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PRELIMINARY TESTS OF A GAS TURBINE
COMBUSTOR WITH AN AIR ATOMIZING
FUEL INJECTOR SYSTEM

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This information is being published in preliminary form in order to expedite its early release.

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SUMMARY

Preliminary tests were made to determine the feasibility of using a simple air atomizing fuel injector in a turbojet combustor. The combustor was one which had been developed previously with swirl atomizing nozzles. A modification was made which allowed the fuel to be injected at low pressures through simple orifices perpendicular to the air stream. The fuel impinged on a flat plate oriented parallel to the air stream and was atomized off the downstream end of the plate.

Three different fuel plate designs were studied. Spray patterns using water in place of fuel were inspected visually and photographed. Then the plate that produced the best results was tested with ASTM A1 fuel under burning conditions. The performance was compared to the performance obtained with swirl atomizing nozzles.

Combustion efficiencies, uncorrected for duct cooling losses varied from 86 to 90 percent with both fuel systems. Pressure losses were also the same. The exit temperature radial profile was hotter at the hub for the combustor with the air atomizing fuel system. The preliminary results are encouraging enough to justify further development of the system.

INTRODUCTION

In most present day turbojet combustor designs, liquid fuel is injected directly into the sheltered combustor primary zone. With such designs, high combustion efficiency requires good atomization of the liquid fuel. Atomization is accomplished by using a nozzle that imparts high velocities

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to the fuel (ref. 1). This kind of fuel injection system has two major difficulties. First, the fuel distribution within the primary zone is determined principally by the fuel velocity and therefore changes with fuel flow rate. Second, the nozzle passage size necessary at low fuel flow rates is so small that there is a tendency for nozzle fouling if the nozzle becomes hot. Both of these problems are aggravated by the trend to higher temperature engines. The required range of fuel flow increases and with it the range of fuel distribution patterns. Even more important, the higher compressor discharge temperature and higher average combustor temperature provide a severe atmosphere for fuel nozzle fouling.

An approach that avoids both of these problems is to use the velocity of the airstream to atomize the liquid fuel. This velocity changes relatively little over the operating range of an engine. Therefore, the fuel distribution pattern is less likely to change significantly. Furthermore, small nozzle passages are not required to promote high liquid velocities and the fouling problem is greatly reduced. The air velocities available for atomization will vary from about 200 to 400 ft/sec in a typical low pressure drop combustor. Tests described in reference 2 have shown that such velocities are adequate to produce droplet sizes comparable to those obtained with swirl atomizers. It was decided, therefore, to conduct some preliminary tests in an actual combustor to evaluate this approach.

The combustor was one that had been developed with swirl atomizing nozzles (ref. 3). The design employs a lean primary zone, typical of advanced combustors. This feature would be expected to accentuate the problem, inherent in air-atomizing fuel systems (ref. 2), of maintaining an adequate lean blowout limit.

The tests were conducted at atmospheric pressure and at 600° F nominal inlet air temperature. They were limited to two values of air flow with combustor air velocities typical of the takeoff and cruise conditions for some advanced engines.

TEST INSTALLATION

The test facility (fig. 1) consisted of a combustion air supply which was metered by an air orifice capable of measuring flows up to 5 pounds

per second. A flow control valve was located downstream of the orifice and directed the air into a direct-fired preheater capable of heating the flow to 600 F. A 3-foot-diameter plenum mixed the airflow and channeled it into the instrumented inlet section where air temperature, static pressure, and total pressure were measured. The test section was a 10-inch long diffuser housing and a 12-inch long combustor housing attached to the inlet instrument section. The rectangular test section housing was 15-inches wide and 10-inches high. Exit temperatures were measured in the exit instrument section. Exhaust products were discharged at atmospheric pressure after passing through a muffler and water spray scrubber system.

Details of the instrumentation are given in figure 2. A jet type fuel conforming to ASTM A-1 specifications was used for the combustor tests.

