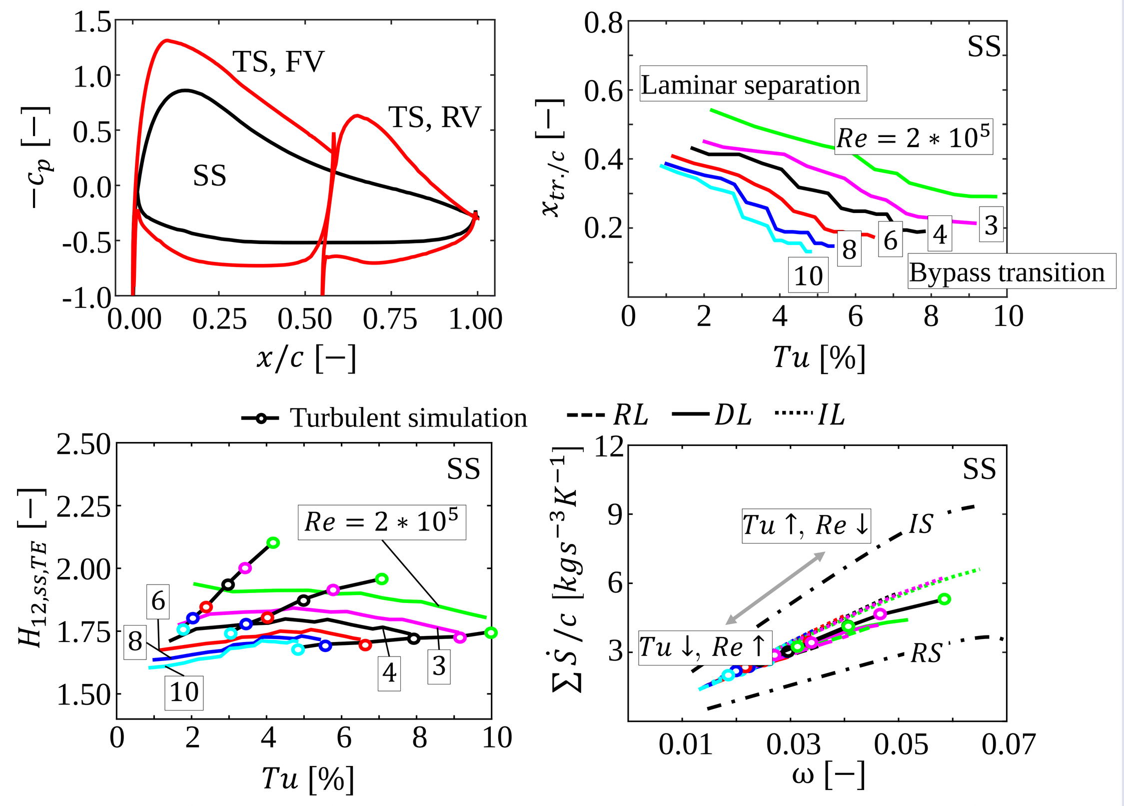

Fig. 2 Influence of Tu and Re on transition behavior, BL loading, and BL entropy production.

Wake Generator

Methodology

- Steady-state and transient simulations assess the impact of periodic unsteady inflow on the BL behavior of the highly loaded compressor cascade.
- Numerical simulations replicate the experimental setup for direct comparison and validation.

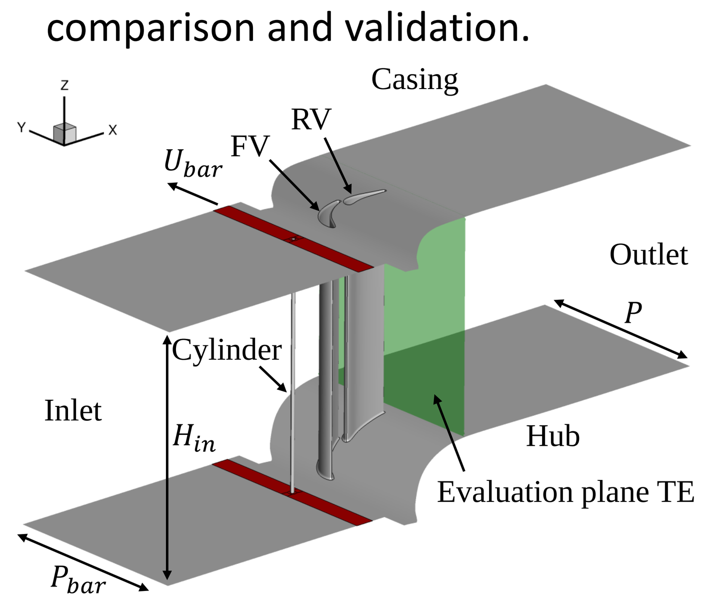

Fig. 3 Numerical flow domain with the cylindrical WG and the investigated TS.

