Enabling Advanced Modeling and Simulations for Fuel-Flexible Combustors

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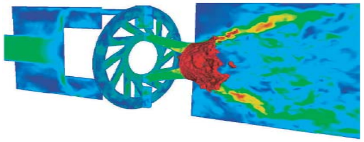
Premixed combustion in a stationary gas turbine



Motivation

- Gas turbines must operate robustly on fuels from gasification of coal and feed-stocks (biomass, petroleum coke)
- Enable computational simulation assisted design and development of fuel-flexible gas turbines with high thermal efficiency and near-zero NO_x emissions
- Demonstrate advanced simulations of flexible fuel combustion validated by reliable experimental data

Objective

- Advanced modeling and simulations for design and optimization of fuel-flexible gas turbine combustors by high-fidelity extensively-tested LES and state-of-the-art models for premixed turbulent combustion
- Advanced modeling by using
  - Large-eddy simulation
  - Consistent flame propagation models [1,2]
  - Coupled progress variable / level set method
  - Heat transfer at the boundaries and through thermal radiation
- Application, adaptation, and improvement of modeling techniques to hydrogen-enriched premixed and partially premixed gas-turbine combustion

Accomplishments

- LES of turbulent lean-premixed hydrogen-air combustion in a low-swirl burner
  - Equivalence ratio: $\phi = 0.37$
  - Laminar flame speed S_L = 10.4 cm/s
- Configuration corresponds to DNS performed at at Lawrence Berkeley National Laboratories

LES inflow conditions [3]:

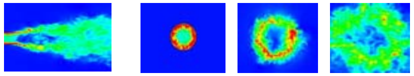
$$u_{i,LES}(t) = u_{i,DNS}(t) + \left[u_{i,DB}(t) - \langle u_{i,DB}\rangle\right]\frac{\sqrt{\langle u'^2_{i,DNS}\rangle}}{\sqrt{\langle u'^2_{i,DB}\rangle}}$$

where

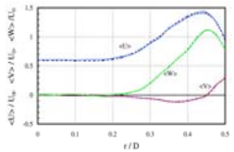
i = z, r, θ, $u_i'^2 = \langle u_i^2 \rangle - \langle u_i \rangle^2$

$u_{i,DNS}$ - from the DNS, $u_{i,DB}$ - from the database [2]

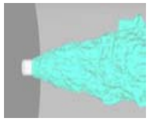
Cold flow simulation of low swirl burner



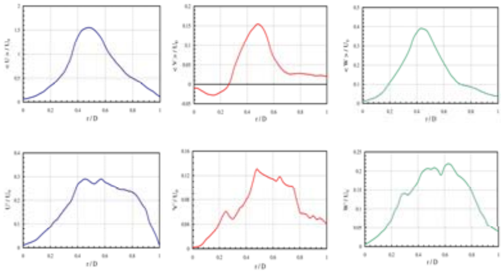
Velocity Magnitude: Values from 0.35m/s (blue) to 12m/s (red).
Left to-right: Axial plane and three radial planes at 0, 5 and 15 cm downstream of the nozzle



Mean inflow velocity profiles:
DNS (dashed) and LES (solid)



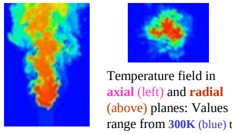
Characteristic flow velocity isosurface $|U|=U_0$=6.34 m/s



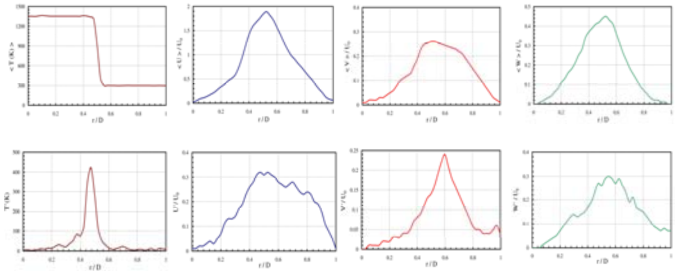
Time averaged swirl burner velocity (top) and rms-velocity (bottom) profiles
Left-to-right: Axial, radial, and azimuthal velocities
D = 5cm – nozzle diameter; U_0 = 6.34 m/s – mean inflow velocity in the axial direction
The co-flow is axial and uniform, with U_{co} = 0.35m/s

Simulation of reacting lean hydrogen/air low swirl burner

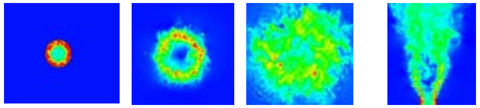
Characteristic flame shape shown by the isotherms: 900K (left) and 1200K (right).



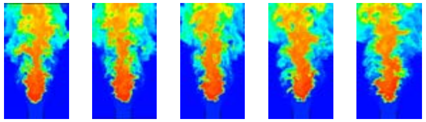
Temperature field in axial (left) and radial (above) planes: Values range from 300K (blue) to 1350K (red).



Time averaged swirl burner parameters (top) and rms-parameters (bottom)
Left-to-right: temperature and axial, radial, and azimuthal velocities



Total velocity field: Values range from 0.35m/s (blue) to 12m/s (red)
Left-to-right: three radial planes taken at 0, 5 and 15 cm ahead of the nozzle, and axial plane



Characteristic dynamics of turbulent flame front
Temperature field is shown by colors ranging from 300K (blue) to 1350K (red)

- **Statistics of cold and reacting flows are similar**
- **Small effects of heat release since $S_L T_b / T_f$ = 0.45 m/s << U_{rms} << U_0**
- **Simulations previously validated with experimental data for methane fuel**
- **Comparison with hydrogen DNS data forthcoming**

Work in progress

- ***Prediction of flow field and inlet boundary conditions***
  - Simulating flow in a nozzle with swirlers
  - Generation of inflow boundary conditions
- ***Effect of fuel composition on laminar flame speed***
  - Tabulation of a laminar flame speed vs pressure, temperature, fuel compositions and equivalence ratio
  - Validation with experimental data on blowout and flashback
- ***Simulation of turbulent premixed burning in model combustors***
  - Implementation of various models for premixed combustion applicable to hydrogen enriched flames
  - Validation using turbine combustors

Future work

- ***Role of the fuel composition, non-unity Lewis numbers and other effects in blowout and flashback***
  - Adaptation and improvement of the model for hydrogen enriched fuels
- ***Incorporation of wall heat transfer into combustion model***
- ***Effect of thermal radiation on flame propagation and NO concentration***
- ***Simulation of real turbine combustor***
  - LES of burning in a real Siemens gas turbine combustor

Summary

- The objective of the project is the demonstration of predictive simulations for hydrogen enriched combustion in gas-turbine engines
- Validation studies include simple flame DNS and experiments and more realistic model combustors

References

[1] E. Knudsen, H. Pitsch, *A partially premixed combustion approach for presumed-PDF LES*, SIAM 12th International Numerical Combustion Conference, Monterey, CA, Apr 1, 2008.

[2] E. Knudsen, H. Pitsch, *A general flamelet transformation useful for distinguishing between diffusive and premixed modes of combustion*, submitted.

[3] J.U. Schluter, H. Pitsch, P. Moin, *Large eddy simulation inflow conditions with Reynolds-averaged flow solvers*, AIAA **42**, 478 (2004).