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EFFECT OF DIFFUSER BLEED ON PERFORMANCE OF AN ANNULAR SWIRL CAN COMBUSTOR

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16. Abstract

A full-scale annular swirl can combustor equipped with diffuser bleed capability was tested at low fuel-air ratio, burning natural gas fuel. Test results show that by drawing off a small amount of air on the inner or outer diffuser wall the radial profile of combustor exit temperature could be changed from a strongly tip biased to a strongly hub biased shape. Furthermore, combustor total pressure loss could be reduced by about one third by using a total bleed rate equal to 6 percent of diffuser inlet flow. At simulated engine idle conditions combustion efficiency was increased from 64 percent to near 100 percent by using 3 percent outer wall bleed. Combustor blowout performance was also improved significantly by using this diffuser bleed scheme.

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SUMMARY

Low power performance tests were conducted on a natural gas fired 106-centimeter- (41.8-in.-) diameter annular combustor modified to permit bleeding a small percentage of the inlet airflow through either the inner or the outer diffuser wall. Simultaneous bleeding through both diffuser walls was also possible. The combustor was of the swirl-can type with the fuel injection and flame stabilization accomplished by an array of 120 swirl cone modules arranged in three concentric rings across the annular passage. The combustor was operated at two test conditions. The first condition simulated cruise but for combustor pressure which was set at 20.7 N/cm^2 (30 psia); the second test condition was a simulation of both idle and altitude operation just prior to flameout.

Test results indicate that at the cruise condition the radial profile of combustor exit temperature could be made tip biased by using about 1.3 percent inner wall bleed and hub biased by applying about 1.1 percent outer wall bleed. Exit temperatures in the tip region could be changed by as much as 370 K (665° F) and in the hub region by as much as 337 K (600° F). Applying bleed on both walls caused the exit temperature profile to become more center peaked than the no bleed profile. The effect of bleed rate on combustor total pressure loss was to bring about a reduction in total pressure loss from 4.7 percent at no bleed to 3.1 percent at a bleed rate of about 6 percent.

At the simulated idle and altitude windmill condition the use of bleed resulted in a significant improvement in combustion efficiency and a delay in combustor blowout as the inlet pressure was gradually decreased and the reference velocity gradually increased. From these results it may be inferred that the emissions of unburned hydrocarbons and carbon monoxide were also reduced at the idle condition. It may further be inferred that relight would be facilitated at the high altitude windmill condition.

INTRODUCTION

This investigation was directed toward improving the performance of annular diffusers of the type installed between the compressor and combustor of gas turbine engines. The function of such diffusers is to reduce the velocity of air discharged from the compressor from a Mach number range of 0.2 to 0.5 to a Mach number range of 0.05 to 0.15 which is necessary for efficient combustion at an acceptable total pressure loss. The particular research objective was to determine to what extent the combustor exit temperature profile, combustion efficiency, total pressure loss, and combustor blowout characteristics could be influenced by the use of diffuser wall bleed, also referred to as diffuser wall suction. Positive test results would indicate that a diffuser equipped with wall bleed capability could be made to perform like a variable geometry device. A combustor equipped with such a diffuser would offer the advantage of performance optimization at each of several operating conditions when installed in an aircraft gas turbine engine.

The use of suction, to prevent separation in short, wide angle diffusers has been attempted since the fifties, as reported, for example, in references 1 and 2. The suction scheme was tested more recently with a very short wide angle annular diffuser (ref. 3). Test results showed that the diffuser exit velocity profile could actually be shaped from a hub peaked to a tip peaked form by a selective combination of inner and outer wall suction. Based on these results, an asymmetric annular combustor equipped with diffuser bleed capability was proposed in reference 3. In this combustor the function of diffuser bleed would be to tailor the combustor inlet airflow distribution to satisfy the demands at various engine operating conditions. If the bleed flow could be used for turbine cooling or auxiliary drive purposes, there might be no net penalty on engine cycle efficiency. The asymmetric diffuser concept was further tested in a cold flow facility as reported in references 4 and 5. The results from these tests were encouraging. It was realized, however, that these cold flow tests did not truly reproduce the conditions existing in combustion chambers. For example, the effects of combustor dome blockage and momentum pressure loss due to heat addition were not accounted for.

The present investigation was directed at including the above effects by testing the diffuser bleed concept in a full-scale annular combustor. Because of space limitations, aircraft engine combustor diffusers usually require large divergence angles. Such wide angle diffusers are prone to flow separation resulting in high pressure loss and poor combustor performance. Under such conditions diffuser bleed might be used to prevent or delay separation and thus improve combustor performance. Even if flow separation is not a problem diffuser wall bleed may affect the combustor inlet airflow distribution and thus provide a method of controlling the combustor exit temperature profile as proposed in reference 3. For the present investigation, the combustor geometry was not designed specifically along the guidelines outlined in reference 3. Rather, it was decided to first evaluate the diffuser bleed concept on existing combustor hardware. The apparatus chosen was a natural gas fired full-scale annular swirl can combustor which was modified to permit removal of a small fraction of the diffuser flow through two circumferential rows of bleed ports installed on both the inner and the outer diffuser wall. This combustor had been designed to evaluate the modular swirl can concept in a full-scale, (106-cm- (41.8-in.-) diam) annular configuration using natural gas fuel. The fuel-injector-flameholder combination for this combustor consisted of an array of 120 separately fueled 60° cone modules. Because of facility limitations the test conditions for the present investigation were restricted to below 21 N/cm^2 (30 psia) and exit temperatures below 1250 K (1800° F).

Hence, the combustor was tested at two low power conditions. The first condition was a simulation of cruise with the combustor inlet temperature at 590 K (600° F) and the inlet pressure at 20.7 N/cm^2 (30 psia). The second test condition simulated both the idling and altitude operation just before flameout of a gas turbine combustor. For this condition the inlet temperature was held at 300 K (80° F) and the pressure was varied from 20.7 to 10.3 N/cm^2 (30 to 15 psia). Data were obtained on the effect of bleed rate on the combustor exit temperature profile and the total pressure loss at the first test condition. At the second condition, the effect of bleed rate on combustion efficiency and combustor blowout was evaluated.

