NASA TECHNICAL NOTE

NASA TN D-7021

EFFECT OF SHORTENING TRANSITION LINER TO DECREASE OVERALL LENGTH OF A RAM INDUCTION COMBUSTOR

by Donald F. Schultz, Porter J. Perkins, and Jerrold D. Wear

Lewis Research Center
Cleveland, Ohio 44135

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • DECEMBER 1970

1. Report No. NASA TN D-7021	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle EFFECT OF SHORTENING TRANSITION LINER TO DECREASE OVERALL LENGTH OF A RAM INDUCTION COMBUSTOR		5. Report Date December 1970
		6. Performing Organization Code
7. Author(s) Donald F. Schultz, Porter J. Perkins, and Jerrold D. Wear		8. Performing Organization Report No. E-5691
		10. Work Unit No. 720-03
9. Performing Organization Name and Address Lewis Research Center National Aeronautics and Space Administration Cleveland, Ohio 44135		11. Contract or Grant No.
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D.C. 20546		13. Type of Report and Period Covered Technical Note
		14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

The change in performance of a 40-inch (102-cm) diameter turbojet combustor originally 30 inches (76 cm) long was determined when it was shortened 5.0 inches (12.7 cm) at the discharge end. Design was for Mach 3.0 cruise inlet-air conditions of 90-psia (62-N/cm^2) total pressure and 1150° F (839 K) inlet-air temperature with an airflow rate of 108.6 lb/sec (49.3 kg/sec). The reduced length caused pattern factors to double (0.22 to 0.40), exit average circumferential temperature profiles to deteriorate, and efficiency to decrease slightly from 100 percent. Total pressure loss, exit average radial temperature profile, and smoke were not affected.

17. Key Words (Suggested by Author(s))	18. Distribution Statement Unclassified - unlimited

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
Unclassified	Unclassified	19	$3.00

*For sale by the National Technical Information Service, Springfield, Virginia 22151

EFFECT OF SHORTENING TRANSITION LINER TO DECREASE OVERALL LENGTH OF A RAM INDUCTION COMBUSTOR

by Donald F. Schultz, Porter J. Perkins, and Jerrold D. Wear

Lewis Research Center

SUMMARY

A 40-inch (102-cm) diameter annular turbojet combustor was tested in two versions, one 30 inches (76 cm) in length and the other 25 inches (63.5 cm). The reduction in length was obtained by removing 5 inches (12.7 cm) from the cooling liners at the downstream end. A slight increase was made in the cooling airflow to the remaining section of the downstream cooling liner. No other changes were made. The combustor dome, swirlers, fuel nozzles, primary zone liner, and diluent zone liner were common in the two combustor versions. Tests of both versions were conducted at conditions corresponding to Mach 3 cruise: 90-psia (62-N/cm^2) total pressure and 1150° F (839 K) inlet-air temperature. The airflow rate was 108.6 pounds per second (49.3 kg/sec).

Shortening the liner resulted in a severe decrease in uniformity of the exit temperature in the circumferential direction. The reduced length caused pattern factors to double (0.22 to 0.40). The average radial temperature profile, however, was affected very little. A slight decrease in combustion efficiency was measured. Total pressure loss and smoke formation were unaffected.

INTRODUCTION

It is generally accepted in the field of turbojet combustors that decreasing the combustor length from fuel nozzles to turbine inlet has an adverse effect on the exit temperature profile, other factors being the same (e.g., refs. 1 and 2). The magnitude and specific nature of this effect is not well documented.

Tests were conducted on a 30-inch (76-cm) long, full-scale annular turbojet combustor designed for operation at Mach 3 cruise. The detailed design of this combustor is reported in reference 3. Upon completion of that program, the combustor was shortened. This was accomplished by removing 5 inches (12.7 cm) from the exit transition liner between the last dilution hole and the combustor exit plane. This reduced the overall length, from compressor exit station to turbine inlet station, from 30 inches (76 cm) to 25 inches (63.5 cm). The cooling flow to the remaining section of the transition liner was increased slightly. No other change to the combustor was made.

Tests were then conducted on the 25-inch configuration to determine the effect of the length reduction on exit temperature profile, combustion efficiency, pressure loss, and smoke intensity. The results are reported herein.

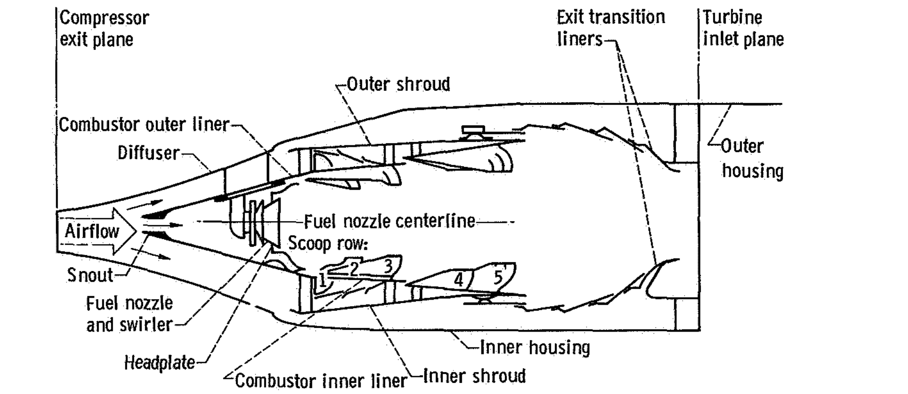
TEST FACILITY AND INSTRUMENTATION

The investigation was conducted in a closed-duct test facility of the Engine Components Research Laboratory at Lewis. Combustor inlet-air temperatures as high as 1050° F (839 K) were obtained in the facility without vitiation. Combustor exit temperatures were measured at 3° increments around the circumference with three five-point aspirated thermocouple probes which traversed circumferentially in the exit plane. Detailed descriptions of the facility and instrumentation are contained in reference 3.

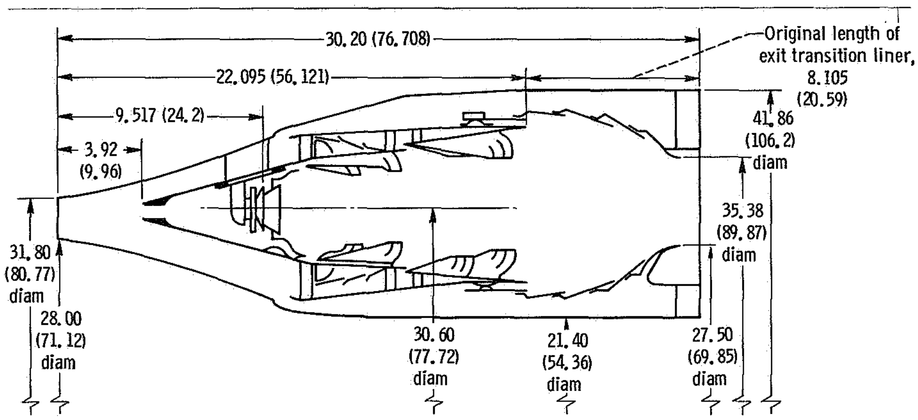
TEST COMBUSTORS

The combustor was designed using the ram-induction approach described in references 3 and 4. With this approach, the compressor discharge air is diffused less than with conventional combustors. The relatively high-velocity air is then captured by scoops in the combustor liner and turned into the combustion and mixing zones. Vanes are used in the scoops to reduce pressure loss caused by the high-velocity turns. The high velocity and steep angle of the entering air jets promote rapid mixing of the fuel and air in the combustion zone and of the burned gases and air in the dilution zone. The potential result of the rapid mixing is a shorter combustor, or, alternatively, a better exit temperature profile in the same length.

