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EFFECT OF VARIOUS DIFFUSER DESIGNS ON THE PERFORMANCE OF AN EXPERIMENTAL TURBOJET COMBUSTOR INSENSITIVE TO RADIAL DISTORTION OF INLET AIRFLOW

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SUMMARY

Further tests were performed on a previously developed experimental combustor that was shown to be insensitive to shifts in the radial velocity at the compressor outlet. The purpose of these tests was to investigate alternate diffuser designs. Rectangular combustors 10 by 15 inches (0.254 by 0.381 m) which were representive of a one-sixth segment of a full annular combustor were used as test models. The alternate diffuser designs investigated were a dump-type diffuser, a 53° wide-angle diffuser, and three diffusers with different axial lengths but similar in design to the diffuser used in the previously developed combustor.

Tests for the dump and wide-angle diffusers were conducted at diffuser inlet Mach numbers of 0.24 and 0.30 at an inlet air temperature of 600° F (589 K). Fuel-air ratio was varied until an average exit temperature of 2200° F (1478 K) was obtained. Performance for these two designs, including efficiency, combustor total-pressure loss, exit temperature profile, and demonstrated insensitivity to radial velocity changes, was similar to that obtained with the original design. This performance indicated that alternate diffuser designs of simple construction may be interchanged with that of the original combustor without penalty.

Evaluation of the three diffusers with different axial lengths was performed only at isothermal conditions with 600° F (589 K) inlet air temperature. At an inlet Mach number of 0.30 the combustor total-pressure loss was reduced from a nominal 7.1 to 5.4 percent as the diffuser length to inlet height ratio was increased from 4.0 to 7.0.

INTRODUCTION

In aircraft turbine engines, the compressor outlet velocity distribution may change because of inlet flow distortion or variation in engine speed. If the changes involve the radial velocity profile, a redistribution of the airflow between the inner and outer annuli of a conventional annular combustor can occur. The combustor exit temperature distribution may be significantly affected by this redistribution, thus jeopardizing the life of the engine.

In preceding work (ref. 1) an experimental combustor was developed to reduce the effect of radial velocity changes on the exit temperature profile. The combustor differed from conventional annular combustors in that all dilution air was supplied to the outer annular passage from a diffuser having a 7° included angle. A desired airflow distribution to the outer liner was maintained by means of scoops. This design was designated as a side-entry combustor. This combustor achieved pressure loss levels comparable to those of several existing combustors while maintaining exit temperature profiles insensitive to flow distortion.

This present study was initiated primarily to determine how several alternate diffuser designs would affect the performance of side-entry type combustors. These alternate diffuser designs were aimed at simplifying fabrication complexities through the use of (1) a dump-type diffuser and (2) a large-angle diffuser. In addition to this work, a further investigation was centered around the diffuser design used in the originally tested combustor. This investigation was an effort to determine if significant reductions in pressure loss could be achieved by altering only the diffuser length of the previously tested combustor. Three original type diffusers with different axial lengths were constructed for this purpose.

The test plan for the dump and large-angle diffusers involved obtaining combustion efficiency, total-pressure loss, and exit radial temperature profiles with uniform and distorted inlet velocity profiles. Two design conditions, in which the diffuser inlet Mach number was 0.24 and 0.30, were selected as major performance recording points. Supplementary data included total-pressure losses for a range of inlet Mach numbers and combustor temperature ratios. Performance of the two alternate diffuser designs was evaluated using the previously tested combustor as a reference.

All tests were conducted in rectangular housings representative of a one-sixth segment of an annular combustor. The design average exit temperature was 2200° F (1478 K). Inlet air temperature for all test runs was held at a nominal value of 600° F (589 K). A jet fuel conforming to ASTM-A1 specifications was used throughout the tests. The fuel had an average hydrogen-carbon ratio of 0.161 and a lower heating value of 18,600 Btu per pound (43 000 J/g).

Tests of the three original diffuser designs with different axial lengths were evaluated only for their isothermal pressure loss over a range of inlet Mach numbers.

APPARATUS

Test Facility

The test facility is described in reference 1 and shown in figure 1. The test section was 10 by 15 inches (0.254 by 0.381 m). Combustion airflow was metered by an air orifice sized to measure flows up to 5.0 pounds per second (2.267 kg/sec). A direct fired preheater and a 36-inch- (0.914-m-) diameter by 56-inch- (1.422-m-) long mixing plenum was used to obtain 600° F (589 K) inlet air. The heated air from the plenum was then passed through an inlet instrument section to the one-sixth segment combustor. Combustion products from the combustor passed through an exit section into a scrubber and atmospheric exhaust section. Distorted inlet velocity profiles were produced by inserting 1/2-inch- (0.013-m-) diameter trip bars in the hub or tip position of the inlet instrumentation section.

Instrumentation

The location of the temperature and pressure instrument planes is shown in figure 2. Details of the number, type, and spacing of the temperature and pressure sensing points are found in reference 1. The recording instruments were the same as those used in reference 1 except that the pressures were recorded by a transducer scanning system instead of by manometers. Recorded pressures were read to the nearest 0.01 pound per square inch (69 N/m^2). Exit temperature readings were read to the nearest 10° F (5.5 K) increment.

Combustor Designs

The experimental combustors were designed to be installed in a rectangular housing 15 inches (0.381 m) wide and 10 inches (0.254 m) high. The diffuser inlet height was 2.0 inches (0.051 m), and the combustor exit height was 4.2 inches (0.107 m).

The previously reported combustor, model II, is shown in figure 3. This combustor used a design which employed inlet diffuser chutes to capture 15.0 percent of the inlet airflow. This airflow was used for film cooling of the firewall and inner liner as well as mixing air for the swirlers. The remaining air was channeled through a straight-walled diffuser, having a 7° included angle, to the outer liner. Scoops situated on the outer liner further distributed desired amounts of airflow to the primary and secondary zones of the combustor.

Two test combustors having dump-type and wide-angle diffusers were investigated in models designated V-A and V-B, respectively. The model V-A diffuser design is shown in figure 4. Model V-A used a 10° inlet diffusion section that was 2.75 inches (0.069 m) long. The diffuser was followed by a sudden expansion region in which the area ratio increased $4\frac{1}{2}$ times. The model V-B diffuser design is shown in figure 5. Model V-B was adapted from the model II combustor by removing the inner diffuser wall along with the inlet chutes. This produced a side-entry combustor having a 53° diffuser angle.