SYMBOLS

f/a	fuel-air ratio
M	Mach number
P_t	total pressure
ΔP	total pressure loss, $P_{t3} - P_{t5}$
T_t	total temperature
V	velocity
δ	pattern factor defined by eq. (1)
η	combustion efficiency

Subscripts:

max	maximum value
ref	reference

3 diffuser inlet

5 combustor exit

APPARATUS

Test Facility

This investigation was conducted in a connected duct test facility at the Lewis Research Center (ref. 6). An overall view of the facility is shown in figure 1. The inner and outer wall bleed pipes which were added for the diffuser bleed program are connected to the combustor by flexible steel hoses attached to adapter flanges. As shown, the pipes duct the respective bleed flows through flow measuring orifices and control valves to the altitude exhaust system. Figure 2 shows the combustor test section along with the inlet and exit adapters and the relative position of the major rig and instrumentation components. The inlet adapter assembly with about $4\frac{1}{2}$ pipe diameters of constant area ducting precedes the combustor housing which includes the diffuser inlet ducting. Downstream of the combustor housing the hot combustor gases pass through the exhaust instrumentation section and finally through a water spray quench system before they are ducted to the facility exhaust. Combustor airflow rates and pressures are regulated by remotely controlled valves both upstream and downstream of the test section. Combustor inlet temperatures up to 920 K (1200° F) can be provided by two indirectly fired heat exchangers.

Combustor

The combustor used for this investigation was a natural gas fired full-scale annular swirl can combustor. The combination fuel injectors and flameholders are formed by an array of 120 60° swirl cones. As shown in figure 3, this combustor was modified to permit bleeding some of the diffuser boundary layer flows through two wall grooves on both the inner and the outer diffuser wall. These grooves were 0.25 centimeter (0.1 in.) wide and 0.63 centimeter (0.25 in.) deep. On the inner wall 440 bleed holes of 0.24 centimeter (0.094 in.) diameter were drilled into each groove; on the outer wall 480 holes of the same diameter were drilled into each groove. The total bleed hole area was 39.4 square centimeters (6.10 in.^{2}) on the inner wall and 43 square centimeters (6.67 in.^{2}) on the outer wall. The bleed flows through these holes were collected in annular chambers welded onto the far side of the walls. From these chambers the bleed flows were ducted to manifolds as indicated, which in turn were connected to

10.2-centimeter (4-in.) pipes which carried the bleed flow through flow measuring orifices and control valves to the facility exhaust system (figs. 1 and 2). Figures 4(a) to (c) show three views of the combustor hardware during the assembly and instrumentation stage.

Instrumentation

Combustion air, diffuser bleed air, and natural gas flow rates were measured by square-edged orifice plates installed according to ASME standards. The bleed rate was defined as the ratio of diffuser bleed flow to combustion airflow. Combustor-inlet total and static pressures were measured at the plane of the diffuser inlet (station 3, fig. 2). Combustor-exhaust total and static pressures and total temperatures were measured at station 5 (fig. 2). Steady-state combustor exhaust total pressures and temperatures were measured by a rotating probe at 3° increments around the exhaust plane circumference. At each point, five temperature and pressure readings were obtained across the annular span. The exhaust thermocouples were platinum/platinum-plus-13-percent rhodium provided with radiation shielded junctions and an aspiration system for high recovery. The pressure readings were obtained by using strain-gage-type transducers.

Test Conditions and Procedure

Table I shows the values of the test parameters for the two test conditions of this program.

For test condition 1 the inlet temperature was raised to the required value while flowing air through the combustor using one of the indirectly fired heat exchangers. After ignition the inlet conditions of pressure, temperature, and airflow were adjusted to the desired values. Performance data were obtained with no bleed and also with various rates of bleed flows on either or both diffuser walls.

For test condition 2 the inlet air was not preheated. Combustor pressure was established at a value where ignition was possible with the bleed valves closed. Performance data were then obtained for no bleed at successively lower inlet pressure values until combustor blowout occurred. The same procedure was repeated several times with various diffuser bleed rates on the inner wall only, the outer wall only and also with bleed on both walls. Since the airflow rate was kept constant for these tests the diffuser inlet velocity and the combustor reference velocity increased as the combustor inlet pressure was decreased.

CALCULATIONS

Combustion Efficiency

Efficiency was determined by dividing the measured temperature rise across the combustor by the theoretical temperature rise. Exit temperatures were measured with five-point traversing aspirated thermocouple probes and were mass-weighted for the efficiency calculation. The inlet temperature was the arithmetic average of readings of eight single-point thermocouples around the inlet circumference. The theoretical temperature rise was computed as a function of fuel composition (heat of formation and hydrogen-carbon weight ratio), inlet-air pressure, inlet-air temperature, and fuel-air ratio. The fuel-air ratio was computed by dividing the total fuel flow by the bleed decremented airflow through the combustor.

Chromatographic analysis of the natural gas indicated about 98 percent hydrocarbons, as shown in table II. The heating value and fuel-air ratios used for theoretical temperature rise and other calculations and figures were based on actual hydrocarbons in the gas. The nonhydrocarbons were considered as air.

Inlet-Air Total Pressure

The inlet total pressure average was obtained by mass-weighting values from eight five-point pressure rakes around the diffuser inlet. Static pressures, used in the mass-weighting calculations, were measured around the circumference on both the inner and outer wall of the inlet annulus.

Combustor Reference Mach Number

The reference Mach number was computed from the total airflow, inlet total pressure and temperature, and reference area (maximum cross-sectional area between inner and outer shrouds, 5260 cm^2 or 830 $in.^2$).

Combustor Reference Velocity

Reference velocity for the combustor was calculated from the reference Mach number and sonic velocity at the combustor-inlet conditions.

Diffuser-Inlet Mach Number

This Mach number was computed from total airflow, diffuser-inlet area, and diffuser-inlet static pressure, and total temperature.

Total Pressure Loss

The total pressure loss is defined as the difference between diffuser-inlet and turbine-inlet mass-weighted total pressure averages. The total pressure loss, therefore, includes the diffuser loss.

Pattern Factor

The exit temperature pattern factor is defined as

$$\delta = \frac{T_{t5,max} - T_{t3}}{T_{t5} - T_{t3}} \tag{1}$$

where T_{t5} and T_{t3} are averages of combustor exit and inlet temperatures, respectively, and $T_{t5,max} - T_{t3}$ represents the difference between the maximum individual temperature occurring at any location in the combustor-exit plane and the average inlet temperature. Under normal conditions this parameter also gives an indication of the peakedness of the radial profile of exit temperature.

