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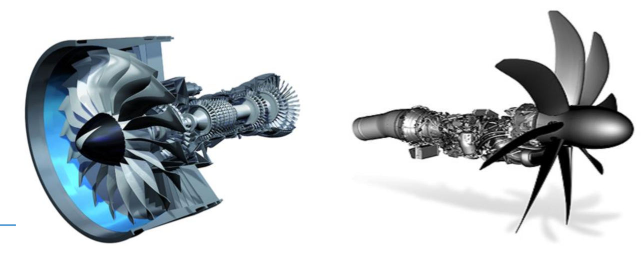
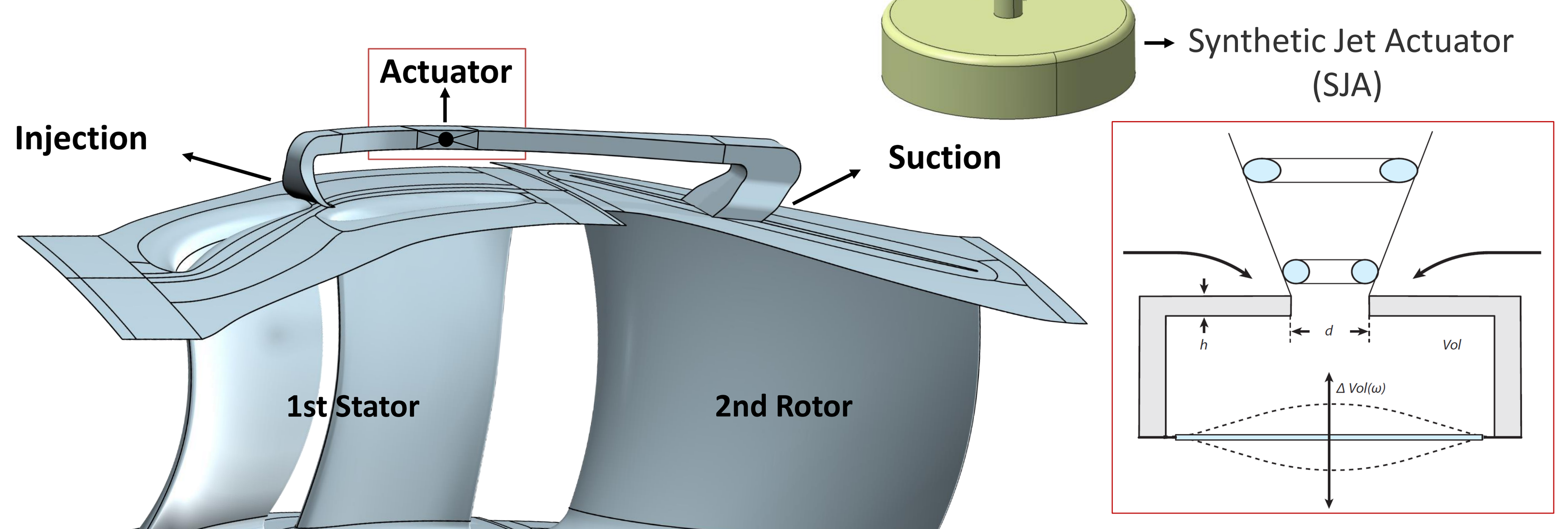


AKTIVER: Active Flow Control in Compressor Components for Future Aircraft Engines

Introduction

Project Goal

Develop an innovative Active Flow Control (AFC) system to enhance compressor performance using a recirculation channel that combines suction with actuator-regulated injection at the casing.

