COMBUSTION OPTIMIZATION STUDIES
FOR STRATIFIED CHARGE AND
DIESEL ENGINES

Progress Report
for Period October 1, 1977 - September 30, 1978

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ABSTRACT

The objectives of the program are 1) To assess the feasibility and operating characteristics of the following high compression, spark ignition (or self ignition), stratified charge (or diesel) engine configuration: compression ratio: 16; open chamber; direct fuel injection; unthrottled operation; 615 cc/cylinder; explored speed range 1000-4000 rpm (expected practical range 600-6000 rpm); fuels: ethanol-diesel mixtures; spark ignition (stratified charge) or self ignition (diesel). 2) To continue the development and the testing of physical and numerical aspects of multi-dimensional combustion models in order to assess and improve their accuracy and to reduce their computation time. 3) To contribute to the achievement of a more fundamental and detailed understanding, characterization, and command of the processes which control efficiency and emissions in internal combustion engines.

The objectives are to be met by comparing, locally and instantaneously, calculated and measured density gradients in the flow field due to direct fuel injection. The computed two-dimensional, unsteady results will be compared with Schlieren film data from a transparent-piston, transparent-head, valveless, engine.

Progress to date is in line with the contract schedule in that: 1) engine modifications to obtain a transparent-piston, transparent-head configuration have been implemented; 2) a gaseous fuel injection system has been designed, built, and operated; 3) shadowgraph records of engine combustion have been obtained; 4) a LDV system for in-cylinder gas velocity measurements has been selected; 5) progress has been made toward measuring in-cylinder pressure, temperature, and composition for complete characterization of the charge; 6) modeling of unsteady gaseous jets have yielded results which match asymptotically known steady state solutions; 7) comparison with unsteady, two-dimensional bomb flames have yielded general scaling procedures for the computation of laminar flames; 8) studies toward modeling of thick sprays have been continued; 9) DISC and other technical meetings have been attended and the results of the program made known to researchers and automotive industries; 10) a very promising technique to apply television to unsteady events with short characteristic time (< 30 ms) has been developed and applied to obtain records of engine flames.

Future work is expected to proceed according to the initially proposed work schedule.
OBJECTIVES AND APPROACH

The objectives of the program are 1) To assess the feasibility and operating characteristics of the following high compression, spark ignition (or self ignition), stratified charge (or diesel) engine configuration: compression ratio: 16; open chamber; direct fuel injection; unthrottled operation; 615 cc/cylinder; explored speed range 1000-4000 rpm (expected practical range 600-6000 rpm); fuels: ethanol-diesel mixtures; spark ignition (stratified charge) or self ignition (diesel). 2) To continue the development and the testing of physical and numerical aspects of multi-dimensional combustion models in order to assess and improve their accuracy and to reduce their computation time. 3) To contribute to the achievement of a more fundamental and detailed understanding, characterization, and command of the processes which control efficiency and emissions in internal combustion engines.

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SIGNIFICANT RESULTS

1) The development of a pulsed illumination, closed circuit television technique for real time viewing of unsteady (>1 μs) events (Appendix D).

2) The definition of two scaling transformations that make possible the accurate numerical computation of multi-dimensional, unsteady laminar flames with simple, uniform mesh, and computation time of the order of 10 minutes on an IBM 360/91 (Appendix A).

PROGRESS TO DATE

Progress is in line with the contract schedule given in the proposal of July 11, 1977, and on the next page. In addition one of the proposed tasks has been expanded (Task 5) and a new one has been added to the advantage of the program and at no additional cost. A brief task by task report follows. Some of the details are given in the four papers of the appendices but much of the recent progress is obviously yet to be written up for formal publications.
WORK SCHEDULE