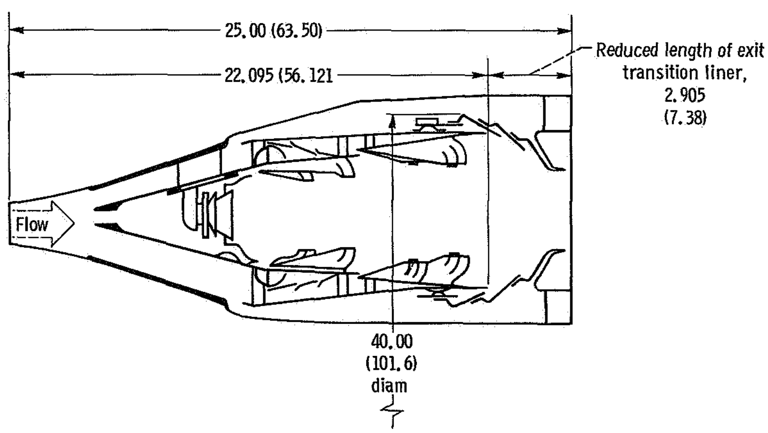
Figure 1(a) shows the major features of the combustor such as the snout, the five rows of scoops, and the transition liner. The snout divides the diffuser into three concentric annular passages. The central passage conducts air to the combustor headplate, and the inner and outer passages supply air to the combustor liners. Five rows of scoops are provided on each of the inner and outer liners to turn the air into the combustion and dilution zones. Figure 1(b) also shows the more important dimensions of the original 30-inch version. Figure 1(c) shows the shortened, 25-inch combustor. The exit transition liners that were shortened contained no air entry holes except those providing film cooling. Details of the transition liners can be compared in figure 2. The 25-inch combustor liners contained one less segment than did the 30-inch combustor



(a) Combustor components.

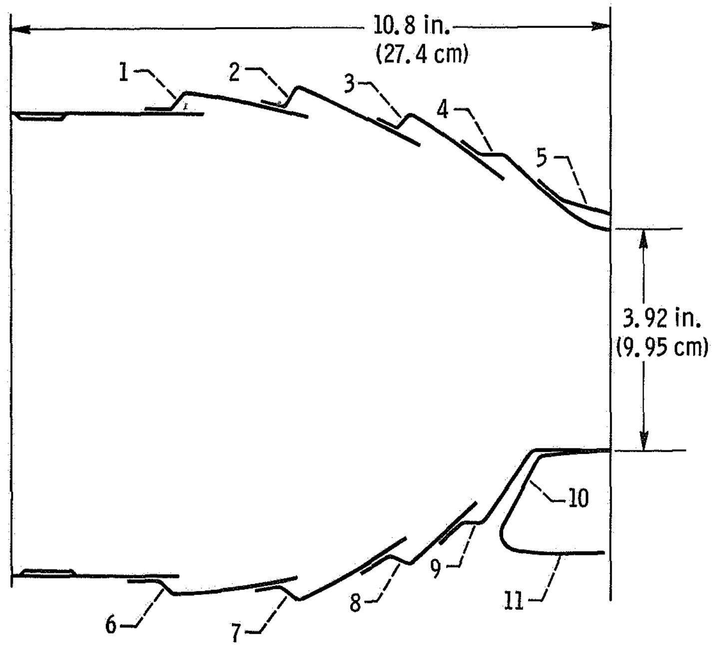


(b) Combustor dimensions (original combustor).



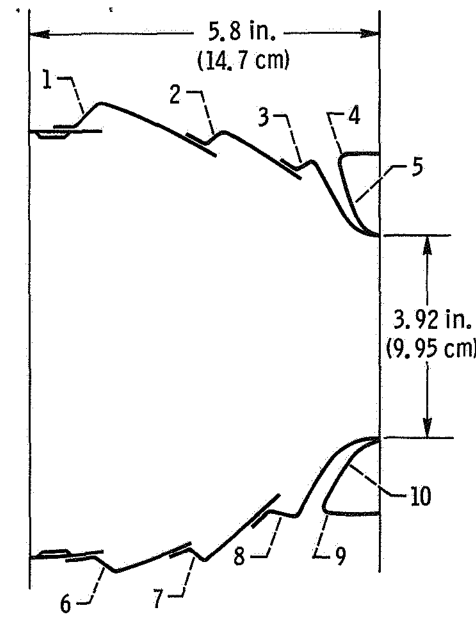
(c) Combustor dimensions (shorted combustor).

Figure 1. - Cross-section sketch of original ram-induction annular combustor. (Dimensions are in inches (cm).)



Number	Number of holes	Hole diameter		Total hole area	
		in.	cm	in.^{2}	cm^2
1	180	0.129	0.328	2.351	15.168
2	180	.120	.305	2.036	13.135
3	180	.120	.305	2.036	13.135
4	180	.166	.422	3.896	25.135
5	180	.094	.239	1.249	8.058
6	120	.129	.328	1.568	10.116
7	120	.129	.328	1.568	10.116
8	120	.129	.328	1.568	10.116
9	120	.182	.508	3.122	20.142
10	150	.104	.264	1.274	8.219
11	30	.104	.264	.255	1.645
Total area of all holes				20.929 in.^{2}	134.987 cm^2

