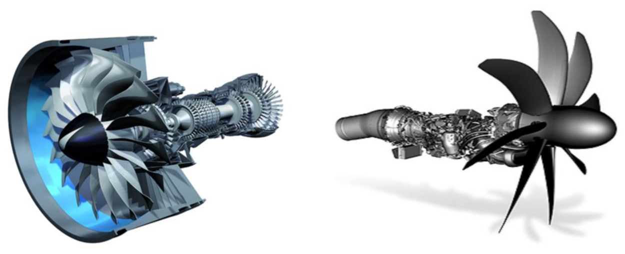
Institute of Turbomachinery and Flight Propulsion
Department of Aerospace and Geodesy
TUM School of Engineering and Design
Technical University of Munich



Potential Analysis and Concept Development for Tip Clearance Control in Axial Compressors

Introduction

Motivation and Objectives

The strive for higher compression rates on future aero engines increases compressor sensibility to tip gap detrimental effects. Moreover, the transient nature of engine operation makes tighter clearance design unrealizable. Motivated by this, the current research has the following objectives:

- Numerical modeling of relevant geometry;
- Assessment of thermal concepts for compressor TCC;
- Detailed modeling of chosen concept;
- Model reduction aiming at concept integration into preliminary design.

Reference Geometry

The reference geometry represents the rear section of a 10-stage axial compressor with a design PR of 17. The rear section was modelled with focus on stage 9.

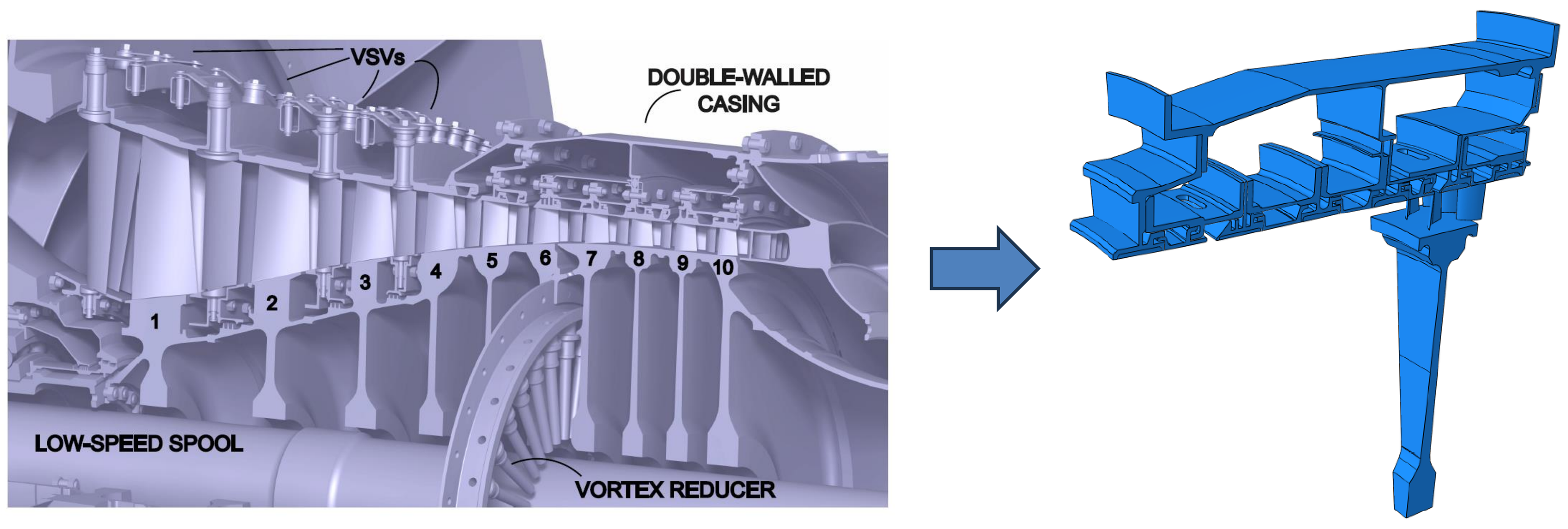


Fig. 1 Reference geometry and modeled section.