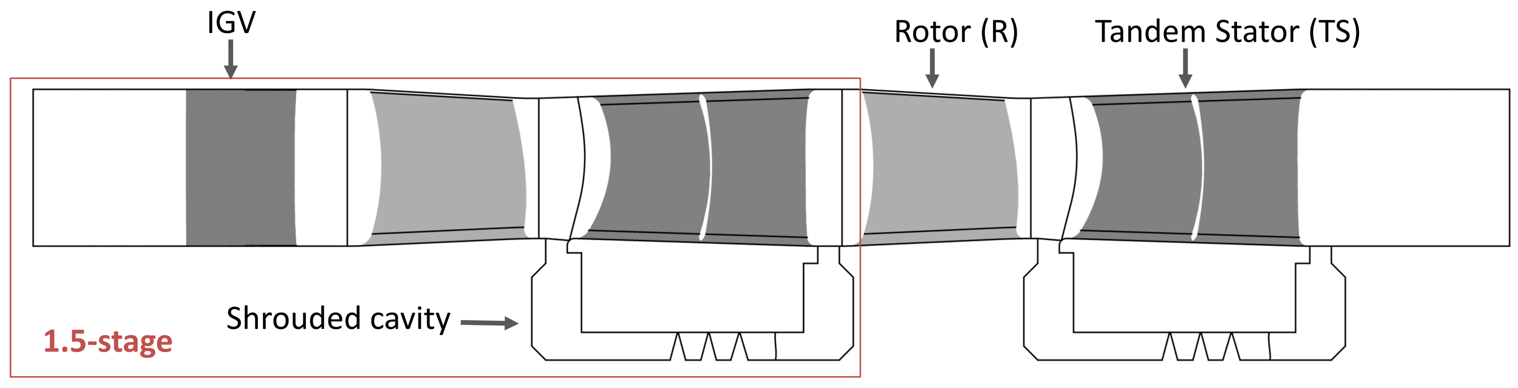


SJAs generate jets via an oscillating membrane, periodically expelling and ingesting fluid into and from a cavity.

Fig. 1 AFC system concept.

Baseline configuration

The FRANCC (Fundamental Research and New Concepts Compressor) features highly loaded 3.5 stages designed for advanced performance analysis. Initial studies were conducted on a 1.5-stage preliminary design, which were later extended to a 2.5-stage configuration with updated geometric features and experimental validation.