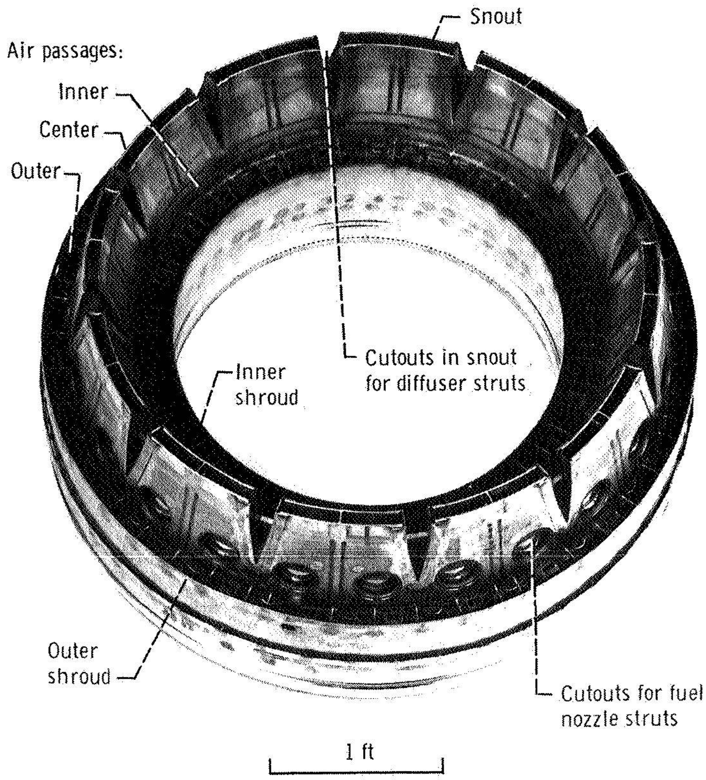
(a) 30-Inch (76-cm) combustor.



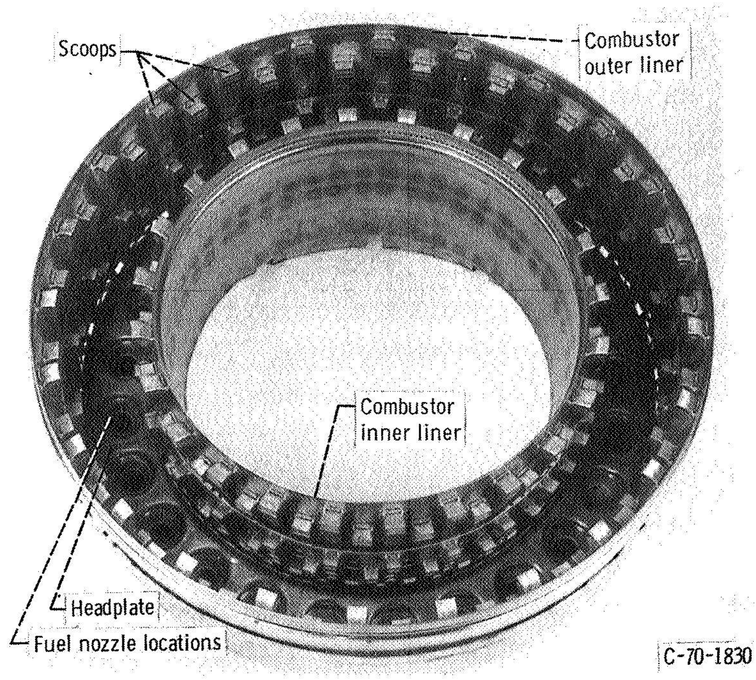
Number	Number of holes	Hole diameter		Total hole area	
		in.	cm	in.^{2}	cm^2
1	180	0.120	0.305	2.036	13.135
2	180	.150	.381	3.179	20.510
3	180	.190	.483	5.101	32.910
4	30	.104	.264	.255	1.645
5	150	.104	.264	1.274	8.219
6	120	.129	.328	1.568	10.116
7	120	.157	.399	2.323	14.987
8	120	.204	.518	3.920	25.290
9	30	.104	.264	.255	1.645
10	150	.104	.264	1.274	8.219
Total area of all holes				21.185 in.^{2}	136.677 cm^2

(b) 25-Inch (63.5-cm) combustor.

Figure 2. - Combustor transition liners.

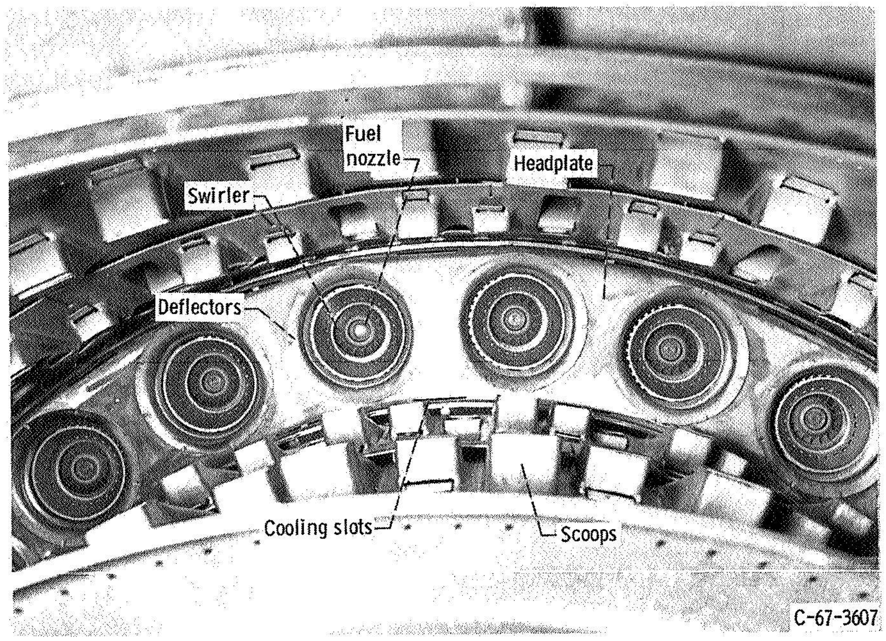


(a) Looking downstream.



(b) Looking upstream.

Figure 3. - Annular ram-induction combustor.



(c) Viewed from downstream end.
Figure 3. - Concluded.

liners. However, the film-cooling-hole area was kept about the same to provide extra cooling to compensate for the increased angle of liner surfaces to the flow of the combustion gases. This was accomplished by using larger cooling holes. The cooling-hole area in the 30-inch combustor was 20.9 square inches (135 cm^2), compared to 21.2 square inches (136.7 cm^2) in the 25-inch combustor. The film-cooling flow was adequate since no transition liner problems were encountered with either configuration.

The snout and the combustor liners are shown in figure 3 for the combustor without the exit transition liners. Figure 3(a) is a view of the snout and the upstream end of the combustor liners. The V-shaped cutouts in the snout fit around struts in the diffuser. The circular holes through the snout walls are for the fuel nozzle struts. Figure 3(b) is a view looking upstream into the combustor liner. The scoops in the inner and outer liners can be seen, as well as the openings in the headplate for the fuel nozzles and swirlers. Figure 3(c) gives a closer view of the liner and headplate, showing the fuel nozzles (a total of 24) and swirlers in place. Simplex nozzles were used for all tests. The shortened combustor contained no changes to the snout, headplate, fuel nozzles, or liners with scoops.

