AUTOIGNITION OF FUELS

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The primary objectives of this research program are to (1) develop a critical experiment capable of determining the autoignition characteristics of aircraft-type fuels in air at elevated temperatures and pressures, and (2) apply the equipment and techniques developed to mapping the ignition delay times of several hydrocarbon fuel-air mixtures. Autoignition data are required for establishing design criteria pertinent to advanced gas turbine engines which employ fuel prevaporization and premixing. The program is directed toward design of the experiment, fabrication of the test equipment, empirical verification that the variables which affect autoignition can be controlled in a manner such that useful quantitative results can be obtained, and parametric evaluation of the autoignition characteristics of several liquid hydrocarbon fuels.

The spontaneous ignition characteristics of hydrocarbon fuels in air have been a subject of investigation for many years; however, none of the previous investigators has been completely successful in isolating and evaluating each of the experimental variables in a controlled manner and over ranges representative of those encountered in advanced gas turbine engines. Consequently, a thorough examination of past efforts in this area was undertaken in order to properly define a critical experiment that determines the effects of all the known or suspected variables on autoignition. It was concluded that parametric autoignition data pertinent to gas turbine engines can be best acquired by conducting a continuous flow experiment using dry, unvitiated air, and providing independent control of pressure, temperature, and fuel-air mixture residence time. In addition, the experiment should minimize flow disturbances and wall effects, and provide for a determination of the fuel-air mixture distribution and the degree of droplet vaporization. These criteria served as a basis for formulating the technical approach from which the experiment design evolved.

The autoignition test apparatus which was developed in the present program consists of an electrical resistance-type air heater, an inlet plenum and flow straightener, a specially-designed premixing-type fuel injector for generating a relatively uniform fuel-air distribution, a cylindrical mixer/vaporizer section comprising several flanged spool pieces to permit length variation over the range 2.5 cm to 150 cm in increments of 2.5 cm, an expander section which provides a sudden expansion at the autoignition station and a water quench, a scavenger afterburner, and a remotely-operated throttle valve located in the exhaust ducting. Details of the test hardware are described in Ref. 1 and shown schematically in the attached illustrations. The inner surface of the mixer/vaporizer sections is relatively smooth and free of wake-producing imperfections as a result of internal machining and the use of alignment dowels. Theoretical analyses of the need for wall cooling to preclude the possibility of ignition in the boundary layer were not able to conclusively demonstrate that cooling would not be required, therefore, the design provides the capability for internal wall cooling; however, this feature is optional (the inner wall has sufficient strength to permit uncooled operation). Uniform inlet velocity profiles are assured by flow baffles and straight sections, and the inlet temperature and pressure are measured using fixed probes.

Normal operating procedure consists of establishing a prescribed condition within the test duct and gradually increasing the air temperature or pressure until autoignition occurs at the exit of the mixer/vaporizer section. This continuous test procedure ensures an accurate determination of the conditions at autoignition. The ignition delay time is equal to the residence time of the fuel-air mixture between the point of injection and the axial position of the flame, and it is computed based upon the average flow velocity. The occurrence of autoignition is determined indirectly using a thermocouple, a differential pressure transducer and photodetectors to make simultaneous measurements of the temperature-rise, pressure-rise and illumination delay times. Upon ignition, the test is terminated abruptly by shutting off the fuel flow and thereby purging the rig with inlet air flow. This test arrangement permits independent variation of each of the important experimental variables (i.e., pressure, temperature, velocity, residence time, and fuel-air ratio) within a fixed range of test conditions.

The generation of a uniform mixture is a prerequisite for the evaluation of the importance of fuel-air ratio; therefore, techniques for obtaining rapid vaporization and mixing with a minimum flow disturbance were studied and several candidate fuel injectors were fabricated and tested. Two fuel injector designs have demonstrated high potential for achieving a uniform spatial distribution of fuel in air. The first, a multiple-strut injector, is one in which fuel is injected normal to the airflow from a large number of injection sites and into segments of approximately equal area. The number and size of the injection orifices were determined from consideration of liquid jet penetration, orifice plugging, and injector sensitivity to combustor pressure oscillations. Efficient atomization results as a consequence of the high shear forces created by the interaction of the high-velocity airstream and the low-velocity fuel jets. Flow disturbance and, therefore, pressure loss are minimized by a streamline shaped design. The second injector is a multiple conical tube type which consists of a concentric array of venturi-shaped air passages into each of which an individual and regulatable flow of fuel is injected near the entrance. Fuel is supplied by means of a small diameter tubing that is sufficiently long to provide ample pressure loss to minimize the effect of rig pressure fluctuations on the fuel flow rate. Airflow nonuniformities are reduced as a result of the pressure loss incurred and atomization is improved by the shear forces created by the increased air velocity.

