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FUNDAMENTAL MODELLING OF KINETICS, MIXING  
AND EVAPORATING IN COMBUSTORS

FINAL TECHNICAL REPORT

J. Swithenbank

Introduction

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➤ An extensive and ambitious study was made with the objective of relating all relevant aspects of current fundamental knowledge of combustion with the performance of actual combustors used in propulsion systems. The results of such a study contributes to establishing realistic design criteria for efficient, stable and low pollution combustors. In particular, an understanding of the fundamental combustion, science and technology limitations permit systems to be optimized at an early stage in the design procedure.

Due largely to the coincidence of several key factors, these studies have been unusually fruitful in so far as the objectives were completely achieved and the results have exceeded our most optimistic hopes. These factors were:-

1. An unusually gifted group of research students.
2. The availability of appropriate apparatus.
3. The successful development of a drop size distribution meter.
4. Timely availability and generous communication of techniques, developed by other combustion research groups, which were complementary to the expertise of our own team.

As with most other research work, this program clearly points the way to several new areas of research as discussed later.

The results of the work have been presented in several publications and documents (Refs. 1-19) and these constitute the meat of the results. This report therefore summarizes the various aspects of the work and the reader is referred to these papers and reports for full details.

Keywords Gas turbine engines; Scramjet engines;  
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## Approach and Conclusions

At the start of this investigation, the available computers and analytical techniques were too primitive to permit the simultaneous solution of the governing equations in three-dimensions including the two-phase and chemical kinetic aspects of combustor flow and a more amenable approach was sought. The technique used was based on the application of global energy balance to the conversion of pressure energy to turbulence energy. This turbulence then mixed the fuel, air and products together with a quantitatively determined mixing intensity by which the ultimate combustion efficiency could be computed (Ref 1). The concepts used and their applicability to scramjet design are detailed in Refs. 2 and 3 and their application to gas turbine combustors in Refs. 4, 5, 6 and 7. These papers developed the stirred reactor network concept for analysing combustor performance and clearly demonstrated its applicability in the prediction of stability limits which were verified experimentally. The results clearly indicated the importance of fuel preparation (dropsizes distribution and droplet velocity) in determining the local air fuel ratio and its effect on overall performance and pollution levels (Ref. 8). The global reaction model used in the early work was then replaced by a detailed chemical kinetic scheme to permit the prediction of pollutants such as  $\text{NO}_x$  and CO (Refs. 9 and 10).

Before further progress could be made, instrumentation development was required, especially for the rapid and accurate determination of droplet size distribution. A laser diffraction dropsizes measuring system was therefore developed together with other instrumentation (especially digital) as reported in Refs. 11, 12, 13 and 14.

At this time, the work was extended into three-dimensional finite difference modelling techniques since appropriate computers, techniques and personnel became available. The first step was to compute the cold flow pattern for a real gas turbine combustor and compare the results with experiment.



Index

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Encouraged by the successful outcome of this study, we proceeded to include the reaction of gaseous fuel in the gas turbine combustor. For the experimental comparison, an air blast atomizer was modified to introduce a premixed air/fuel mixture into the combustor. Satisfactory predictions of temperature profiles were obtained and a critical comparison of the measured hot turbulence intensity at exit with the theory confirmed the validity of the method. These results were published in Ref. 15.

Concurrent studies were carried out on the trajectories of the fuel droplets including evaporation effects and these were published in Ref. 16.

A new technique for the identification of residence time distributions, micro-mixing and interconnections in stirred reactor networks was also devised as presented in Ref. 17. This technique is based on the deduction of the combustor transfer function by the cross-correlation of pseudo-random tracer input/output responses. The full capabilities of this technique have not yet been explored and it is hoped that this topic will form the basis of future USAF sponsored work.

Since most gas turbine burners incorporate swirlers, a preliminary investigation of a multi-swirler design was carried out, as reported in Ref. 18. This demonstrated clearly the effect of swirl velocity distribution and shows that the swirl number parameter  $S$ , commonly used to characterise swirling flow, is quite inadequate for many practical situations. Further studies to derive a multi-parameter technique are indicated.