The 30-inch configuration used in these tests was the one designated Model F in reference 3. Model F was the final configuration arrived at after a period of combustor development and contained modifications made to improve exit temperature pattern fac-

TABLE I. - TEST RESULTS

(a) 25-Inch (63.5-cm) combustor

Inlet-air total temperature		Inlet-air total pressure		Airflow rate		Reference velocity		Diffuser inlet Mach number	Fuel-air ratio	Exit-mass-weighted average temperature		Combustor pressure loss, ΔP/P, percent	Combustion efficiency, percent	Pattern factor	Stator factor	Rotor factor
^{o}F	K	psia	N/cm^2	lb/sec	kg/sec	ft/sec	m/sec			^{o}F	K					
1046	836	60.3	41.6	63.8	28.9	122.0	37.2	0.261	0.0132	1839	1277	4.29	96.9	0.323	0.326	0.056
1046	836	60.2	41.5	63.8	28.9	122.2	37.2	.261	.0158	1986	1359	4.28	97.4	.367	.315	.066
1043	835	60.1	41.4	62.9	28.5	120.5	36.7	.259	.0189	2138	1443	4.64	96.1	.426	.362	.073
1046	836	60.0	41.4	77.2	35.0	148.1	45.1	.324	.0130	1840	1277	6.62	98.3	.318	.331	.056
1048	838	59.7	41.2	76.8	34.8	148.2	45.2	.329	.0158	2008	1371	6.07	99.2	.354	.316	.066
1046	836	60.2	41.5	76.2	34.6	145.5	44.3	.320	.0185	2152	1451	6.17	99.0	.408	.345	.071
1053	840	60.3	41.6	87.3	39.6	167.0	50.9	.377	.0117	1752	1229	8.49	96.2	.337	.301	.050
1049	839	59.7	41.2	88.8	40.3	171.0	52.1	.386	.0158	2000	1366	8.38	98.3	.354	.320	.067
1050	839	59.8	41.2	87.8	39.8	168.8	51.5	.382	.0188	2153	1451	7.76	97.4	.411	.358	.074
1052	840	59.7	41.2	105.2	47.7	201.9	61.5	.481	.0128	1848	1282	12.00	100.5	.359	.327	.056
1051	839	59.6	41.1	104.3	47.3	200.3	61.1	.478	.0154	1990	1361	12.02	99.5	.378	.351	.064
1052	840	59.4	41.3	101.9	46.2	194.7	59.3	.467	.0185	2138	1443	12.15	97.2	.423	.386	.069
591	584	90.0	62.1	110.4	50.1	99.1	30.2	.250	.0136	1489	1083	3.22	101.8	.557	.479	.081
593	585	90.1	62.1	109.9	49.8	98.7	30.1	.248	.0188	1789	1249	3.78	98.7	.699	.640	.089
1052	840	59.9	41.3	103.9	47.0	198.8	60.6	.473	------	----	----	11.54	-----	-----	-----	-----
1051	839	60.8	41.9	74.9	33.9	142.0	43.4	.311	------	----	----	6.39	-----	-----	-----	-----
1046	836	60.4	41.6	63.0	28.5	120.1	36.6	.258	------	----	----	7.93	-----	-----	-----	-----
1046	836	59.8	41.2	87.6	39.7	168.1	51.3	.378	------	----	----	7.97	-----	-----	-----	-----
(b) 30-Inch (76-cm) combustor																
1055	841	59.2	40.8	66.6	30.2	130.7	39.8	0.278	0.0119	1806	1259	3.22	102.6	0.171	0.211	0.016
1054	841	59.5	41.0	65.3	29.6	127.6	38.9	.272	.0151	1970	1350	3.58	100.2	.205	.238	.0238
1060	844	60.5	41.7	64.9	29.4	124.6	38.0	.267	.0163	2057	1398	4.28	100.0	.248	.200	.051
1055	841	58.7	40.5	64.3	29.2	127.3	38.8	.271	.0185	2124	1435	3.08	96.7	.254	.282	.034
1058	843	59.7	41.2	64.7	29.3	126.2	38.5	.270	.0207	2287	1526	3.92	100.4	.223	.247	.032
1052	840	58.7	40.5	77.5	35.2	152.8	46.6	.336	.0126	1810	1261	4.96	97.9	.211	.211	.021
1051	839	59.9	41.3	80.2	36.4	154.8	47.2	.342	.0148	1962	1345	6.79	101.5	.185	.174	.022
1098	838	61.4	42.3	77.2	35.0	144.7	44.1	.317	.0163	2056	1398	5.70	101.0	.255	.212	.052
1051	839	59.9	41.3	76.7	34.8	148.0	45.1	.327	.0191	2154	1452	6.08	96.8	.225	.253	.031
1053	840	59.2	40.8	78.6	35.7	153.7	46.8	.338	.0206	2273	1518	5.59	100.0	.218	.243	.034
1056	842	59.1	40.7	94.1	42.7	184.1	56.1	.421	.0120	1806	1259	8.66	101.8	.204	.206	.020
1056	842	59.2	40.8	94.0	42.6	183.7	56.0	.421	.0147	1962	1345	8.98	101.4	.204	.225	.025
1053	840	58.7	40.5	93.8	42.5	184.2	56.1	.423	.0181	2150	1450	8.61	101.4	.219	.245	.032
1047	837	59.1	40.7	94.1	42.7	182.9	55.7	.420	.0201	2260	1511	9.14	101.7	.232	.241	.036
1055	841	59.5	41.0	101.7	46.1	196.7	60.0	.465	.0133	1872	1295	11.18	100.8	.224	.232	.028
1052	840	59.3	40.9	100.6	45.6	195.1	59.5	.459	.0162	2034	1385	10.49	100.1	.233	.236	.031
1057	843	58.9	40.6	103.2	46.8	201.9	61.5	.478	.0185	2178	1465	10.48	101.4	.247	.257	.035
1055	841	60.1	41.4	100.5	45.6	192.6	58.7	.454	.0190	2175	1464	12.47	98.9	.243	.245	.037
1049	838	59.1	40.7	102.3	46.4	198.5	60.5	.469	.0204	2265	1514	10.74	100.7	.256	.268	.038
604	591	90.6	62.5	111.6	50.6	100.2	30.5	.253	.0133	1504	1091	3.76	102.5	.366	.344	.046
603	590	90.5	62.4	107.8	48.9	96.8	29.5	.243	.0138	1527	1104	3.33	102.0	.310	.298	.040
612	595	90.6	62.5	110.7	50.2	100.2	30.5	.252	.0159	1669	1183	3.81	102.2	.323	.261	.044
606	592	90.5	62.4	111.8	50.7	100.7	30.7	.254	.0158	1664	1180	3.87	102.9	.401	.337	.035
605	591	90.5	62.4	111.8	50.7	100.7	30.7	.254	.0182	1812	1262	3.91	103.1	.390	.342	.063
1051	839	59.2	40.8	72.5	32.8	141.8	43.3	.307	------	----	----	5.03	-----	-----	-----	-----
1045	836	59.2	40.8	90.3	40.8	176.3	53.8	.400	------	----	----	7.94	-----	-----	-----	-----
1042	834	59.7	41.2	102.6	46.4	197.2	60.2	.466	------	----	----	10.92	-----	-----	-----	-----
1051	839	59.7	41.2	64.4	29.2	125.1	38.2	.267	------	----	----	4.38	-----	-----	-----	-----

tor. The first row of scoops was completely blocked except for a small film-cooling flow of air, and the fourth and fifth rows of scoops were blocked in the center third of the outlet passage.

