# Active Pattern Factor Control for Gas Turbine Engines

Small variations in fuel/air mixture ratios within gas turbine combustors can result in measurable, and potentially detrimental, exit thermal gradients. Thermal gradients can increase emissions, as well as shorten the design life of downstream turbomachinery, particularly stator vanes. Uniform temperature profiles are usually sought through careful design and manufacturing of related combustor components. However, small component-to-component variations as well as numerous aging effects degrade system performance. To compensate for degraded thermal performance, researchers are investigating active, closed-loop control schemes. Most of this work is being done at AlliedSignal Engines under contract to the NASA Lewis Research Center (NASA Contract NAS3-27752).

Engine manufacturers assess thermal gradient performance by specifying and measuring a combustor's pattern factor (PF), which typically is defined as

$$PF = (T4_{peak} - T4_{avg})/T4_{avg}$$

where $T4$ refers to the combustor exit temperature. The specific control objective, then, is to reduce PF and subsequently achieve and maintain a more uniform, two-dimensional temperature profile at the combustor exit plane. The control system configuration includes temperature sensing, digitally implemented control logic, and variable fuel flow modulators. A schematic diagram of the configuration is shown in the following figure. This diagram also highlights an implementation design requirement. The PF control must be integrated with the existing fuel control design such that it does not affect the overall commanded power level of the engine.
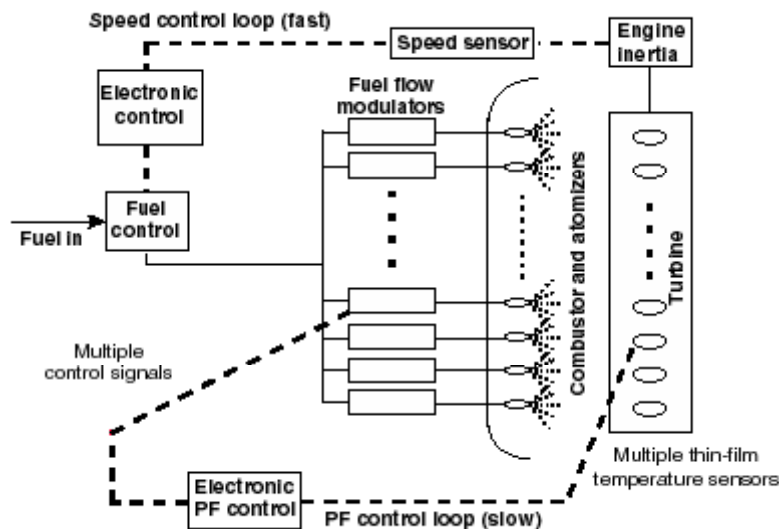
PF control system.

The PF control system is composed of multiple temperature sensors and fuel modulators circumferentially placed around the combustor. Sensor and actuator counts, and their

respective locations, have been determined from spatial resolution and controllability requirements. Several different state feedback control laws have been developed and analyzed. The schemes include optimal (or performance-index-based) control, proportional-integral control, harmonic control, peak detection/switching control, spatial averaging control, and fuzzy logic control. Simulation studies have been completed to determine the relative merits of each approach.
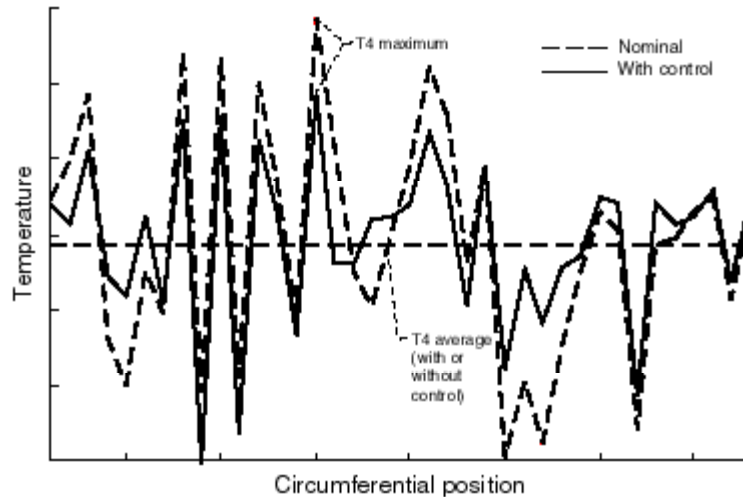
PF circumferential temperature profiles. Change in PF with control, -19 percent; change in rms with control, -34 percent.

This graph is an example of the simulation output showing the analytical effects of PF control on a nominally perturbed temperature profile. The dashed trace is that of the circumferential, nonuniform temperature profile with the PF control switched off. The solid trace shows the resultant temperature profile after closed-loop control is switched on. Although the temperature excursions from $T4_{avg}$ are not completely eliminated, peak temperatures are reduced. This equates to significant reduction in PF. Equally important, the average magnitude of the temperature excursions is notably reduced.

The next developmental step is to integrate the sensors, actuators, and control logic with actual combustor hardware to verify the analytical results. PF control is being developed by AlliedSignal Engines of Phoenix, Arizona, under NASA Lewis' Advanced Subsonic Technology (AST) Propulsion and Noise Reduction contract.

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