TECHNISCHE UNIVERSITÄT DRESDEN

Annular High-Pressure Turbine Test Rig for the Investigation of Secondary Flow Structures

Hans Hager(TUD) // Martin Lange (TUD) // Anna-Lisa Laufer (GE Aerospace) // Marios Patinios (GE Aerospace) // Ronald Mailach (TUD)

Motivation

The ongoing development of high-pressure turbines (HPT) in jet engines and stationary gas turbines, yields for higher efficiencies. Modern engines are required to operate at higher temperatures and total pressure ratios, which adds significant challenges to the study of high-performance high-pressure turbines—particularly due to rising secondary flow losses in the low aspect ratio vanes. The secondary flows, shown in Fig. 1, can account for up to 50% of the total vane loss. With increasing performance requirements, their contribution is expected to grow further. To assess the contribution of the individual effects, the full annulus high-pressure turbine cascade rig (FAHR) , was developed (see Fig.2).

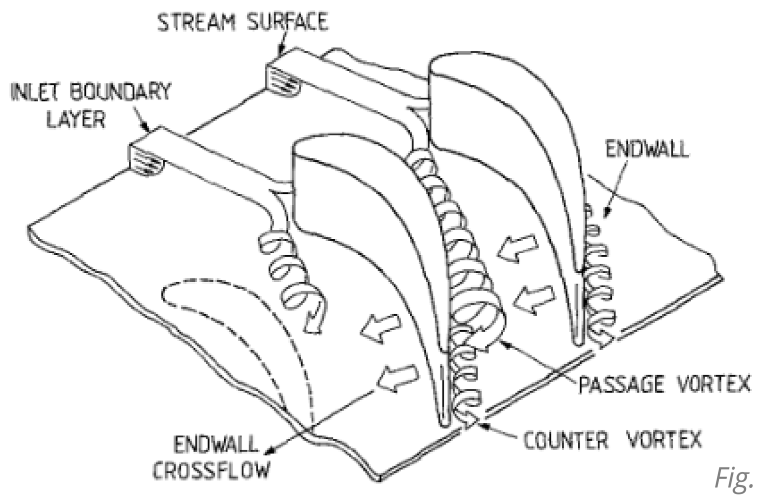

Fig. 1

It operates at Mach number similarity with vane sizes close to true scale. The vanes are assembled into a full annulus vane row cascade.

Sectorized Cascade

The cascade consists out of 48 vanes, adapted from the design of a modern second-stage high-pressure turbine. For this investigation two vane profiles, front-loaded and aft-loaded, have been designed by GE Aerospace. For both vane designs, a basic geometry and one with increased fillet radius and trailing edge thickness (TET) have been implemented in a sectorized vane row, see Fig. 3. To ensure flow uniformity, both vane designs feature similar throat areas and nearly identical inlet angles and nearly identical exit angles at the design point.