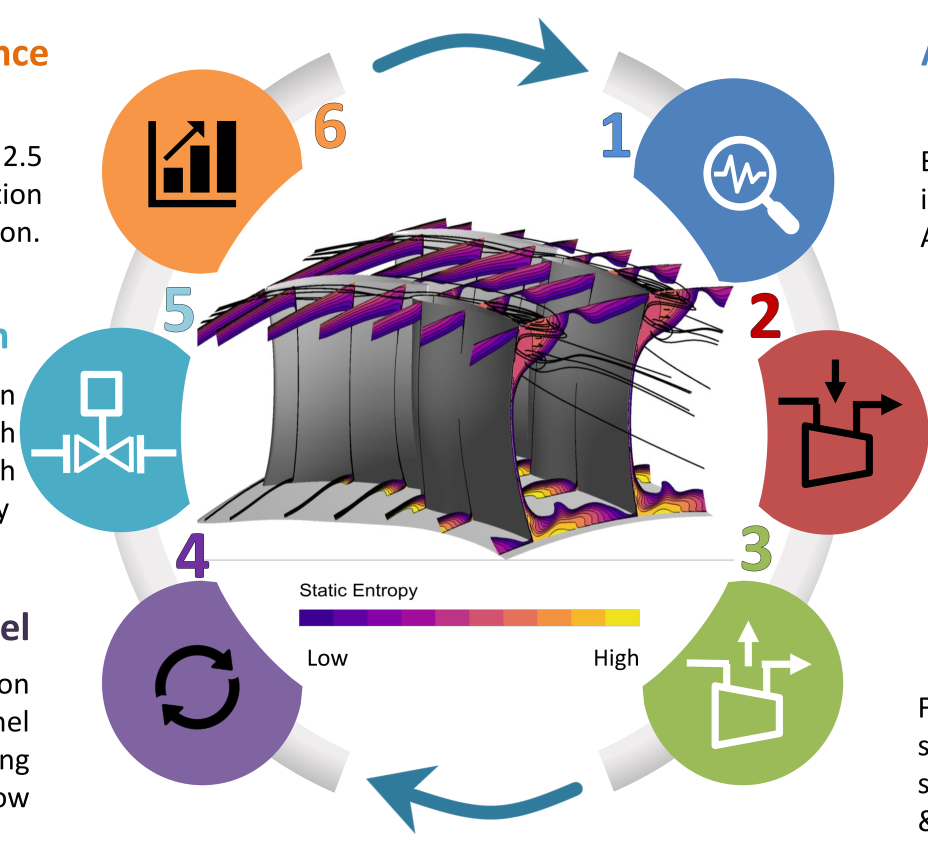


Blade count	Design rotational speed	Inlet Design corrected $\dot{m}$	Design flow coefficient	Design work coefficient	Hub-to-Tip Ratio
40 (IGV), 40 (R), 40 (TS)	1485.24 rpm	17.95 kg/s	0.57	0.59	0.8

Fig. 2 Meridional view and main parameters of the reference low-speed 2.5-stage axial compressor.

Methodology

Study phases



Evaluate performance improvement (6)
Evaluate AFC benefits in 2.5 stages considering actuation costs and blade optimization.

Analyze compressor performance (1)
Baseline performance to identify loss regions & best AFC locations.

Injection sensitivity study (2)
Focused on first stator: design slot geometry, and determine ideal injection locations.

Bleeding sensitivity study (3)
Focused on the second stage rotor: Design suction slots to optimize geometry & locations.

Recirculation channel (4)
Connect injection & suction locations, evaluate channel configurations determining dimensions and mass flow rates.

Actuator integration (5)
Integrate actuator design into AFC system through boundary conditions, with potential for real geometry

Numerical Validation & Modeling

- **Compressor model:** The 3.5-stage compressor model is validated against experiments, forming the basis for AFC studies using steady-state and transient simulations.
- **Surface Modeling:** Parameterized CAD models enable flexible design of slots, channels, and actuators for the AFC system.

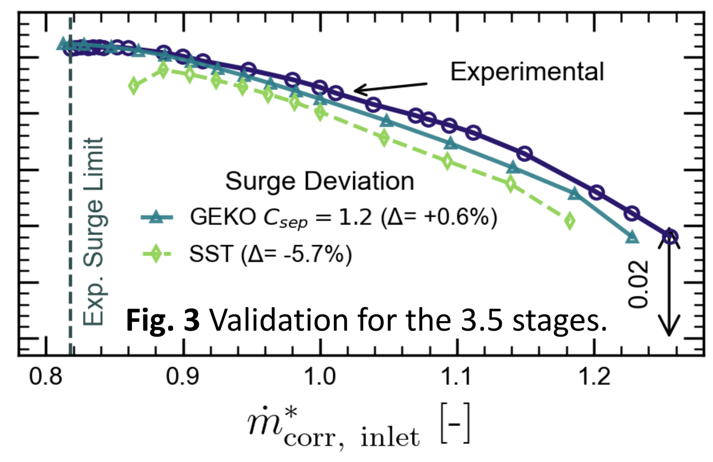


Fig. 3 Validation for the 3.5 stages.

- **Actuator Modeling:** Synthetic Jet Actuators (SJAs) are designed by simulations with dynamic meshing for standalone use and integration into the recirculation channel.