Units

The U.S. customary system of units was used for primary measurements and calculations. Conversion to SI units is done for reporting purposes only. In making the conversion, consideration is given to implied accuracy which may result in rounding off the values expressed in SI units.

RESULTS AND DISCUSSION

The effect of diffuser bleed on the low power performance of an annular combustor was evaluated. Test parameters determined without and with diffuser bleed were combustor exit temperature profile, combustion efficiency, total pressure loss, and combustor blowout characteristics at low inlet temperature.

Radial Profiles of Combustor-Exit Temperature

The effect of diffuser bleed on the combustor-exit temperature profile is indicated in figure 5 for test condition 1 (table I). For the case of bleed on one wall only (fig. 5(a)) it is seen that the center peaked and slightly tip biased profile at no bleed can be altered significantly by the application of bleed on either diffuser wall. Thus, with about 1.25 percent bleed on the inner wall the temperature profile becomes more tip biased suggesting that the airflow rate has been increased in the hub region and decreased in the tip region of the combustor annulus. This results in a tip temperature increase of approximately 78 K (140° F) and in a hub temperature decrease of approximately 105 K (190° F) compared to values of the "no bleed" temperature profile.

With bleed on the outer wall only the change in profile is even more dramatic. As shown in figure 5(a) the temperature profile becomes strongly hub biased by applying 1.1 percent bleed on the outer wall. The hub temperature is increased by approximately 220 K (400° F) and the tip temperature is decreased by about 284 K (510° F).

Changes in pattern factor δ and combustion efficiency η are also indicated in figure 5. The pattern factor is seen to increase as bleed is applied on either wall. This occurs because the already low airflow rate in the annulus center, as indicated by the center peaked "no bleed" temperature profile, is decreased further as more airflow is shifted toward the diffuser wall having bleed applied to it. Moreover, since the airflow distribution without bleed is already hub biased, applying bleed on the inner wall of the diffuser resulted in smaller exhaust temperature profile changes than those obtained by using outer wall bleed. The effect of bleed on combustion efficiency will be discussed in a subsequent section.

The combustor-exit temperature profile changes with bleed on both diffuser walls are shown in figure 5(b). It is interesting to note that the profiles become more peaked as the wall bleed rate is increased. As pointed out previously, the reason for this increased peakedness is that airflow is redistributed towards the inner and outer walls of the combustor at the expense of airflow in the central core region, which was low to begin with.

Total Pressure Loss

The effect of bleed rate on combustor total pressure loss is shown in figure 6. The data points shown include measurements at isothermal conditions and also with burning.

The total pressure loss at an inlet Mach number of 0.28 decreased from 4.7 percent with no bleed to about 3.1 percent at a total bleed rate of 6 percent. This reduction in combustor total pressure loss by approximately one third results mainly from a significant reduction in diffuser wall separation effects. The reduction of reference velocity, due to the diffuser mass flow rate having been reduced by the bleed rate, accounts for only one third of the total reduction in combustor total pressure loss.

Combustion Efficiency and Blowout Performance

As indicated on figure 5, the effect of bleed rate on combustion efficiency was small at test condition 1, because combustion efficiency was high even without bleed.

At the simulated idle and altitude windmill condition (test condition 2), the effect of bleed rate on combustion efficiency was significant, as shown in figure 7. This figure shows the variation of combustion efficiency as diffuser-inlet total pressure (and reference velocity) were varied for no bleed and also for various bleed schemes. The most dramatic improvement over the "no bleed" performance was obtained by applying 3 percent bleed on the outer wall. At 20.7 N/cm^2 (30 psia) combustion efficiency was increased from 64 percent to 100 percent. At about 14 N/cm^2 (20 psia) blowout occurred when no bleed was used; with outer wall bleed the overall combustion efficiency was still about 63 percent at this pressure. At the 3 percent outer wall bleed rate combustor blowout was delayed until the inlet pressure was lowered to 10.2 N/cm^2 (14.8 psia) and the reference velocity simultaneously increased to 30 meters per second (100 ft/sec).

One explanation for the fact that outer wall bleed produced the most significant performance improvements is that, because of the greater outer wall divergence angle (fig. 3), some flow separation occurred on the outer wall without bleed. This caused the "no bleed" airflow distribution to be hub biased to begin with. Hence, inner wall bleed could not be expected to alter the combustor airflow distribution significantly. With outer wall bleed, however, the airflow distribution was apparently changed to a more tip biased distribution. As a result the local velocities and fuel air ratios at the inner, center, and outer swirl can module row were changed to near ideal values, thus raising combustion efficiency and improving the blowout characteristics.

Emissions of Unburned Hydrocarbons and Carbon Monoxide

No exhaust gas emissions were measured during this investigation. However, the combustion efficiency data obtained with various airflow distributions at test condition 2 suggest that the exhaust gas composition can be changed by varying the radial distribution of fuel-air ratio. Such data were obtained in reference 7, albeit at different test conditions, by radial staging of fuel in a three row swirl can combustor of similar design to that of the combustor tested in the present study. The airflow distribution was not varied in reference 7. The emission index values obtained in reference 7 are shown in figures 8 and 9 for unburned hydrocarbons and carbon monoxide, respectively. It is interesting to note that the lowest emission indices (i.e., the highest combustion efficiency values) were obtained with the peak fuel-air ratio existing at the inner module row. This is in complete agreement with the results of the present study, which also showed that the highest values of combustion efficiency at test condition 2 occurred when the fuel-air ratio was highest at the inner module row. In the present study this condition was obtained by using outer wall diffuser vleed which resulted in a tip biased distribution of airflow.

Applicability of Results to Gas Turbine Combustor Design

This study was directed at measuring the effect of diffuser bleed rate on combustor airflow distribution as reflected by the radial profile of combustor-exit temperature. Test results indicate this effect to be significant for combustors with wide angle diffusers as tested in this study. Other benefits found to result from diffuser bleed were reduced combustor total pressure loss, improved efficiency or reduced exhaust emissions at the simulated idle condition, and delayed blowout at low combustor inlet pressure and temperature. The fact that these performance gains were obtained with a combustor not specifically matched to the diffuser bleed scheme is encouraging. Where the combustor performance differed from the postulated performance of the diffuser bleed combustor proposed in reference 3, such difference can be explained on the basis of combustor design. Thus the fact that diffuser bleed increased rather than decreased the pattern factor, does not disprove the merits of diffuser bleed but rather serves to point out that successful application of diffuser bleed requires careful matching of the bleed type diffuser and the combustor.