RESULTS AND DISCUSSION

The combustors were tested at two inlet-air temperatures, 600° and 1050° F (589 and 839 K) using ASTM A-1 fuel. The design average exit temperature was 2200° F (1478 K). This value was not obtained with the 25-inch combustor due to excessive local temperature peaks which would damage the exit temperature probes. The total pressure for all tests was 90 psia (62.0 N/cm^2) with 600° F (589 K) inlet-air temperature, and 60 psia (41.4 N/cm^2) with 1050° F (839 K) inlet-air temperature. Table I is a listing of test results for the 30- and 25-inch combustors over a range of operating conditions. The 30-inch combustor evaluated in reference 3 was retested during this program to obtain a more direct comparison of the two designs.

Pressure Loss

Figure 4 shows combustor pressure loss as a function of diffuser inlet Mach number. There was no apparent change in pressure loss due to shortening the combustor. The diffuser inlet Mach number was calculated from the diffuser inlet static pressure, total temperature, airflow, and diffuser inlet area.

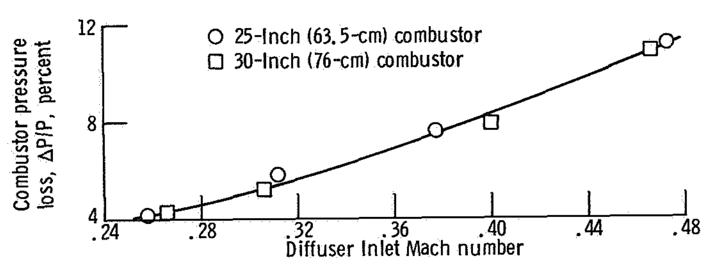


Figure 4. - Isothermal combustor pressure loss. Combustor inlet total pressure, 60 psia (41.4 N/cm^2); combustor inlet total temperature, 1050° F (839 K).

Combustion Efficiency

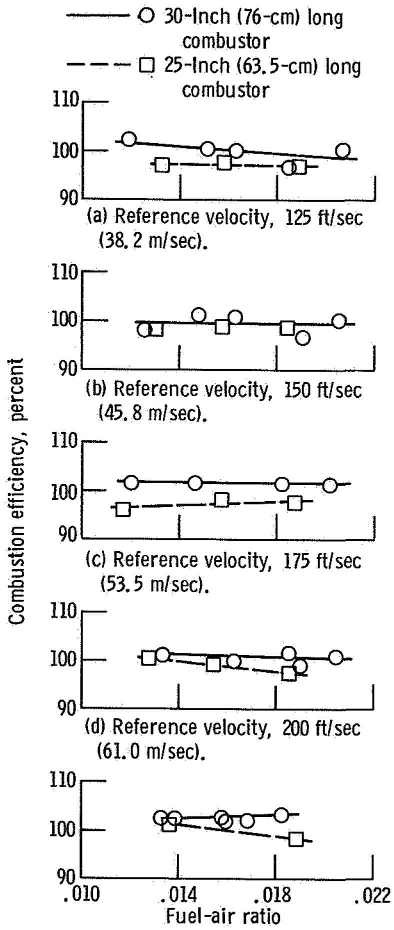
Efficiency was determined by dividing the measured temperature rise across the combustor by the theoretical temperature rise. The exit temperatures were measured with five-point traversing aspirated thermocouple probes and were mass-weighted for the efficiency calculation. Each mass weighted average temperature used 585 temperatures.

Combustion efficiency of the 30-inch combustor was 100 percent at conditions of 60 and 90 psia (41.4 and 62.0 N/cm^2) inlet-air total pressure, 600° F (589 K) and 1050° F (839 K) inlet-air temperature, and reference velocities from 100 to 200 feet per second (30.5 to 61.0 m/sec), respectively. The reference area selected for the reference velocity calculation was the combustor cross-sectional area at the leading edge of the inside-diameter and outside-diameter shrouds. Combustion efficiency decreased 2 to 3 percent with the shorter combustor at these conditions, as shown in figure 5.

Radial Temperature Profile

The design temperature profile at the combustor exit plane is determined by the stress and cooling characteristics of the turbine in a particular engine application. For the purpose of evaluating the combustor, a design exit average radial temperature profile typical of advanced engines was selected. The measured exit average radial temperature profile for both the 30- and 25-inch combustors is compared with the design temperature profile in figure 6. The open symbols indicate the exit average temperatures measured at each radial position. Also shown are the maximum temperatures at each radial position measured at any point around the circumference (solid symbols). The effect of shortening the combustor on the exit average radial temperature profile was small. However, shortening the combustor had a significant effect on the maximum temperature. The shorter combustor had maximum temperatures as much as 225° F (142 K) above those of the longer combustor at similar operating conditions.

Figure 7 shows the variation of exit average radial temperature profiles and maximum temperatures as a function of reference velocity. Figure 7(a) shows that reference velocity has virtually no effect on the exit average radial temperature profile of the 30-inch combustor. The maximum temperatures are, at most, only 272° F (151 K) higher than the average temperature. There seems to be a trend for the maximum temperature to increase as reference velocity increases, although the effect is not large. Figure 7(b) shows variation of temperature profile with reference velocity for the 25-inch combustor. Again, the exit average radial temperature profile is unaffected by changes in reference velocity. The maximum temperature, however, increased by as



(e) Reference velocity, 100 ft/sec (30.5 m/sec).

Figure 5. - Variation of combustor efficiency with reference velocity for the 30- and 25-inch (76- and 63.5-cm) combustors. Figures 5(a) to (d): inlet-air total pressure, 60 psia (41.4 N/cm^2); inlet-air total temperature, 1050° F (839 K). Figure 5(e): inlet-air total pressure, 90 psia (62.0 N/cm^2); inlet-air total temperature, 600° F (589 K).

