Chaotic Oscillation in Diffusion Flame Induced by Radiative Heat Loss

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The Theory

• Fluctuations in combustion have been numerically shown to behave as chaotic systems
• Flame front behavior has been shown to include “irregularities” near extinction, suggestive of chaotic behavior
• This paper seeks to account for radiative heat loss (previously ignored) – a radiative loss term may force the system to chaos
• Better understanding of system’s chaotic dynamics leads to better understanding of the physical mechanism of flame
The Model

\[ \frac{\partial \theta}{\partial t} = L_e \frac{\partial^2 \theta}{\partial x^2} + D_a Y_o Y_f e^{-\frac{\tau_a}{\theta}} - RD_a (\theta^4 - \theta_0^4) \]

\[ \frac{L_e}{\partial t} = \frac{\partial^2 Y_o}{\partial x^2} - D_a Y_o Y_f e^{-\frac{\tau_a}{\theta}} \]

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Time Series Analysis and Informational Entropy Considerations

• Proven technique in the study of nonlinear dynamical systems
• Mutual Information – measure of predictability
  – Characteristic Chaotic Behavior
• Parallelism of Neighboring Trajectories
  – Deterministic vs. Stochastic
• Permutation entropy
Results

Figure 2. Time evolution of nondimensional temperature of flame front $\Theta$ for different Damköhler numbers $D_a$.

Figure 4. Bifurcation process of $\Theta$ as a function of $D_a$. 
Bifurcation Diagrams
Results (cont’d)

• Deterministic not stochastic
• Period doubling behavior – Feigenbum constant
• Transition from low-dimension chaos to high-dimension chaos to flame instability
• Dynamics heavily dependent on Damköhler number
• Radiative heat loss qualitatively affects system dynamics