

Combustion Gasification & Propulsion Laboratory

Prof P.J.Paul



P.J.PAUL

Professor, Dept of Aerospace Engineering
Combustion, Gasification & Propulsion Lab

Indian Institute of Science

Bangalore 560012 INDIA

Tel: 91-80-2360 0536

Fax: 91-80-2360 1692

email: paul@cgpl.iisc.ernet.in

Academic Qualification

B.Sc (Engg.) : 1971, Kerala University, India

M.E (Aeronautical) : 1973, Indian Institute of Science, Bangalore, India

Ph.D : 1982, Indian Institute of Science, Bangalore, India

Teaching

A few courses relating to combustion, rocket propulsion, liquid propellant rockets were being offered during the period as a faculty member of the Institute.

Research and Scientific Investigations:

The research work conducted is in combustion, propulsion, and related fields. The broad areas include laminar premixed and diffusion flames, heterogeneous combustion, nozzle flows and combustion flow interaction in practical systems.

Development of 2-D code for low speed flows:

The code was written based on finite volume discretization and can be used for arbitrary geometry. Some of the problems tackled using this code are lifted diffusion flames, sandwich composite propellant burning, secondary combustion chamber modeling of RAM jets, heat transfer and flow in large spheres.

Secondary combustion chamber of integral ram rockets:

The aim of the study was to obtain a primary jet configuration which would enhance the mixing between primary and secondary jets. The results of the investigation has generated an optimum primary nozzle configuration. The L/D required for mixing has been brought down from 5--6 to about 3 through careful experimental study.

Solid fuel combustion:

Modeling of solid fuel spheres to obtain the burn times in during flaming and glowing mode of combustion. Char combustion and gasification in various oxygen and carbon dioxide atmosphere have been completed. Limiting oxygen concentration below which combustion of char does not proceed has been identified.

The future plan of work include modeling of turbulent combustion. The attempt would be to derive a relatively small number of equations from the

Navier-Stokes equations which would reproduce the chaotic behavior of turbulent flow. Even though some model equations have been shown to show characteristics of turbulent flow in the literature the relation between these model equations and Navier Equations has not been brought out. Hence the attempt here would be to derive the equations from the Navier- Stokes equations themselves and to see if meaningful turbulent features can be predicted from them.

Developmental & consultancy work:

Stress Relieving of vessel.

Prediction of soak back temperature of propellant walls of the Liquid

Apogee Motor (LAM) of INSAT-II sponsored by ISAC.

A consultancy project from VSSC, Trivandrum for design and fabrication of test facility for hybrid rocket motor.

Investigation of kinetics of systems of interest to propellant chemistry.

International Visits

Visited Ann Arbor, Michigan, USA in 1984 to attend 20 Symposium on Combustion. Also visited after the Symposium Georgia Institute of Technology, Atlanta, USA, Princeton University, MBB, Bremen, West Germany and ONERA, Paris, France.

Munich, West Germany in 1988 to attend 21st International Symposium on Combustion.

Seattle, Washington, USA in 1988 to attend 22nd International Symposium on Combustion.

Orleans, France in 1990 to attend 23rd International Symposium on Combustion.

Irvine, California, USA in 1994 to attend 25th International Symposium on Combustion. Also visited The Royal Institute of Technology, Stockholm, Sweden for discussion on joint project between IISc and RIT.

List of Publications

Books

Editor (with Prof. H.S. Mukunda) of the Proceedings of the Fourth National Meet on Recent Advances in Biomass Gasification and Combustion, 1993

Refereed Journals

- H.S. Mukunda, V.K. Jain and P.J. Paul, A Review of Hybrid Rockets - Present Status and Future Potential, Proc. Indian Acad. Sci, C2, Part I, May 1979, 21, pp.215, 1977.
- P.J. Paul, H.S. Mukunda, H.K. Narahari and V.K. Jain, Regression Rate Studies in Hypergolic Systems, Combustion Science and Technology, 26, pp.17-24, 1981.
- P.J. Paul, H.S. Mukunda and V.K. Jain, Regression Rates in Boundary Layer Combustion, Proc. 19th International Symposium on Combustion, pp. 717-729, 1982.
- H.S. Mukunda, P.J. Paul, U. Shrinivasa and N.K.S. Rajan, Combustion of Wood Spheres --- Experiments and Model Analysis, Proceedings of the 20th Symposium (International) on Combustion, 1984.
- M.S. Hegde, P.J. Paul, and H.S. Mukunda, Free Convective Combustion on Vertical Surfaces - Variable Property Analysis and Experiments, Proc. 20th International Symposium on Combustion, 1986.

