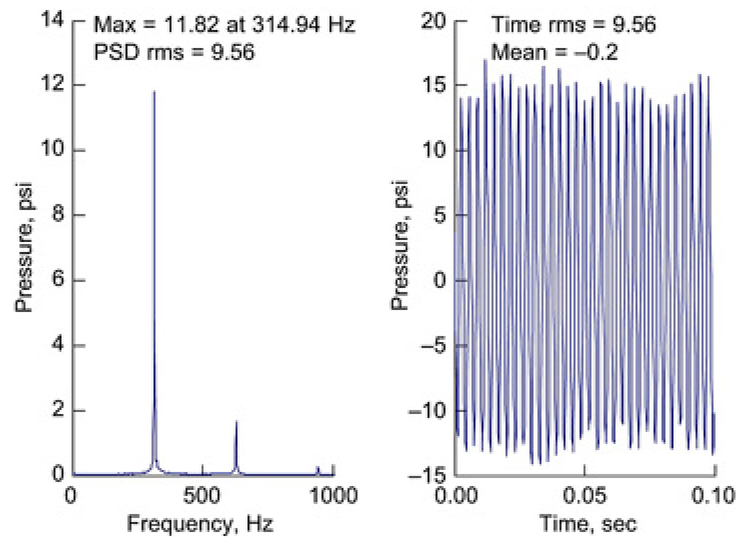
Model-Based, Multiscale Self-Tuning Controller Developed for Active Combustion Control

New challenges concerning system health-monitoring and life-extending robust controls for the Ultra-Efficient Engine Technology Project, as well as other advanced engine and power system concepts at NASA and elsewhere, have renewed the control community's interest in smart, model-based methods. In particular, these challenges have further motivated efforts at the NASA Glenn Research Center to exploit the versatility and superiority of the dynamic features extraction of multiscale analysis for controls--such as with "wavelets" and "wavelet filter-banks." The accomplishments reported herein pertain to the active suppression of combustion instabilities in liquid-fuel combustors via fuel modulation. The fundamentals and initial success of this innovation were reported (ref. 1) for a unique demonstration of active combustion control (a research collaboration of NASA Glenn with Pratt & Whitney and the United Technologies Research Center, UTRC). This demonstration, conducted in 2002 at UTRC on the NASA single nozzle rig (SNR) combustor, was the first known suppression of high-frequency instability with a liquid-fueled combustor. The SNR is based on a high-powered military engine combustor that exhibited well-known instabilities.

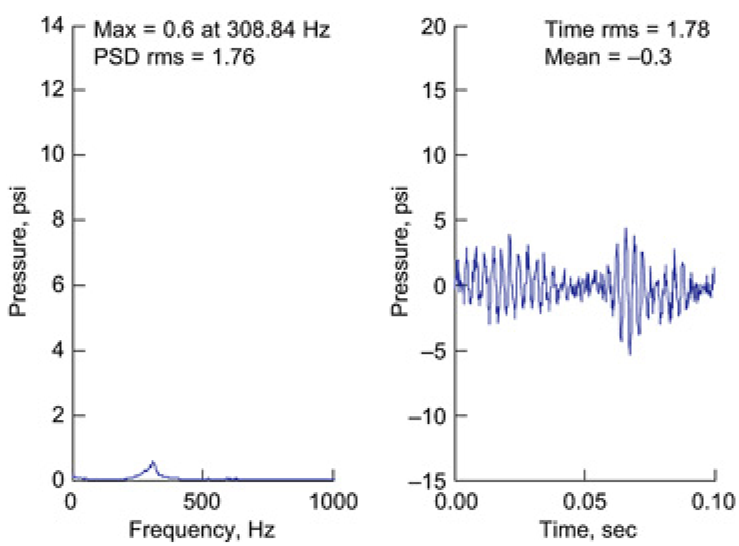
Continuing studies of combustion instabilities and control were conducted during 2004 with the SNR installed at NASA. This latest research included a significant extension of this model-based, multiscale method to create a (autonomous) self-tuning controller. The controller showed much improvement in performance and robustness for different test rig configurations. This approach involves integrating suitable multiscale representations of system responses within the control dynamics model. The multiscale-enhanced (or scale-selective) model and associated performance metrics are used to automatically adjust and fine-tune control and model sensitive parameters to improve robustness and performance.

During the summer of 2004, this model-based self-tuning controller was demonstrated with great success for three vastly different configurations on the SNR by changing the plenum size upstream of the fuel nozzle: a high-frequency configuration (with an instability frequency greater than 500 Hz), a middle-frequency configuration, and a low-frequency configuration (with a dominant instability frequency around 300 Hz). The most dramatic results were achieved for the low-frequency case (which had a high signal-to-noise ratio). The instability was reduced by more than 90 percent rms as well as at the amplitude-spectrum peak (see the following graphs). Even for the more challenging high-frequency and middle-frequency configurations (where the signal-to-noise ratio was very low and the instability weaker), the controller consistently reduced the instability amplitude at the amplitude-spectrum peak by 50 percent without peak splitting. This was a notable improvement in com-parison to the initial 30-percent reduction achieved in 2002 for the high-frequency configuration. The controller converged fairly quickly toward its optimal points despite having very little a priori information on system parameters. Its good performance and robustness indicated that it could be applied to the lean-direct-injection combustors being developed at NASA.



Low-frequency instability (314 Hz) created in the NASA Single Nozzle Combustion Rig (June 4, 2004). PSD, power spectral density. (PLA1C1psi, run 425, 040602, point pt016.)

Long description of figure 1. Graph showing an amplitude spectra peak of 12 pounds per square inch near 314 hertz and a smaller peak of 1.8 pounds per square inch near 630 hertz. The time-domain companion plot shows pressure oscillations close to 15 pounds per square inch off either side of the mean.



Low-frequency instability (314 Hz) suppressed by the multiscale extended Kalman controller (June 4, 2004). PSD, power spectral density. (PLA1C1psi, run 425, 040602, point pt080.)

Long description of figure 2. Graph showing an amplitude spectra peak reduced to 0.6 pounds per square inch. The time-domain companion plot shows pressure oscillations of about 1.7 pounds per square inch root-mean-square.

Reference

1. Le, Dzu K.; Delaat, John C.; and Chang, Clarence T.: Control of Thermo-Acoustics Instabilities: The Multi-Scale Extended Kalman Approach. NASA/TM--2003-212536-REV1 (AIAA-2003-4934), 2003. http://gltrs.grc.nasa.gov/cgi-bin/GLTRS/browse.pl?2003/TM-2003-212536-REV1.html

Find out more about this research at
http://www.grc.nasa.gov/WWW/cdtb/projects/combustor/

Glenn contacts: Dr. Dzu K. Le, 216-433-5640, Dzu.K.Le@nasa.gov; and John C. DeLaat, 216-433-3744, John.C.DeLaat@nasa.gov
Author: Dr. Dzu K. Le
Headquarters program office: Aeronautics Research
Programs/Projects: UEET