Differences between the two test combustors and model II included their swirler type and inner liner design. To speed testing of model V-A and V-B, axial swirlers were used in place of the radial ones of model II. The model V inner liners provided louver film cooling air by means of upstream metering holes. The louver airflow for model II was obtained from rectangular slots. Besides these differences, model V-A further differed from models II and V-B in that its outer liner was 13.6 inches (0.345 m) long. Models II and V-B used the same outer liner, which was 11.1 inches (0.282 m) long. The extra length of model V-A resulted from its short diffuser and sudden expansion region. However, the outer liner scoops, slot sizes, and positions for all three models were the same. The result of these changes was to produce a 1.8-percentage increase in airflow to the firewall and lower liner of models V-A and V-B over model II. The airflow distribution to the various sections of the test combustors is shown in figures 4 and 5. The airflow distribution was based on an analysis of open area.

The three model II type diffusers with different axial lengths are shown in figure 6. These three models had diffuser axial length to inlet height ratios L/D of 4.0, 5.5, and 7.0. The diffuser exit to inlet area ratios of the three models were constant at 1.42. The inlet diffuser chutes, firewall, and liners used with these models were similar in design to model II. The major difference was the lack of swirlers in the firewall openings. Perforated screening was placed over the openings to speed construction and testing of the models.

TEST CONDITIONS

Two nominal test conditions at inlet temperatures of 600° F (589 K) were used. The first was an inlet Mach number of 0.24 and the second was a Mach number of 0.30. Complete test conditions are listed in table I. Fuel-air ratios were set to approach design average exit temperatures of 2200° F (1478 K). Uniform and distorted radial inlet velocity profiles were established at the two conditions. Performance data at the design points included exit temperature distribution, total-pressure loss, and combustion efficiency.

Tests of the three model II type diffusers were conducted over a range of inlet Mach numbers at 600° F (589 K) and 1 atmosphere pressure. Performance data included only isothermal pressure loss plotted against inlet Mach number.

RESULTS AND DISCUSSION

Two turbojet combustor segments with dump and wide-angle diffusers were investigated in side-entry configurations. These combustor segments were designated as models V-A and V-B. Data for the model V-A and V-B combustors with uniform and distorted inlet velocity profiles are presented in table II. Supplemental performance with uniform profiles is included in table III. In addition to these data, results from a side-entry combustor with three L/D values are presented in table IV.

Combustion Efficiency

Combustion efficiency was defined as the percentage ratio of actual enthalpy rise to theoretical rise and was calculated by the method described in reference 2. Combustor average exit temperatures were corrected for radiation based on the method of reference 3. Combustion efficiency was calculated using the enthalpy tables from reference 4 and standard enthalpy curves which account for products of combustion.

At test condition A the efficiency for models V-A and V-B was 97.3 and 92.6 percent. At test condition B the efficiency for model V-A was 97.4 percent and for model V-B was 98.3 percent. Model II was 97.5 efficient at condition A and 94.6 efficient at condition B. The variation of combustion efficiency with fuel-air ratio for models V-A and V-B is plotted with model II supplementary data (ref. 1) in figure 7.

Exit Temperature Profiles

To describe the quality of the combustor outlet temperature profiles, the following temperature parameters from reference 5 were used:

$$\bar{\delta} = \frac{T_{max} - T_{av}}{T_{av} - T_{in}} \tag{1}$$

where T_{max} is the maximum individual temperature at any point, T_{av} is the average exit temperature, and T_{in} is the average inlet temperature,

$$\delta \text{ stator} = \frac{(T_{r,local} - T_{r,design})_{max}}{T_{av} - T_{in}} \tag{2}$$

where $(T_{r,local} - T_{r,design})_{max}$ is the largest temperature difference between the highest local temperature on any radius and the design temperature for that same radius, and

$$\delta \text{ rotor} = \frac{(T_{r,av} - T_{r,design})_{max}}{T_{av} - T_{in}} \tag{3}$$

where $(T_{r,av} - T_{r,design})_{max}$ is the largest temperature difference between the average circumferential temperature at any radius and the design temperature for that same radius. The design temperature is shown in figures 8 and 9 and is typical of some advanced aircraft. The terms radial and circumferential are used as though the test sections were a sector of an annulus.

Typical uniform, tip-peaked, and hub-peaked inlet velocity profiles for models II, V-A, and V-B at test conditions A and B are shown in figures 8(a) and 9(a). The exit temperature profiles of models V-A and V-B at test conditions A and B are plotted with model II in figures 8(b) and 9(b). To eliminate any combustor side-wall effects, the end-wall thermocouple readings were deleted from the circumferential average of the temperatures at each radial position. They were also excluded in the calculations of the temperature parameters. The model V combustors satisfactorily demonstrated an insensitivity of the radial exit temperature profiles to distorted inlet velocity profiles. The temperature pattern factors for these two models at test conditions A and B are compared to those of model II in table V.

Pressure Loss

Combustor total-pressure loss was defined by the following equation:

$\Delta P/P_3 =$

$$\frac{\text{(average diffuser inlet total pressure) - (average combustor exit total pressure)}}{\text{average diffuser inlet total pressure}} \quad (4)$$

The total-pressure losses for models V-A and V-B at design and isothermal conditions are compared to those for model II in figure 10. No significant change was noted in total-pressure loss performance over model II.

The isothermal pressure loss data for the combustor with the three different L/D values are presented in figure 11. At an inlet Mach number of 0.30, a reduction in pressure loss from nominal values of 7.1 to 6.7 percent was obtained when the diffuser L/D was increased from 4.0 to 5.5. A reduction in pressure loss to a nominal 5.4 percent was obtained when the L/D was further increased to 7.0. The decrease in combustor pressure loss was attributed to lower diffuser losses from boundary-layer separation and greater uniformity of diffuser exit airflow.

