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The program on Air Force Research on Aero Propulsion Technology (AFRAPT) was conceived by the Air Force Office of Scientific Research, with the support of a consortium of universities, as a means of exposing graduate students to aeropropulsion technology as part of their graduate study experience. The students typically were in residence during the academic year, and were employed by one of the gas turbine companies during summer. During the period of 1989 to 1998, Princeton University actively participated in this program. A total of four students received M.S.E. degrees and seven students received Ph. D. degrees, with either total or partial support from AFRAPT.

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Final Report (1989 to 1998)

# AIR FORCE RESEARCH IN AERO PROPULSION TECHNOLOGY

(Grant Number: AFOSR-89-0473)

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## Summary

The program on Air Force Research on Aero Propulsion Technology (AFRAPT) was conceived by the Air Force Office of Scientific Research, with the support of a consortium of universities, as a means of exposing graduate students to aeropropulsion technology as part of their graduate study experience. The students typically were in residence during the academic year, and were employed by one of the gas turbine companies during summer.

During the period of 1989 to 1998, Princeton University actively participated in this program. A total of four students received M.S.E. degrees and seven students received Ph. D. degrees, with either total or partial support from AFRAPT. The following is a list of these students:

M.S.E. Graduates
R. Brady
J. Gatto
J. Kistler
K. Whaling

Ph. D. Graduates
S. Davis
J. Emdee
J. Eng
J. Ghandhi
R. Lawson
P. Papas
S. Zeppieri

The faculty who participated in the supervision are:
Professor F.V. Bracco
Professor F.L. Dryer
Professor I. Glassman
Professor C.K. Law
Professor P.D. Ronney

Princeton University is pleased to have participated and contributed to this worthwhile program. Specifics on individual trainees are presented next.

## Narrative on Individual Trainees

**R. Brady**

The trainee was enrolled in 1991 under Professor C.K. Law's supervision on an experimental study of the spatially- and temporally-resolved species, temperature, and velocity profiles within vaporizing multicomponent droplets. Mr. Brady withdrew from study in 1993 due to personal reasons.

**S. Davis**

The trainee was enrolled in 1992, under the supervision of Professor C.K. Law, and graduated with a Ph.D. in 1998. His thesis topic was "An experimental and kinetic modeling study of the pyrolysis and oxidation of selected $C_3$-$C_8$ hydrocarbons'. He is presently an NSF Fellow, working at CNRS-Marseille in France. The archival publications resulting from his thesis research are the following.

(a) "Laminar flame speeds and oxidation kinetics of benzene/air and toluene/air flames," by S.G. Davis, H,Wang, K. Brezinsky, and C.K. Law, *Twenty-Sixth Symposium (International) on Combustion*, The Combustion Institute, Pittsburgh, PA, pp. 1025-1033 (1996).

(b) "Laminar flame speeds and oxidation kinetics of iso-octane/air and n-heptane/air flames," by S.G. Davis and C.K. Law, *Twenty-Seventh Symposium (International) on Combustion* The Combustion Institute, Pittsburgh, PA, pp. 521-528 (1998).

(c) "An experimental and kinetic modeling study of propyne oxidation," by S.G. Davis, C.K. Law, and H. Wang, *Twenty-Seventh Symposium (International) on Combustion*, The Combustion Institute, Pittsburgh, PA, pp. 305-312 (1998).

(d) "Determination of and fuel structure effects on laminar flame speeds of $C_1$ to $C_8$ hydrocarbons," by S.G. Davis and C.K. Law, *Combustion Science and Technology*, Vol. 140, pp. 427-450 (1999).

(e) "Propyne pyrolysis in a flow reactor: an experimental, RRKM, and detailed kinetic modeling study," by S.G. Davis, C.K. Law, and H. Wang, *J. Phys.-Chem.* Vol. 103, pp. 5889-5899 (1999).

(f) "Propene pyrolysis and oxidation kinetics in a flow reactor and laminar flames," by S.G. Davis, C.K. Law, and H. Wang, *Combustion and Flame*, in press.

**J. Emdee**

The trainee was enrolled in 1986 under the supervision of Professor I. Glassman, and graduated with a Ph. D. in 1991. His thesis topic was "An experimental and modeling study of the high temperature oxidation of the xylenes". His industrial sponsor was the United Technologies Research Center.

