References

[1]Young, M., personal communication, Beltran, Inc., Brooklyn, NY, 1990.

[2]Hites, M. H., "Combustion of Metalized Propellants with Kevlar Fibers," M.S. Thesis, Univ. of Illinois at Urbana–Champaign, IL, 1992.

[3]Dold, J. W., "Flame Propagation in a Nonuniform Mixture: The Structure of Anchored Triple-Flames," *Dynamics of Reactive Systems*, Vol. 113, Progress in Astronautics and Aeronautics, AIAA, Washington, DC, 1988, pp. 240–248.

[4]Lewis, B., *Combustion, Flames, and Explosions of Gases*, 3rd ed., Academic, London, 1987, pp. 233–236.

[5]Brewster, M. Q., and Hardt, B. E., "Influence of Metal Agglomeration and Heat Feedback on Composite Propellant Burning Rate," *Journal of Propulsion and Power*, Vol. 7, No. 6, 1991, pp. 1076–1078.

[6]Price, E. W., "Combustion of Metalized Propellants," *Fundamentals of Solid-Propellant Combustion*, Vol. 90, Progress in Astronautics and Aeronautics, AIAA, New York, 1984, pp. 479–513.

Hot-Streak Clocking Effects in a 1-1/2 Stage Turbine

Daniel J. Dorney*
Western Michigan University, Kalamazoo, Michigan 49008-5065
and
Karen Gundy-Burlet†
NASA Ames Research Center, Moffett Field, California 94035

Nomenclature

C_t = ratio of local-to-freestream temperature
X = axial distance

Introduction

GAS turbine combustors can contain both circumferential and radial temperature gradients. These temperature gradients arise from the combination of the combustor core flow with the combustor bypass and combustor surface cooling flows. It has been shown both experimentally (e.g., Ref. 1) and numerically (e.g., Ref. 2) that temperature gradients can have a significant impact on the secondary flow and wall temperature of the first-stage rotor. A recent numerical study has shown that this phenomenon can also extend to second-stage stator airfoils.[3] A combustor hot streak such as this has a greater streamwise velocity than the surrounding fluid, and therefore, a larger positive incidence angle to the rotor (or other downstream blade row) as compared to the freestream. For hot streaks that do not impinge upon the first-stage stator airfoils, the rotor incidence variation through the hot streak and the slow convection speeds on the pressure side of airfoil surfaces combine to cause the hot-streak gases to accumulate on the pressure surfaces of downstream blade rows. The focus of the current effort has been to study the effects of the combustor hot-streak position on the temperature distributions of downstream airfoil surfaces. Two- and three-dimensional unsteady Navier–Stokes analyses have been used to study a 1-stator/1-rotor/1-stator/1-hot-streak configuration, and determine the impact of the combustor hot-streak position on the time-averaged first-stage rotor and second-stage stator surface temperatures.

Received April 29, 1995; revision received Nov. 13, 1995; accepted for publication Dec. 20, 1995.

*Assistant Professor, Department of Mechanical and Aeronautical Engineering. Senior Member AIAA.

†Research Scientist, Design Cycles Technology Branch. Senior Member AIAA.

Solution Procedure

The two- and three-dimensional computational analyses use a time-marching, implicit, finite difference scheme. The procedure is third-order spatially accurate and second-order temporally accurate. The inviscid fluxes are discretized according to an upwind-biased scheme, whereas the viscous fluxes are calculated using central differences. An alternating direction, approximate-factorization technique is used to compute the time-rate changes in the primary variables. In addition, Newton subiterations are used at each global time step to increase stability and reduce linearization errors. In this study, two Newton subiterations were performed at each time step.