Unsteady flow field

- Formation of a Kármán vortex street in the cylinder wake, characterized by periodic vortex shedding.
- Transient interaction of the wake with the suction side BL, leading to localized turbulence and BL thickening.

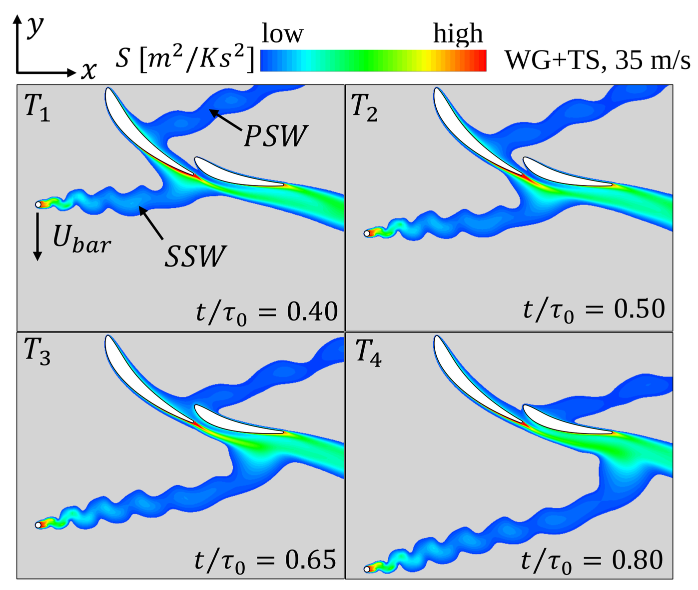

Fig. 4 Wake-vane interaction at four time steps for the TS for $U_{bar} = 35\ m/s$.

Unsteady operating behavior

- Development of characteristic BL regions for both the SS and TS.
- FV of the TS behaves similarly to the SS, exhibiting comparable wake-induced transition.
- Suction side BL of the RV is shielded by the FV wake, reducing unsteady effects.
- RV is primarily influenced by the WG's pressure side wake branch (PSW).
- Increased wake-induced turbulence leads to higher entropy generation and greater overall airfoil losses.

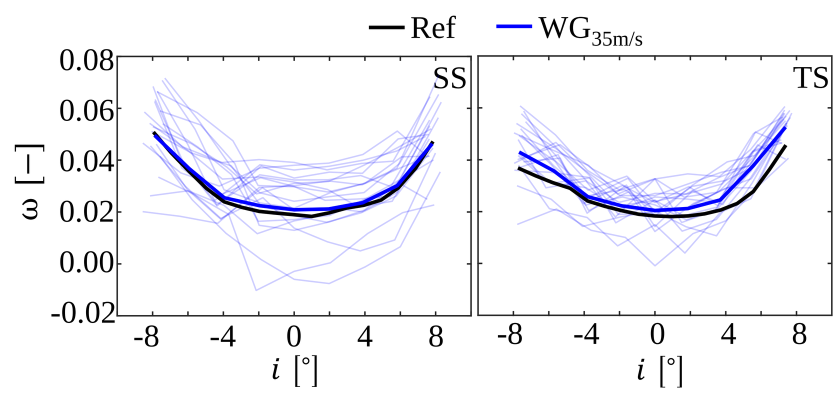

Fig. 5 Unsteady performance characteristics.