SUMMARY OF RESULTS

Two turbojet combustor segments using dump and wide-angle diffusers, in a side-entry configuration, produced the following results when compared to a previously tested side-entry combustor having a diffuser with a 7° included angle:

1. At design conditions, the efficiency for models V-A and V-B, with uniform inlet velocity profiles, varied from 92.6 to 98.3 percent. Efficiency data for the previously tested model II ranged from 94.6 to 97.5 percent.
2. Exit temperature profiles showed the same insensitivity as model II to inlet velocity profiles that were purposely distorted to hub-peaked or tip-peaked positions.
3. Temperature pattern factors for the model V-A and V-B combustors ranged from 0.16 to 0.32 compared to values of 0.25 to 0.32 for the previously tested model II.
4. Models V-A and V-B produced no major increase in combustor total-pressure loss when compared to the model II combustor.

Tests of a model II type combustor with three different values of diffuser length to inlet height ratio L/D showed that the combustor total-pressure loss decreased as the L/D was increased. When the L/D was changed from 4.0 to 7.0, at an inlet Mach number of 0.30, the pressure loss decreased from a nominal value of 7.1 to 5.4 percent.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, October 28, 1970,
720-03.

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TABLE I. - NOMINAL TEST CONDITIONS

Test condition	Diffuser inlet Mach number, M_3	Inlet total pressure, P_3		Airflow rate, W		Reference velocity, V_r		Combustor reference Mach number, M_r
		psia	N/m^2	lb/sec	kg/sec	ft/sec	m/sec	
A	0.24	16.0	1.10×10^5	3.17	1.44	77.8	23.7	0.049
B	.30	17.0	1.17×10^5	4.12	1.87	97.4	29.7	.061

TABLE II. - MODEL V-A AND V-B COMBUSTION PERFORMANCE DATA

Model	Inlet velocity profile	Diffuser inlet Mach number, M_3	Inlet total pressure, P_3		Airflow rate, W		Inlet total temperature, T_3		Total-pressure loss, $(\Delta P/P_3)\times 100$, percent	Reference velocity, V_r		Average exit temperature,[b] T_4		Exit temperature pattern factor			Combustion efficiency,[c] η_c, percent	Fuel-air ratio, F/A
			psia	atm[a]	lb/sec	kg/sec	°F	K		ft/sec	m/sec	°F	K	$\overline{\delta}$	δ stator	δ rotor		
V-A	Uniform	0.25	14.85	1.05	3.09	1.40	602	590	5.83	78.8	24.0	2288	1528	0.18	0.18	0.05	97.3	0.0284
	Uniform	.31	15.17	1.07	4.01	1.82	600	589	9.45	99.7	30.4	2176	1458	.16	.16	.04	97.4	.0262
	Hub-peaked	.26	14.73	1.04	3.21	1.45	605	591	6.18	82.4	25.1	2241	1484	.17	.17	.08	93.7	.0288
	Hub-peaked	.32	14.97	1.06	4.04	1.83	592	584	10.0	100.9	30.8	2173	1463	.18	.18	.08	98.0	.0262
	Tip-peaked	.26	14.8	1.04	3.18	1.44	601	589	6.53	81.1	24.6	2315	1537	.25	.26	.08	97.7	.0288
	Tip-peaked	.32	15.05	1.06	4.07	1.85	587	581	10.85	100.8	30.7	2189	1472	.20	.19	.07	99.0	.0262
	Uniform	.26	14.37	1.01	3.12	1.41	598	588	5.12	81.7	24.9	----	----	----	----	----	----	------
	Uniform	.33	14.51	1.02	4.00	1.81	599	588	8.66	103.9	31.7	----	----	----	----	----	----	------
	Uniform	.37	14.62	1.03	4.54	2.06	600	589	11.62	117.2	35.7	----	----	----	----	----	----	------
V-B	Uniform	0.25	14.99	1.05	3.13	1.42	594	585	5.72	78.2	23.8	2184	1464	0.27	0.28	0.06	92.6	0.0280
	Uniform	.32	15.20	1.06	4.08	1.85	602	590	9.17	101.5	30.9	2105	1420	.32	.33	.06	98.3	.0250
	Hub-peaked	.25	14.83	1.03	3.10	1.41	602	590	6.23	79.0	24.1	2212	1426	.25	.24	.08	92.5	.0267
	Hub-peaked	.31	15.07	1.04	3.92	1.78	602	590	9.34	98.1	29.9	2045	1385	.32	.32	.08	91.8	.0253
	Tip-peaked	.25	14.70	1.03	3.10	1.40	602	590	5.66	79.6	24.3	2217	1482	.27	.27	.06	97.4	.0269
	Tip-peaked	.31	14.87	1.04	3.90	1.77	602	590	8.31	98.9	30.1	2071	1400	.23	.22	.06	92.8	.0255
	Uniform	.34	14.85	1.04	4.16	1.88	599	589	8.84	105.3	32.1	----	----	----	----	----	----	------
	Uniform	.29	14.63	1.02	3.54	1.06	601	589	6.33	91.8	28.0	----	----	----	----	----	----	------
	Uniform	.25	14.55	1.01	3.08	1.40	594	586	4.93	79.0	24.1	----	----	----	----	----	----	------
	Uniform	.21	14.49	1.01	2.60	1.18	602	590	3.68	66.4	20.2	----	----	----	----	----	----	------

[a] Based on local barometric pressure.

[b] Based on central 30 exit temperatures individually adjusted for radiation and used to calculate exit temperature pattern factors δ stator, δ rotor, and $\overline{\delta}$.

[c] Based on entire 40 exit temperatures individually adjusted for radiation.