TEST COMBUSTORS

A cross-section of the test combustor is shown in figure 3. In this configuration 85 percent of the total airflow was channeled to the outer passage, 5 percent to the lower liner for cooling and 10 percent through the air atomizing channel. The atomizing channel was 0.62-inches high. It contained a flat plate located at the downstream end of the channel and extending downstream of the combustor headplate. Fuel was injected against the plate supplied from 13 equally spaced holes in a half-inch-diameter tube placed below the surface on the lower wall of the atomizing channel.

The details of the fuel injection tube are shown in figure 4. The fuel orifices were drilled to 0.046 inch diameter and spaced one inch apart. Shown in figure 5 are the three fuel plate geometries investigated. Plate I was a continuous 1/16 inch thick plate with a 3/8 inch diameter rod attached to its downstream edge. Plate II was the same plate with no attachment. Plate III was a discontinuous 1/16 inch plate designed so that only alternate fuel jets would impinge.

Figure 6 shows the combustor with plate I installed. The rectangular opening below the plate is for the fuel tube. The inner and outer walls of the atomizing channel are parallel.

The swirl atomizing nozzle combustor used for comparison tests in figure 7. The two combustors had the same inner and outer liners, fire-wall location and diffuser exit height. There were three principal differences. The first was that 20 percent of the total airflow was used for swirler airflow and lower liner cooling. This left only 80 percent of the air flowing through the outer passage compared to 85 percent for the combustor shown in figure 3. The second difference was that 12 percent of the air entered the primary zone through axial swirlers and holes surrounding the five swirl atomizing fuel nozzles, creating a different primary zone flow pattern. The third difference was that the fuel nozzle center line was 1 inch higher in the combustor than the fuel plates in the air atomizing design. This was necessitated by the diffuser shape of the original combustor.

PROCEDURE

For visual tests with the three air atomizing fuel plates, the combustor inner and outer liners were removed and the outer annulus and inner cooling passages sealed off. With a given fuel plate in position, the fuel tube was connected to a water supply and the pressure varied from 1.0 to 60 psi. For a given fuel tube pressure, the channel air velocity was varied from 140 feet per second to 425 feet per second and a range of water-air ratios from 0.13 to 0.140 was observed. Water injection velocities varied from 7.5 feet per second to 57.9 feet per second. The fuel plate geometry that performed the best was then installed in the actual combustor and tested at the conditions listed in table I. Results of these tests were compared to the swirl atomizing combustor operated under similar test conditions.

RESULTS AND DISCUSSION

Water Spray Tests

Photographs of typical water spray patterns from the three different air atomizing geometries (fig. 8) show the quality and direction of the spray. Visual estimates of the amount of unatomized water, spray

droplet size, spray penetration and irregularities in spray patterns were made.

The first configuration, Plate I, was a 1/16 inch thick plate which extended 1/4 inch past the channel exit with a 3/8 inch diameter bar welded across its length (fig. 5). The channel height was 0.62 up to its exit point where it was reduced to match the bar diameter. Initial tests with this design produced an extremely fine and unsymmetrical spray with unsatisfactory amounts of unatomized water leaving the channel. With the channel exit widened to 0.62 inches, the unatomized water decreased only slightly. The water spray jets were observed to strike the plate, flow along its surface and around the roll bar. At this point, the water was partially atomized in such a direction that no spray penetrated above the plane of the plate. The remaining water rolled off the bar toward the lower liner. The tendency of the water to separate at a low angle from the bar and remain partially unatomized was noted at channel velocities ranging from 142 to 425 feet per second and water-air ratios from 0.012 to 0.140. Water injection velocities for this range were 7.5 to 57.9 feet per second. No further tests were conducted with plate I.

Plate II (fig. 5) was the same plate used in the first tests with the roll bar removed. With this configuration, the spray was symmetric about the center line of the channel. The spray angle as estimated from photographs varied from 20 to 35 degrees with the large angles occurring at the lower air velocities and higher water-air ratios. A 20 percent increase in the axial distance the spray jet penetrated from the channel exit was observed when air velocities were increased from 150 feet per second to 425 feet per second. The spray droplet sizes appeared to range through a large spectrum with no appreciable unatomized water present except when water-air ratios exceeded 0.03 or channel velocities were less than 150 feet per second.