For the combustor tested the "no bleed" airflow distribution downstream of the swirl can array indicated low flow in the center, somewhat higher flow along the outer wall, and very high flow along the inner wall. Applying bleed on both walls caused even more air to be forced toward the walls, thus further depleting the central region of the combustor annulus. This airflow profile will result in a highly center peaked combustor-exit temperature profile, assuming uniform fuel flow at each of the three swirl module rows.

A combustor designed to operate with diffuser bleed should have reduced blockage in the central region of the annulus to preclude a center deficient airflow distribution when no bleed is used. Furthermore, in an asymmetric combustor of the type proposed in reference 3, the combustor blockage would have to be positioned in the diffuser exit plane in such a way that the inner wall bypass area is greater than the bypass area near the outer wall.

SUMMARY OF RESULTS

Low power performance of a full-scale annular swirl can combustor equipped with diffuser wall bleed capability was evaluated at two test conditions. The first condition simulated low power cruise operation and the second was a simulation of altitude operation just prior to flameout. The following results were obtained:

1. At test condition 1 the application of as little as 1.1 percent bleed on the inner or the outer wall of the diffuser resulted in drastic changes in combustor-exit temperature profile from a tip biased profile for inner wall bleed to a strongly hub biased profile for outer wall bleed.

2. The application of diffuser bleed on one or both diffuser walls resulted in a continuous reduction of combustor total pressure loss as the bleed rate was increased. At a diffuser inlet Mach number of 0.28 combustor total pressure loss was reduced from 4.7 percent at no bleed to 3.1 percent at a total bleed rate of 6 percent.

3. The use of diffuser bleed at test condition 2 improved combustor performance by making the combustor airflow distribution more uniform. The following performance gains were realized:

   a. Combustion efficiency was improved. For example, at an inlet pressure of 20.7 N/cm^2 (30 psia), combustion efficiency was increased from 64 percent at no bleed to 100 percent by applying 3 percent bleed on the outer wall.

   b. The combustor flameout condition was shifted to lower pressure and higher reference velocities. By applying 3 percent outer wall bleed, for example, combustor flameout was delayed at test condition 2 from 14 N/cm^2 (20 psia) and a reference velocity of 22 meters per second (73 ft/sec) to 10.2 N/cm^2 (14.8 psia) and a reference velocity of 30 meters per second (100 ft/sec).

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, February 12, 1974,
501-24.

REFERENCES

1. Manoni, L. R.: Wide Angle Diffuser Employing Boundary Layer Control. Report R-95460-12, United Aircraft Corp., Mar. 1952.
2. Wilbur, Stafford W.; and Higgenbotham, James J.: Investigation of a Short-Annular-Diffuser Configuration Utilizing Suction as a Means of Boundary Layer Control. NACA TN 3996, 1957.
3. Juhasz, Albert J.; and Holdeman, James D.: Preliminary Investigation of Diffuser Wall Bleed to Control Combustor Inlet Airflow Distribution. NASA TN D-6435, 1971.
4. Juhasz, Albert J.: Control of Exit Velocity Profile of an Asymmetric Annular Diffuser Using Wall Suction. NASA TM X-2710, 1973.
5. Juhasz, Albert J.: Performance of an Asymmetric Short Annular Diffuser with a Nondiverging Inner Wall Using Suction. NASA TN D-7575, 1974.
6. Adam, Paul W.; and Norris, James W.: Advanced Jet Engine Combustor Test Facility. NASA TN D-6030, 1970.
7. Niedzwiecki, Richard W.; Trout, Arthur M.; and Mularz, Edward: Performance of a Swirl-Can Combustor at Idle Conditions. NASA TM X-2578, 1972.

TABLE I. - NOMINAL COMBUSTOR OPERATING CONDITIONS

Operating condition	Pressure		Temperature		Airflow rate		Reference velocity		Fuel-air ratio
	N/cm^2	psia	K	F	kg/sec	lb/sec	m/sec	ft/sec	
1	20.7	30.0	589	600	19.5	43	30	100	0.015
2	10.3 to 20.7	15 to 30	300	80	19.5	43	15 to 30	50 to 100	.015

TABLE II. - PHYSICAL PROPERTIES OF NATURAL GAS

Density,[a] kg/m^3 (lb/ft^3)	0.7320 (0.0457)
Calculated net heat of combustion, J/kg (Btu/lb)	$49\,770\times10^3$ (21 397)
Normalized chromatographic analysis, vol.%	
Methane	93.50
Ethane	3.53
Propane	0.53
C_4, C_5, and C_6 hydrocarbons	0.32
Nitrogen	1.05
Carbon dioxide	1.07
Oxygen	trace

[a]At temperature of 289 K (60° F) and pressure of 10.159 N/cm^2 (30.00 in. Hg at 32° F).