Preliminary Concept Assessment

Heat Pipes

Heat pipes are sealed two-phase devices which take advantage of vaporization and fluid flow to effectively transport heat. Screen meshes in the inner walls provide capillary forces to ensure the presence of a liquid film. Different phenomena define the operational envelope of such devices.

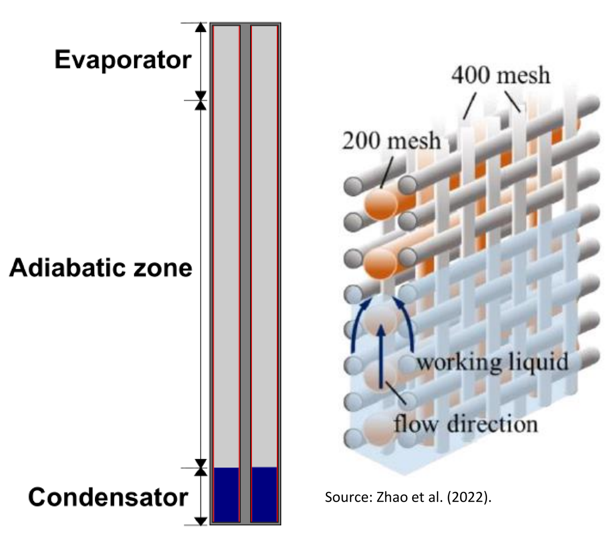


Fig. 2 HP geometry and screen mesh concept.

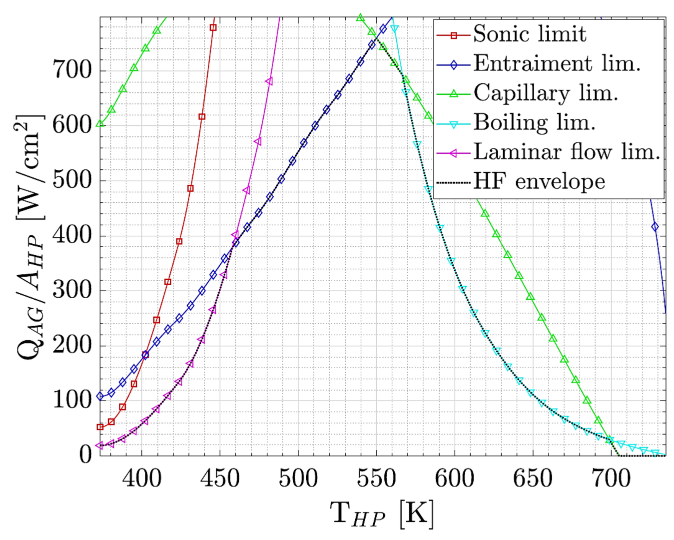


Fig. 3 HP theoretical operational envelope.

Impingement Cooling

Impingement is an effective method to realize surface cooling. In combination with heat pipes, localized heat removal can be achieved with minor structural modifications.

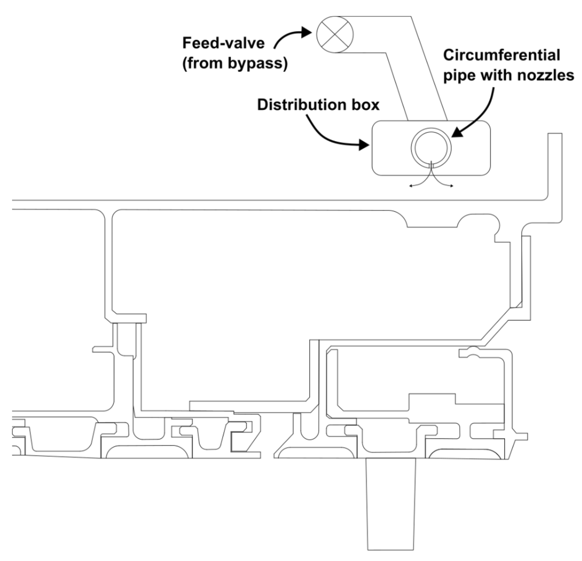


Fig. 4 External cooling system concept.

Tab. 1 Cooling air properties from correlation-based model.