TASKS

1. Modification of the Single Cylinder Engine
2. Implementation of Gaseous Fuel Injection
3A. Schlieren and/or Shadowgraph Recording of Gas and Liquid Jets without Combustion
3B. Schlieren and/or Shadowgraph Recording of Gas and Liquid Jets with Spark Ignition
3C. Schlieren and/or Shadowgraph Recording of Gas and Liquid Jets with Self Ignition
4. Gas Velocity Measurements
5. Measurements of Engine Operating Parameters
6A. Modeling of Gaseous Jets without Combustion
6B. Modeling of Gaseous Jets with Spark Ignition
6C. Modeling of Gaseous Jets with Self Ignition
7. Comparisons with Bomb Data
8. Modeling of Thick Sprays
9. Participation in DISC Meetings
10. Development of Pulsed Illumination Television System
Task 1: Modification of the Single Cylinder Engine

The modification that called for the implementation of a transparent-piston, transparent-head design has been completed but not fully tested as yet. The engine has been fired at a compression ratio of 8.5, and motored but not fired with gas and liquid injection at a compression ratio of 16. Since this is the only engine of its type we currently have in operation, we are proceeding with care because major damage to it would result in significant detrimental effects on the program. Moreover the work schedule does not call for firing at high compression ratio as yet. Problems which were encountered and solved include: piston slapping and galling; displacement and breakage of the piston window; poor sealing, resulting in dirtying of the windows remains a limiting factor but not a preclusive one.

Task 2: Implementation of Gaseous Fuel Injection

The gaseous fuel injector has been designed, built, and operated with methane at pressures up to 1500 psia and under firing conditions at compression ratio of 8.5.

Task 3A: Schlieren and/or Shadowgraph Recording of Gas and Liquid Jets without Combustion.

Instead of high speed filming, a television technique has been developed to obtain the proposed records. The new technique has been applied to steady and transient propane torch flames in standard air, to spray jets in the motored engine, and to premixed methane-air flames in the firing engine at compression ratio of 8.5 (see Appendix D). The general quality of the picture is more than adequate for the goals of this project except for the case of non-combusting gas jets in the engine. Work is in progress to improve sensitivity and/or contrast, particularly for the gaseous jet application.

Tasks 3B, 3C: Not yet active, according to the work schedule.

Task 4: Gas Velocity Measurement

The scope of this task has been considerably expanded to include the initial implementation of a two-color LDV system. Only the initial implementation is being covered by this contract. It was felt that hot wire anemometry and the mean gas velocity in the combustion chamber during motoring would have constituted insufficient information in the long run. Accordingly time was devoted to a review of the LDV measuring technique, to its application to the IC engines, and to the selection of LDV instrumentation. The selected system includes a Lexel argon ion laser with temperature tuned etalon for the stable, single axial mode output it provides as a result of its Invar resonator structure and the temperature tuned etalon. Some of the funds for this instrumentation have been provided by our department and industrial donations. To complete it, funds have been requested of DOE. As previously mentioned,
only the initiation of our LDV efforts has been included in this program. Additional funds are being sought for its full implementation.

Task 5: Measurement of Engine Operating Parameters.

In the proposal, the engine operating parameters mentioned were the standard ones of speed, torque, fuel flow rate, air flow rate, injection timing, spark timing, etc. This task has been significantly expanded to include the application of techniques which will allow us to characterize the cylinder charge precisely. Computations of engine combustion have shown it to be sensitive to the size and composition of the charge. Measurements of total air and fuel flow rates and educated guesses as to scavenging efficiency are not adequate. Simultaneous measurement of cylinder pressure (by piezoelectric transducer), composition (by sampling and analysis of cylinder gas), and temperature (by an infrared line inversion technique) will allow us to determine the actual size and equivalence ratio of the charge. To achieve a greater control of our experiment and a better characterization of the charge, a report was forwarded to DOE for instrumentation funds for a speed control system for our dynamometer and for a gas analysis unit.

Task 6A: Modeling of Gaseous Jets Without Combustion

Computations of unsteady, two-dimensional (axisymmetric) incompressible jets have been performed with very small grid sizes (of the order of 100 μ) to study the transient of the formation of the jet and to verify that the computed steady state converges to the known and experimentally measured one. The appropriate limit was recovered. The transient of the gaseous jet exhibits similarities with that of an atomized spray as recently observed by Reitz ("Atomization and Other Breakup Regimes of a Liquid Jet" Ph.D. Thesis No. 1375-T, MAE Department, Princeton University). These similarities are currently under study since the investigation of similarities and differences of gas and spray jets constitutes one of the major objectives of this project.