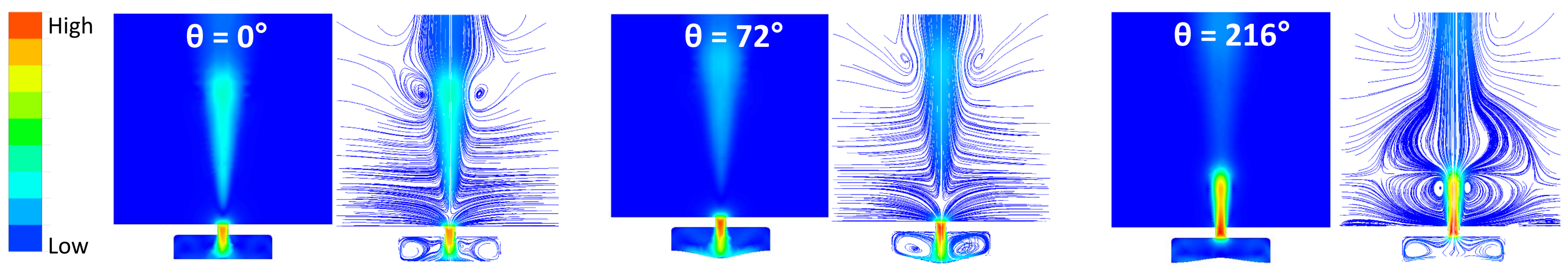


Fig. 4 Instantaneous internal and external flowfields, θ denotes the phase angle of the jet oscillation period.

Results

Injection study

The aerodynamic effect of injection in the Tandem Stator is studied through a parametric analysis of the injector geometry and location using RANS simulations. The Coanda configuration, characterized by its radius of curvature, is optimized by tuning key geometrical parameters and the injection ratio for an optimal balance of momentum coefficient and space constraints. The injector location varies from the pressure side of the Front Vane (FV) to the suction side of the Rear Vane (RV), expressed as a normalized Chordwise Location (ζ) in terms of chord fraction (z).