TABLE III. - SUPPLEMENTARY PERFORMANCE DATA FOR MODELS V-A AND V-B WITH UNIFORM INLET VELOCITY PROFILES

Model	Diffuser inlet Mach number, M_3	Inlet total pressure, P_3		Airflow rate, W		Inlet total temperature, T_3		Total-pressure loss, $(\Delta P/P_3)\times100$, percent	Reference velocity, V_r		Combustion efficiency, η_c, percent	Fuel-air ratio, F/A	Temperature pattern factor	Average exit temperature, T_4	
		psia	atm	lb/sec	kg/sec	^{o}F	K		ft/sec	m/sec			$\overline{\delta}$	^{o}F	K
V-A	0.26	14.67	1.02	3.16	1.47	602	590	5.63	81.5	24.8	80.4	0.006	0.23	906	759
	.25	14.78	1.03	3.16	1.47	602	590	5.89	80.9	24.7	91.6	.012	.22	1270	961
	.25	14.79	1.03	3.14	1.42	598	589	6.12	79.8	24.3	95.3	.018	.26	1640	1180
	.25	14.86	1.04	3.14	1.42	602	590	6.06	79.8	24.3	96.4	.022	.20	1878	1294
	.25	14.99	1.05	3.14	1.42	605	591	6.63	79.4	24.2	97.8	.027	.19	2139	1438
	.25	15.06	1.05	3.11	1.41	605	591	6.21	78.3	23.9	95.9	.032	.21	2278	1516
	.33	14.75	1.03	4.12	1.87	593	586	8.72	104.6	31.9	77.1	.004	.27	830	716
	.33	14.90	1.04	4.12	1.87	598	589	9.04	104.0	31.8	93.8	.009	.24	1163	901
	.33	15.04	1.05	4.12	1.87	602	590	9.16	103.5	31.5	97.8	.014	.25	1459	1061
	.32	15.42	1.08	4.10	1.86	603	590	10.14	100.6	30.7	99.2	.028	.21	2168	1460
V-B	0.25	14.87	1.04	3.13	1.42	594	586	5.82	78.8	24.0	92.5	0.026	0.27	2096	1416
	.26	14.82	1.03	3.13	1.42	594	586	5.62	78.1	23.8	94.8	.023	.28	1919	1316
	.25	14.73	1.03	3.13	1.42	594	586	5.58	79.5	24.2	90.1	.016	.31	1563	1119
	.25	14.65	1.02	3.13	1.42	594	586	5.52	80.1	24.4	88.4	.011	.23	1264	958
	.30	15.11	1.05	3.84	1.74	602	590	8.30	95.9	29.0	100.0	.026	.27	2131	1434
	.32	15.17	1.06	4.08	1.85	602	590	8.98	101.5	30.9	99.1	.020	.31	1878	1294
	.32	15.10	1.05	4.08	1.85	602	590	8.94	101.6	30.9	95.1	.015	.34	1548	1110
	.32	14.98	1.04	4.08	1.85	602	590	8.88	102.0	31.1	87.8	.010	.24	1178	911

TABLE IV. - PERFORMANCE DATA FOR TEST MODELS WITH DIFFERENT DIFFUSER AXIAL LENGTH TO INLET HEIGHT RATIOS

Diffuser model	Diffuser length-height ratio, L/D	Diffuser inlet Mach number, M_3	Inlet total pressure, P_3		Airflow rate, W		Inlet total temperature, T_3		Total-pressure loss, $(\Delta P/P_3)\times 100$, percent
			psia	atm	lb/sec	kg/sec	°F	K	
1	4.0	0.367	16.16	1.11	4.48	2.03	604	590	10.6
		.332	15.75	1.09	4.02	1.92	606	592	8.71
		.321	15.36	1.07	3.52	1.59	604	590	6.81
		.254	15.05	1.05	3.05	1.38	593	586	5.26
		.212	14.75	1.03	2.53	1.15	594	586	3.60
		.169	14.53	1.02	2.02	.92	604	590	2.41
2	5.5	0.382	16.59	1.12	4.70	2.13	608	593	10.67
		.353	16.14	1.10	4.34	1.97	604	590	9.00
		.329	15.93	1.09	4.03	1.83	601	589	8.11
		.291	15.54	1.07	3.54	1.60	602	590	6.27
		.247	15.22	1.05	3.00	1.36	601	589	4.59
		.214	15.00	1.04	2.60	1.18	600	589	3.50
		.162	14.74	1.02	1.95	.88	610	595	2.10
3	7.0	0.396	16.13	1.13	4.72	2.14	607	594	9.34
		.364	15.75	1.10	4.35	1.97	606	592	7.55
		.334	15.56	1.09	3.99	1.81	605	591	6.74
		.294	15.24	1.08	3.51	1.56	599	589	5.22
		.251	14.99	1.06	2.99	1.36	607	594	4.02
		.214	14.79	1.05	2.57	1.16	598	588	3.01
		.165	14.58	1.03	1.98	.89	598	588	1.89

TABLE V. - TEMPERATURE PATTERN FACTORS

Model	Test condition	Exit temperature pattern factor		
		$\bar{\delta}$	δ stator	δ rotor
II	A	0.27	0.30	0.05
II	B	.26	.26	.05
V-A	A	.18	.18	.04
V-A	B	.16	.16	.05
V-B	A	.27	.28	.06
V-B	B	.32	.33	.06

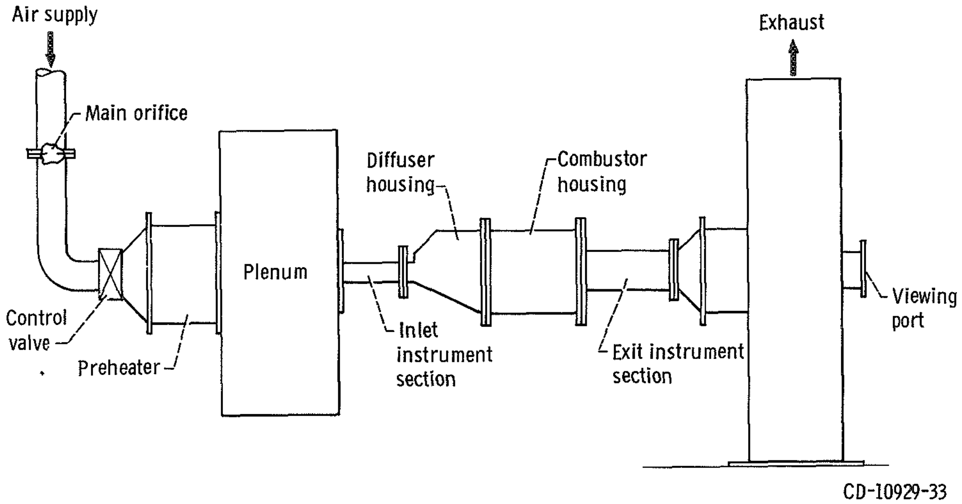

Figure 1. - Schematic diagram of combustor test facility.