Parametric tests to map the ignition delay characteristics of Jet-A fuel were conducted at pressures of 10, 15, 20, 25, and 30 atm, inlet air temperatures up to 900K and fuel-air equivalence ratios of 0.3, 0.5, 0.7, and 1.0. Residence times in the range of 1 to 50 msec were obtained by interchanging spool pieces to create six different mixer/vaporizer lengths (6, 23, 53, 84, 99, and 130 cm) and by testing at two different airflow rates (0.5 and 1.0 kg/sec). The resulting free-stream velocities were in the range 20 to 100 m/sec. As expected, the results indicate that the ignition delay times decrease with increasing air temperature and pressure. Also, the data show that, for lean mixtures, ignition delay times decrease with increasing equivalence ratios.

Future work will concentrate on obtaining detailed autoignition data for a variety of fuels, including JP-4, No. 2 diesel oil, ERBS and cetane, and investigating the effects of chemical and physical properties of fuels on autoignition.

References

Spadaccini, L. J.: Development of an Experiment for Determining the Autoignition Characteristics of Aircraft-Type Fuels. NASA CR-135329, September, 1977.

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Introduction

- Premixed-prevaporized combustion can provide low NOx emissions
- Autoignition is a serious problem
- Existing autoignition data are inadequate

Ignition Delay

- Physical delay
  - Droplet formation, heating and vaporization
  - Diffusion
  - Mixing
- Chemical delay
  - Preflame reactions
  - Cool-flame ignition, $\Delta T \sim 400K$
  - Hot-flame ignition, $\Delta T \sim 1500K$

