Active Control for Fuel-Flexible Volumetrically-Efficient Combustion

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1. Introduction

Air pollution is one of the key issues facing the combustion of fossil fuels. In gas turbine combustors, there is only a small range of air-fuel ratios where both NOx and CO emission levels can be kept very low, i.e., concentrations below a single-digit ppm. One problem of operating the combustors at these air-fuel ratios is, however, that it also makes them susceptible to combustion instability. This problem is further complicated when different types of fuels are used as the occurrence of combustion instability becomes even more unpredictable.

Active combustion control (ACC) could be an ideal solution for addressing this problem, as it allows the gas turbine combustors to operate at desired air-fuel ratios while actively suppressing combustion instabilities [1]. By actively controlling the combustion dynamics, ACC would make it possible to use different types of fuels without sacrificing reliability or emissions compliance. The objectives of this study are (i) to study various pollutant reduction mechanisms that can be used for in situ dynamic control strategy, (ii) to investigate various enabling technologies for environmentally-safe fuel-flexible combustor operation, and (iii) to develop a closed-loop active-combustion-control technique designed to minimize air pollution in fuel-flexible combustors.

2. Key Features

Two examples of active combustion control are to be presented. The first example concerns active instability suppression using a small amount of secondary fuel injection [2]. A closed-loop feedback control technique was used to dynamically pulse the secondary fuel at proper timing with respect to pressure oscillations. This resulted in suppression of combustion instability, reducing peak spectral amplitude of pressure by nearly 20 dB while breaking up large coherent structures associated with combustion instability (see Figure 1).

The second example concerns active control of turbulent diffusion flames to minimize soot formation [3]. By acoustically forcing both the fuel flow and the air flow separately and controlling the timing between the fuel injection and air flow oscillations, dynamic interaction between the two reactant streams was controlled. This resulted in drastically different flame characteristics depending on the fuel injection timing. Figure 2 displays and contrasts the flame structures obtained by two different injection timings.

3. Conclusions

Active combustion control technology offers a definite possibility of drastic performance improvement in gas turbine combustors by integrating rapid development in electronic timing control with enhanced understanding in the multidisciplinary areas of fluid physics, combustion chemistry, engine performance, control algorithms, and actuator/sensor diagnostics. Strong scientific basis covering combustion dynamics, flow physics, adaptive control, flow diagnostics and sensing associated with small-scale active combustion control experiments will help develop the active combustion control into a critical enabling technology in next-generation fuel-flexible environmentally friendly energy conversion devices.

4. References

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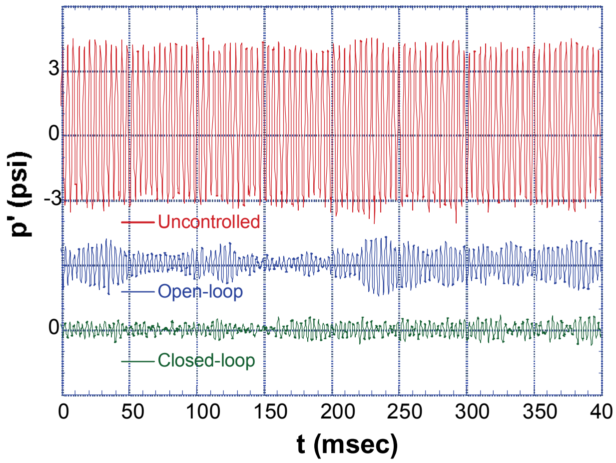

Figure 1. Comparison of uncontrolled and controlled pressure oscillation amplitudes [2].

a) b)

Figure 2. Actively controlled diffusion flames, a) efficient and b) sooty flames [3].

Author Biographies

Dr. Ken H. Yu is Associate Professor of aerospace engineering at the University of Maryland, College Park, MD, U.S.A. Dr. Yu is one of the leading authorities in combustion control involving high-speed propulsion engines such as ramjets, scramjets, and gas turbines. He has done pioneering research work on numerous combustion and mixing control technologies being developed today including active combustion control in liquid-fueled ramjets and cavity-based mixing enhancement in scramjets. His primary research interest is in understanding basic physical mechanisms associated with various time-dependent phenomena involving turbulent shear flow, passive and active jet mixing enhancement, pulsed fuel injection, combustion control, and other thermo-acoustic processes to improve the aeropropulsion performance and reduce pollution. He has authored or co-authored over 150 technical publications in various subject areas covering combustion instabilities, active control, supersonic mixing enhancement, plume afterburning, high-angle-of-attack aerodynamics, waste incineration, and other propulsion-combustion related processes involving high-speed engines. His work has resulted in nine U.S. patents and four best paper awards. He is Associate Fellow of AIAA, and has served as Chair of the AIAA Propellants & Combustion Technical Committee, and Associate Editor of AIAA Journal of Propulsion and Power.

Dr. Ashwani Gupta is Distinguished University Professor at the University of Maryland. He received his Ph.D. and higher doctorate, D.Sc, from The University of Sheffield, U.K. He has co-authored three books, over 8 chapters in different books and over 450 technical papers. He is a Fellow of AIAA, ASME, SAE and the Institute of Energy, U.K. He is co-editor of the Environmental and Energy Engineering series of books published by CRC press. He is an associate editor of the AIAA J. Propulsion and Power, J. Applied Science, Intl. J. of Reacting Systems, and Intl. J. Spray and Combustion Dynamics. He has received several national awards and best paper awards from AIAA and ASME. At the University of Maryland, he is recipient of the College of Engineering Research award and President Kirwan Research award and prize.