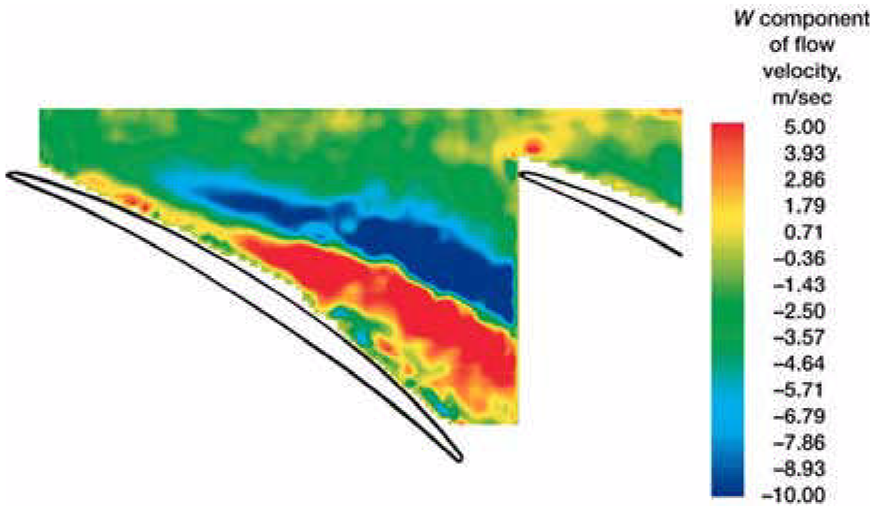
Tip-Clearance Vortex Characterized With Three-Dimensional Digital Particle Image Velocimetry

An optical measurement technique known as Three-Dimensional Digital Particle Image Velocimetry (3-D DPIV) was used to characterize the tip clearance flow in NASA Glenn Research Center's low-speed axial compressor. 3-D DPIV is a technique in which a stereoscopic imaging system consisting of two cross-correlation cameras is used to record particles entrained in a flow as a laser light sheet is pulsed at two instances in time. Although 3-D DPIV has been used elsewhere, this is the first time it has been used to measure compressor tip clearance flows. In-house modifications of the DPIV system include the use of effective seeding technology and a novel system to perform a priori calibrations at all five measurement planes, greatly reducing facility run time.

Computational fluid dynamics predictions, which are used to guide design changes toward improving the efficiency and operating range of turbomachinery, can be verified and improved by comparison with 3-D DPIV measurements of the actual tip clearance flow. This measurement campaign dealt with the characterization of the tip clearance vortex in the first stage of a four-stage axial compressor. The tip clearance vortex is formed in compressors operating with a clearance gap between the moving rotor blade tips and the stationary casing when a leakage flow, forced from the pressure side of the blade over the blade tip, forms a vortical structure on the suction side of the blade.

3-D DPIV is ideally suited to measure the clearance vortex for two reasons: (1) this technique captures the entire blade passage flow at one instant in time, so that wandering of the vortex during the measurement does not smear out velocity gradients in the flow field, and (2) the spanwise component of velocity changes sign across the vortex core, providing a more accurate measurement of the vortex location than was available with previous two-dimensional measurement approaches. These two attributes of the data will enable computational fluid dynamics researchers to validate their predictions to a level of accuracy not previously attainable.

In an effort to understand the effects of this flow phenomenon on the operation of the low-speed axial compressor, data were acquired at two mass flow coefficients: 0.395 (design operating point) and 0.35 (operating point just above stall). In order to identify the spatial extent, location, and magnitude of the tip clearance vortex for each mass flow condition, data were acquired at five equally spaced spanwise locations, from 90- to 100-percent span. The data in the figure show a cross section of the tip clearance vortex at 94-percent span and a mass flow coefficient of 0.395, where the color contours represent the radial velocity component. The blue (flow towards the hub) and red (flow towards the casing) regions illustrate the extent of the tip clearance vortex. The interface between the blue and red regions delineates the location of the vortex core.



A cross section of flow within a low-speed compressor shows a strong tip clearance vortex. The color contours indicate the magnitude of the radial velocity component. The blade tips are outlined in black.

Find out more about this research.
http://www.grc.nasa.gov/WWW/OptInstr/au/folkmpw.html

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