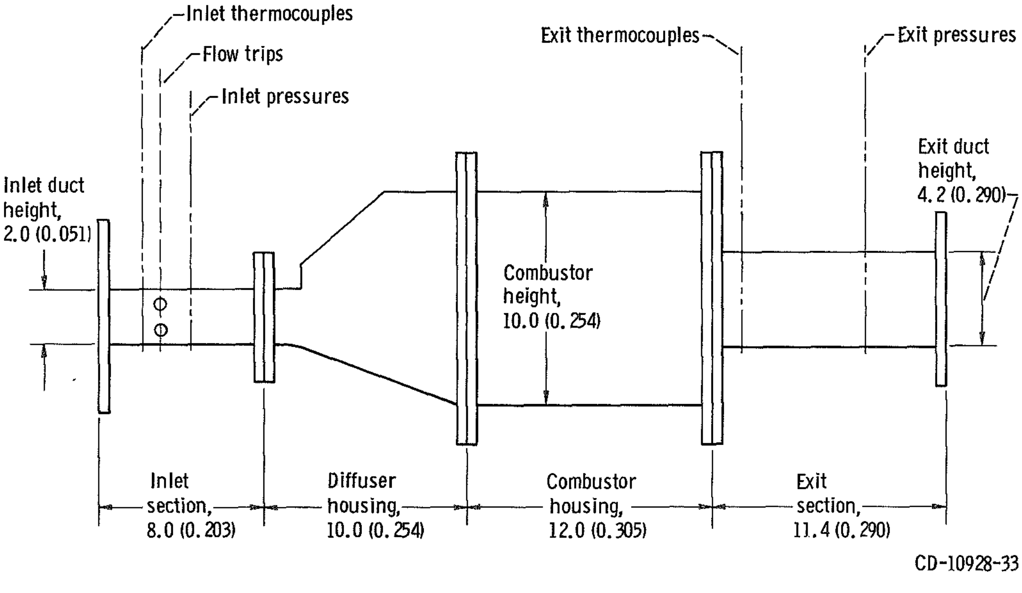

Figure 2. - Test sections and instrumentation stations. (Dimensions are in inches (m).)

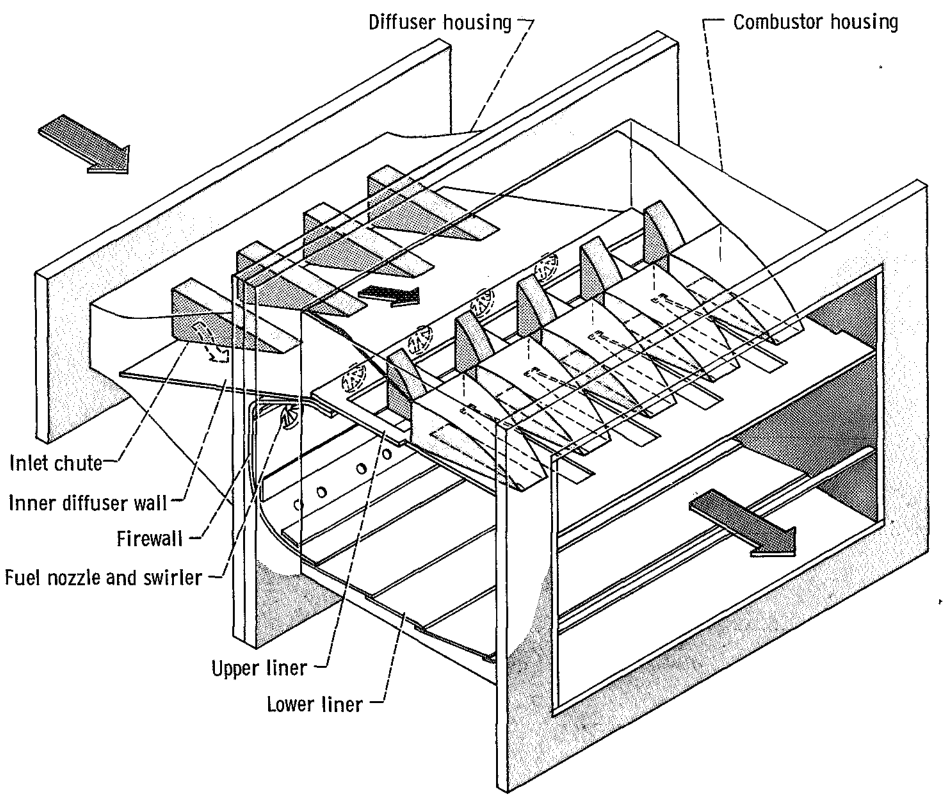

Figure 3. - Model II combustor and housings.

