

STEM

Experimental Investigation of Hub Leakage Flow Through Stator Knife Seals in an Axial Compressor

Student researcher:
Jordan K. Lewis, Senior

When looking at the efficiency of a high-speed compressor, secondary leakage flow through the stator hubs can influence the compressor's performance. Compressors work by passing a fluid between alternating rotational and stationary reference frames, further diffusing the flow in each stage. The static pressure in the system increases with each stage as the flow diffuses. The fluid will always want to flow from high pressure to low pressure, resulting in flow leaking backward through the compressor. Computational fluid dynamics (CFD) programs are useful tools for predicting how a compressor design under various operating conditions will affect the performance. CFD works with set boundary conditions for the flow through the system; however, boundary conditions modeling secondary leakage flows are difficult to model and implement, as outlined in "An Experimental Characterization of Tip Leakage Flows and Corresponding Effects on Multistage Compressor Performance," a 2015 PhD dissertation at by Purdue University's R. A. Berdanier.

The purpose of this experiment was to quantify how much flow is leaking through the shrouded stator cavities and to provide data that can be used as boundary conditions to calibrate and validate a CFD mesh of flow through the compressor. The primary measurement device in this experiment was a piezoresistive Kulite pressure transducer. An LQ-062 Kulite transducer was placed on each side of the knife seal for stators 1 and 2. Each pressure transducer measured the resulting voltage at each operating condition, and through a voltage pressure calibration the difference between the upstream and downstream pressure measurements was calculated.

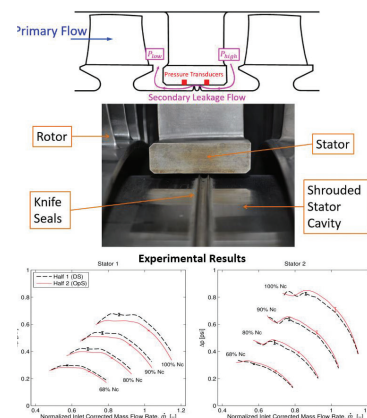
The testing consisted of running the compressor at speeds of 68%, 80%, 90%, and 100%. Data points from the transducers were taken intermittently as the throttle was adjusted to provide a range of corrected mass flow rates. The experiment was repeated multiple times on different days and on opposite halves of the compressor to account for leakage deviations from eccentricity of the rotor, manufacturing tolerances, and other geometric defects.

The data were processed and the change in pressure across the knife seals in stators 1 and 2 were plotted with respect to the normalized corrected flow rate. The resulting plot denoting the

knife seal pressure difference at constant speeds can be combined with a total pressure ratio map of the compressor to quantify the flow leaking through the knife seals at each operating point of the compressor. The measured secondary leakage flow can then be used to calibrate and validate a CFD model of secondary flows because the CFD has comparable experimental data allowing known boundary conditions to be created for the mesh.

These data are significant for the future development of CFD due to the ability to better predict losses in a compressor system. In addition to the opportunities for future CFD technology, some trends in the leakage flow also were discovered through this experiment. Particularly, in stator 2, there is a slight decrease in the knife seal pressure difference as the stability limit is approached. Further experimentation and analysis are recommended to determine the reasoning for why this phenomenon occurs.

Research advisor Nicole L. Key writes: "Secondary flows, including leakage flows, are challenging to model in multistage compressors, but they have tremendous impact on efficiency and stall margin. Jordan has developed a strategy for measuring the air leakage under shrouded stators, which will enable a deeper understanding of the flow physics associated with these secondary flows."



The schematic model of the experimental setup demonstrates the flow path of secondary leakage flows and the placement of the pressure transducers across the knife seals in the shrouded stator cavity. From conservation of momentum, the change in pressure (Δp) across the knife seals can be used to quantify the secondary leakage flow through the shrouded stator cavities, providing boundary conditions for a CFD mesh at various operating conditions.