Plate III was a 1/16 inch thick discontinuous plate designed so that alternate jets from the fuel tube would strike and miss the plate (fig. 5).

Performance of this configuration was unsatisfactory, with heavy and irregular spray patterns directed into the lower half of the combustor.

Combustion Tests

Plate II was chosen for evaluation at combustor design conditions. Table I presents the test conditions and results for the air atomizing combustor and the swirl atomizing nozzle combustor. Pressure loss and combustor efficiencies were about the same for the two combustors. The relatively low efficiencies (86 to 90 percent) were due partly to heat loss from the combustor by cooling the housing walls with a water spray.

The exit temperature profiles of the two combustors are shown in figure 9. The relatively hot hub of the air atomizing combustor may be due to the design differences in the two combustors mentioned previously. No attempt was made to improve the design of the air atomizing combustor.

CONCLUDING REMARKS

These tests were only preliminary. Much further work is required to establish the potential of the air atomizing system. In particular, the problem of lean blowout at reduced pressures could not be examined. Nevertheless, a simple air atomizing fuel injection system could provide a symmetrical, well atomized spray and could produce stable burning with reasonable efficiencies at typical combustor design point operating velocities.

1. Radcliffe, A. : Fuel Injection, Section D. Design and Performance of Gas Turbine Power Plants. Vol. XI of High-Speed Aerodynamics and Jet Propulsion. W. R. Hawthorne and W. T. Olson, eds., Princeton Univ. Press, 1960, pp. 92-118.
2. Lefebvre, A. H. ; and Miller, D. : The Development of an Air Blast Atomizer for Gas Turbine Application. Rep. COA-AERO-193, College of Aeronautics, Cranfield, England, June 1966.
3. Humenik, Francis M. : Performance of a Turbojet Combustor Insensitive to Radial Inlet Airflow Distortion. Proposed NASA Technical Note.

TABLE I. - TEST CONDITIONS AND RESULTS

Model	Air atomizing combustor		Swirl atomizing combustor	
	Run number			
	001	002	003	004
	Test condition			
	A	B	A	B
Air flow, lb/sec	3.45	4.46	3.34	4.41
Inlet temperature, °F	605	610	600	604
Inlet static pressure	14.7	15.2	15.0	15.3
Reference velocity	88.8	111.6	83.8	109.1
Inlet Mach number	0.28	0.35	0.26	0.34
Pressure loss, percent average exit	6.5	10.7	6.6	10.0
Temperature, °F	1757	1841	2115	1939
Maximum exit temperature, °F	2440	2505	2610	2435
Fuel-air ratio	0.0184	0.020	0.028	0.023
Combustion efficiency, percent	88.4	89.7	86.4	89.5
Channel velocity, ft/sec	145	181	-----	-----
Fuel pressure, psia	84	110	210	290
Fuel injection velocity, ft/sec	76.6	87.7	-----	-----