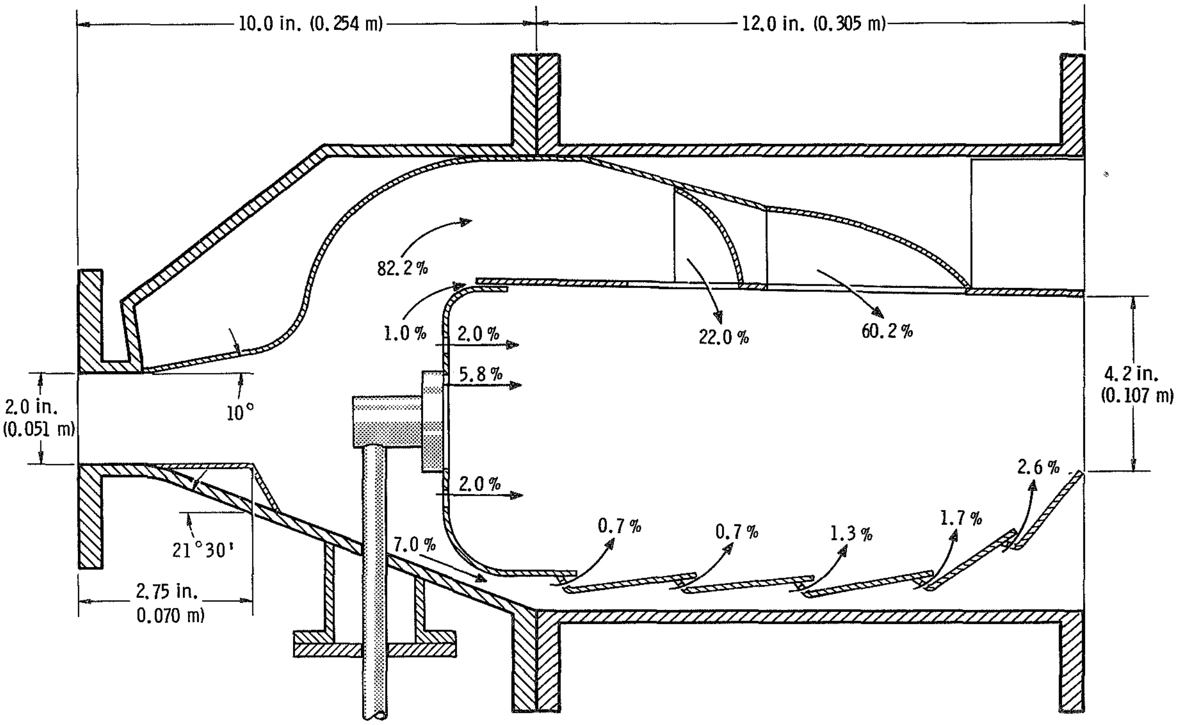

Figure 4. - Side-entry model V-A airflow distribution.

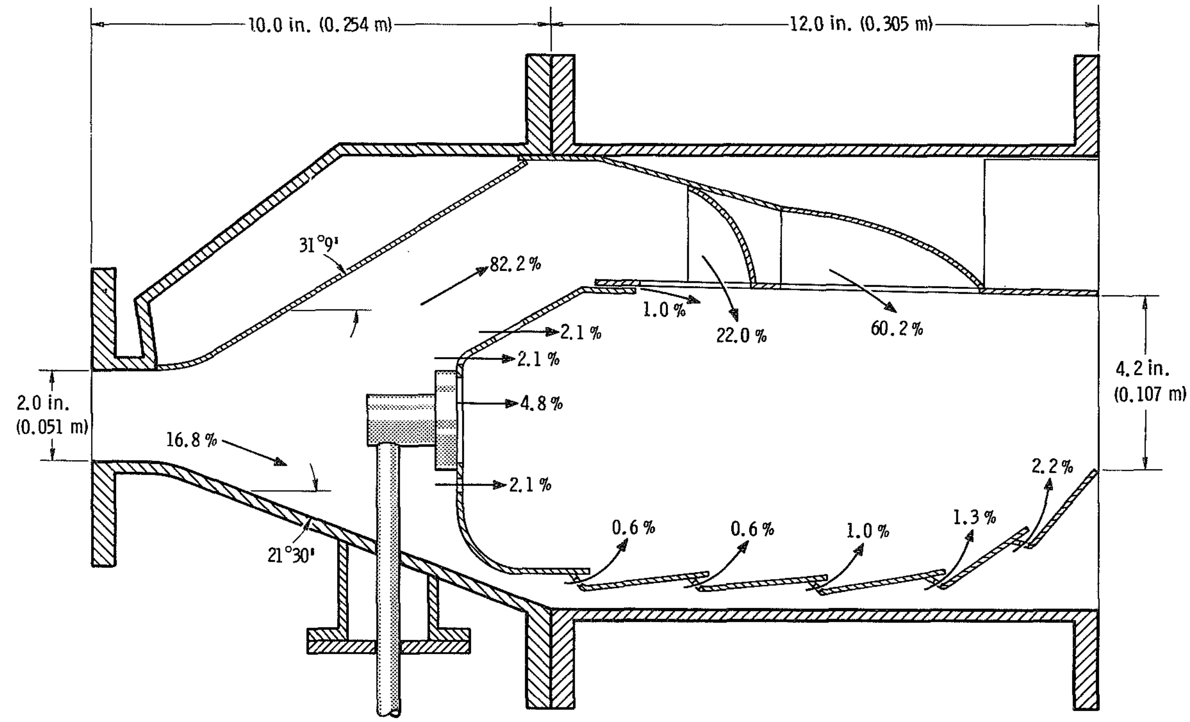

Figure 5. - Side-entry model V-B airflow distribution.