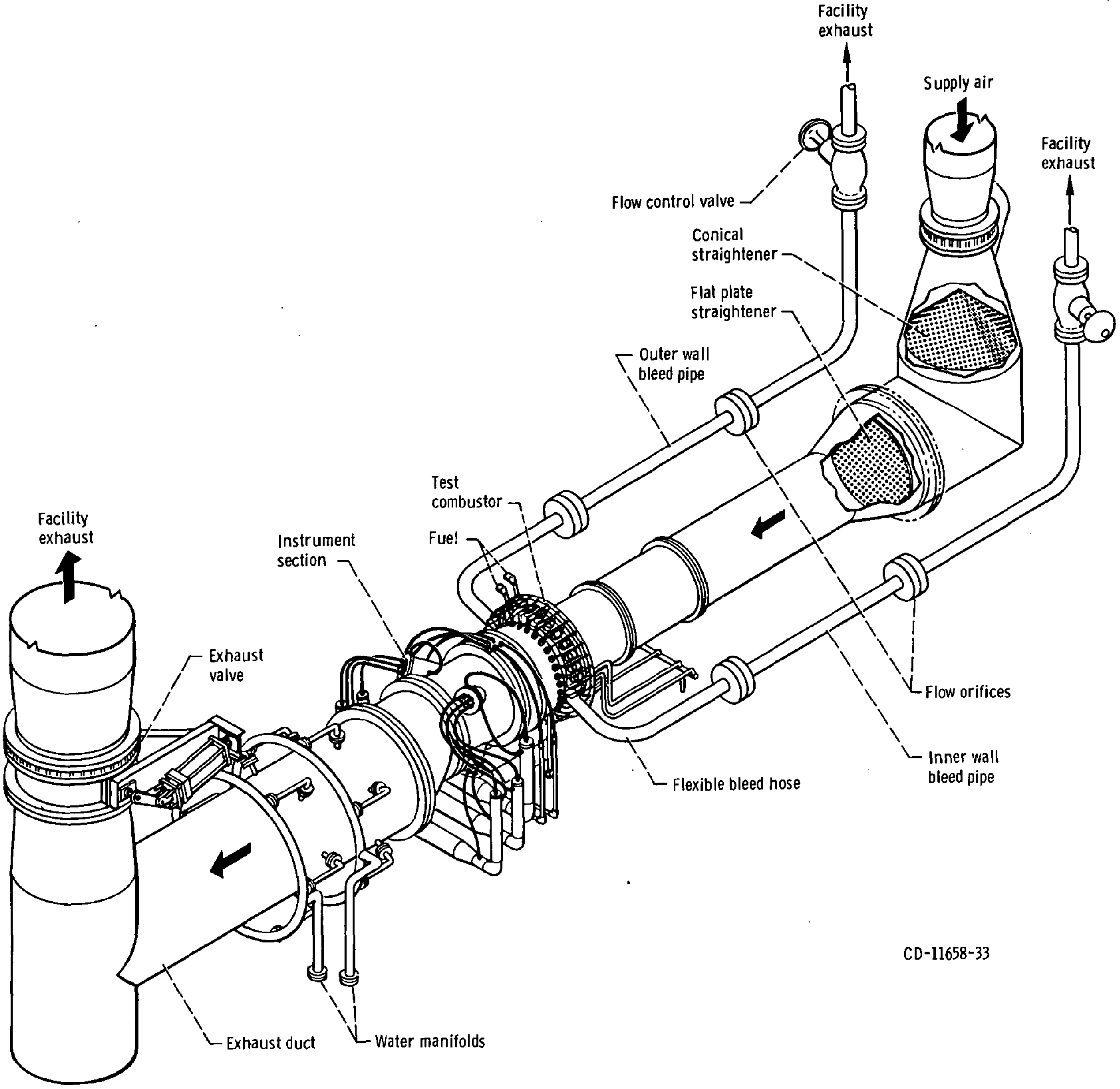


Figure 1. - Test facility.

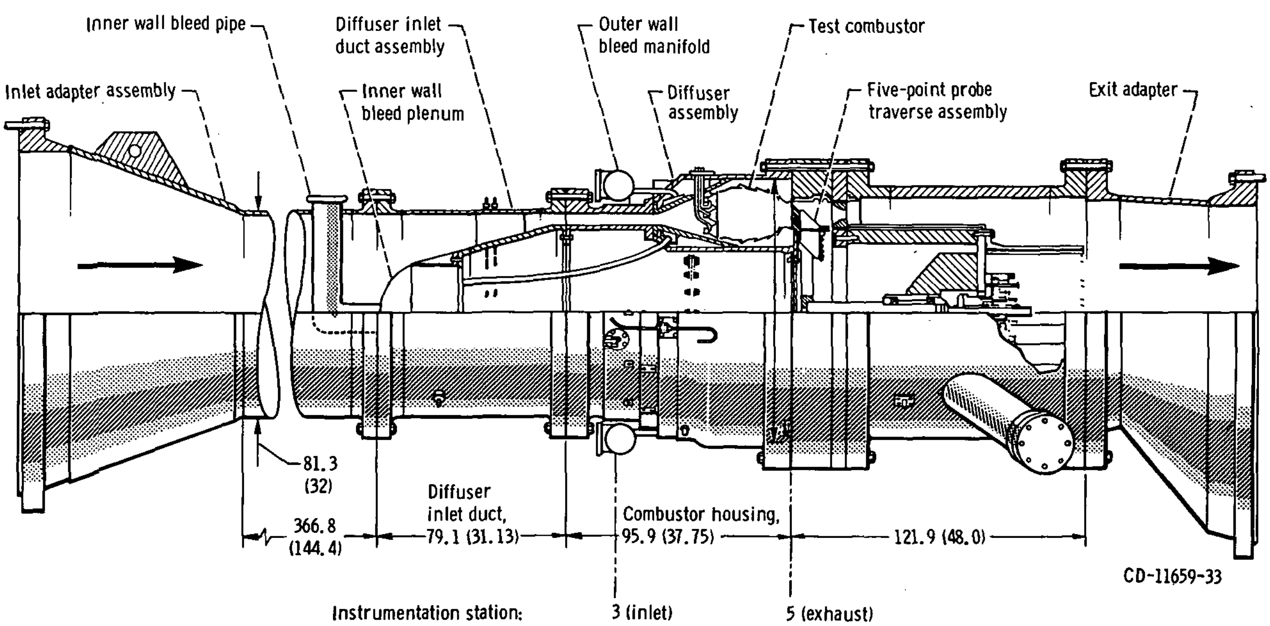


Figure 2. - Test section for full-scale annular combustor equipped with diffuser bleed. (Dimensions are in cm (in.).)