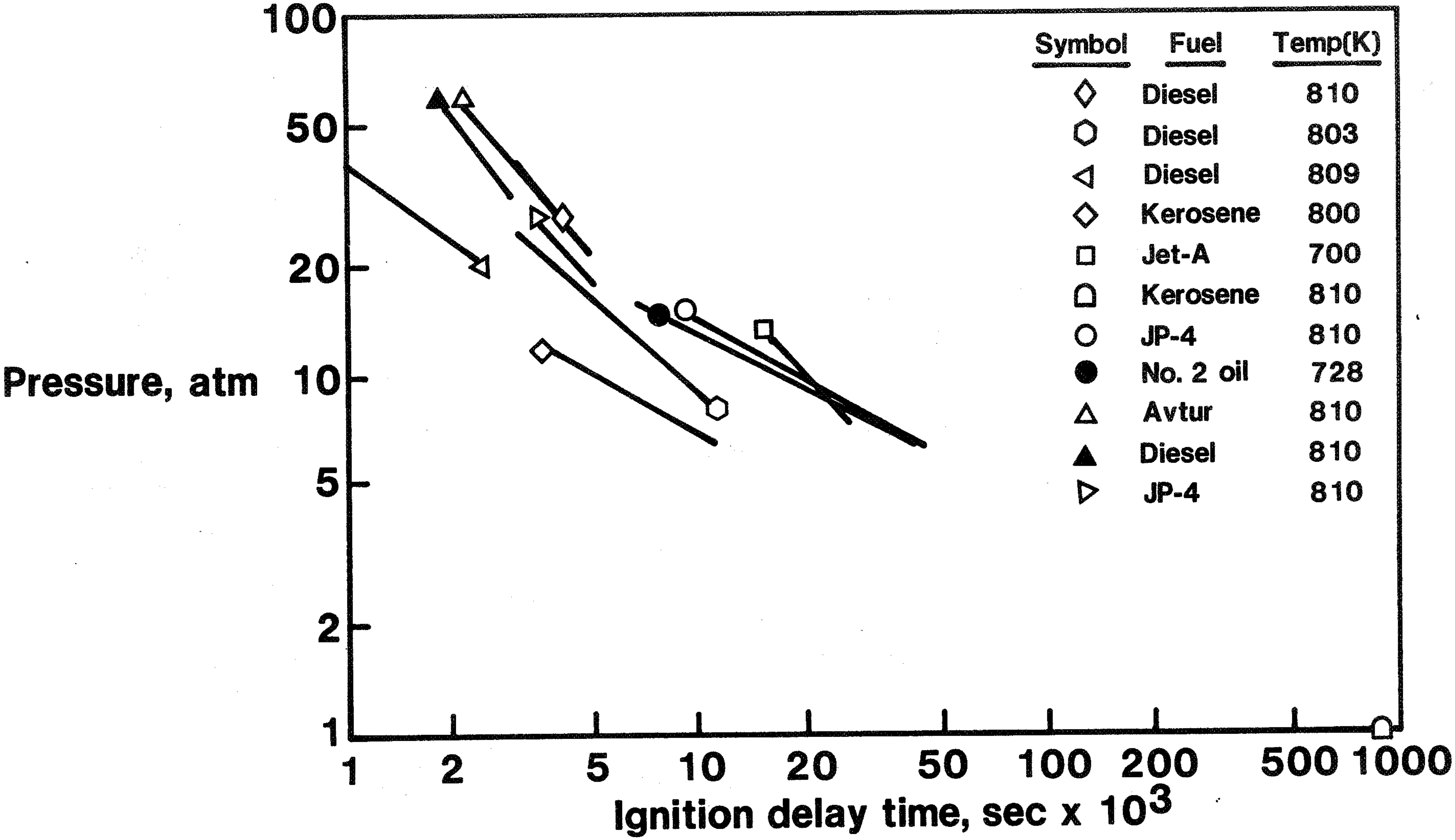
Ignition Indicators

- Temperature rise
- Pressure rise
- Light emission
- Formation of critical species

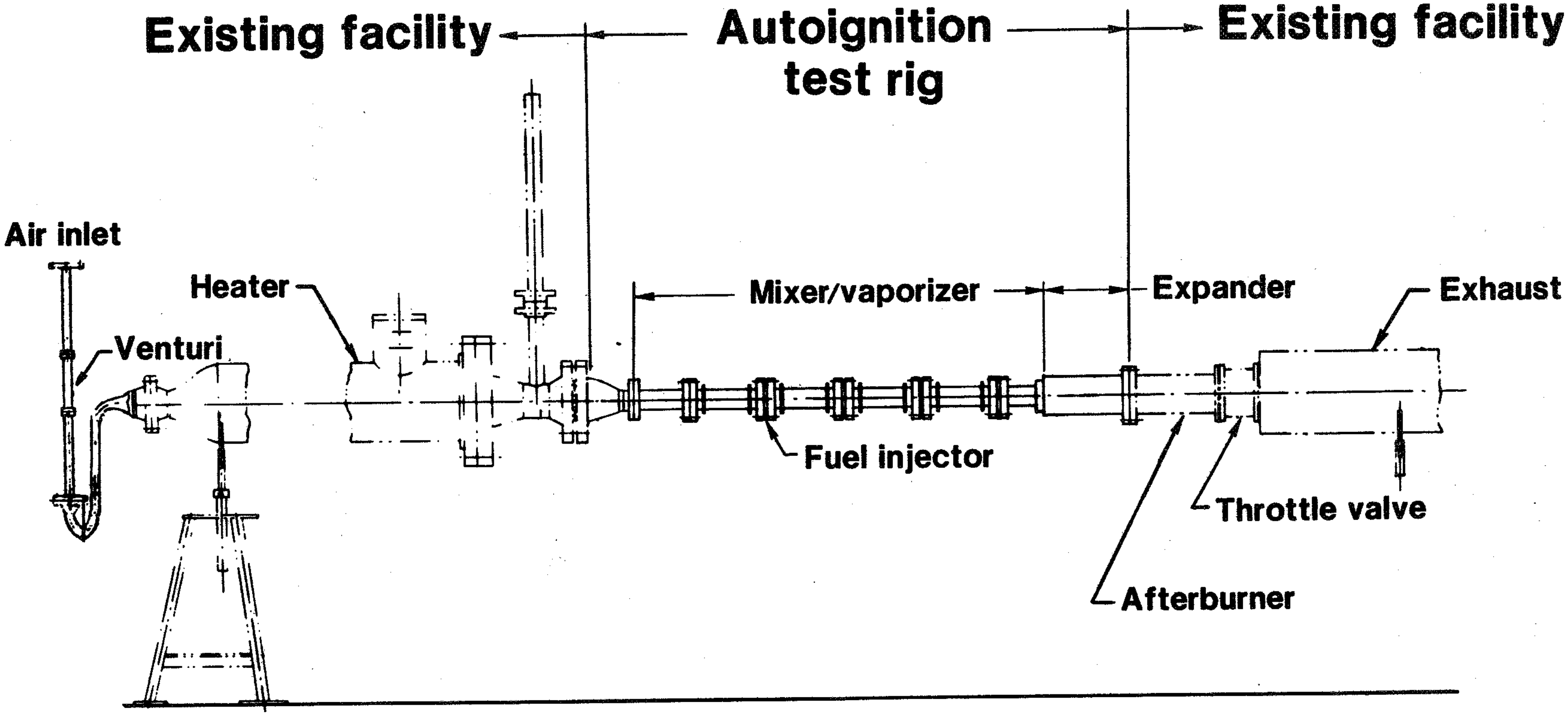
Candidate Test Apparatus for Ignition Delay Measurements

