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**On The Structure, Propagation, and Stabilization of
Laminar Premixed Flames**

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Summary

The primary objective of the funded program was to qualitatively understand and quantitatively determine the structure and dynamics of laminar premixed flames. The investigation was conducted using laser-based experimentation, computational simulation with detailed chemistry and transport, and activation energy asymptotic analysis. Phenomena investigated spanned practically all aspects of premixed flames, including the dynamics of stretched flames, flamefront instability, partially-premixed flames, effects of chain mechanisms and flame curvature on the flame response, the possibility of adiabatic flame stabilization, the near-invariance of the structure of stretched flames, the rational determination of laminar flame speeds, and the formulation of a chain-thermal theory of fundamental flammability limits.

High-lights of the above accomplishments were discussed in the annual reports submitted to the program monitor, while details of the investigation are reported in thirty journal publications listed in the following.

Journal Publications

1. "Analysis of Some Nonlinear Premixed Flame Phenomena," by S.H. Chung and C.K. Law, *Combustion and Flame*, Vol. 75, pp. 309-323 (1989).
2. "Diffusional-Thermal Instability of Adiabatic Flame Propagation in Dissociation Equilibrium," by B.H. Chao and C.K. Law, *Journal of Fluid Mechanics*, Vol. 201, pp. 1-12 (1989).
3. "Dynamics of Stretched Flames," by C.K. Law, *Twenty-Second Symposium (International) on Combustion*, The Combustion Institute, Pittsburgh, PA, pp. 1381-1402 (1989). **Invited Paper**
4. "Experimental and Numerical Determination of Laminar Flame Speeds of Methane/(Ar, N₂, CO₂)-Air Mixtures as Function of Stoichiometry, Pressure, and Flame Temperature," by D.L. Zhu, F.N. Egolfopoulos, and C.K. Law, *Twenty-Second Symposium (International) on Combustion*, The Combustion Institute, Pittsburgh, PA, pp. 1539-1545 (1989). **Silver Medal**
5. "Laminar Flame Speeds of Methane/Air Mixtures Under Reduced and Elevated Pressures," by F.N. Egolfopoulos, P. Cho, and C.K. Law, *Combustion and Flame*, Vol. 76, pp. 375-391 (1989).
6. "On the Structure and Extinction Dynamics of Partially-Premixed Flames: Theory and Experiment," by C.K. Law, T.X. Li, S.H. Chung, J.S. Kim, and D.L. Zhu, *Combustion Science and Technology*, Vol. 64, pp. 199-232 (1989).
7. "Chain Mechanisms in the Overall Reaction Orders in Laminar Flame Propagation," by F.N. Egolfopoulos and C.K. Law, *Combustion and Flame*, Vol. 80, pp. 7-16 (1990).
8. "Combustion in Microgravity: Opportunities, Challenges and Progress," by C.K. Law, *AIAA Paper No. 90-0120*, 28th Aerospace Sciences Meeting, Reno, Nevada, 1990. **Invited Paper**
9. "Structure and Extinction of Diffusion Flames with Flame Radiation," by B.H. Chao, C.K. Law, and J.S. Tien, *Twenty-Third Symposium (International) on Combustion*, The Combustion Institute, Pittsburgh, PA, pp. 523-531 (1991).
10. "On the Opening of Burke-Schumann Flame Tip and the Effects of Curvature on Diffusion Flame Extinction," by H.G. Im, C.K. Law, and R.L. Axelbaum, *Twenty-Third Symposium (International) on Combustion*, The Combustion Institute, Pittsburgh, PA, pp. 551-558 (1991).
11. "A Kinetic Criterion of Flammability Limits: The C-H-O-Inert System," by C.K. Law and F.N. Egolfopoulos, *Twenty-Third Symposium (International) on Combustion*, The Combustion Institute, Pittsburgh, PA, pp. 413-421 (1991).