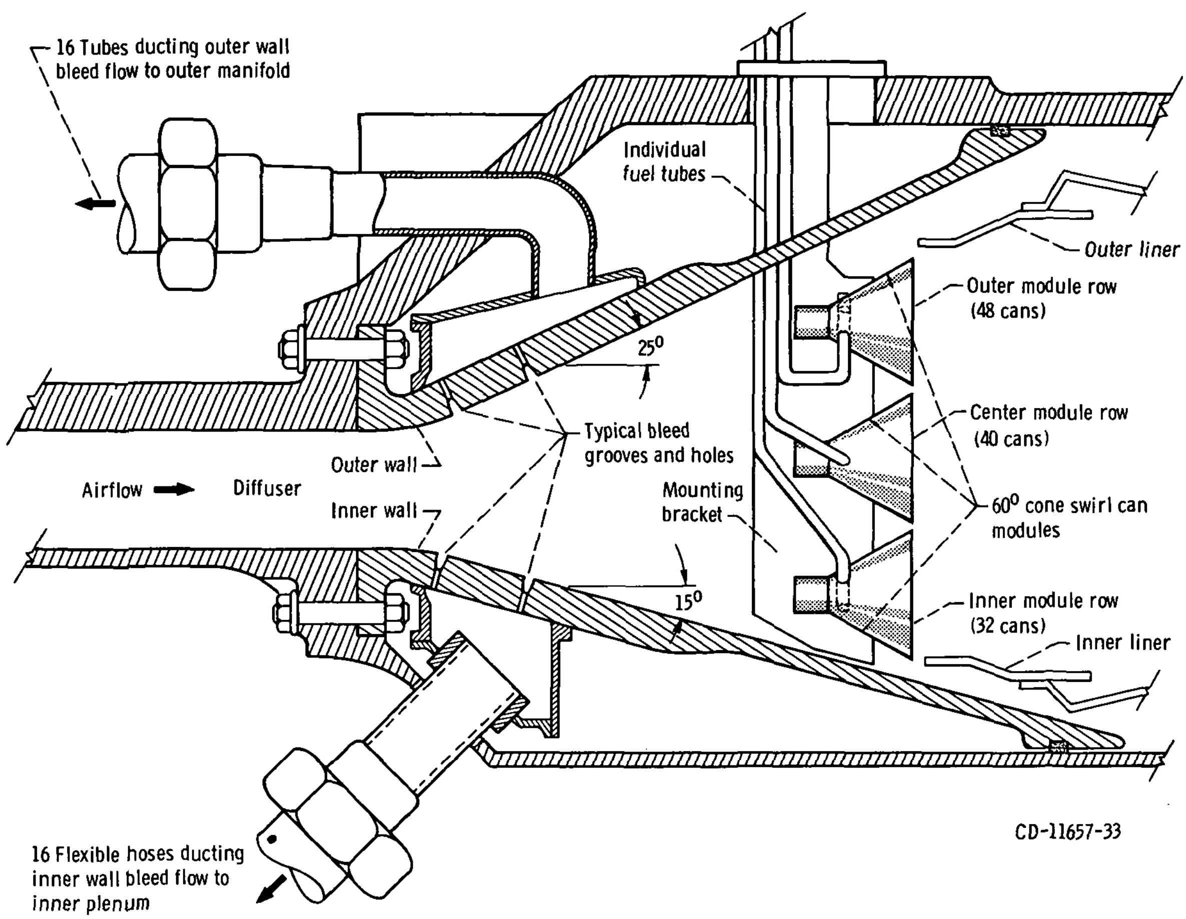
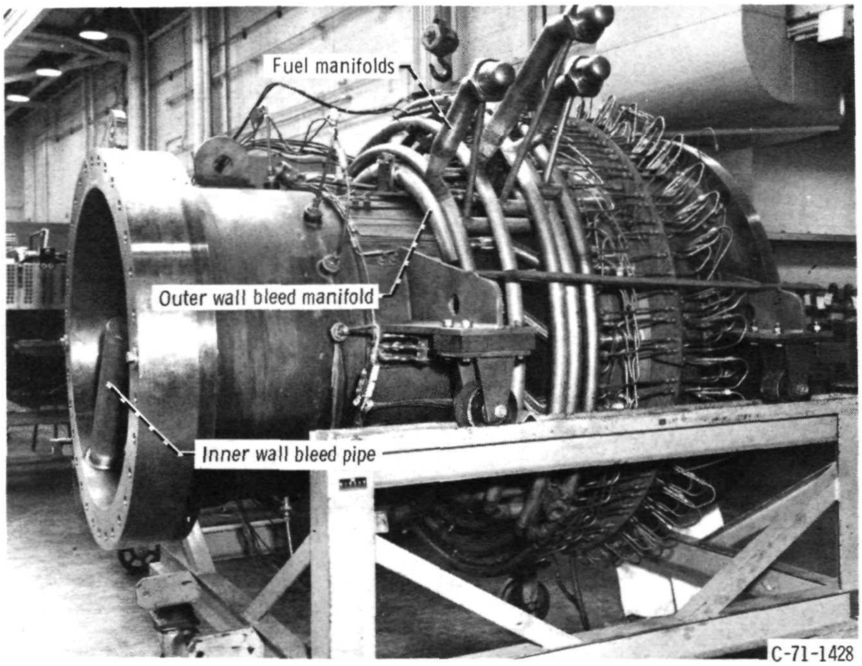
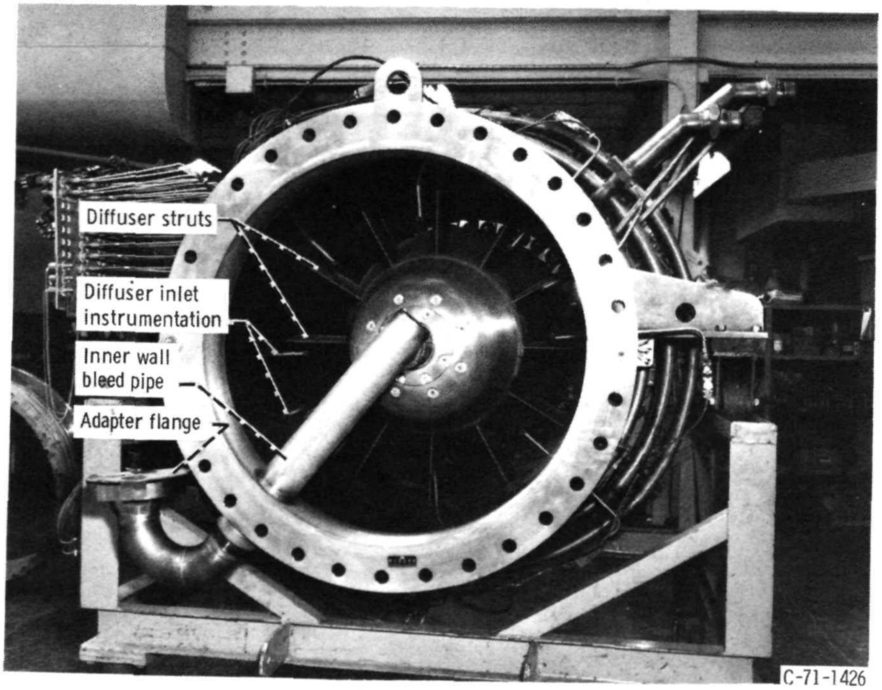


Figure 3. - Section through diffuser and combustor.