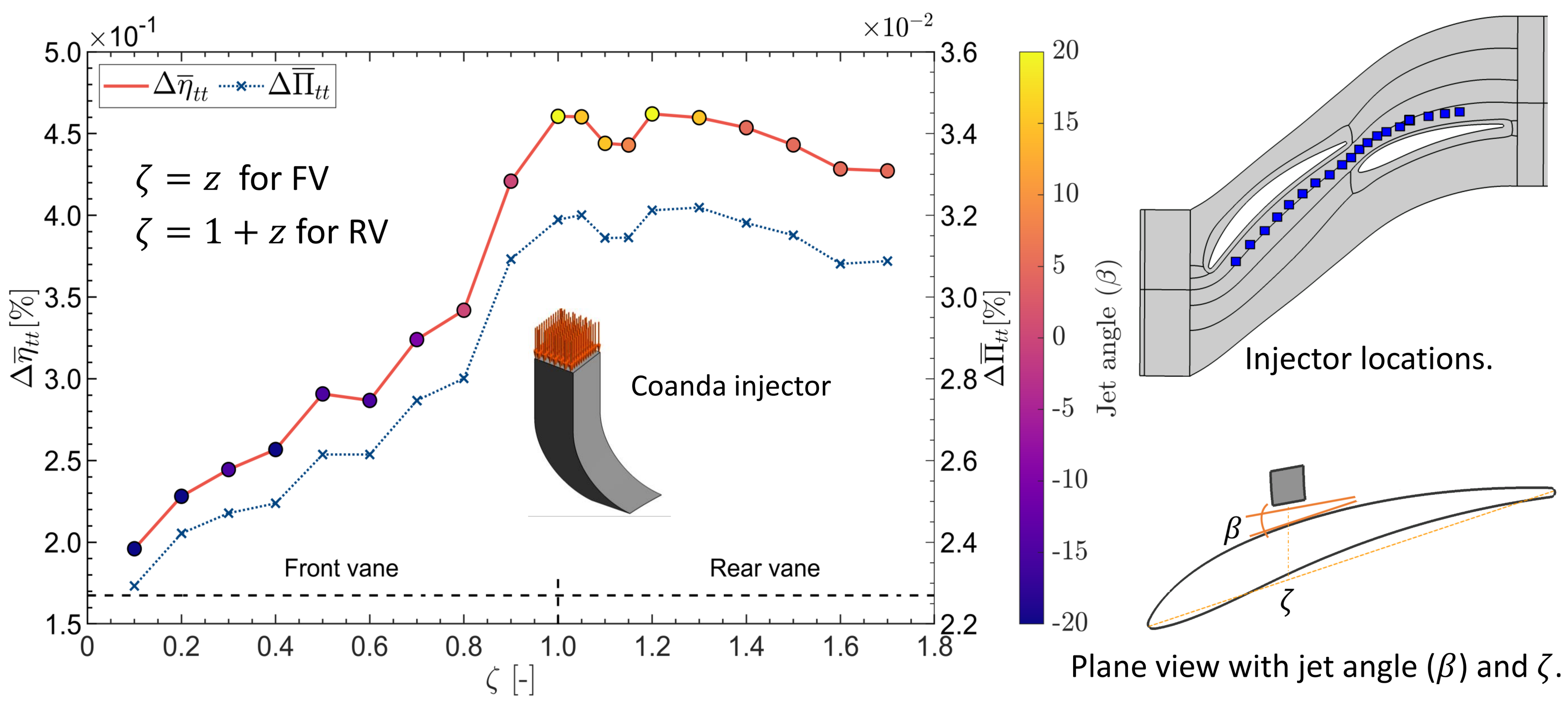


Fig. 5 Efficiency and Total pressure ratio variations with injector location. The colormap indicates the jet angle which indicates the alignment of the injector relative to the blade.

Injection is beneficial across all examined locations, with the largest benefits in the tandem gap area and the rear vane suction side.

Suction study

Suction slot refinement was studied using a circumferential casing slot modeled in the rotor frame with RANS. Beneficial rotor suction locations were found between 50–70% chord length, with inclination angles of 60–90°. These findings will guide the integration of discrete suction slots in the final recirculation channel geometry.

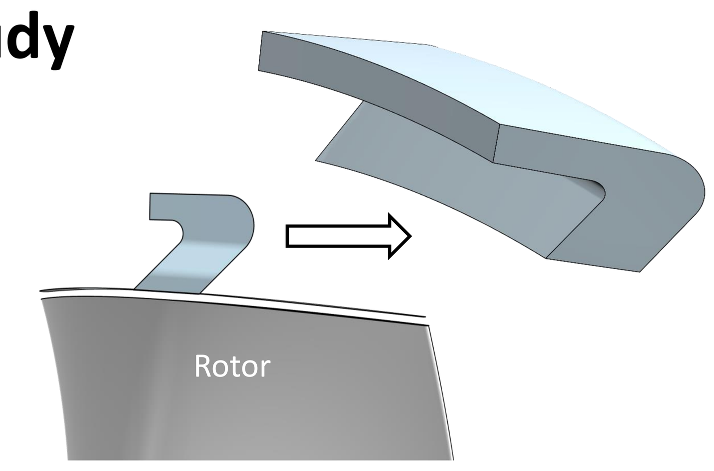


Fig. 6 Axial and 3D view of circumferential suction slot.

Flow Control via Recirculation and Actuation

- A preliminary channel model features a Coanda injector in the first stator (S1) and a suction patch at the second rotor (R2) outlet to redirect flow from R2 to S1. SJA enhances this effect by adding periodic momentum, modeled via boundary conditions

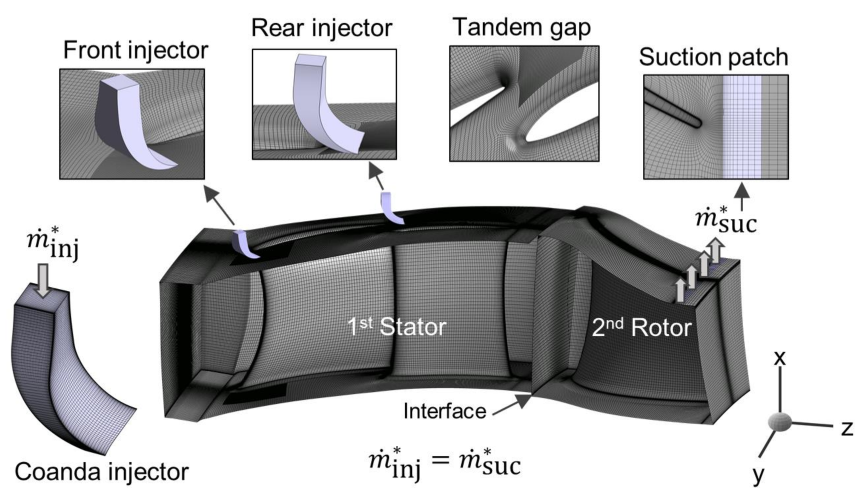


Fig. 7 Mesh showing injector and suction patch locations.