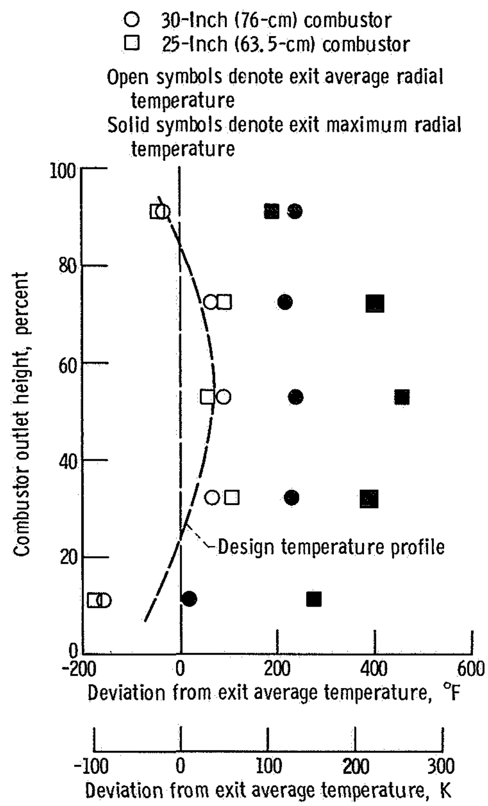


Figure 6. - Comparison of exit average radial temperature profiles for 30- and 25-inch (76- and 63.5-cm) combustors. Inlet-air temperature, 1050° F (839 K); inlet total pressure, 60 psia (31.4 N/cm^2); reference velocity, 150 feet per second (45.8 m/sec).

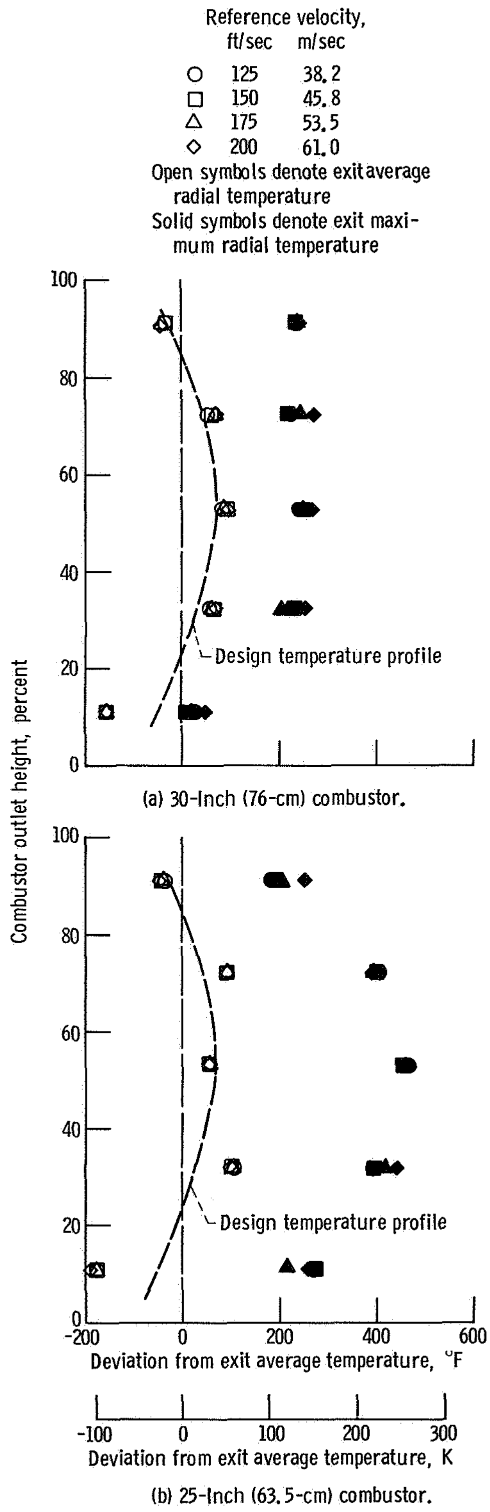


Figure 7. - Variation of exit average radial temperature profile with reference velocity. Inlet-air temperature, 1050° F (839 K); inlet-air pressure, 60 psia (41.4 N/cm²); exit average temperature, 2150° F (1450 K).

much as 466° F (259 K) above the local average temperature, and the hottest temperatures were about 2600° F (1700 K).

Combustor Exit Temperature Distribution Parameters

The following temperature distribution parameters were established to describe combustor exit temperature distributions:

$$\text{Stator factor} = \frac{\left(T_{r,local} - T_{r,design}\right)_{max}}{\Delta T}$$

where $\left(T_{r,local} - T_{r,design}\right)_{max}$ is the largest temperature differential between the highest local temperature on any radius $T_{r,local}$ and the design temperature for that radius, and where ΔT is the average temperature rise across the combustor. The design temperature $T_{r,design}$ was obtained from a design radial temperature profile which is typical of profiles encountered in advanced supersonic engines

$$\text{Rotor factor} = \frac{\left(T_{r,av} - T_{r,design}\right)_{max}}{\Delta T}$$

where $\left(T_{r,av} - T_{r,design}\right)_{max}$ is the largest temperature differential between the average circumferential temperature on any radius and the design temperature for that radius.

Another temperature distribution parameter in common usage in the aircraft industry was also employed. This parameter is the pattern factor and is defined by the expression:

$$\text{Pattern factor} = \frac{T_{max} - T_{av}}{\Delta T}$$

where T_{max} is the highest local combustor exit temperature, T_{av} is the average combustor exit temperature, and ΔT is the combustor temperature rise.

Preliminary evaluation of combustor exit temperature profile is frequently made using the pattern factor. A more refined assessment of the temperature profile as it affects the turbine stator and rotor separately can be made using the parameters stator factor and rotor factor. The parameter stator factor is a measure of the maximum positive exit temperature deviation from the design temperature to which any stator blade will be exposed. A low value of stator factor is desired so that stator blade life will not be reduced, nor blade cooling flow requirements become excessive due to local hot spots. The parameter rotor factor is a measure of the maximum average exit temperature deviation from the design temperature to which the turbine rotor will be exposed. Since the turbine rotor, due to its rotation, tends to average the temperature circumferentially, the maximum average temperature difference at any radius is of interest.

Figure 8(a) is a comparison of the stator factor values for the 30- and 25-inch combustors. At an average combustor temperature rise of 1100° F (611 K), the stator factor value for the 25-inch combustor is almost 50 percent higher than for the 30-inch combustor (0.39 compared to 0.23).

The increase in rotor factor due to shortening the combustor is shown in figure 8(b). The rotor factor was $2\frac{1}{2}$ times greater for the short combustor than for the long combustor. This, however, is less of a problem than the increase in stator factor, in that the absolute magnitude of the temperature deviation from the design profile is small in the case of the rotor factor, being 30° F (17 K) for the 30-inch combustor and 78° F (43 K) for the 25-inch combustor. The temperature deviation associated with the stator factor increased from 274° F (152 K) to 363° F (202 K) above the design temperature profile at the same condition.