Tasks 6B, 6C: Not yet active, according to the work schedule

Task 7: Comparison with Bomb Data

The comparison between measured and computed two-dimensional, unsteady laminar flames in a bomb has already yielded a significant result and may be in the process of yielding a second one. The significant result is the definition of two scaling transformations that render possible the accurate numerical computation of multi-dimensional, unsteady flames with simple, uniform mesh and computer time of the order of 10 minutes on an IBM 360/91 (see Appendix A). The technique has broad potential for application to fundamental studies of the structure of laminar flames. The study of unsteady laminar flames is of interest within this program because, in the absence of turbulence, only two controlling processes are left which require modeling simplifications: chemical kinetics and wall heat transfer. Accordingly the validity of the two simplifications can be assessed independently from the additional ones needed to compute turbulent flows. Recently, and in the course of this study, we also think we have found a way of determining the energy lost through wall heat transfer directly from the experimental data and without any major
assumption. Moreover the method would be applicable to engine data as well. The exploration and testing of the method is in progress.

Task 8: Modeling of Thick Sprays

Progress in this task is expected to be very slow. We are currently seeking an appropriate way of formulating the problem since for thick sprays a set of conservation equations which are likely to be amiable to numerical solution is currently unknown. Our earlier work on feasibility studies of the computation of sprays has now been summarized in a paper (Appendix B).

Task 9: Participation in DISC Meeting

We participated in, and contributed three presentations to, the 7th DISC meeting at Lawrence Livermore Laboratory in March 21-22, 1978 and look forward to the next meeting at Los Alamos Scientific Laboratory. Several other technical meetings were also attended including the Squid Workshop on Combustion and Chemical Kinetics in Engines, September 1977 for which we were asked to contribute a paper (Appendix C).

Task 10: Development of a Pulsed Illumination Television System

The development of this very promising technique of applying television to unsteady events with short characteristic time (< 30 ms) has been added to the program at no additional cost. For details please consult the paper of Appendix D.

TIME ALLOCATION AND FUTURE PROGRESS

During the first nine months of the present contract term the principal investigator has spent approximately 20% of his time on the project; it is expected that he will spend about 25% of his time on the project during the remainder of the term. Future progress on the research tasks is expected to be made in compliance with the rate outlined in the Work Schedule.
BUDGET FOR SECOND YEAR OF CONTRACT NO.  
EC-77-S-02-4191.A002

I. Salaries

A. Prof. F. V. Bracco (Principal Investigator) 25 4,850
   Dr. R. Steinberger (Member of the Research Staff) 75 13,200
   Dr. S. Syed (Member of the Research Staff) 75 10,400
   D. D. Santavicca (Member of the Research Staff) 25 6,600
   Mr. J. Semler (Technical Associate) 25 5,950

B. Two Graduate Students (Assistants in Research)
   Summer (Full time, 2 months) 2,520
   Academic (1/2 time, 10 months) 6,200
   Tuitions 6,000

II. Personnel Benefits
21.5% of IA 8,815

III. Expendable Material & Supplies
(including 50% of Yearly Maintenance cost of HP-2108 Minicomputer) 20,065

IV. Travel
3,000

V. Publications
2,000

VI. Subtotal Direct Costs
89,600

VII. Indirect Costs (64% of VI)(see Cost Sharing Xc below) 46,592

VIII. Direct Costs Not Subject to Indirect Costs
   Computer (IBM 360/91 @$620/hr) 18,808
   University Machine Shop ($15.65/hr) 4,000
   Permanent Equipment 6,000

IX. Total 165,000
X. Cost Sharing

a. $2,173 of Prof. Bracco's Academic Year plus $1840 of Personnel Benefits and Indirect Costs

b. $4,200 of Students' tuition plus $2184 of Indirect Costs

c. Audited and Approved Indirect Cost Rate of 64%. However, since the limit on fiscal year funding was estimated on basis of the earlier rate of 52% the amount of indirect cost to be collected will not be increased. Thus the difference between 52% and 64% will be cost sharing ($10,752).