Large Eddy Simulation (LES): 21st Century Mixing Models for Combustion — Time Dependent and 3-D

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The measurement of the temporal distribution of fuel in gas turbine combustors is important in considering pollution, combustion efficiency, and combustor dynamics and acoustics. Much of the previous work in measuring fuel distributions in gas turbine combustors has focused on the spatial aspect of the distribution. The temporal aspect, however, has often been overlooked, even though it is just as important. In part, this is caused by the challenges of applying real-time diagnostic techniques in a high-pressure and high-temperature environment.

A simple and low-cost instrument that non-intrusively measures the real-time fuel-to-air ratio (FAR) in a gas turbine combustor has been developed. The device uses a dual-wavelength laser-absorption technique to measure the concentration of most hydrocarbon fuels, such as jet fuel, methane, and propane. The device can be configured to use fiber optics to measure the FAR inside a high-pressure test rig without the need for windows. Alternatively, the device can be readily used to test rigs that have existing windows without modifications.

An initial application of this instrument was to obtain time-resolved measurements of the FAR in the premixer of a lean, premixed, prevaporized (LPP) combustor at inlet air pressures and temperatures as high as 17 atm @ 800 K, with liquid JP-8 as the fuel. Results will be presented that quantitatively show the transient nature of the local FAR inside a LPP gas turbine combustor at actual operating conditions. The high-speed (kHz) time resolution of this device, combined with a rugged fiber optic delivery system, should enable the realization of a flight-capable, active feedback and control system for the abatement of noise and pollutant emissions in the future. Other applications that require an in-situ and time-resolved measurement of fuel vapor concentrations should also find this device to be of use.

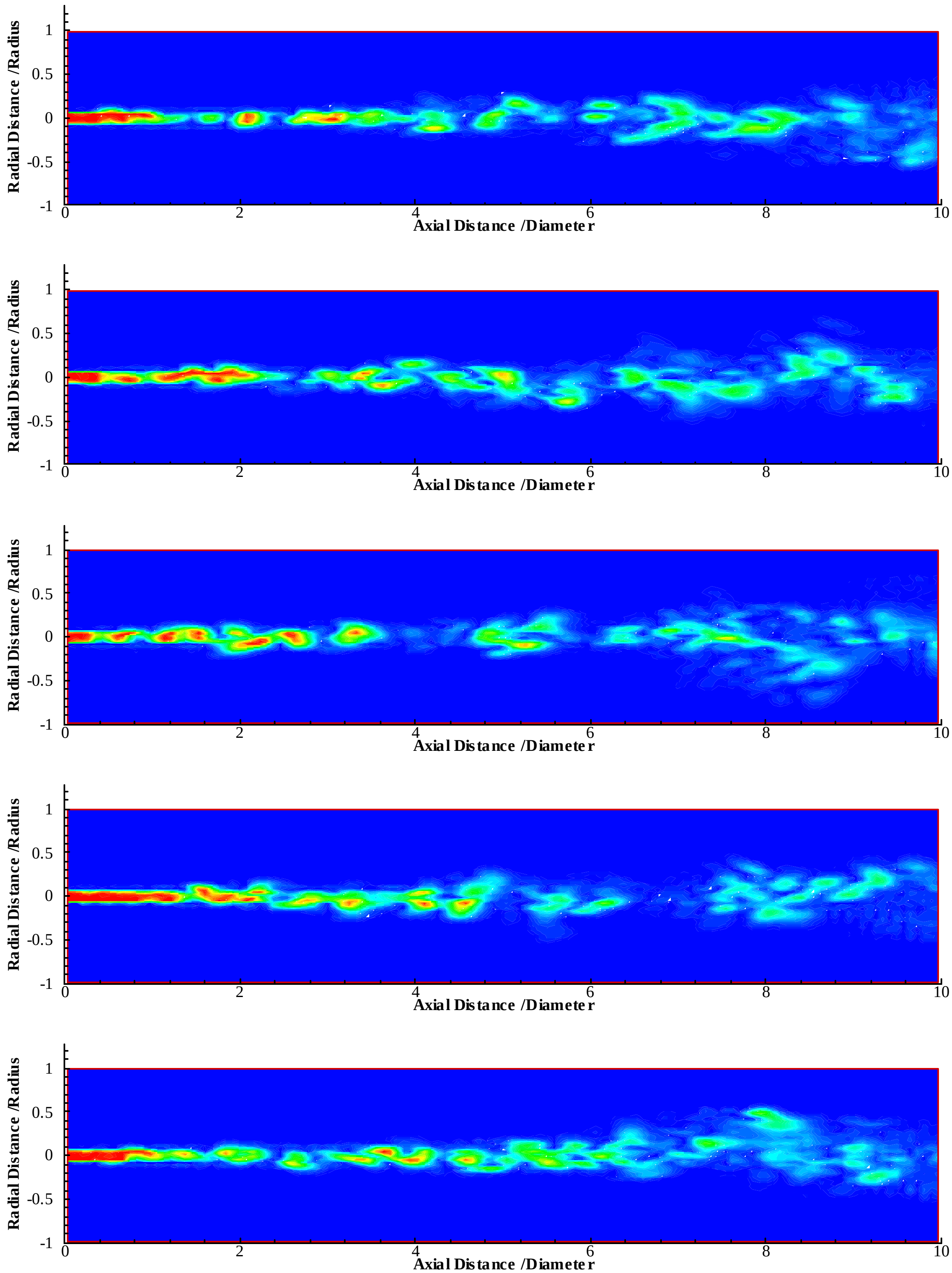
It is well known that time-dependent fluctuations in a combustor often lead to poorer performance. For example, poor temporal fuel-air mixing increases NO_X unnecessarily and may lead to damaging fluctuations in pressure. Yet, most numerical models of combustion are time-independent (RANS), and thus, time resolved details are not predicted. LES produces time-dependent predictions at the expense of more computer cycles. With the steady increase in computational speed, the time-resolved predictions are approaching the accuracy of RANS predictions. (See the figures.) Given that LES also yields the vast insight gained by time resolution (as shown in the figures), LES will become the preferred model in the 21st century.