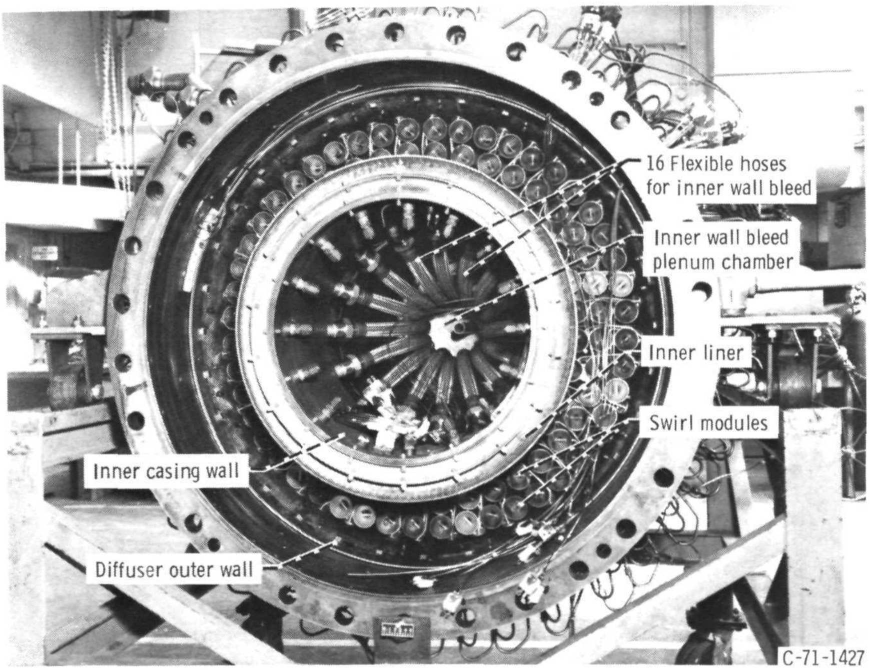


(a) Side view.



(b) Downstream view.

Figure 4. - Combustor test section.



(c) Upstream view with outer liner removed.

Figure 4. - Concluded.

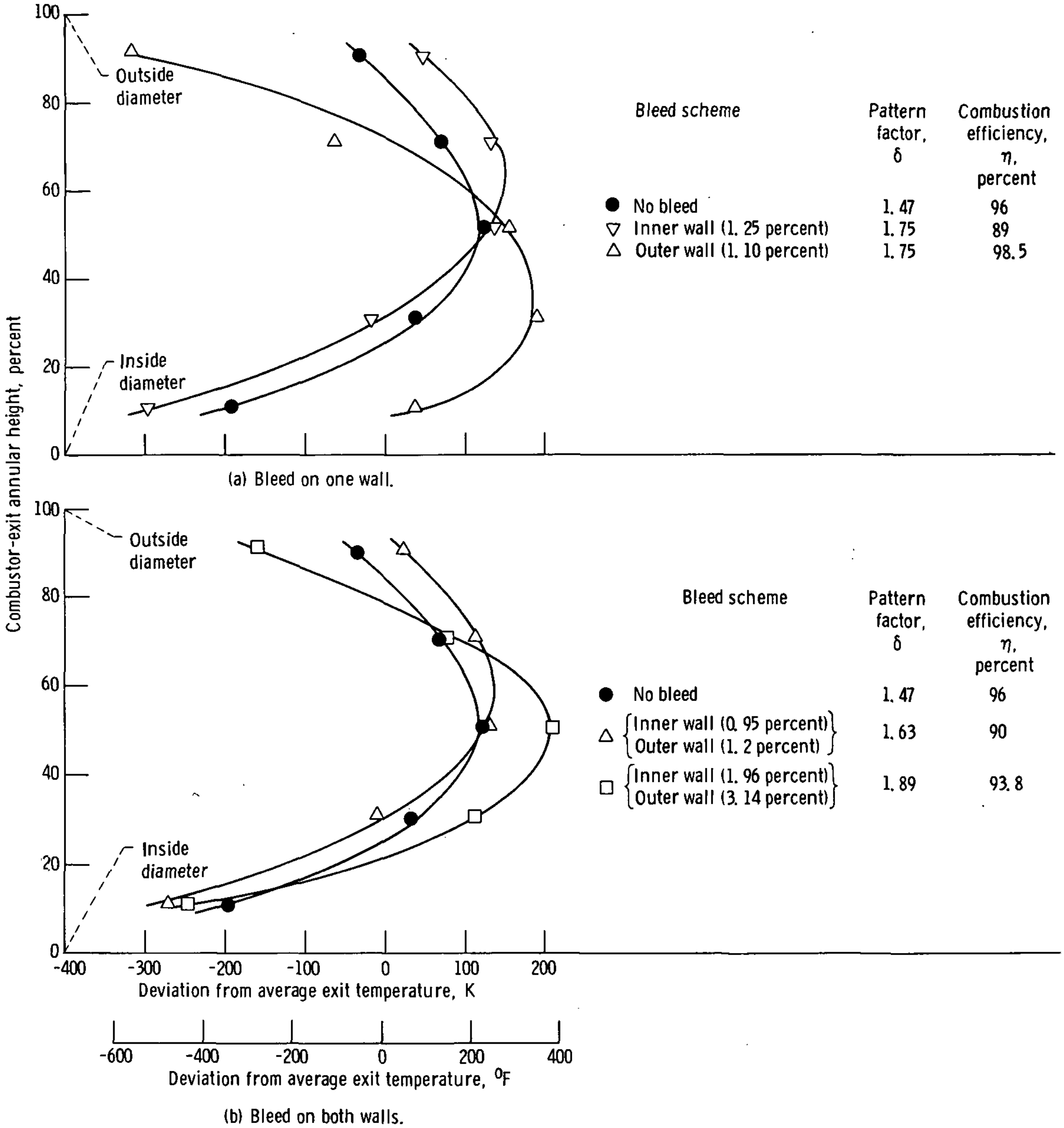


Figure 5. - Effect of diffuser bleed on radial profile of combustor-exit temperature. Combustor-exit total temperature, 1230 K (1750° F); fuel-air ratio, 0.015.