Sectorization

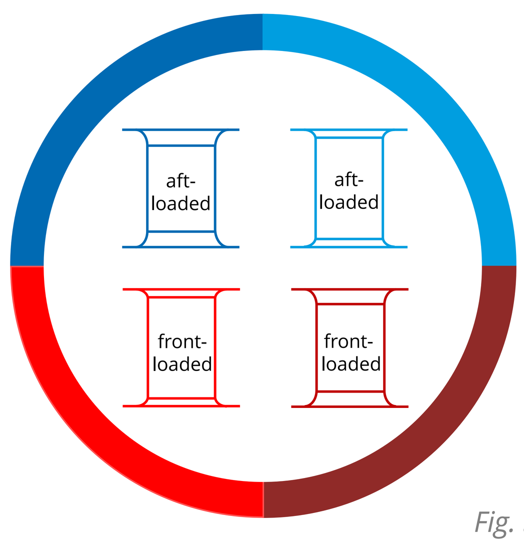

Fig. 3

Inlet static pressure

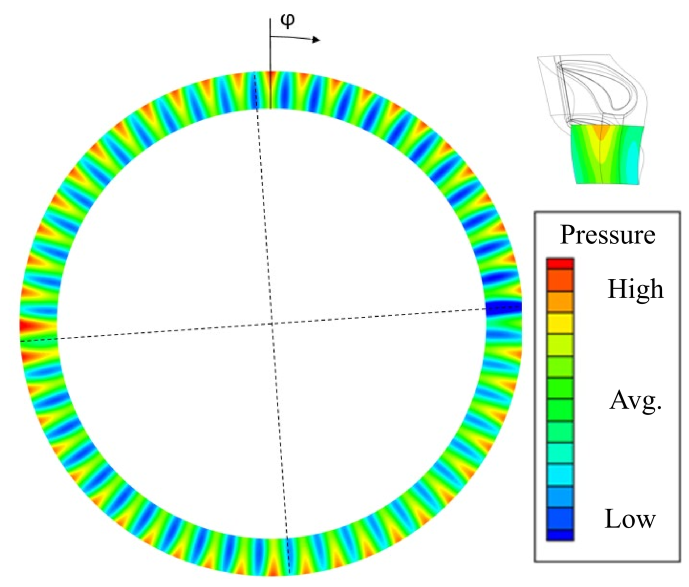

Fig. 4

Pretest CFD results, see Fig. 4, revealed that the flow uniformity is disrupted at the boundaries between the sectors, but not in the mid-passages of each sector. Experiments verified that the influence on mid-passages is negligible.

Instrumentation

- Five-hole probes (see Fig. 5)
- Hot wire probes (see Fig. 6)
- Profile pressure taps
- Various p_t-rakes, boundary layer-rakes, static pressure taps and temperature probes

Inlet Flow Conditioning

- Inlet grids
  - Turbulence quantities
  - Radial p_t distribution
- Inlet Guide Vanes (IGV)
  - Inlet swirl

Fig. 5

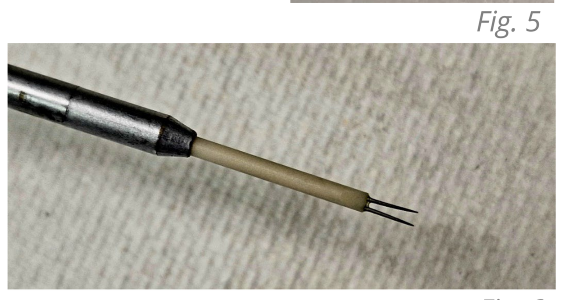

Fig. 6

Exemplary Results

Increase of feature size:

- increases secondary loss core size (see Fig.7)
- shifts the secondary loss cores towards midspan (see Fig.7)
- influences vortex interactions (see Fig.8)

* Base features references a front-loaded vane with fillet radius and trailing edge thickness having a conventional size. Large features references the same vane with doubled fillet radius and doubled trailing edge thickness.

Total pressure loss coefficient $\zeta = \frac{\overline{p_{t,IN}} - \overline{p_{t,EX}}}{\overline{p_{t,EX}} - \overline{p_{s,EX}}}$

Vorticity in axial direction $\overrightarrow{\omega_z} = \frac{\partial \vec{u}_x}{\partial y} - \frac{\partial \vec{u}_y}{\partial x}$