A comparison of the pattern factor with the average combustor temperature rise for the 30- and 25-inch combustors is shown in figure 8(c). The combustor suffered significant increases in the pattern factor as a result of shortening the mixing length. The pattern factor nearly doubled (0.40 compared to 0.22) at a temperature rise of 1100° F (611 K) with the 25-inch combustor.

Circumferential Temperature Profile

Figure 9 shows the circumferential variation of exit temperature. The temperatures shown are averages of the five radial temperature measurements at any one circumferential position. Data were taken every 3° around the circumference. These data were obtained at 60 psia (41.4 N/cm^2) inlet-air total pressure, 1050° F (839 K) inlet-air temperature, and 150-foot-per-second (45.7 m/sec) reference velocity.

In figure 9(a), temperature peaks are evident downstream of each strut in the diffuser for the 30-inch combustor. The 25-inch combustor shows similar temperature peaks but of increased magnitude (fig. 9(b)). Also, additional hot spots are evident. A comparison of figures 9(a) and (b) shows that the reduction in mixing length has adversely affected the exit average circumferential temperature profile. Although the radial temperature profiles were only slightly affected by the reduced length, the effect on

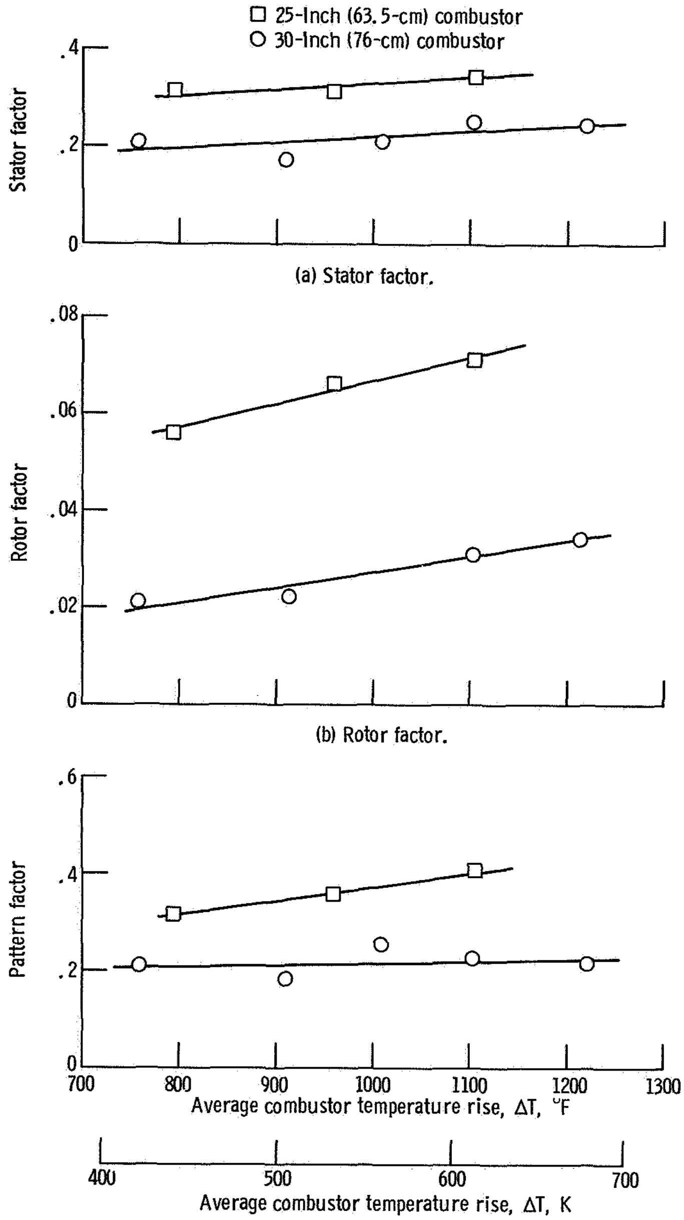


Figure 8. - Comparison of exit temperature stator, rotor, and pattern factors for the 25- and 30-inch (63.5- and 76-cm) combustors. Inlet-air total pressure, 600 psia (41.4 N/cm²), inlet-air total temperature, 1050° F (839 K); reference velocity, 150 feet per second (45.7 m/sec).