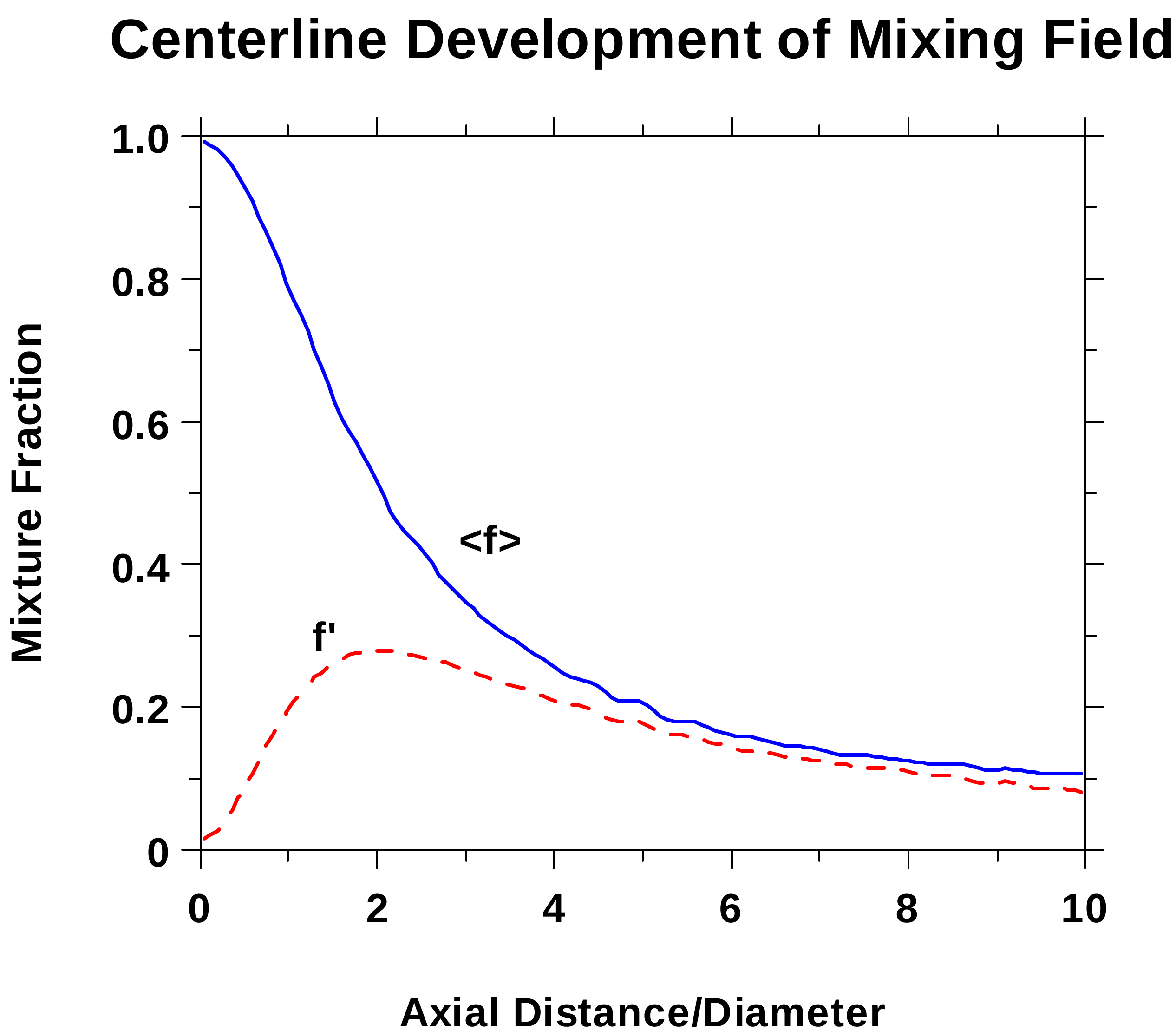
Nguyen, Quang-Viet, Mongia, R.K., and Dibble, R.W. 1998. Real-Time Optical Fuel-to-Air Ratio Sensor for Gas Turbine Combustors, p. 124-130 in *Proceedings of SPIE*, vol. 3535, no. 14.