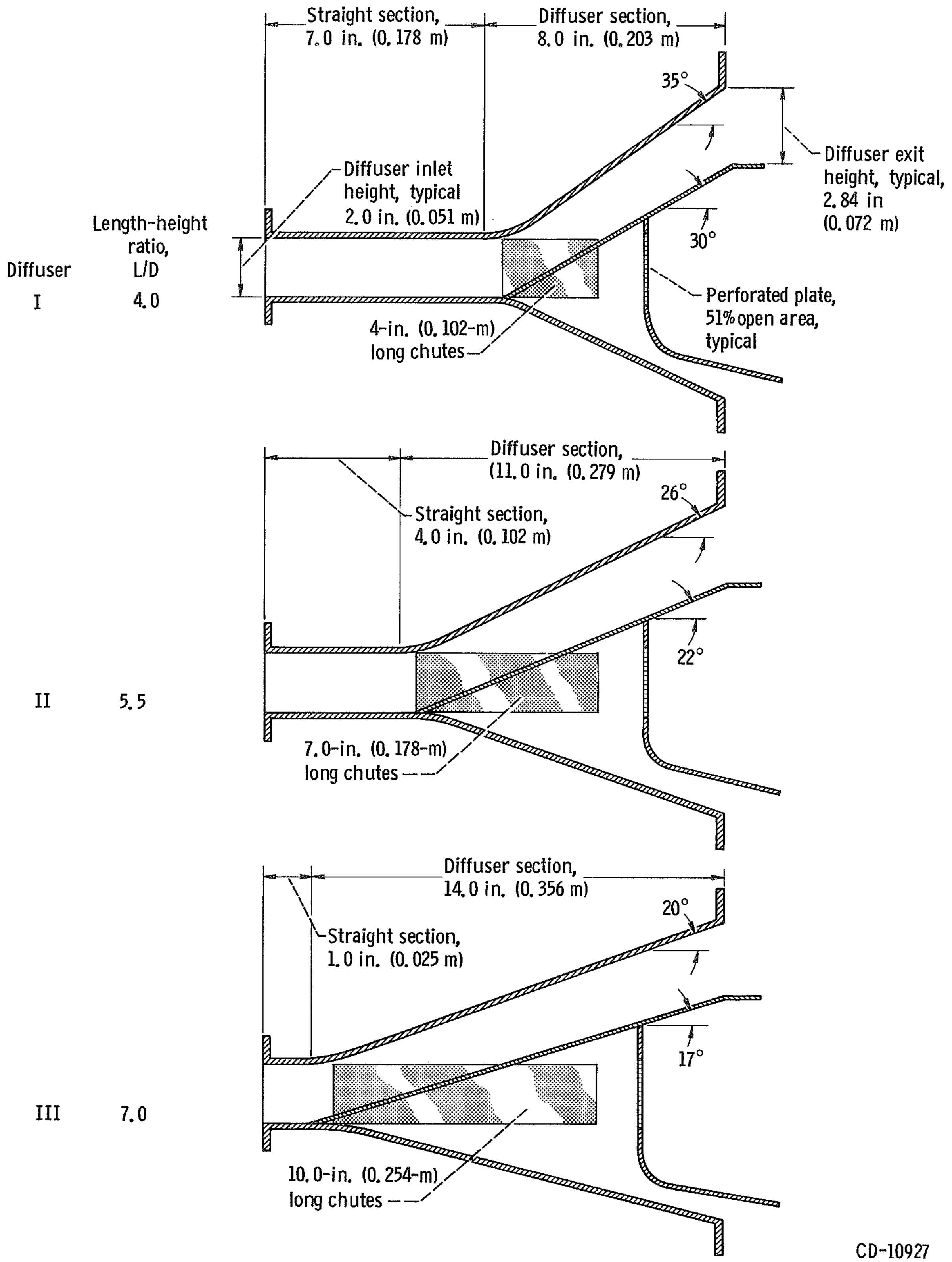

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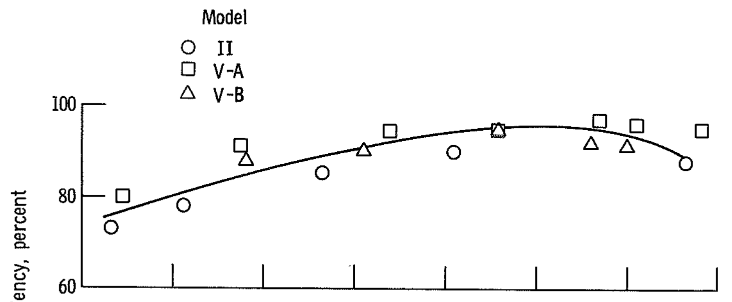
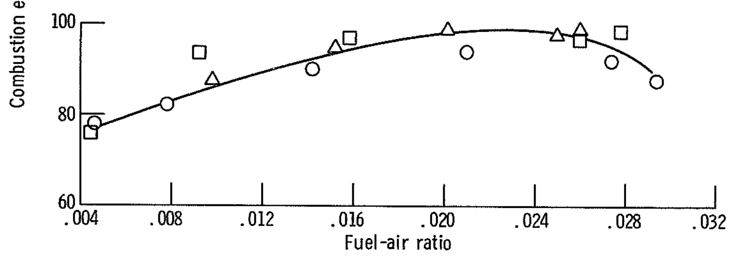
Figure 6. - Schematic view of three diffusers with different length-height ratios.

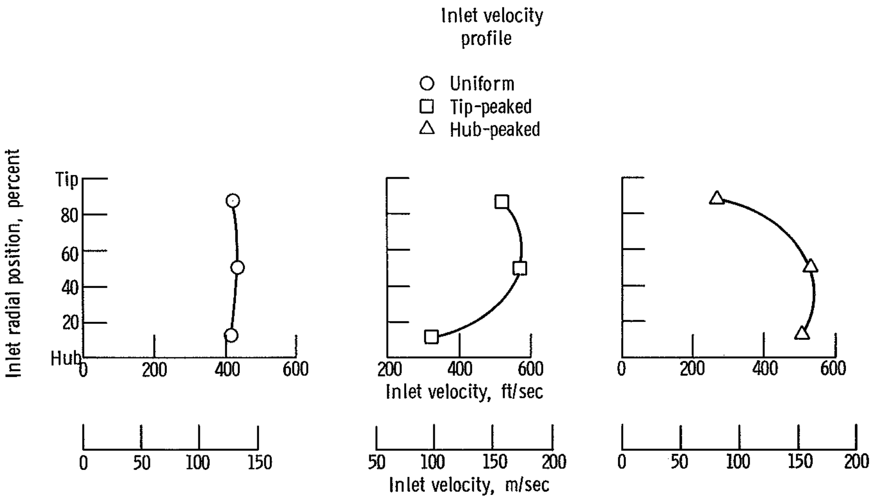


(a) Design condition A.

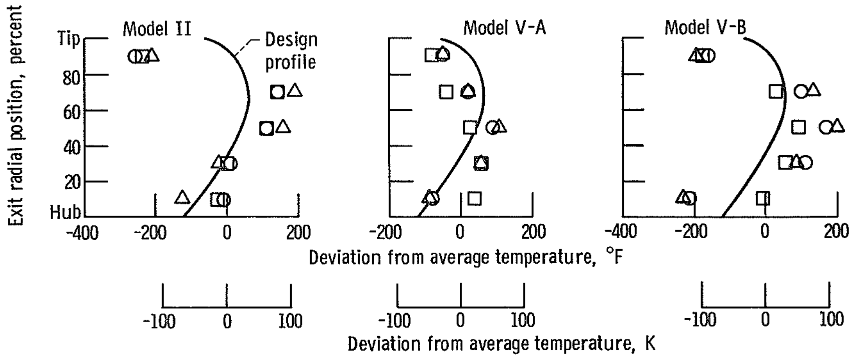


(b) Design condition B.

Figure 7. - Combustion efficiency as function of fuel-air ratio.

