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

Heat and Mass Transport

Reactivity

Radiation

Temperature Change

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

Change in O_2 Concentration

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

Change in Fuel Concentration

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

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

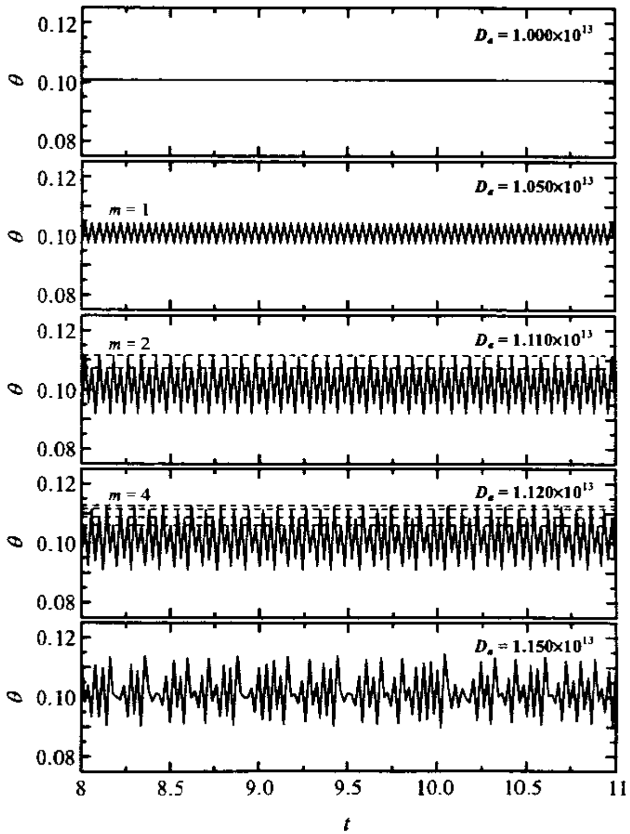


Figure 2. Time evolution of nondimensional temperature of flame front θ for different Damköhler numbers D_a.

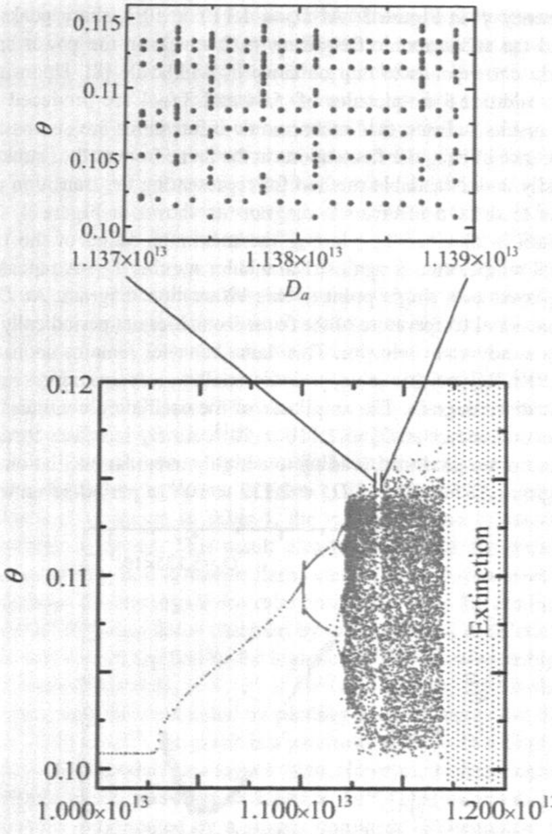
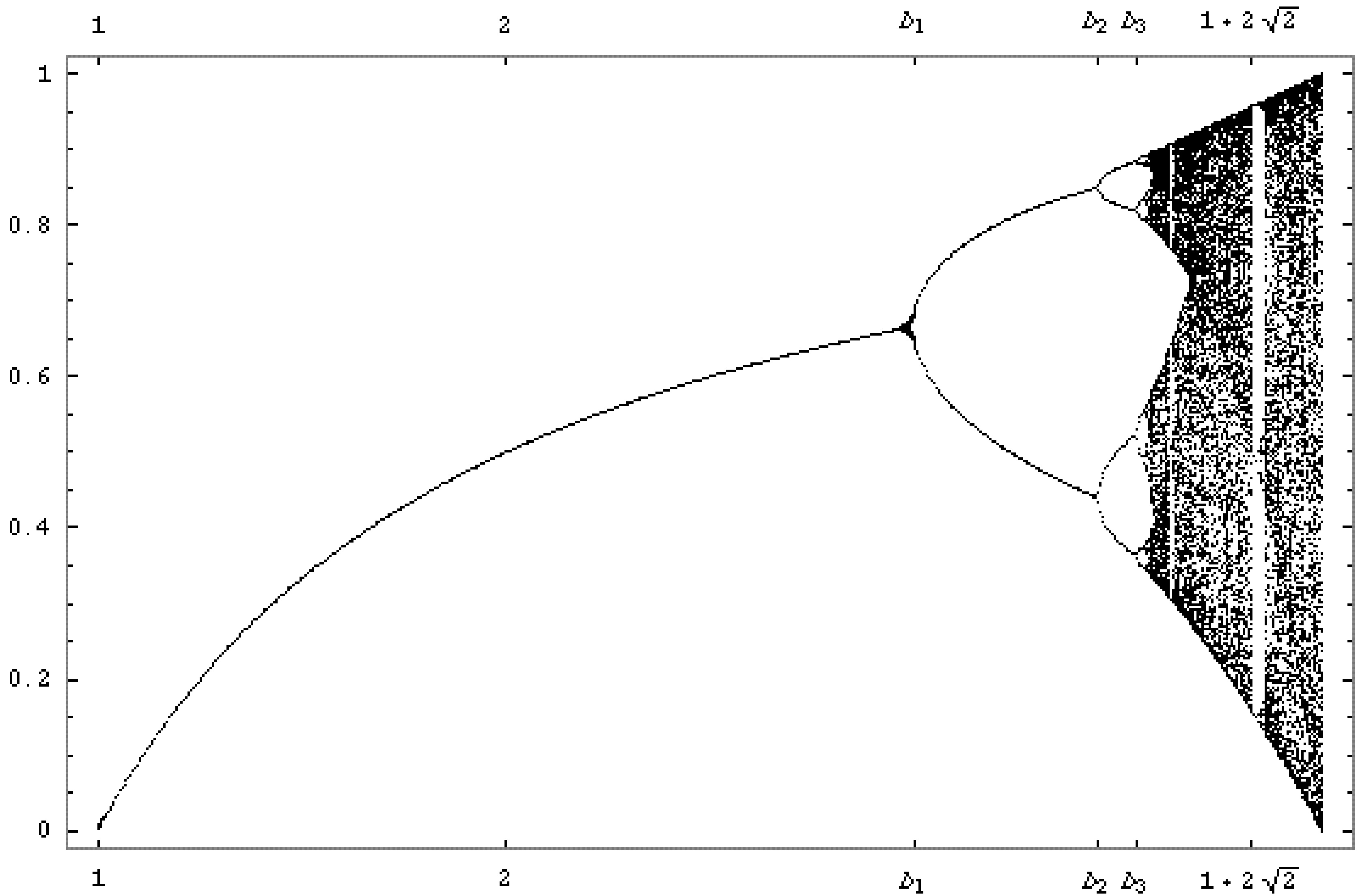


Figure 4. Bifurcation process of θ as a function of D_a.

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