Numerical Experiments

A series of numerical simulations of hot-streak migration through a 1-1/2 stage turbine have been conducted using both two- and three-dimensional unsteady Navier–Stokes procedures. The geometry used in the experimental hot-streak tests was the 1-1/2 stage turbine configuration of the United Technologies Large Scale Rotating Rig (LSRR) (Ref. 1). For the hot-streak experiments, the LSRR was configured to resemble the first 1-1/2 stages of a high-pressure turbine, typical of those used in aircraft gas turbine designs. In the experiment[1] and previous numerical studies,[2] the hot streaks were introduced between two stator airfoils of the LSRR. The temperature of the hot streak was twice that of the surrounding inlet flow, whereas the hot-streak static and stagnation pressures were identical to the freestream. The hot streak was seeded with CO_2 and the path of the hot streak determined by measuring CO_2 concentrations at various locations within the turbine stage using the blade surface static pressure taps. In the current two-dimensional numerical simulations, the hot streak is introduced to the inlet of the first stator passage in the form of a sine-wave temperature profile. In the three-dimensional simulations, similar to the experiment, the hot streak is modeled as a circular jet at 40% of the span. In both the two- and three-dimensional simulations, the hot-streak position has been varied in the gapwise direction along the first-stator inlet. The two positions of primary interest are 1) when the hot streak does not impinge on the first-stage stator and 2) when the hot streak fully impinges upon the first-stage stator. A hot-streak temperature of 1.2 times that of the surrounding inlet flow was chosen for this investigation.

The computational grid topology used in the 1-stator/1-rotor/1-stator/1-hot-streak two-dimensional simulations contained 29,733 computational grid points. The two-dimensional simulations were run for 18 blade-passing cycles, at 3000 time steps per cycle, on a DEC Alpha 3000-400 workstation. The computational grid used in the three-dimensional simulations contained approximately 2,700,000 grid points. The three-dimensional simulations were run for 10 cycles on a Cray C90 supercomputer.

Two-Dimensional Simulations

Figure 1 shows the minimum, maximum, and time-averaged surface temperatures along the surface of the rotor for the case in which the hot streak does not impinge upon the first stator. The temperatures along the suction surface show large excursions from the time-averaged temperature distribution, while the variations along the pressure surface are much smaller. The time-averaged temperatures along the pressure surface of the blade, however, are higher than along the suction surface. This phenomenon is similar to that observed in previous experiments[1] and numerical simulations,[2] in which the hot streak was introduced between the first-stage stator blades. The current results for the second-stage stator suggest the same type of temperature redistribution as the rotor. Figure 2 illustrates the minimum, maximum, and time-averaged surface temperatures along the rotor for the case in which the hot streak fully impinges on the first-stage stator. In this case the time-averaged temperatures along the suction surface of the blade are higher than along the pressure surface. It is hypothesized that the hot streak is convected with the low-momentum fluid of the stator wake, and therefore, is not predisposed to migrate towards the pressure surface of the rotor. The results for the second-stage stator are very similar to those for the rotor.

Three-Dimensional Simulations

Three-dimensional simulations have been performed to determine if radial and secondary flows modify the conclusions drawn from the two-dimensional simulations. Figure 3 shows the time-averaged temperature distribution along the rotor at 50% span and at the no-impingement conditions. The pressure surface of rotor experiences much higher time-averaged temperatures than the suction surface. This phenomenon was observed across almost the entire span of the blade. Similar results were observed on the second-stage stator. Figure 4 illustrates the rotor time-averaged temperature distribution at the 50% span location for the full-impingement conditions. The temperatures on the pressure surface of the rotor are significantly reduced, and are lower than the temperatures on the suction surface over the aft 30% of the blade. Again, similar trends were observed for the second-stage stator.

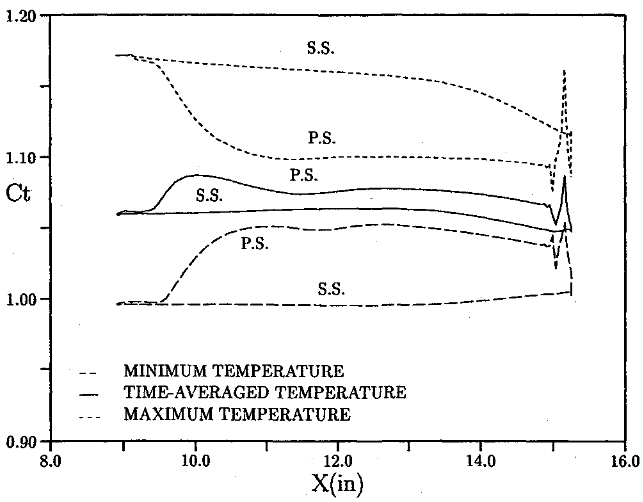

Fig. 1 Minimum, maximum, and time-averaged temperatures for the rotor (no impingement).