- K.N. Lakshmisha, P.J. Paul, N.K.S. Rajan, G. Goyal and H.S. Mukunda, Behaviour of Methane-Oxygen-Nitrogen Mixtures Near Flammability Limits, Proceedings of the 22nd International Symposium on Combustion, pp 1573-1578, 1988.
- G. Goyal, P.J. Paul, H.S. Mukunda and S.M. Deshpande, Time Dependent Operator Split and Un-split Schemes for One Dimensional Flames, Combustion Science and Technology, 60, pp. 167-189, 1988.
- L.T. Chitilapilly, S. Venkateswaran, P.J. Paul and H.S. Mukunda, Flow Measurements in a Model Ramjet Secondary Combustion Chamber, JI. Propulsion and Power, v. 6, pp 727--732, Nov-Dec 1990.
- K. N. Lakshmisha, P. J. Paul, H. S. Mukunda, On the flammability limit and heat loss in flames with detailed chemistry, Proceedings of the 23rd symposium (international) on Combustion, pp 433--440, 1990.
- R. Balu, A.G. Marathe, P.J. Paul and H.S. Mukunda, Analysis of performance of a Hot- gas injection thrust vector control system, JI. Propulsion and Power, pp 580-585, v. 7, July-August 1991.
- G. Goyal, P.J. Paul, H.S. Mukunda, Computational studies on One-Dimensional laminar premixed on H₂-NO Flames, Combustion and Flame, v. 88, pp 28--36, 1992.
- S. Dasappa, P.J. Paul, H. S. Mukunda, and U Shrinivasa, Gasification of wood-char spheres in CO₂-N₂ mixtures--Analysis and Experiments, Chemical Engineering Science, v. 49, No. 2, pp. 223--232, 1993
- D. P. Mishra, P.J. Paul, H. S. Mukunda, Stretch effects extracted from inward and outward propagating spherical flames, Combustion and Flame, v. 97, pp 35--47, 1994
- D. P. Mishra, P.J. Paul, H. S. Mukunda, Stretch effects extracted from propagating spherical premixed flames with detailed chemistry, Combustion and Flame, 1994
- S. Dasappa, H. V. Sridhar, P. J. Paul, and H. S. Mukunda, On the combustion of wood char spheres in O₂/N₂ mixtures -Experiments

and Analysis, In the Proceedings of the 25th symposium (international) on Combustion, 1994.

- H. S. Mukunda, S. Dasappa, P. J. Paul, N. K. S. Rajan, and U. Shrinivasa., Gasifiers and combustors for biomass---technology and field studies, Energy for Sustainable Development, v. 1, pp 27--38, 1994.
- H. S. Mukunda, P. J. Paul, S. Dasappa, U. Shrinivasa, N. K. S. Rajan, H. Sharan, R. Beuhler, P. Hasler and H. Kaufmann., Results of an Indo-Swiss Programme for Qualification, and Testing of an 300 kW IISc-Dasag Gasifier, Energy for Sustainable Development, v. 1, pp 46-49, 1994.
- H. S. Mukunda, and P. J. Paul., Universal behaviour of the erosive burning behaviour in solid propellants, Combustion and Flame
- Debasish Chakraborty, Nagaraj Upadhyaya H.V., Paul P.J. and Mukunda H.S. "A Thermochemical exploration of a 2-D Reacting Supersonic Mixing Layer" Phys. Fluids 9 (11), November 1997, pp 3513-3522.

Proceedings in International Conferences

- B.N. Raghunandan, A. Vidyarthi, H.S. Mukunda, P.J. Paul, Fluid flow Studies on Radial Injectors in Liquid Rocket Engines, Proceedings of the Second Asian Congress on Fluid Mechanics, Beijing, China, October 2-30, 1983.

Proceedings in National Conferences

- P.J. Paul, H.S. Mukunda and V.K. Jain, A Study of the Low Frequency Instability in Hybrid Rocket Engines, Paper presented at the Rocket Propulsion Symposium, IAT, Pune, 1978.
- P.J. Paul, V.K. Jain, H.S. Mukunda and M. Chanda, Studies on the Hybrid Rocket Motor, Proc. Fourth Seminar on Gas Turbines, pp. 259-264, November 1979.
- P.J. Paul, T. Venkateswara Rao, H.K. Narahari, A.S.N. Sarma, H.S. Mukunda and V.K. Jain, Studies on the Development of Hybrid Propulsion

System, Proc. Fourth Seminar on Gas Turbines, pp. 241-258, November 1979.

- H. S. Mukunda, P. J. Paul and H. K. Narahari, Integral Ram Rockets (IRR's), Problems and Prospects, Presented at the Specialist Workshop on Integral Ram Rocket, Hyderabad, India, September 1983.
- H.S. Mukunda, P.J. Paul and H.K. Narahari, 'Integral Ram Rockets (IRR's) - Problems and Prospects, Presented at the Specialist Workshop on Integral Ram Rocket, Hyderabad, India, September 1983.
- D. P. Mishra, P. J. Paul and H. S. Mukunda, Flame speed of wood gas at ambient and engine operating conditions, Third National Conference on Biomass Gasification, Baroda, Nov 1991.
- S. Dasappa, P. J. Paul, H. S. Mukunda and U. Shrinivasa, On the modelling of gasification of char spheres with Carbon dioxide, Carbon monoxide, and Nitrogen, Third National Conference on Biomass Gasification, Baroda, Nov 1991.
- H. S. Mukunda, P. J. Paul, U. Shrinivasa, S. Dasappa, and K. Krishna Kant, Development of Powdery Biomass Gasifiers, Third National Conference on Biomass Gasification, Baroda, Nov 1991.
- H. V. Sridhar, S. Dasappa, P. J. Paul, H. S. Mukunda and U. Shrinivasa., On the combustion of wood-char spheres in vitiated air-analysis and experiments, Fourth National Conference on Biomass Gasification, Mysore, Jan 1993.
- Purandar Chakravarty, D. P. Mishra, P.J. Paul, and H. S. Mukunda., The theoretical calculations of the limits of flame propagation for producer gas mixture, Fourth National Conference on Biomass Gasification, Mysore, Jan 1993.
- Shrikant Kanitkar, Purandar Chakravarty, P. J. Paul and H. S. Mukunda., The flame speeds, temperature and limits of flame propagation of producer gas-air mixtures --- experimental results, Fourth National Conference on Biomass Gasification, Mysore, Jan 1993.