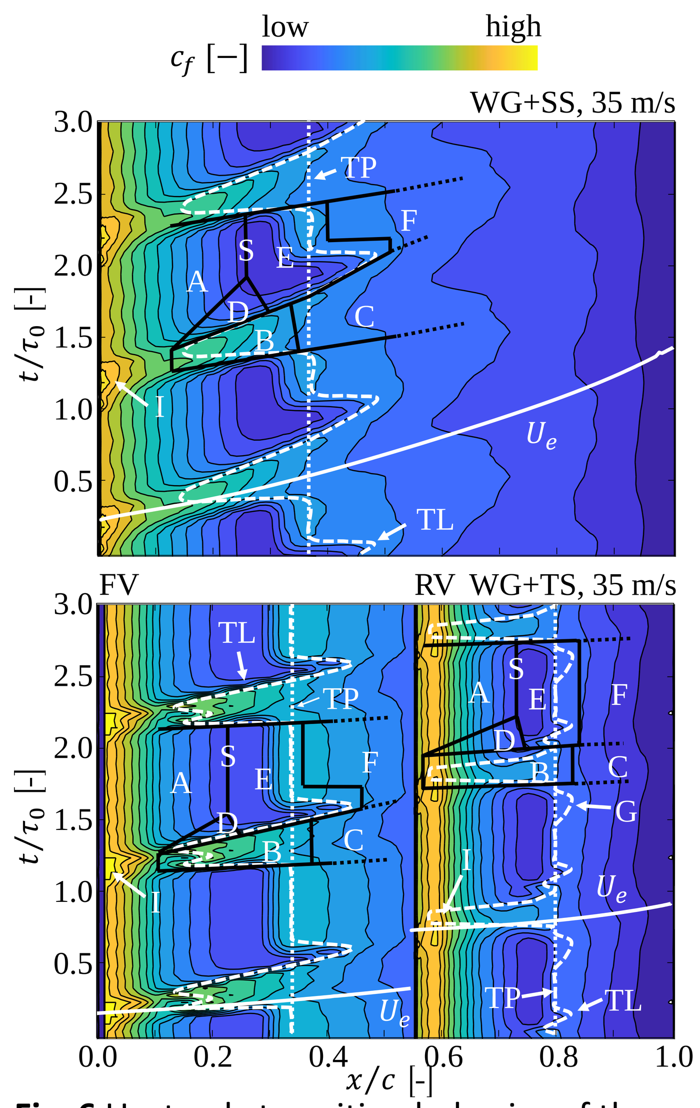

Fig. 6 Unsteady transition behavior of the SS (top) and TS (bottom) for $U_{bar} = 35\ m/s$.

Surface Structures

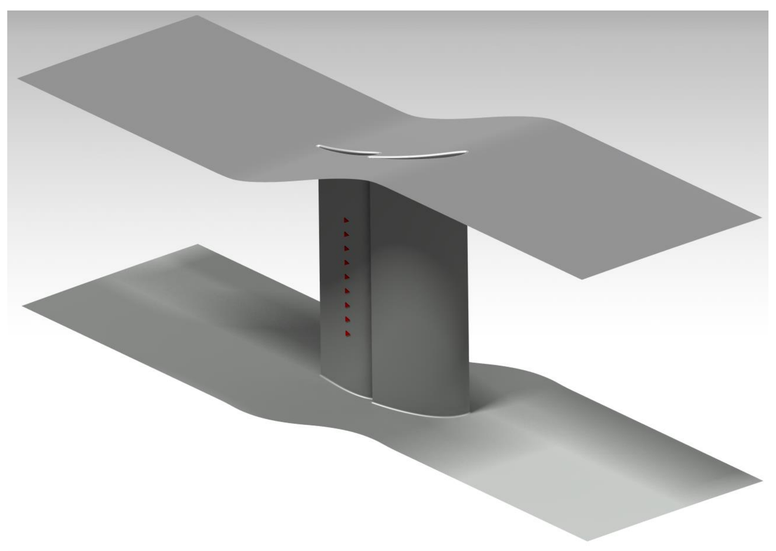

Fig. 7 TS with triangular surface structures on the RV.

Outlook

- Stabilize the BL and mitigate the risk of laminar flow separation.
- Achieve an optimal balance between low BL losses from extended laminar flow and high stability in the highly loaded turbulent BL region.
- Determine the most effective surface structure topology.

Measurement Techniques

Fig. 8 Pressure and temperature sensors SVMtec (top); CTA from DANTEC (bottom).

Used sensors

- Static airfoil surface pressure, wall shear stress (hot films), wake traversal (5-hole probes), velocity and turbulence (hot-wire probes), total temperature and pressure for operating point control.

Equipment

- PSC8 Rack (SVMtec) with 88 differential pressure sensors (2.5 kPa), TSC12-T Rack (SVMtec) with 12 Type-T thermocouples, StreamLine Pro Constant Temperature Anemometry (CTA) with 4 modules (DANTEC DYNAMICS).