The culmination of the present overall research program was presented at the Project Squid workshop on "Gas Turbine Combustor Design Problems" at Perdue University, May 1978. This paper presents several highlights of the study and represents one of the first successful attempts to relate all the fundamental features of two-phase, three-dimensional reacting flow to a practical aerospace combustion system using both finite difference and reactor network techniques.

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#### References

1. J. Swithenbank, "Flame Stabilization in High Velocity Flow", Combustion Technology, Ed. Palmer and Beér, pp. 91-127, Academic Press, 1974.
2. J. Swithenbank, I. Poll, D.D. Wright and M.W. Vincent, "Combustor Design Fundamentals", Proceedings of the 14th Int. Symp. on Combustion. The Combustion Institute, 1973.
3. M.T. Jaques, R. Payne and J. Swithenbank, "The Role of Tubulence in Scramjet Combustor Design", Proceedings of the 1st International Symposium on Air Breathing Engines, June 1972.
4. I. Poll, R. Payne, J. Swithenbank and M.W. Vincent, "Combustor Modelling", Proceedings of the 2nd International Symp. on Air Breathing Engines. The Royal Aero. Soc., 1974.
5. J. Swithenbank, "Some Unresolved Problems in the Fluid Mechanics of Combustion", Jl. Fluids Eng., Vol. 97, Series 1 number 3, Sept. 1975.
6. A.K. Gupta, J. Swithenbank and G. Rock, "Combustor Modelling Comparison of Some Theoretical and Experimental Results", Proc. European Symp. on Combustion, Sept. 1975, pp. 763-768.
7. A.K. Gupta, J.R. Tippetts and J. Swithenbank, "Modulated Swirl Combustor", Proceeding of 2nd European Combustion Conference, pp. 690-696. 1974
8. J. Swithenbank and P.G. Felton, "The Effect of Fuel Preparation on Gas Turbine Combustor Performance", European Combustion Conference, Sept. 1975, pp. 647-653.
9. D.S. Prior and J. Swithenbank, "Hetrogeneous Partially Stirred Reactor Analysis", AFOSR 76-0060TR.
10. D.S. Prior, J. Swithenbank and P.G. Felton, "The Stirred Reactor Modelling of a Low Pollution, Liquid Fuelled Combustor", AIAA 15th Aerospace Sciences Conference. Aeronautics and Astronautics Vol. 54, 1977.
11. J. Swithenbank, J.M. Beér, D.S. Taylor, D.J. Abbott and G.C. McCreath, "A Laser Diagnostic Technique for the Measurement of Droplet and Particle Size Distribution", Progress in Astronautics and Aeronautics, Vol. 53, "Experimental Diagnostics in Gas Phase Combustion", Ed. B. Zinn, AIAA, 1977.
12. A.K. Gupta and J. Swithenbank, "Modern Diagnostics for the Measurement of Fluctuating Quantities in Flames", J. Inst. F., 1977.
13. J. Swithenbank, "Measurement in Combustion Processes", Measurement of Unsteady Fluid Dynamic Phenomena, Ed. B. Edwards, Hemisphere Press, 1977.
14. J. Swithenbank, "Analogue and Digital Storage and Display Systems", Measurements of Unsteady Fluid Dynamic Phenomena, Ed. B. Edwards, Hemisphere Press, 1977.

15. P.G. Felton, J. Swithenbank and A. Turan, "Progress in Modelling Combustors", Vth Int. Symp. on Comb. Processes. Krakow, Sept. 1977, Archives of Thermodynamics and Combustor Processes.
16. F. Boysan and J. Swithenbank, "Spray Evaporation in Recirculating Flow", AFOSR 78-0842TR, 17th Int. Symp. on Comb. The Combustion Institute, 1978.
17. J. Swithenbank and A. Turan, "Some Infra-Red Applications in Combustion Technology", AFOSR 79-0006TR, SIRA Conference on Infra-Red Instrumentation Techniques, London 1978.
18. A.K. Gupta, J.M. Beér and J. Swithenbank, "On the Operational Characteristics of a Multi-Annular Swirl Burner", Combustion Science and Technology. 1977
19. J. Swithenbank, A. Turan and P.G. Felton, "3-Dimensional 2-Phase Mathematical Modelling of Gas Turbine Combustors", Project Squid Workshop, "Gas Turbine Combustor Design Problems", Ed. A. Lefebvre, 1979.