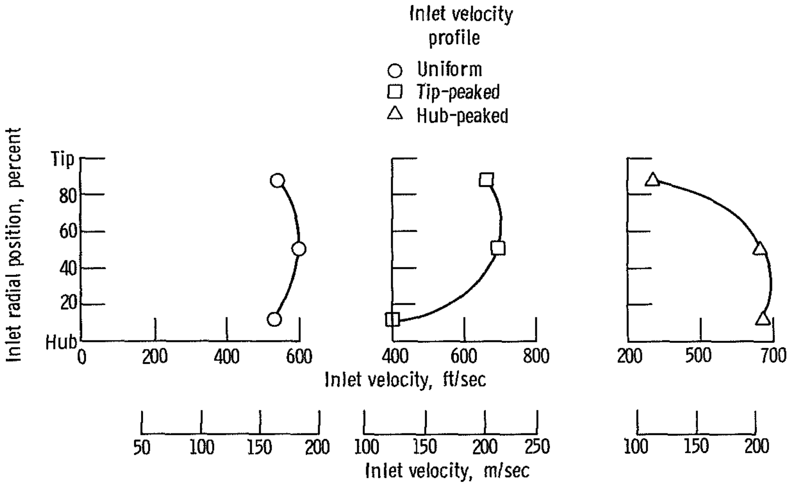


(a) Typical inlet velocity profiles.

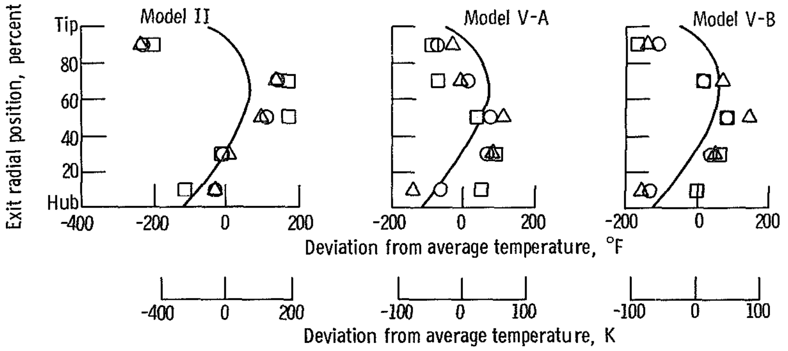


(b) Exit temperature profiles.

Figure 8. - Effect of three types of inlet velocity profile on exit radial temperature for test condition A.



(a) Typical inlet velocity profiles.



(b) Exit temperature profiles.

Figure 9. - Effect of three types of inlet velocity profile on exit radial temperature for test condition B.

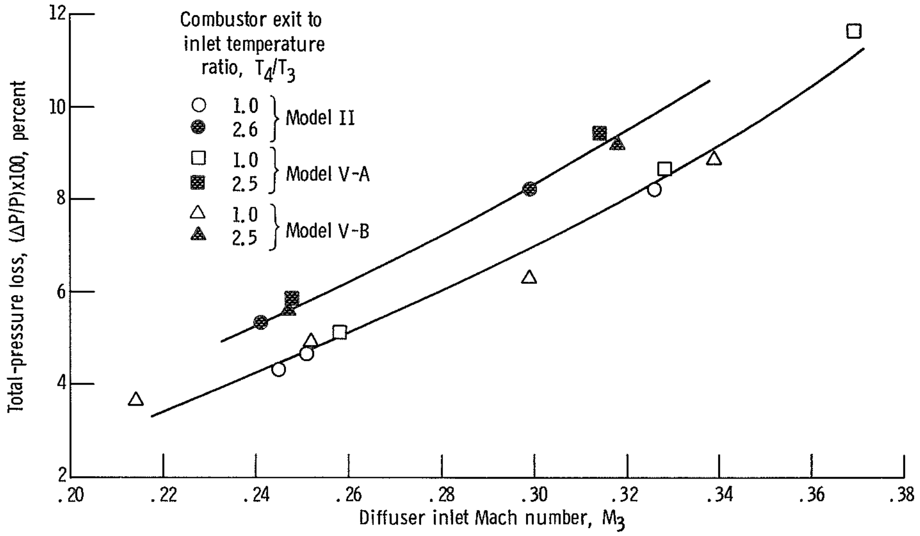


Figure 10. - Total-pressure loss.

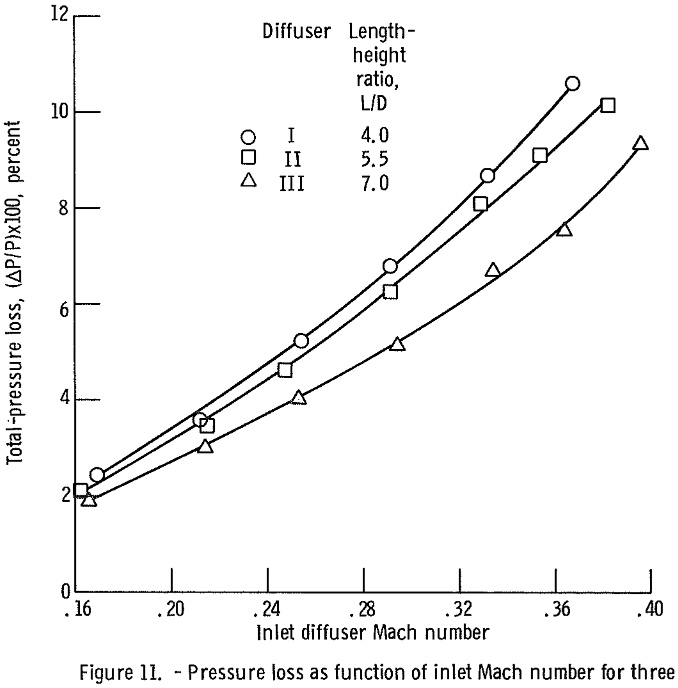


Figure 11. - Pressure loss as function of inlet Mach number for three length height ratios.

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15. Supplementary Notes

16. Abstract

Further tests were performed on a previously developed experimental combustor insensitive to shifts in the radial velocity profile at the compressor outlet. The purpose was to investigate alternate diffuser designs for this type combustor. Test conditions were atmospheric pressure, 600° F (589 K) inlet air temperature, and average exit temperatures up to 2200° F (1478 K). The fuel used was ASTM A-1. The performance of a dump-type diffuser and a 53° wide-angle diffuser showed that these designs of simple construction may be interchanged with that of the previously developed combustor without penalty. Tests of three diffusers with different axial lengths but similar to the design used in the previously developed combustor were investigated only at isothermal conditions with 600° F (589 K) inlet air. When the diffuser length to inlet height ratio was changed from 4.0 to 7.0, at an inlet Mach number of 0.30, the combustor total-pressure loss decreased from a nominal value of 7.1 to 5.4 percent.

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