12. "On Closure in Activation Energy Asymptotics of Premixed Flames," by C.K. Law, B.H. Chao and A. Umemura, *Combustion Science and Technology*, Vol. 88, pp. 59-88 (1992).
13. "Mechanisms of Flame Stabilization in Subsonic and Supersonic Flows," by C.K. Law, *Major Research Topics in Combustion* (Eds.: M.Y. Hussaini, A. Kumar and R.G. Voigt), Springer-Verlag, New York, pp. 201-236 (1992). **Invited Position Paper**
14. "On Adiabatic Stabilization of Inverted Flames," by C.J. Sung, C.K. Law, and A. Umemura, *Twenty-Fourth Symposium (International) on Combustion*, The Combustion Institute, Pittsburgh, PA, pp. 205-212 (1992).
15. "A Unified Chain-Thermal Theory of Fundamental Flammability Limits," by C.K. Law and F.N. Egolfopoulos, *Twenty-Fourth Symposium (International) on Combustion*, The Combustion Institute, Pittsburgh, PA, pp. 137-144 (1992).
16. "Asymptotic Theory of Flame Extinction with Surface Radiation," by B.H. Chao and C.K. Law, *Combustion and Flame*, Vol. 92, pp. 1-24 (1993).
17. "Laminar Flame Propagation with Volumetric Heat Loss and Chain Branching-Termination Reactions," by B. H. Chao and C.K. Law, *International Journal of Heat and Mass Transfer*, Vol. 37, pp. 673-680 (1994).
18. "On the Geometry and Burning Intensity of Bunsen Flames," by C.J. Sung, K.M. Yu, and C.K. Law, *Combustion Science and Technology*, Vol. 100, pp. 245-270 (1994).
19. "On the Structural Sensitivity of Purely-Strained Planar Premixed Flames to Strain Rate Variations," by C.K. Law, C.J. Sung, G. Yu, and R.L. Axelbaum, *Combustion and Flame*, Vol. 98, pp. 139-154 (1994).
20. "Thermophoretic Effects on Seeding Particles in LDV Measurements of Flames," by C.J. Sung, C.K. Law, and R.L. Axelbaum, *Combustion Science and Technology*, Vol. 99, pp. 119-132 (1994).
21. "Some Aspects of the Freely-Propagating Premixed Flame in a Spatially-Periodic Flow Field," by K.M. Yu, C.K. Law, and C.J. Sung, *Combustion and Flame*, Vol. 97, pp. 375-383 (1994).
22. "On Adiabatic Stabilization and Geometry of Bunsen Flames," by C.J. Sun, C.J. Sung, and C.K. Law, *Twenty-Fifth Symposium (International) on Combustion*, The Combustion Institute, Pittsburgh, PA, pp. 1391-1398 (1994).
23. "Structural Response of Counterflow Diffusion Flames to Strain Rate Variations," by C.J. Sung, J.B. Liu, and C.K. Law, *Combustion and Flame*, Vol. 102, pp. 481-492 (1995).

24. "On Non-Huygens Flame Configuration in Stagnation Flow," by C.J. Sung, J. Y. D. Trujillo, and C.K. Law, *Combustion and Flame*, Vol. 103, pp. 247-251 (1995).
25. "On Stretch-Affected Flame Propagation in Vortical Flows," by B.T. Helenbrook, C.J. Sung, C.K. Law, and W.T. Ashurst, *Combustion and Flame*, Vol. 104, pp. 460-468 (1996).
26. "Further Studies on Effects of Thermophoresis on Seeding Particles in Measurements of Strained Flames," by C.J. Sung, J.S. Kistler, M. Nishioka, and C.K. Law, *Combustion and Flame*, Vol. 105, pp. 189-201 (1996).
27. "Analytical Description of the Evolution of Two-Dimensional Flame Surfaces," by C.J. Sung, C.J. Sun and C.K. Law, *Combustion and Flame*, Vol. 107, pp. 114-124 (1996).
28. "On the Scalar Structure of Nonequidiffusive Premixed Flames in Counterflow," by C.J. Sung, J.B. Liu, and C.K. Law, *Combustion and Flame*, Vol. 106, pp. 168-183 (1996).
29. "Response of Counterflow Premixed and Diffusion Flames to Strain Rate Variations at Reduced and Elevated Pressures," by C.J. Sun, C.J. Sung, D.L. Zhu, and C.K. Law, *Twenty-Sixth Symposium (International) on Combustion*, The Combustion Institute, Pittsburgh, PA, pp. 1111-1120 (1996).
30. "On the Aerodynamics of Flame Surfaces," by C.K. Law, C.J. Sung, and C.J. Sun, *Annual Review of Heat Transfer*, Vol. VIII, (Ed.: C.-L. Tien), Begell House, pp. 93-151 (1997).