**J. Eng**

The trainee was enrolled from 1990 to 1998. He took a leave of absence in the summer of 1994, and worked at the General Motors Research Laboratories from 1994 to 1998. Hence he was not in residence at Princeton during this period. He was supervised by Professors C.K. Law and F.L. Dryer. He graduated with a Ph. D. in 1998, with the dissertation entitled "A study of hydrocarbon emissions from a homogeneous charge spark ignition engine". He has the following archival publications.

(a) "On burner-stabilized cylindrical premixed flames in microgravity," by J.A. Eng, C.K. Law, and D.L. Zhu, *Twenty-Fifth Symposium (International) on Combustion*, The Combustion Institute, Pittsburgh, PA, pp. 1711-1718 (1994).

(b) "On the structure, stabilization, and dual response of flat-burner flames," by J.A. Eng, D.L. Zhu, and C.K. Law, *Combustion and Flame*, Vol. 100, pp. 645-652 (1995).

**J. Gatto**

The trainee was enrolled in 1991 to 1994 under the supervision of Professor F.L. Dryer, and graduated with an MSE in 1997. His thesis topic was "The kinetics of nitrogen dioxide".

**J. Ghandhi**

The trainee was enrolled in 1989 under the supervision of Professor F.V. Bracco, and graduated with a Ph.D. in 1995. His thesis topic was "Fuel distribution measurements in a direct-injection stratified charge engine". His industrial sponsor was the United Technologies Research Center and he is currently an Assistant Professor at the University of Wisconsin at Madison. He has the following archival publication.

(a) "On the fluorescent behavior of ketones at high temperatures," by J.B. Ghandhi and P.G. Felton, Experiments in Fluids, Vol 21, pp. 143-144, 1996.

**J. Kistler**

The trainee enrolled in 1992 under the supervision of Professor C.K. Law, and graduated with an MSE in 1995. His thesis topic was "An experimental investigation on the extinction of counterflow diffusion flames in an oscillating flow field". He has two archival publications.

(a) "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).

(b) "Extinction of counterflow diffusion flames under velocity oscillations," by J.S. Kistler, C.J. Sung, T.G. Kreutz, C.K. Law, and M. Nishioka, *Twenty-Sixth Symposium (International) on Combustion*, The Combustion Institute, Pittsburgh, PA, pp. 113-120 (1996).

**R. Lawson**

The trainee enrolled in 1987 under the supervision of Professor F.L. Dryer, and graduated with an MSE in 1990. His thesis topic was "Some observations

on the char burnout properties of heavy fuel cenospheres: Initial results using a small fluidized bed reactor". He has one archival publication.
(a) "Fluidized bed studies of carbon particle oxidation: Gas-phase surface products and surface area evolution," by N.R. Purzer, R.A. Yetter, F.L. Dryer, and R.J. Lawson, *Combustion Science and Technology*, Vol. 110-111, pp. 147-167 (1995).

**P. Papas**
The trainee enrolled in 1988 under the supervision of Professor I. Glassman, and graduated with a Ph.D. in 1994. His thesis topic was "An additive approach to supersonic combustion: use of silane in hydrogen-air systems and consideration of pyrophoretic metals". His industrial sponsor was the United Technologies Research Center. He has the following archival publication.
(a) "Effects of Pressure and Dilution on the Extinction of Counterflow Nonpremixed Hydrogen-Air Flames," by P. Papas, I. Glassman, and C.K. Law, *Twenty-Fifth Symposium (International) on Combustion*, The Combustion Institute, Pittsburgh, PA, pp. 1333-1339 (1994).

**K. Whaling**
The trainee enrolled in 1988 under the supervision of Professor P.D. Ronney, and graduated with an MSE in 1991. His thesis topic was "Stationary premixed flame in spherical and cylindrical geometry". His industrial sponsor was GE Aircraft Engines. He has one archival publication.
(a) "Stationary premixed flames in spherical and cylindrical geometries," by P.D. Ronney, K.N. Whaling, A. Abbud-Madrid, J.L. Gatto, and V.L. Pisowicz, *AIAA J.* Vol 32, pp. 569-577 (1994).

**S. Zeppieri**
The trainee enrolled during the periods of 1989 to 1991, and 1994 to 1999, respectively under the supervision of Professors P.D. Ronney and I. Glassman. His thesis topic was "High temperature experiment and computational studies of the pyrolysis and oxidation of endothermic fuels". His industrial sponsor was Textron-Lycoming.