Re_j [–]	13859
Ma_j [–]	0.433
D_j [mm]	3.0
N_j [–]	130
$\dot{m}_j$ [g/s]	0.57
$\dot{m}_{total}$ [g/s]	74.12
$p_{s,j}/p_{s,amb}$ [–]	1.10
$p_{t,pl}$ [kPa]	50.67
α_j [$W/m^2.K$]	321.1

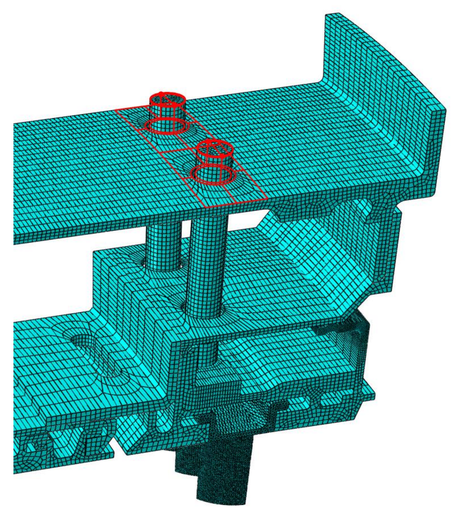


Fig. 5 FEM implementation.

Preliminary Assessment Results

Clearance Closure with Localized Effect

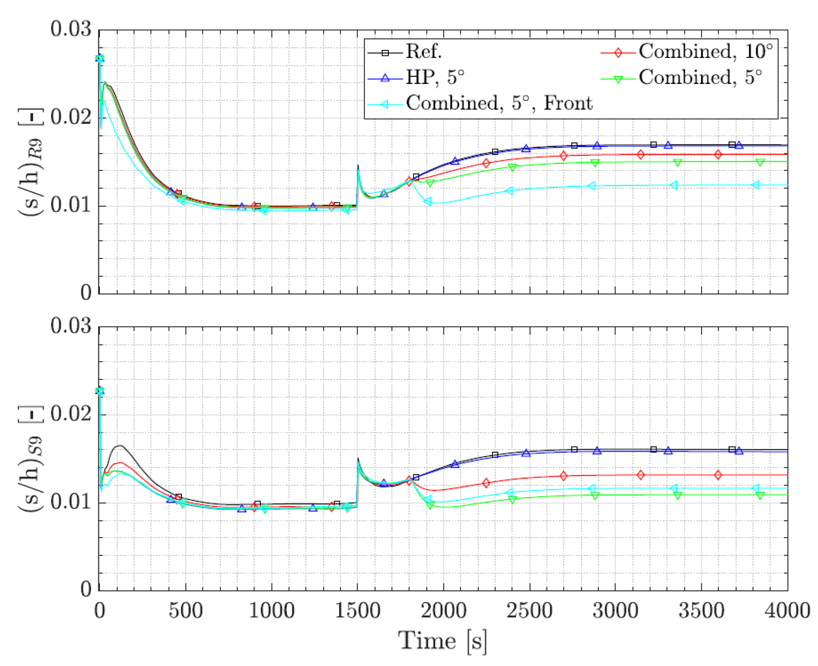


Fig. 6 Stage 9 relative clearances.

FEM calculations have shown positive influence of the combined concept over cruise tip clearances, with around of 0.5% of closure. Isolated concepts were limited in their influence. Also, different heat pipe positioning highlighted the localized effects of the system.

Outlook

Future research steps include:

- Coupling of solid-equivalent HP model on the FEM environment for proper structural integration;
- Thermostructural optimization of integrated system;
- Detailed modeling and optimization of impingement cooling system.

Detailed Heat Pipe Model

CHT and Solid-Equivalent Model

A dual modeling approach for the heat pipes was implemented aiming at cost-effectively reproducing HP behavior. A conduction-equivalent model based on simplifying assumptions provides good approximations for wall temperatures at very low computation effort. The CHT model provides a complete picture of the thermofluidic regime inside the device. The calculated pressure drops can be use to assess whether the wick is able to sustain the cyclic flow at the given operational condition.