	Disadvantages
● Constant volume bomb	Difficult to premix low-vapor-pressure fuels without significant chemical reaction
● Motored and fired reciprocating engines	Varying pressure, temperature, velocity, turbulence and fuel spray characteristics
● Shock tube	Difficult to adapt for use with low vapor pressure fuels
● Continuous flow rig Continuous combustion Intermittent combustion	Susceptible to flashback

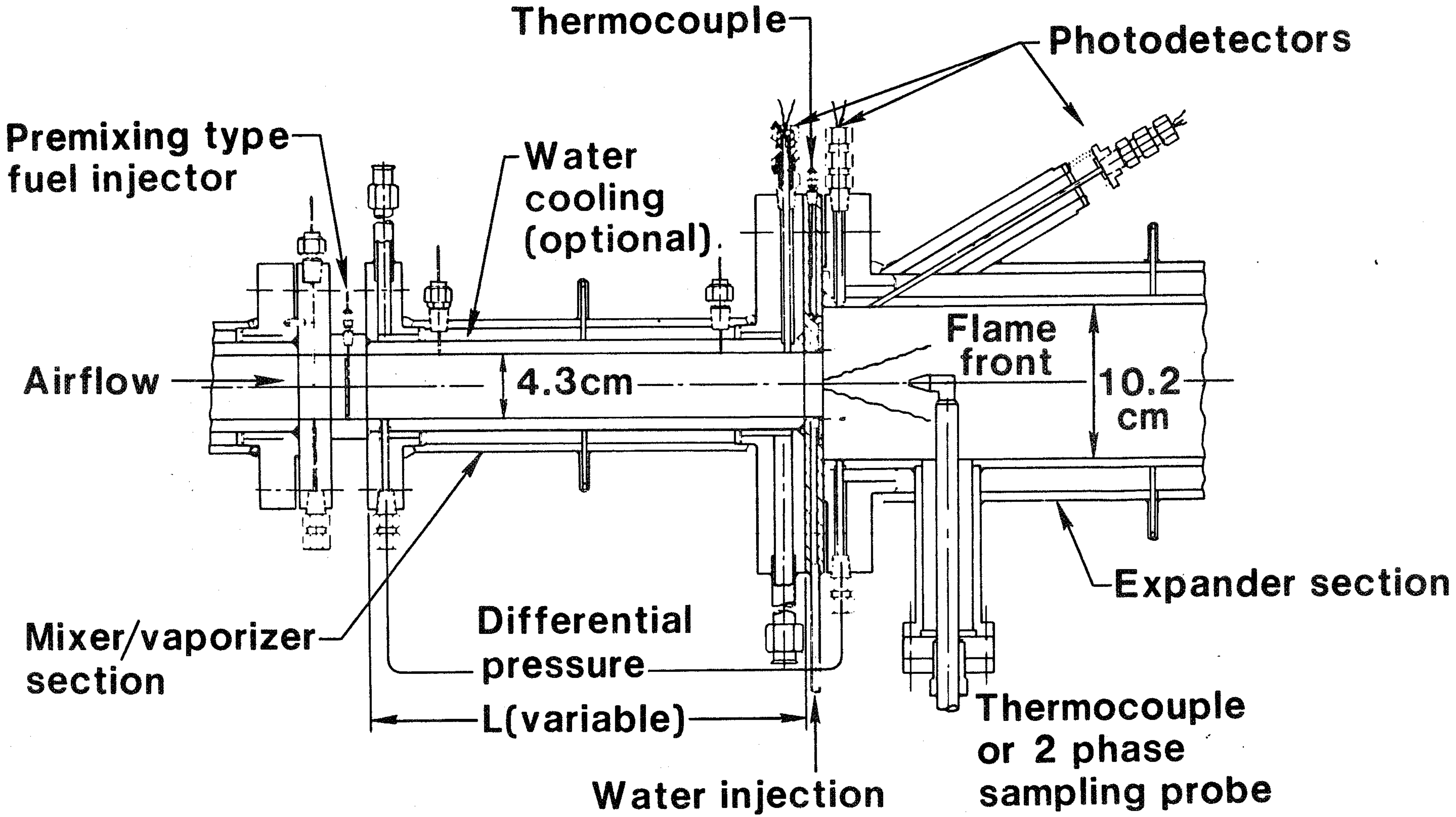
Correlation of Ignition Delay Data