- Sridhar, G. A. Rakesh, J. Srinivasan, S. Dasappa, P. J. Paul and H. S. Mukunda., Experimental studies on the performance of Hamara ST-5 stirling engine and possibilities for performance improvement, Fourth National Conference on Biomass Gasification, Mysore, Jan 1993.
- H. S. Mukunda, P. J. Paul., Fundamental combustion and gasification problems of biomass and biomass derived gaseous fuels, Invited paper, pp. 109--117, Proceedings of the First ISHMT-ASME Heat and Mass Transfer Conference, Jan 1994.
- K. N. Lakshmisha, P. J. Paul and H. S. Mukunda., Computational studies of Hydrogen/ air flames near rich flammability limits, pp. 763--769, Proceedings of the First ISHMT-ASME Heat and Mass Transfer Conference, Jan 1994.
- D. P. Mishra, P. J. Paul, and H. S. Mukunda., Computational studies on the flame propagation in producer gas-air mixture and experimental comparisons, pp. 256--262, Proc. 13th National conference on IC engines and combustion, Jan 1994.
- D. P. Mishra, P. J. Paul, and H. S. Mukunda., Computational studies of the effects of ambient parameters on stretched H₂/air premixed flames with detailed kinetics, pp. 277--283, Proc. 13th National conference on IC engines and combustion, Jan 1994.
- D. P. Mishra, P. J. Paul, and H. S. Mukunda., Computation of 2D reacting gas phase in sandwich propellant, Proc. Airbreathing engines and Aerospace propulsion, v. II, pp 462--471, Dec 1994
- Nagaraj Upadhyaya H.V., Debasish Chakraborty, Paul P.J. and Mukunda H.S. "Computational studies on 2-D mixing layers under hypervelocity conditions", 15th National Conference on I.C.Engines and Combustion, Anna University, Chennai, December 17-19, 1997.

Reports, Internal and for Consultancy:

- P. J. Paul, T. N. Krishnan Prasad and H. S. Mukunda., On the optimum oxidiser to fuel ratios, Internal report, Propulsion Group, Aero. Engg., Dept. HRM, March 1974.
- P. J. Paul and H. S. Mukunda., Performance of some hybrid fuels, internal report, Propulsion Group, Aero. Engg., Dept. HRM, 005, April 1974.
- P. J. Paul, T. C. Lazar. S. Venkateswaran, S. Chandran, H. S. Mukunda, Flow studies in dump regions of secondary combustors of integral Ram rockets, JATP-85-003 (R), 1985.
- H. S. Mukunda, B. N. Raghunandan, N. K. S. Rajan and P. J. Paul, High velocity burners and Stress relieving of Horton Spheres, Technical Rept. on consultancy project, Oct. 1985.
- Mukunda, P.J. Paul, J. Srinivasan, A.G. Marathe, Space Craft engine Soak back Heat Transfer Analysis, December 1988.
- S. Venkateswaran, P.J. Paul and H. S. Mukunda, Studies on Secondary combustion Chamber, JATP-85-014, September 1985.
- P. J. Paul and H.S. Mukunda, Numerical Solution of flow Field in the Secondary Combustion Chamber: Basic Mathematical Model, JATP-850021, December 1985.
- S. Venkateswaran, P.J. Paul and H. S. Mukunda, Experimental Studies and Model Secondary Combustion Chamber of an IRR, JATP-86-003, February 1986.
- S. Venkateswaran, P.J. Paul and H. S. Mukunda, Experimental Studies on a Model Secondary Combustion Chamber of an ITT, JATP-86-006, April 1986.
- P. J. Paul, Studies on Secondary Combustion of an IRR - Combustion Studies, JATP- 86-009, May 1986.
- S. Venkateswaran, P. J. Paul and H. S. Mukunda, Studies on Model Secondary Combustion Chamber of an IRR, JATP-86-010, June 1986.

- S. Nedunchezian, P. Venugopal Rao, P.J. Paul and H.S. Mukunda, Studies on Scramjet Combustion Chamber, JATP-89-006, August 1989.
- A.Rajan, G.V. Rao, H.S. Mukunda, J.Srinivasan and P.J. Paul, Thermal Performance of LAM Engine, May 1990.
- A.Rajan, G.V. Rao, H.S.Mukunda, J. Srinivasan and P.J. Paul, Thermal Performance of RCS, May 1990.