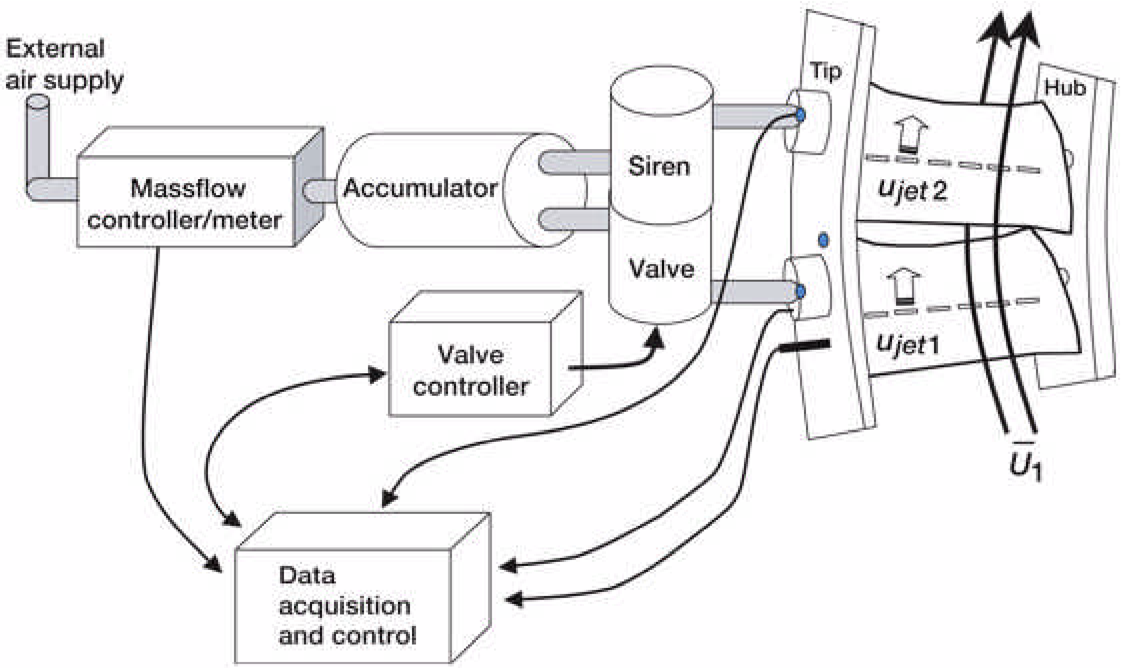
Active Closed-Loop Stator Vane Flow Control Demonstrated in a Low-Speed Multistage Compressor

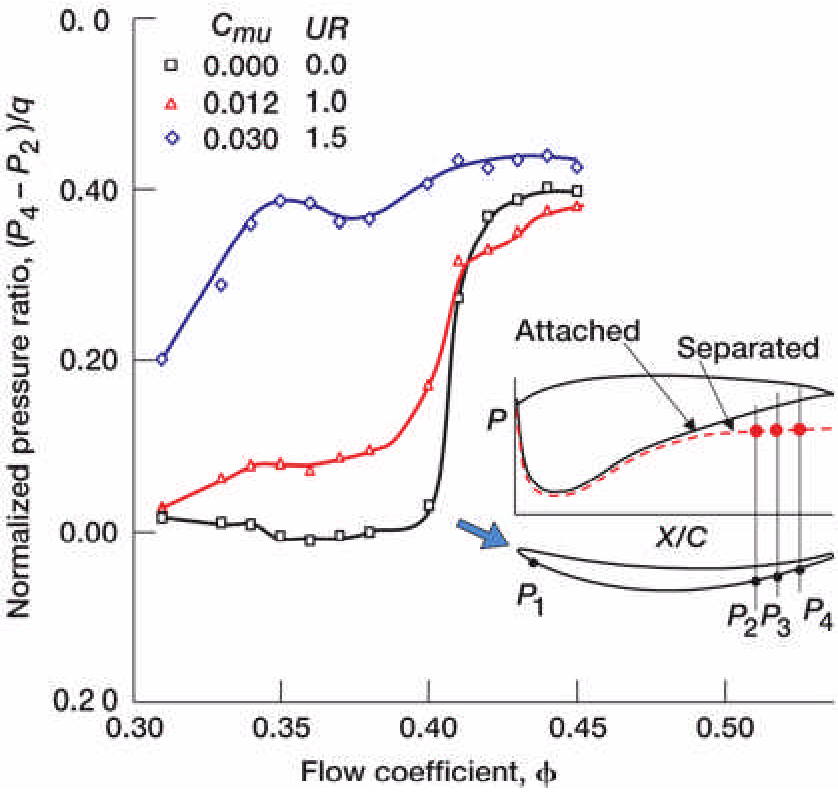
Closed-loop flow control was successfully demonstrated on the surface of stator vanes in NASA Glenn Research Center's Low-Speed Axial Compressor (LSAC) facility. This facility provides a flow field that accurately duplicates the aerodynamics of modern highly loaded compressors. Closed-loop active flow control uses sensors and actuators embedded within engine components to dynamically alter the internal flow path during off-nominal operation in order to optimize engine performance and maintain stable operation.



Flow-control actuation system. $\hat{U}_1$, *free-stream velocity;* u_{jet}, *jet velocity out of the vane.* Illustration showing external air supply, massflow controller/meter, accumulator, siren, valve, tip, hub, U_{jet} 1 and 2, valve contoller, and data acquisition and control.