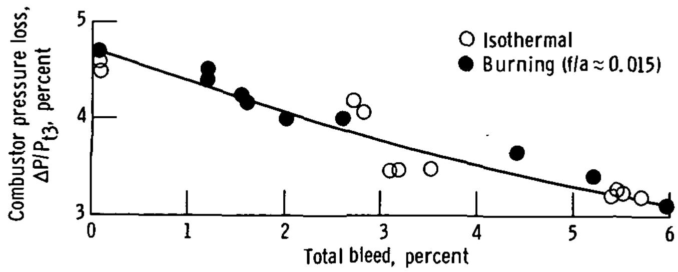


Figure 6. - Effect of bleed rate on combustor total pressure loss. Diffuser-inlet Mach number, 0.28; diffuser-inlet total pressure, 20.7 N/cm^2 (30 psia); diffuser-inlet total temperature, 590 K (600° F).

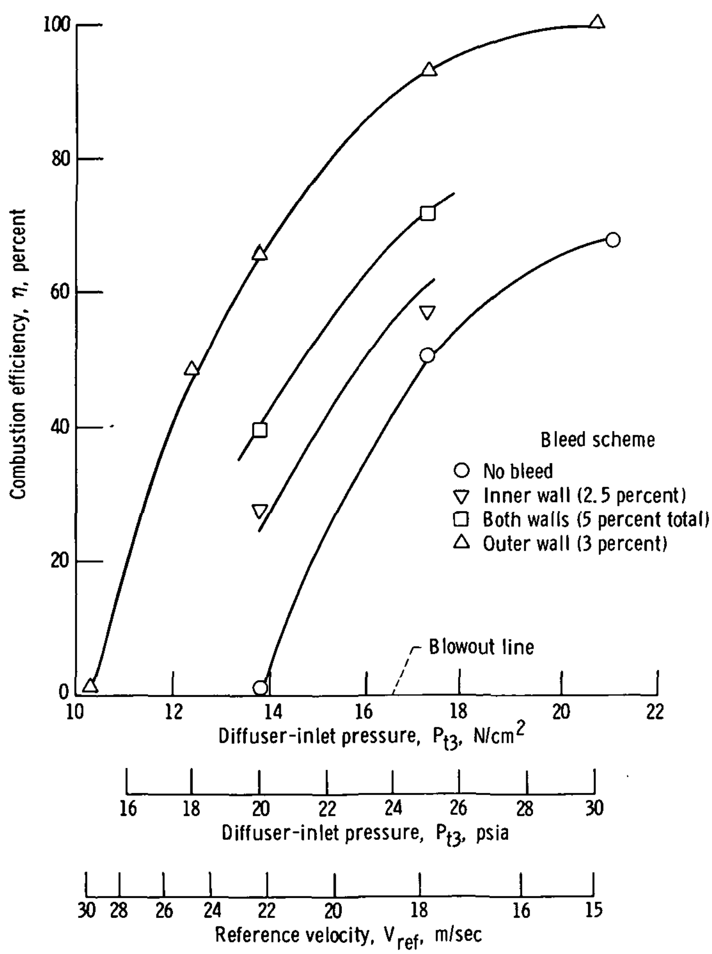


Figure 7. - Combustor performance at inlet temperature of 301 K (82° F) with bleed variation.

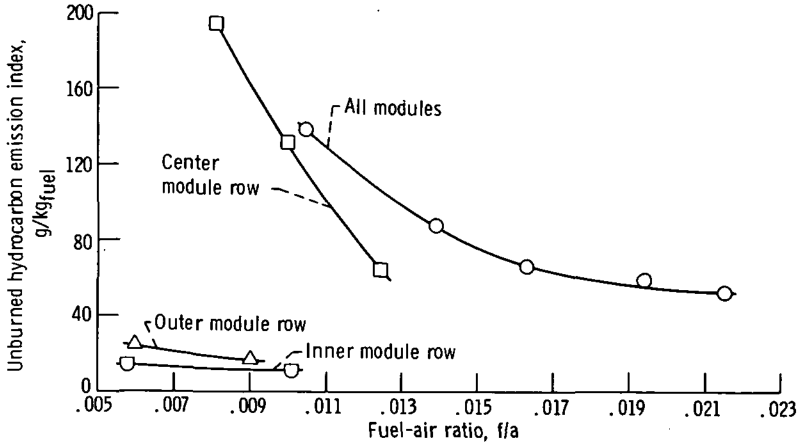


Figure 8. - Unburned hydrocarbon emissions during idle tests with radial fuel staging. Inlet air temperature, 478 K (400° F); inlet air pressure, 4 atmospheres; reference velocity 26 meters per second (85 ft/sec). (Test results taken from ref. 7.)

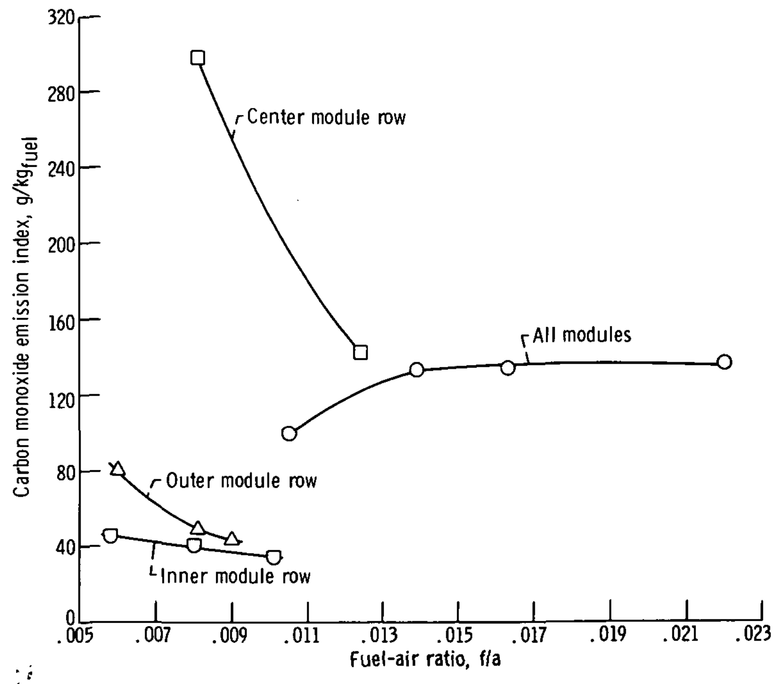


Figure 9. - Carbon monoxide emissions during idle tests with radial fuel staging. Inlet air temperature, 478 K (400° F); inlet air pressure, 4 atmospheres; reference velocity, 26 meters per second (85 ft/sec). (Test results taken from ref. 7.)

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