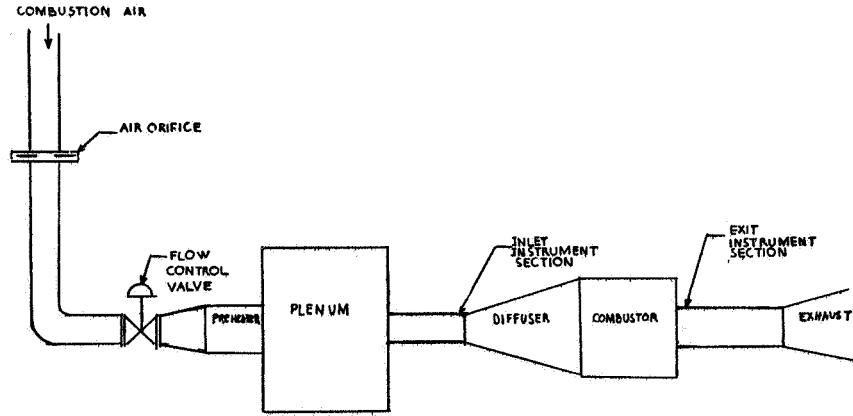


FIGURE-1 COMBUSTOR TEST FACILITY

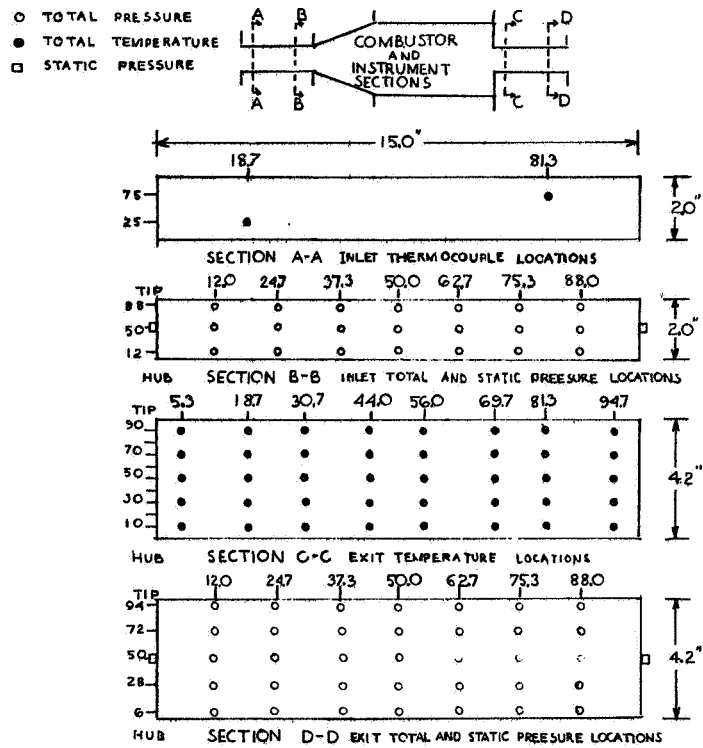


FIGURE - 2 LOCATION OF TEMPERATURE AND PRESSURE PROBES IN PERCENTAGE OF DUCT HEIGHT AND WIDTH.