In highly loaded modern compressors, the flow tends to separate from the stator airfoils under conditions of low mass flow and distortion. These conditions are often encountered during takeoff, landing, and (for military aircraft) the extreme maneuvers encountered during combat operations. Flow separation acts as a blockage in the flow path that limits pressure recovery and may even trigger the severe mechanical stress conditions known as stall and surge. Closed-loop active flow control uses sensors and actuators to sense and delay the onset of separation by injecting air ahead of the separation line. The preceding diagram shows the experimental configuration for the system, including surface static pressure taps to monitor separation along the stator, an unsteady pressure transducer in the compressor casing to monitor velocity perturbations from the downstream rotor, and a control computer to perform closed-loop detection of the pressure signals and to command the injection through the stator vane.

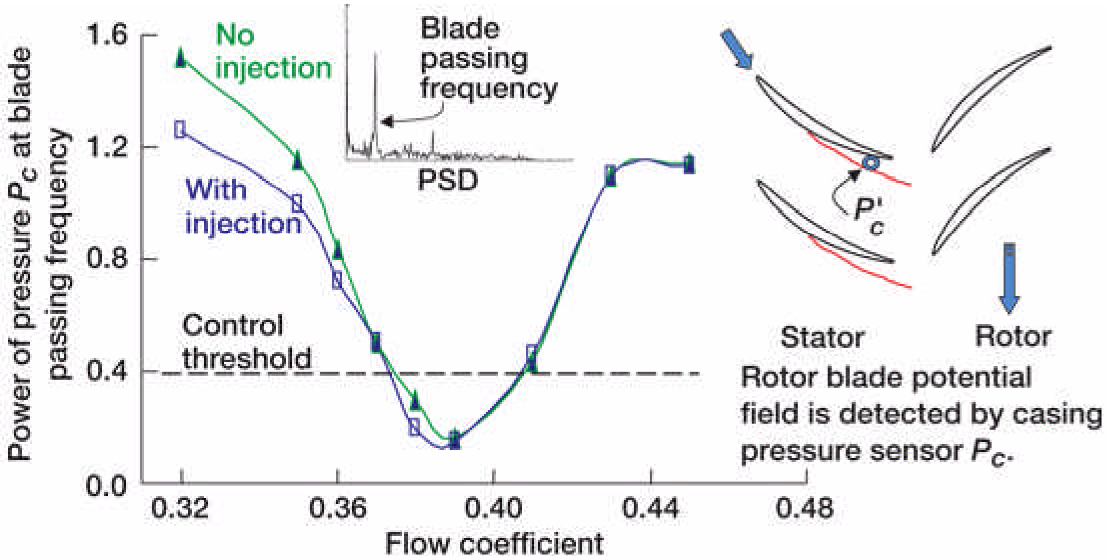
As part of this closed-loop control sys-tem, two methods were developed to determine separation along the vane. The first method employs suction-surface static pressure taps located at 70- and 85-percent chord and at 56-percent span. The pressure rise between these two locations provides the controller with the pressure gradient over the rear of the vane. The following figure shows the pressure rise measurements that were acquired over the vane with and without steady air injection. As the flow coefficient through the compressor decreased, separation occurred across the vane, which is shown as a drop in pressure rise at flow coefficients below 0.40. With the use of steady injection, this pressure rise was maintained across the vane. This strategy thus uses the pressure difference across the vane to monitor separation. When the pressure difference across the vane is greater than 0.3, a control command turns on injection.



Sensing separation from blade surface sensors. Surface static pressure gradient usable as control input. P_1, P_2, P_3, *and* P_4, *pressures along vanes;* C_{mu}, *momentum coefficient; UR, velocity ratio.*

Graph of normalized pressure ratio, (P_4 - P_2) divided by q, versus flow oefficient for various momentum coefficients and velocity ratios.

The second separation detection scheme (final figure) uses a pressure transducer located in the casing next to the vane suction surface at 85-percent chord. This scheme is based on time-series analysis of casing static pressure. The wake shed from the vane causes an unsteady loading on the downstream rotor. The first Fourier harmonic of the rotor blade passing frequency is a measure of the wake-induced pressure variation generated by the rotor. Since vane surface separation increases wake strength, separation can be detected from the casing static pressure signal by monitoring the power in the first harmonic (see the figure above). In a control strategy for the vane, the power of the first Fourier harmonic of the pressure signal is used to determine when to switch injection on. Both these strategies are detailed further in reference 1.



Sensing separation from casing static pressure. The rotor blade potential field is detected by the casing pressure sensor. PSD, power spectral density.

Graph of power of pressure P_c at blade passing frequency versus flow coefficient for data with injection and without injection, showing control-threshold line and sketch of stator and rotor blades. Rotor blade potential field is detected by the casing pressure sensor P_c.

This work describes two successful active flow-control strategies for compressors. Modern compressors must be designed to accommodate a broad range of operating conditions in a safe and efficient manner. Since overall engine performance is driven by compressor performance, advances in compressor technology that reduce weight and parts count, reduce fuel consumption, and lower maintenance costs will decrease the cost of aircraft ownership significantly. Active flow-control strategies may deliver such advances.

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Reference

1. Culley, Dennis E., et al.: Active Flow Separation Control of a Stator Vane Using Surface Injection in a Multistage Compressor Experiment. NASA/TM-2003-212356, 2003. http://gltrs.grc.nasa.gov/cgi-bin/GLTRS/browse.pl?2003/TM-2003 -

212356.html

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