Experimental Setup

The wind tunnel with WG

- The experimental setup utilizes a 7.339 m long wind tunnel, powered by a radial blower with a maximum output of 12.6 kW, capable of generating flow velocities up to $Ma = 0.137$, depending on the nozzle configuration.
- The WG consists of a rotatable platform integrating the airfoil carrier, an electric motor, a rotating bar system, and upstream/downstream traversal access.
- The WG enables $\pm 10°$ rotation around the design incidence and features adjustable endwall panels to compensate for any resulting gaps.
- The airfoil carrier accommodates 5 SS vanes or 3 TS vanes, plus two fake blades serving as channel barriers.
- The modular WG design allows for quick and easy exchange of the entire airfoil carrier to facilitate different test configurations.
- The bar pitch is adjustable to match the airfoil pitch.
- The WG has a maximum power output of 5.5 kW, achieving a bar speed of 25 m/s, with the potential to increase up to 35 m/s.

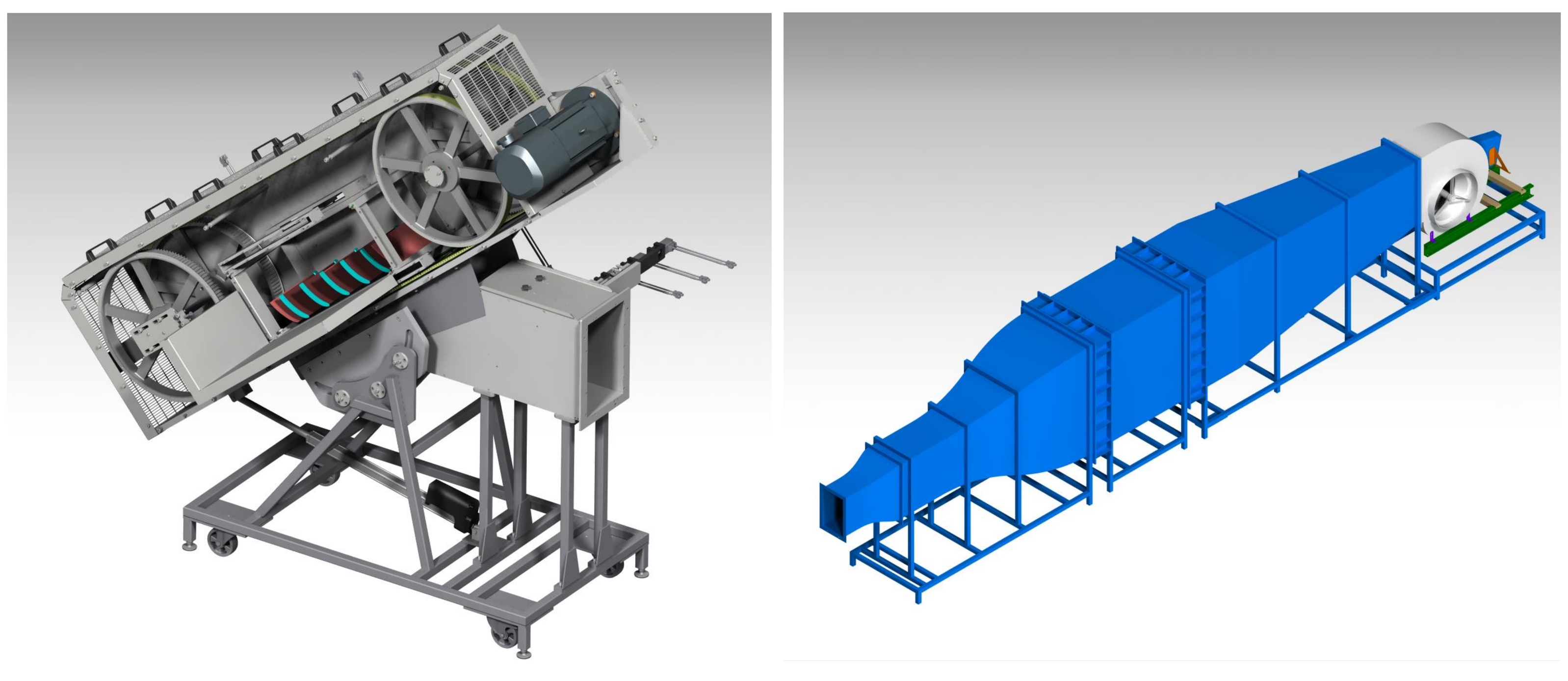

Fig. 9 Isometric view of the WG (left) and the current wind tunnel (right).

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