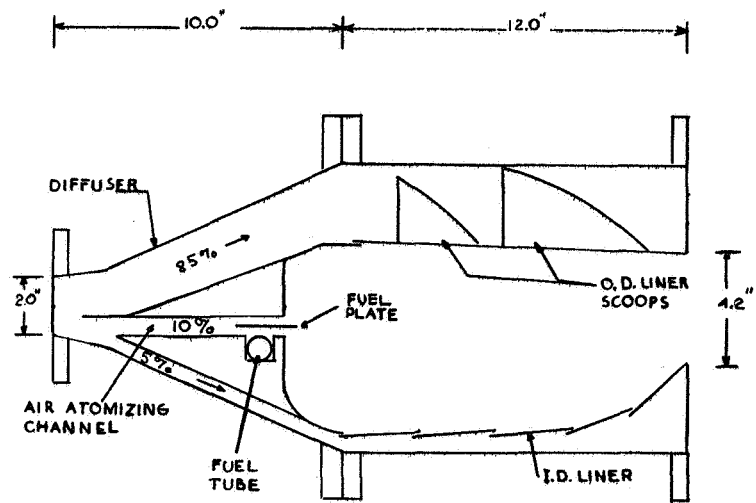


FIGURE 3 AIR ATOMIZER TEST COMBUSTOR

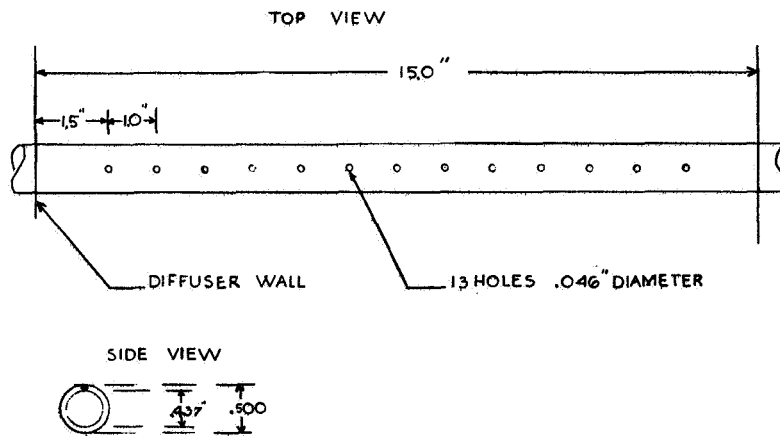


FIGURE 4 AIR ATOMIZER FUEL TUBE DIMENSIONS AND ORIFICE LOCATIONS

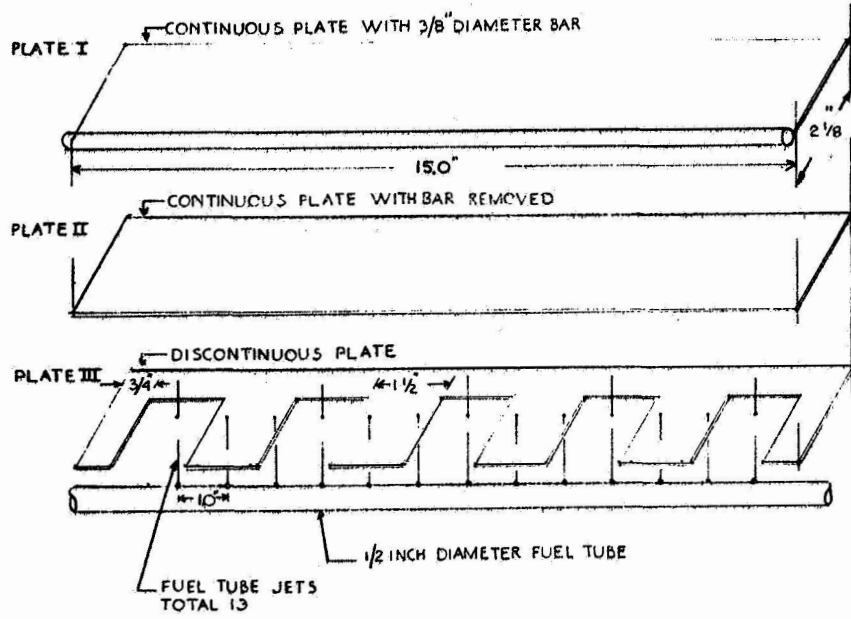


FIGURE 5 1/16" THICK CHANNEL FUEL PLATES

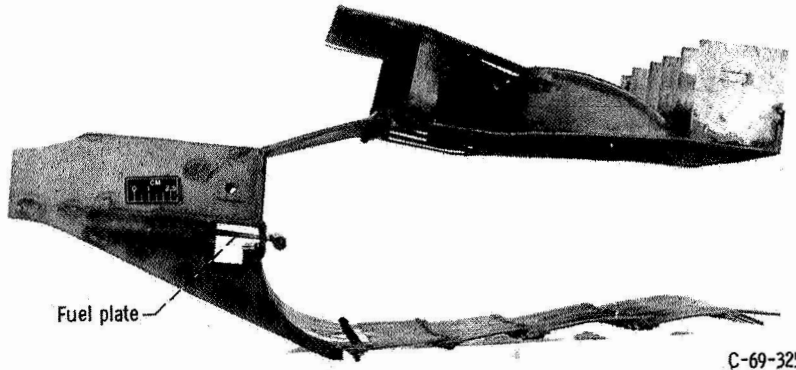


Figure 6. - Combustor with fuel plate I installed.

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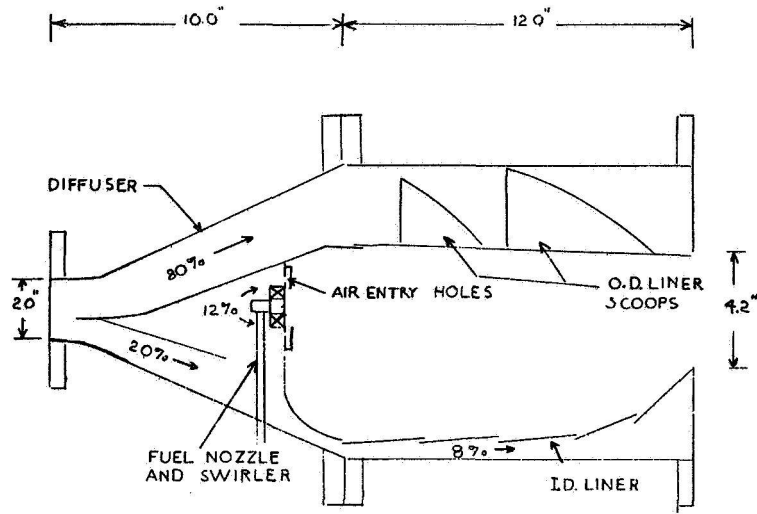