Parameters of LES for Mixing in a Pipe

- 3-Dimensional simulation
- Grid System: 128x32x32 (x=10D, $\theta=360^{o}$, R=D/2)
- Accuracy: fourth-order in space, third-order in time
- Subgrid turbulence model: Germano Dynamics
- 50,000 steps to reach statistically stationary state
- Typical CPU time ~ 5 days on Alpha Dec 500au run on Linux 6.0

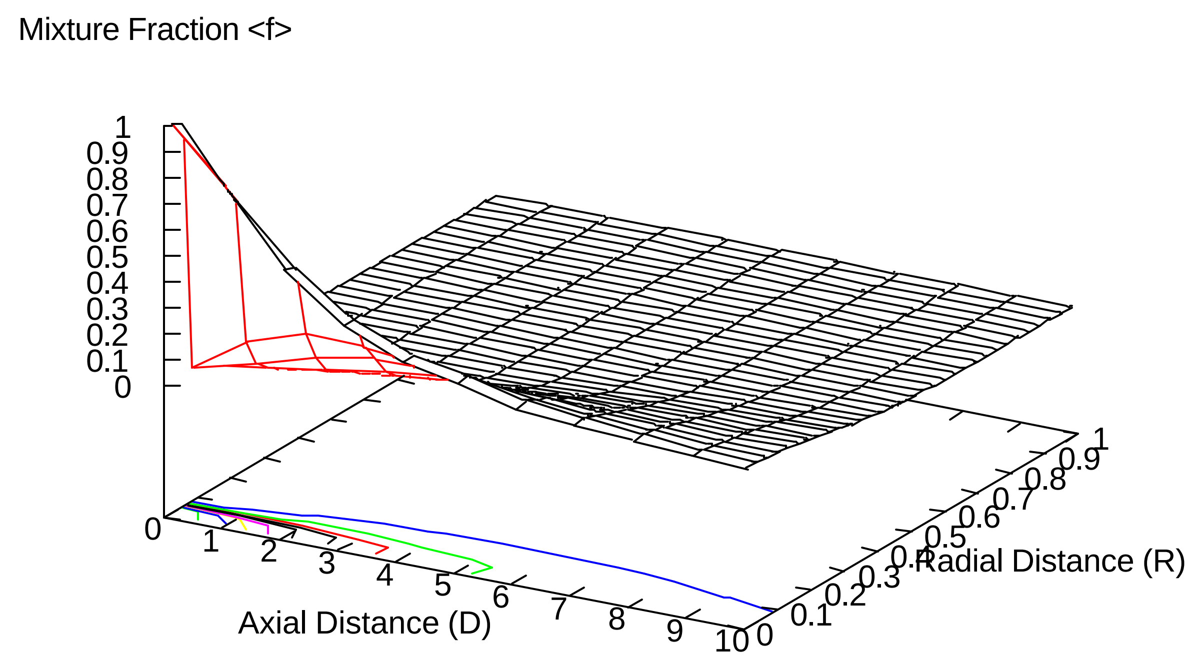
Snapshots of Mixture Fraction Distribution in a Pipe