- The recirculation channel provides steady injection but has limited momentum transfer, while SJA alone causes strong internal recirculation. Adding SJA enhances jet strength without disrupting the flow.

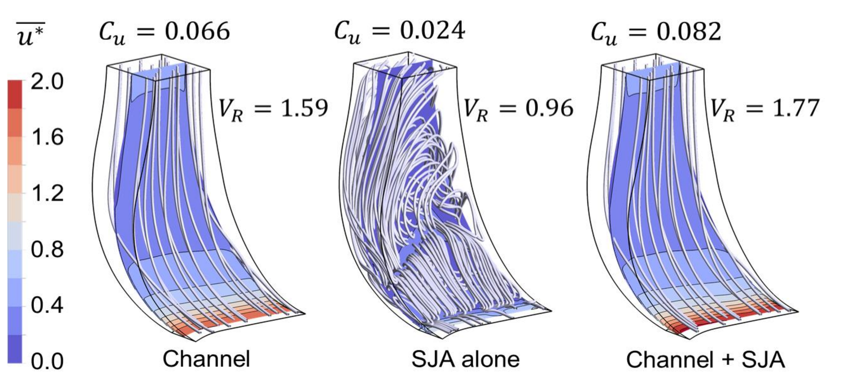


Fig. 8 Velocity field for different flow control configurations.

- Increasing SJA velocity amplitudes improves S1 performance but induces redistribution effects in R2. The optimal frequency is 1–2 times the Blade Passing Frequency (BPF). Phase effects are minor for S1 but more influential in R2.

Case	Frequency	Velocity peak
Ref	1 BPF	20 m/s
30U	1 BPF	30 m/s
2F	2 BPF	20 m/s

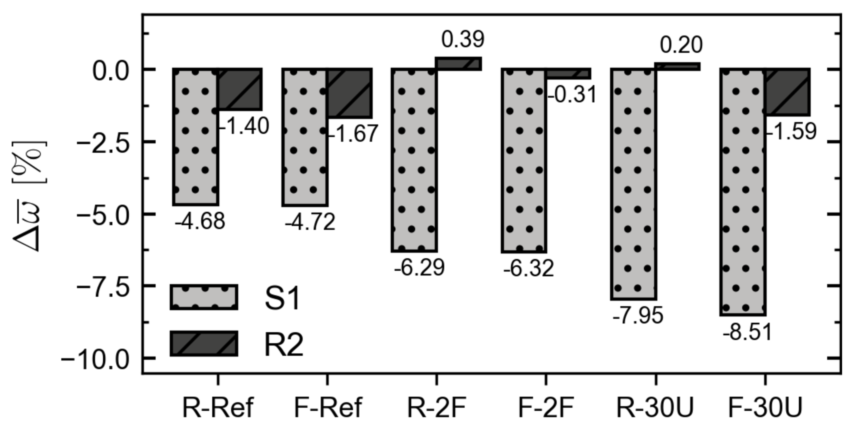


Fig. 9 Loss reductions in S1 & R2 for refined configurations.

- Refined configurations were analyzed for rear (R) and front (F) injectors. The F-30U case performs best, reducing S1 losses by 8.5% at the design point while maintaining rotor stability across operating conditions with an efficient actuation cost.
- The next phase will establish the final channel geometry, integrating refined suction and injection slots to determine the precise baseline mass flow. SJA will be included, initially using boundary conditions, with potential for actuator geometry later.

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