FIGURE 7 SWIRL NOZZLE COMBUSTOR

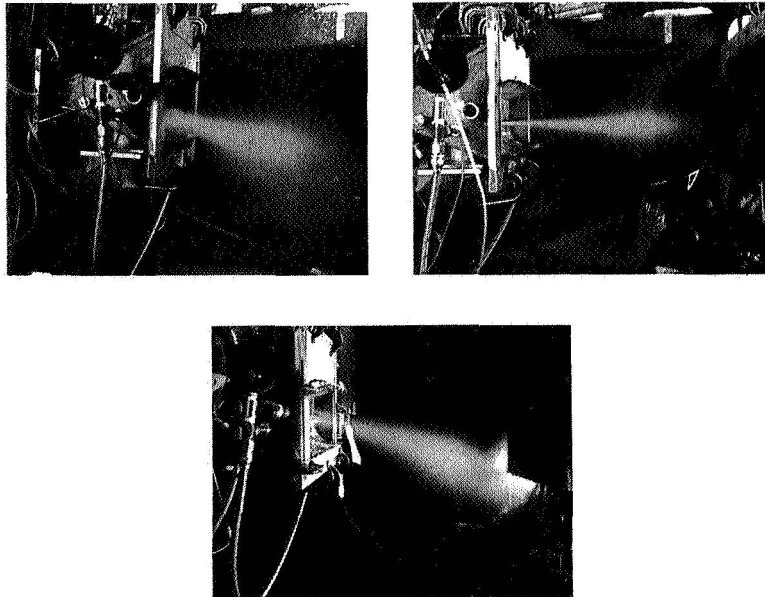


Figure 8. - Water spray patterns for three air atomizer fuel collection plates. Top left - Plate 1, top right - Plate 2, bottom - Plate 3.

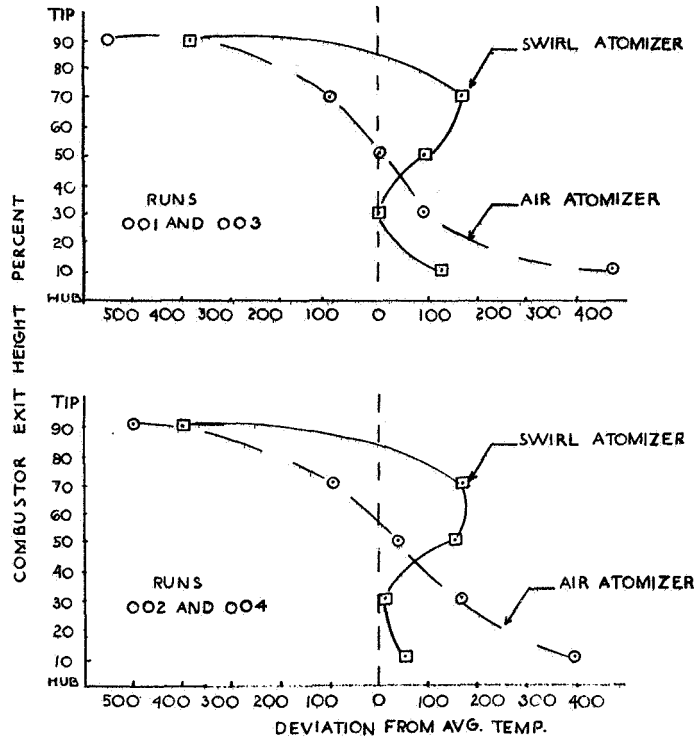


FIGURE 9 - EXIT TEMP. PROFILES