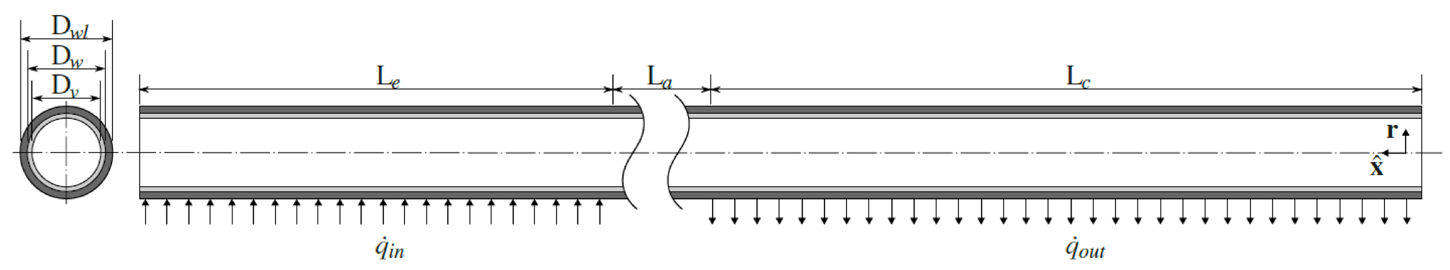


Fig. 7 Geometry of modeled heat pipe.

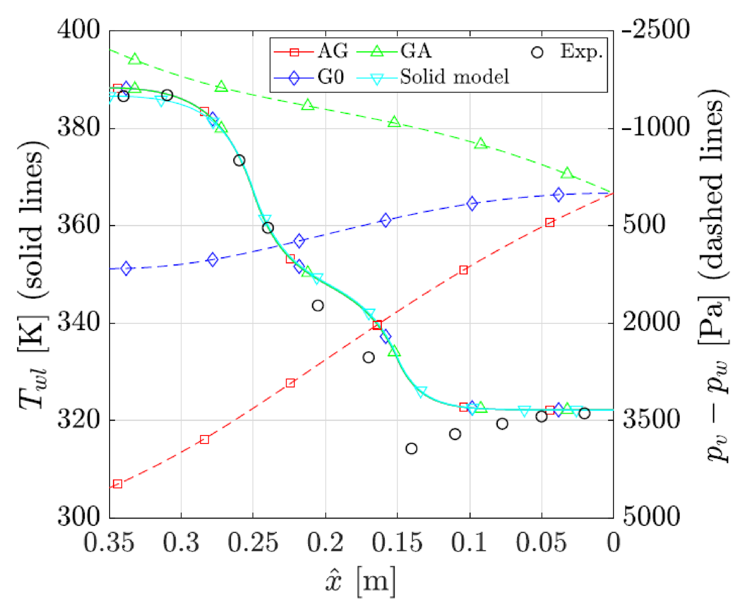


Fig. 8 Wall temperatures and wick pressure drops for different HP orientations.

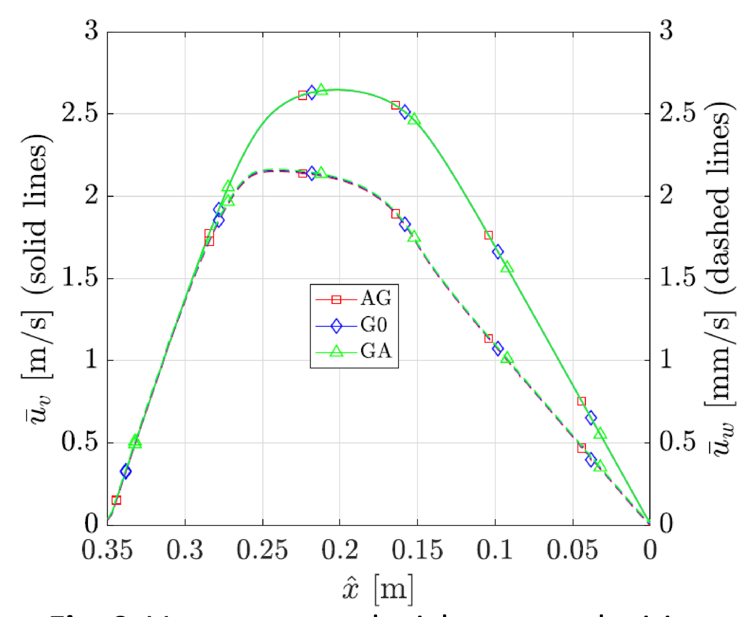


Fig. 9 Vapor core and wick mean velocities.