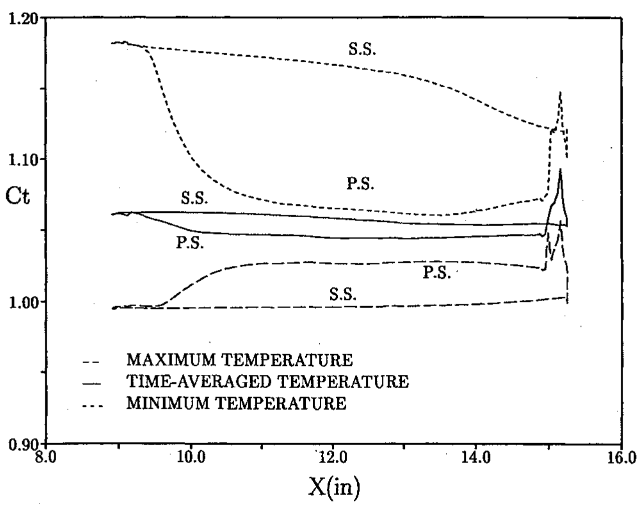

Fig. 2 Minimum, maximum, and time-averaged temperatures for the rotor (full impingement).

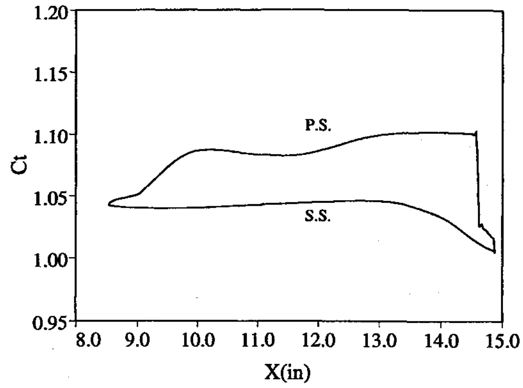

Fig. 3 Time-averaged temperatures along the rotor, 50.0% span (no impingement).

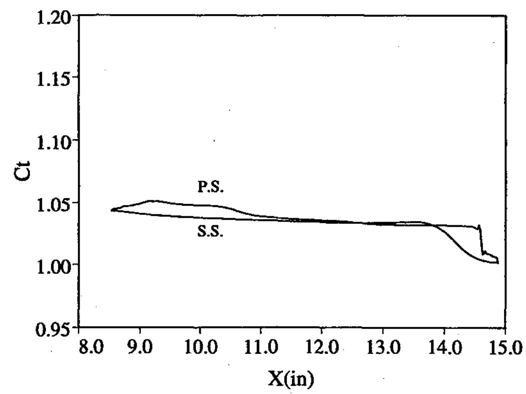

Fig. 4 Time-averaged temperatures along the rotor, 50.0% span (full impingement).

Thus, Figs. 1–4 suggest that a possible strategy for minimizing the surface temperatures of downstream blade rows may be to impinge the hot streak on the first-stage stator so that it mixes with the stator wake. Although impinging the hot streak on the first stator will increase the need for cooling this blade, the cooling requirements of subsequent blade rows will be significantly reduced.

Conclusions

Two- and three-dimensional simulations have been performed for a 1-1/2 stage turbine geometry in which the position of the hot streak was varied to produce different levels of impingement upon the first-stage stator. If the hot streak impacts upon the first-stage stator, the hot gases are convected with the stator wake, causing a significant reduction in the time-averaged temperatures on the pressure surfaces of the downstream blade rows. If the hot streak does not impinge on the first-stage stator, the pressure surfaces of the downstream blade rows reach much higher time-averaged temperatures.

References

[1]Butler, T. L., Sharma, O. P., Joslyn, H. D., and Dring, R. P., "Redistribution of an Inlet Temperature Distortion in an Axial Flow Turbine Stage," *Journal of Propulsion and Power*, Vol. 5, No. 1, 1989, pp. 64–71.

[2]Dorney, D. J., Davis, R. L., Edwards, D. E., and Madavan, N. K., "Unsteady Analysis of Hot Streak Migration in a Turbine Stage," *Journal of Propulsion and Power*, Vol. 8, No. 2, 1992, pp. 520–529.

[3]Dorney, D. J., Ng, B. C., Al-Habbas, A., and Gundy-Burlet, K., "Numerical Simulations of Hot Streak Migration in a 1-1/2 Stage Turbine," AIAA Paper 95-0181, Jan. 1995.