Autoignition Test Assembly



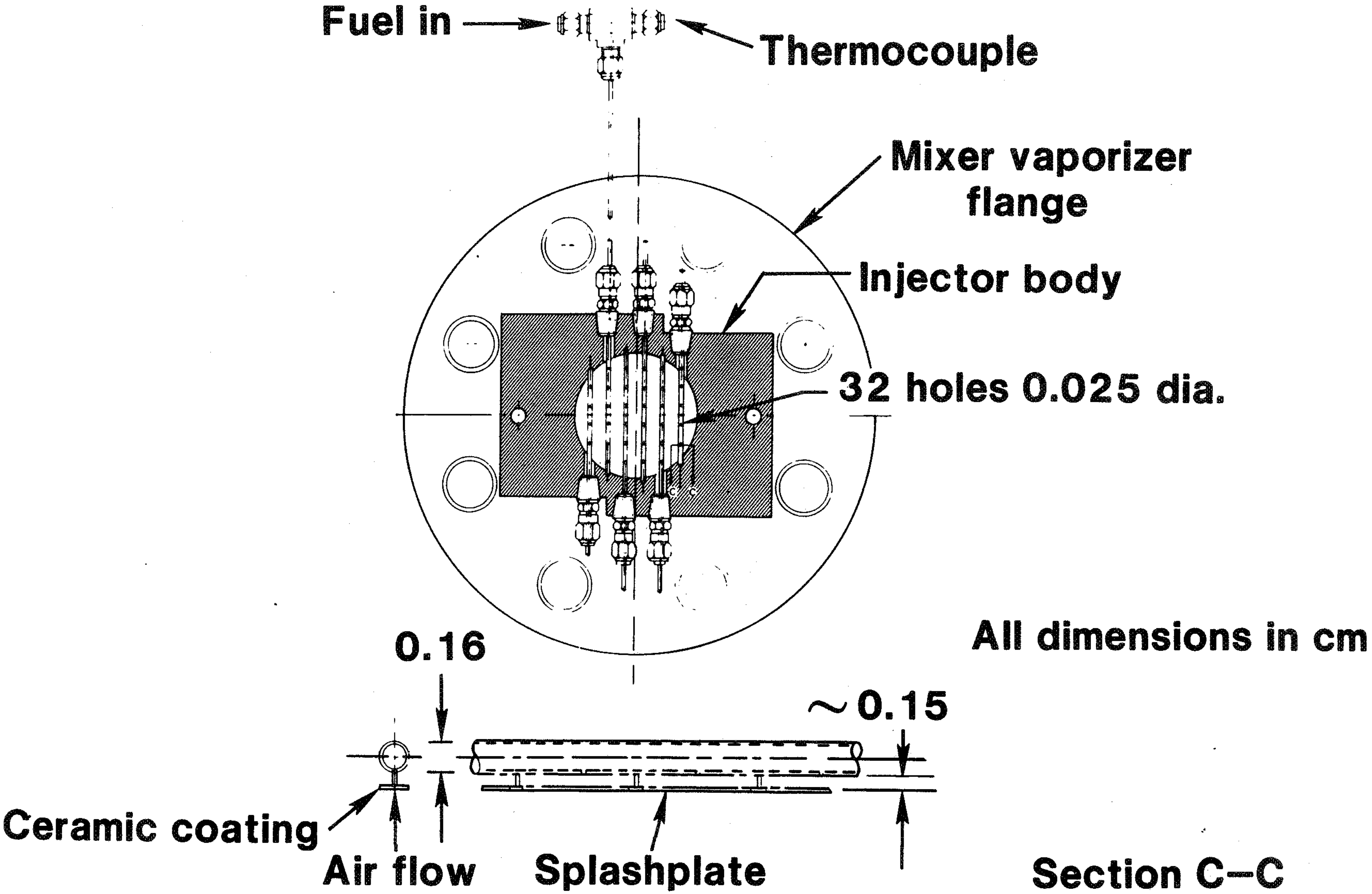
Autoignition Test Section



Fuel Injector Design Criteria

- Rapid vaporization and mixing
- Minimum flow disturbance
- Insensitive to combustor pressure oscillations
- Low pressure loss

Distributed Source Injector



Fuel in

Thermocouple

Mixer vaporizer flange

Injector body

32 holes 0.025 dia.

All dimensions in cm

0.16

~0.15

Ceramic coating

Air flow

Splashplate

Section C–C