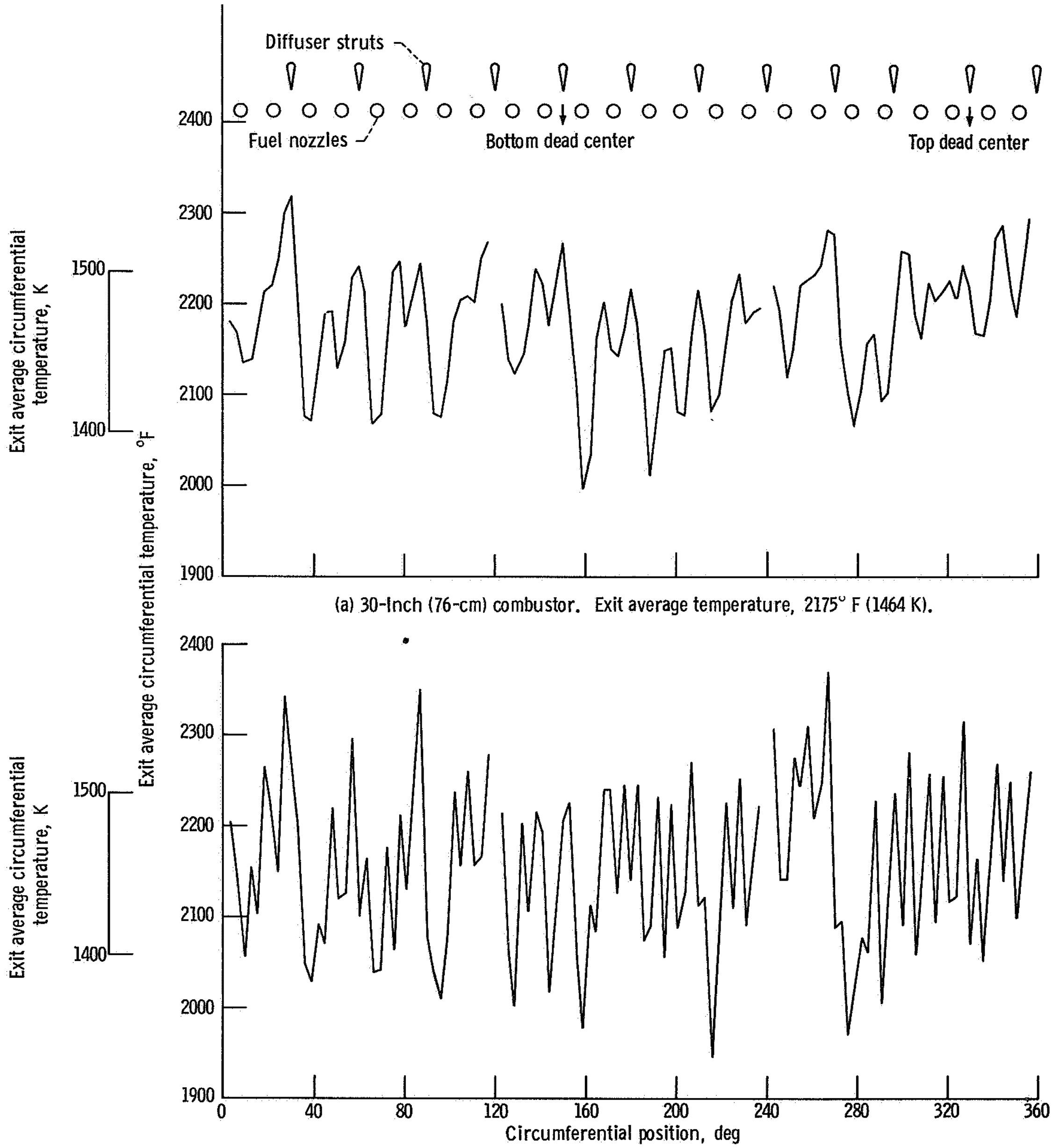


Figure 9. - Comparison of exit average circumferential profiles. Inlet-air pressure, 60 psia (41.4 N/cm^2); inlet-air total temperature, 1050° F (839 K); reference velocity, 150 feet per second (45.7 m/sec).

the circumferential profile was large. It is apparent that the addition mixing length is very beneficial in flattening the circumferential profile.

Some additional tests were made with the 25-inch combustor in an attempt to improve the exit average circumferential temperature profile. In general, the approach taken was that of trying to deflect, direct, or admit secondary air from the number 4 and 5 scoops into the observed hot areas in the exhaust. However, as specific hot areas were cooled by mixing the additional secondary air, other areas became excessively hot due to the withdrawal of that same secondary air. Thus, no real improvement in the exit temperature profile was obtained.

It appeared that testing a short version of a combustor might be useful in the development of some combustors. The effects of various liner scoops and possibly of fuel nozzles could be traced more easily. Many variations in exit temperature seen in the 25-inch combustor were obscured when the combustor was lengthened.

Smoke Emission

A Von Brand Smokemeter and a Welsh Densichron Reflection Unit (3832A) were used to obtain smoke data. A Welsh Gray Scale (3827T) was used as a calibration reference. A gas sample flow rate of 0.3 standard cubic feet per minute per square inch of filter paper (2.19×10^{-5} $m^3/(sec)(cm^2)$) was maintained with a 2-psig- (1.38-N/cm^2-) above-atmospheric pressure above the moving filter paper tape and a 5-inch mercury (8.5-N/cm^2) vacuum below the filter paper tape. Clean filter paper readings were taken for reference.

Smoke numbers with both combustors were below the threshold of visible smoke (between zero and 6 with most readings less than 1) for conditions of 60-psia (41.4-N/cm^2) combustor total pressure, 1050° F (839 K) inlet-air temperature, and reference velocities between 125 and 200 feet per second (38.1 to 61.0 m/sec). At 90-psia (62.0-N/cm^2) combustor total pressure, 600° F (589 K) inlet-air temperature and reference velocities near 100 feet per second (30.5 m/sec), the maximum smoke number obtained was 20 (slightly visible smoke). The smoke number increased with increasing fuel-air ratio. No trend with differences of combustor length was apparent.

SUMMARY OF RESULTS

The reduction in combustor length from 30 inches (76 cm) to 25 inches (63.5 cm) by removing 5 inches (12.7 cm) from the exit transition liners had the following effects:

1. The exit average radial temperature profile was not significantly changed.

2. The exit average circumferential temperature profile was significantly changed. Local temperature peaks associated with diffuser struts in the 30-inch combustor were magnified in the 25-inch combustor. Also, additional hot spots not present in the 30-inch combustor appeared in the 25-inch combustor.

3. Exit temperature parameter values increased as follows:

	30-Inch (76-cm) combustor	25-Inch (63.5-cm) combustor
Pattern factor	0.22	0.40
Stator factor	.23	.34
Rotor factor	.030	.072

4. Combustor pressure loss did not change.

5. Combustion efficiency decreased about 3 percent from 100 percent.

6. Smoke emission did not change and was below the threshold value of visible smoke.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, September 1, 1970,
720-03.

REFERENCES

1. Dooley, Philip G.: Design and Development of Combustion Chambers for Turbine Engines. Paper 65-WA/GTP-8, ASME, Nov. 1964.

2. Lefebvre, A. H.; and Norster, E. R.: A Design Method for the Dilution Zones of Gas Turbine Combustor Chambers. Rep. CoA-AERO-169, College of Aeronautics, Cranfield, Feb. 1966.

3. Rusnak, J. P.; and Shadowen, J. H.: Development of an Advanced Annular Combustor. Rep. PWA-FR-2832, Pratt & Whitney Aircraft (NASA CR-72453), May 30, 1969.

4. Chamberlain, John: The Ram-Induction Combustor Concept. Presented at the Third AIAA Propulsion Joint Specialist Conference, Washington, D.C., July 17-21, 1967.

NASA-Langley, 1970 —— 28 E-5691

"The aeronautical and space activities of the United States shall be conducted so as to contribute . . . to the expansion of human knowledge of phenomena in the atmosphere and space. The Administration shall provide for the widest practicable and appropriate dissemination of information concerning its activities and the results thereof."

— NATIONAL AERONAUTICS AND SPACE ACT OF 1958

NASA SCIENTIFIC AND TECHNICAL PUBLICATIONS

TECHNICAL REPORTS: Scientific and technical information considered important, complete, and a lasting contribution to existing knowledge.

TECHNICAL NOTES: Information less broad in scope but nevertheless of importance as a contribution to existing knowledge.

TECHNICAL MEMORANDUMS: Information receiving limited distribution because of preliminary data, security classification, or other reasons.

CONTRACTOR REPORTS: Scientific and technical information generated under a NASA contract or grant and considered an important contribution to existing knowledge.

TECHNICAL TRANSLATIONS: Information published in a foreign language considered to merit NASA distribution in English.

SPECIAL PUBLICATIONS: Information derived from or of value to NASA activities. Publications include conference proceedings, monographs, data compilations, handbooks, sourcebooks, and special bibliographies.

TECHNOLOGY UTILIZATION PUBLICATIONS: Information on technology used by NASA that may be of particular interest in commercial and other non-aerospace applications. Publications include Tech Briefs, Technology Utilization Reports and Notes, and Technology Surveys.

Details on the availability of these publications may be obtained from:

SCIENTIFIC AND TECHNICAL INFORMATION DIVISION

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Washington, D.C. 20546