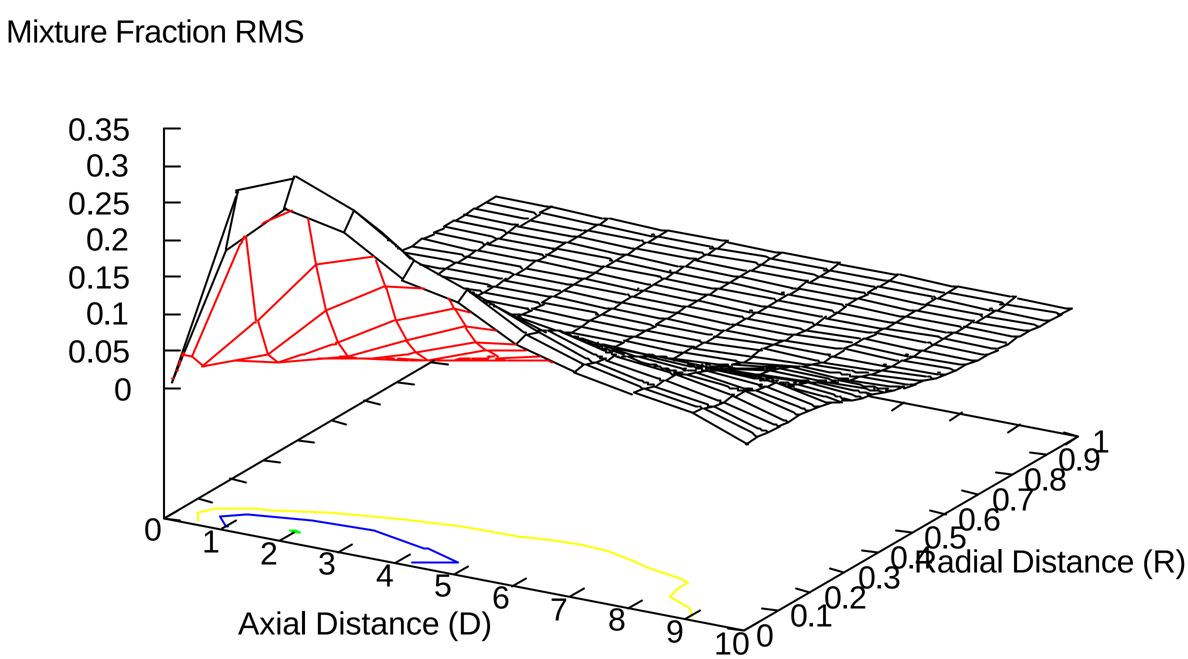


Centerline Development of Mixing Field
Mixture Fraction
1.0
0.8
0.6
0.4
0.2
0
<f>
f'
0
2
4
6
8
10
Axial Distance/Diameter

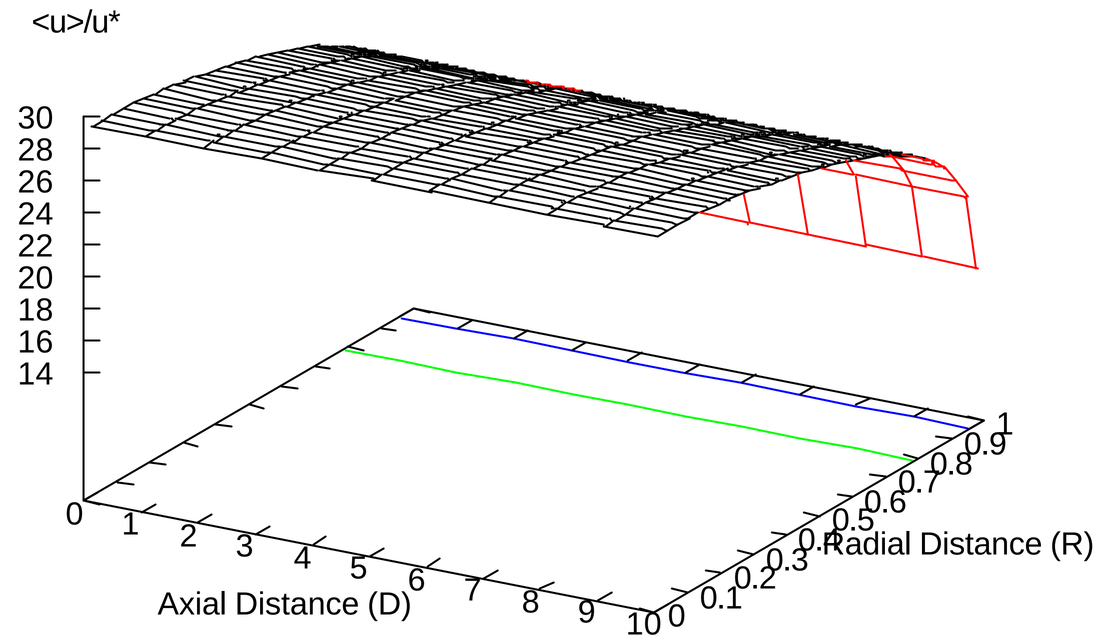
LES of Mixing in a Pipe: Reynolds number based on friction velocity =1050



LES of Mixing in a Pipe: Reynolds number based on friction velocity =1050



Mean Axial Velocity Normalized by Friction Velocity



Axial Velocity Variance Normalized by Friction Velocity