Base features* Large features*

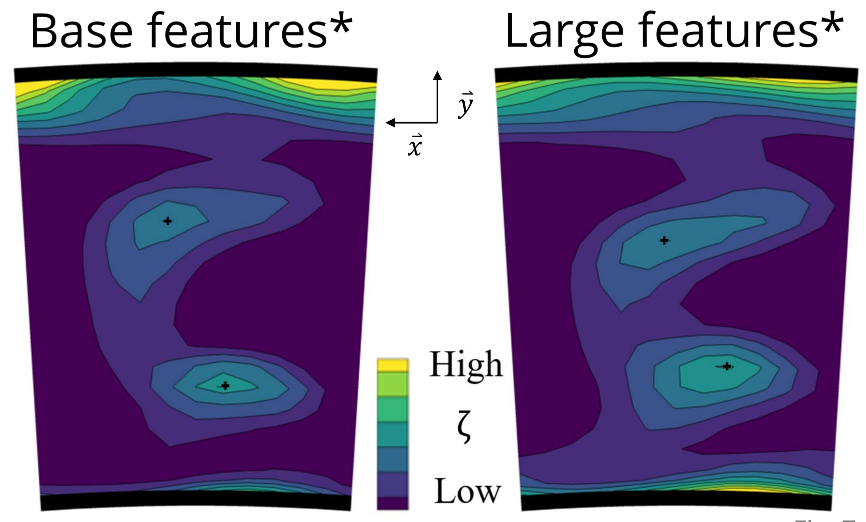

Fig. 7

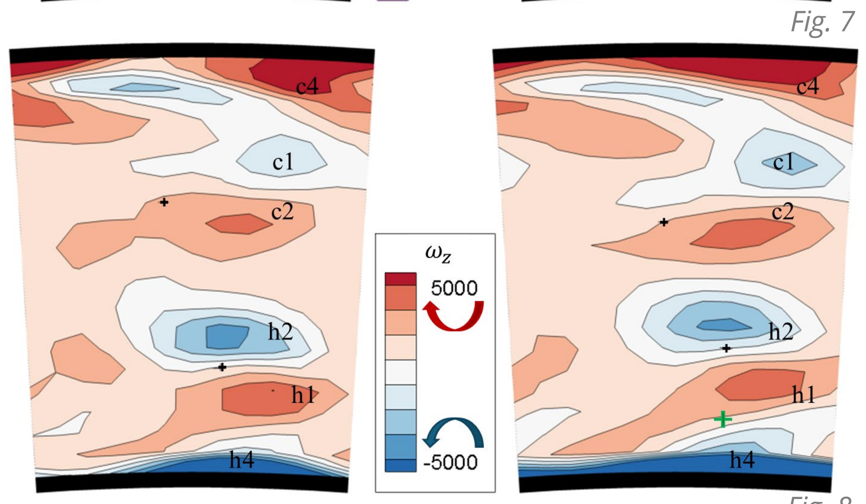

Fig. 8

Rig Cross Section

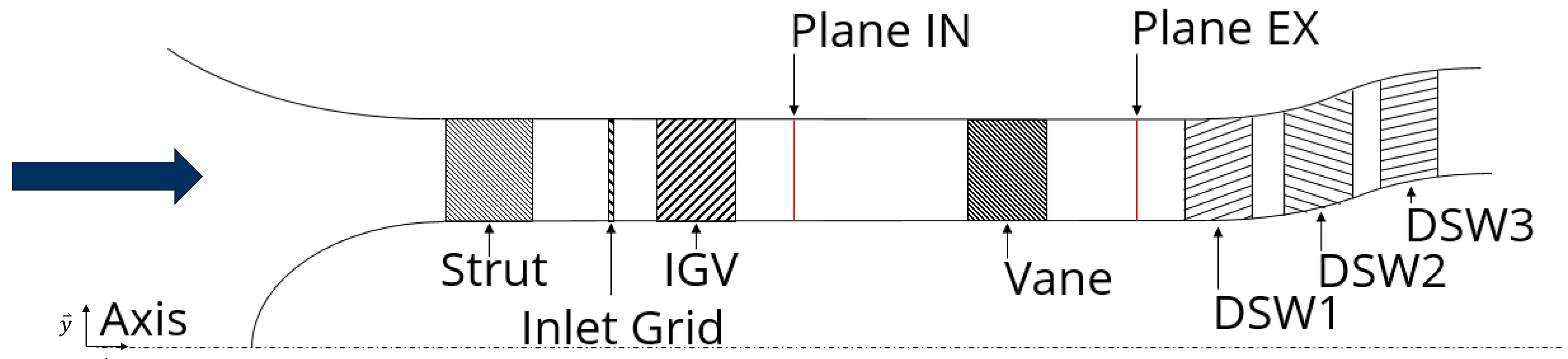

Fig. 2

Figures:

Fig. 1 Secondary flows in turbine vanes (simplified) [1]
Fig. 2 Simplified cross section of rig
Fig. 3 Sectorization of full annulus
Fig. 4 Static pressure field ~ 50% chord length upstream of vanes
Fig. 5 Five-hole probe
Fig. 6 Hot wire probe
Fig. 7 Total pressure loss contours for geometry variation
Fig. 8 Z-vorticity contours for geometry variation

Source:

[1] L. S. Langston, "Secondary Flows in Axial Turbines-A Review" Ann. N. Y. Acad. Sci., 934(1), 2006, doi: 10.1111/j.1749-6632.2001.tb05839.x

Member of the network of: DRESDEN concept SCIENCE AND INNOVATION CAMPUS

Co-funded by: Bayerisches Staatsministerium für Wirtschaft, Landesentwicklung und Energie

GE Aerospace