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PRELIMINARY EVALUATION OF A PERFORATED SHEET FILM-COOLED LINER IN A TURBOJET COMBUSTOR

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SUMMARY

The performance of a turbojet combustor with a perforated sheet film-cooled liner was compared with the performance of the same combustor with a conventional stepped continuous-slot film-cooled liner. Both combustors used a jet-type fuel conforming to ASTM A-1 specifications. Tests were conducted at near atmospheric pressure, with combustor inlet air temperatures at 600° F (589 K), and combustor average exit temperatures up to 2368° F (1571 K). The perforated sheet film-cooled liner performed its function well and had no detrimental effects on combustion efficiency, total pressure loss, or exit radial temperature profile.

INTRODUCTION

Conventional film-cooled liners for turbojet combustors are fairly complex sheet metal structures and are costly to manufacture. Furthermore, great care must be taken that slight warpage of the liner does not alter coolant flow, causing extremely hot areas to develop on the liner. It is desirable to have a simpler type of liner, both from a manufacturing standpoint and a durability standpoint.

One of the simplest types of film-cooled liner is a plain perforated sheet. The film cooling effectiveness of this type of liner is less than that of conventional types, which usually employ some type of continuous cooling slot (ref. 1). The lower effectiveness is caused by the initial velocity component of the jets away from the liner, causing the jets to penetrate into the main air stream instead of being injected tangentially along the liner. However, the relative ease of fabrication and the structural stability of the perforated sheet film-cooled liner make it worthy of consideration.

In this investigation, a perforated sheet film-cooled liner was fabricated to replace the conventional stepped liner in a combustor which had been developed to a good level of performance. The combustor with the conventional liner was used as a reference combustor, against which performance data of the same combustor with a perforated sheet film-cooled liner were evaluated. Tests were conducted at near atmospheric pressure, with combustor inlet air temperature at 600° F (589 K), and combustor average exit temperatures up to 2368° F (1571 K).

TEST INSTALLATION

A 10- by 15-inch (0.254- by 0.381-m) test section containing a reference combustor (fig. 1), which is described fully in reference 2, was installed in a test facility (fig. 2) connected to the Laboratory air supply and exhausted through a quenching station and a noise suppressor to the atmosphere. Combustion air at near-atmospheric pressure was directed through a vitiating preheater where it was heated to 600° F (589 K) prior to entering the test combustor. A set of screens was installed downstream of the preheater to provide a uniform velocity profile entering the test combustor.

The test combustor was identical with the reference combustor shown in figure 1 except for removal of the lower film-cooled liner. This liner was replaced with one made of perforated sheet (fig. 3). Neither liner admitted any air other than film cooling air. The conventional liner was designed to admit 3 to 4 percent of the total combustor air as film cooling air. Based on relative liner flow areas, with suitable discharge coefficients, it was estimated that the perforated sheet liner admitted 6 to 8 percent of the total combustor air.

Film cooling considerations dictate that, for a given open area in a perforated sheet, many small holes are preferable to fewer larger holes. The smaller holes give a more uniform cooling film as opposed to several widely spaced jets produced by a few larger holes. Also, smaller holes can be expected to allow a shallower penetration of the cooling air into the main air stream. However, for the materials ordinarily used for combustor liners, there are practical limitations on the minimum size of hole which can be economically produced. As a compromise, the perforated sheet used in this investigation had a triangular pattern of 0.125-inch (0.0032-m) diameter holes on 0.541 inch (0.014 m) centers (fig. 3), giving 4.8 percent open area. Two considerations were important: the hole pattern must repeat before the jet is dissipated in the axial direction; and a jet introduced through a circular hole into a moving stream does not spread laterally to any appreciable extent (ref. 1). Both considerations were met by orienting the perforated sheet as shown in figure 3, so that the hole pattern repeats each 11.5 hole diameters in the direction of air flow, and the lateral distance between holes is less than 1.5 hole diameters.

INSTRUMENTATION

Air flow rates were measured by a square-edged orifice installed in accordance with ASME specifications. Fuel flows to the preheater and test section were measured by turbine flowmeters.

Locations of the combustor inlet and exit instrumentation planes are indicated in figure 2. The positions of the temperature and pressure probes in these planes are shown in figure 4. Combustor inlet temperatures were measured by two iron-constantan thermocouples (Section A-A, fig. 4). Inlet pressures were measured by seven three-point total-pressure rakes and by two wall static-pressure taps (Section B-B, fig. 4). Combustor exit temperatures were measured by eight five-point total-temperature rakes (Section C-C, fig. 4). The temperature probes were constructed of platinum/platinum-13 percent rhodium wires, 0.020-inch (0.00051-m) diameter, and were of the bare-wire wedge type. Exit pressures were measured by seven five-point total-pressure rakes and by two wall static-pressure taps (Section D-D, fig. 4).

Temperatures of the perforated sheet film cooling liner were measured by four chromel-alumel skin thermocouples mounted on the coolant passage side (fig. 3).

RESULTS AND DISCUSSION

Film Cooling Effectiveness

With combustor reference velocities of 77 and 100 feet per second (23.5 and 30.5 m/sec), combustor exit average temperature was varied from 1118° F (876 K) to 2368° F (1571 K). Combustor inlet temperature was 600° F (589 K); combustor inlet pressure was near-atmospheric (runs 1 to 7, inclusive, table I). Skin temperatures at four locations on the coolant passage side of the perforated sheet film cooling liner were recorded. These temperatures are shown in table II. The temperatures measured by thermocouples 1 and 2, located on the liner ramp, are plotted as a function of combustor exit average temperature in figure 5. Thermocouples 3 and 4 measured only slightly higher than thermocouple 2.

At a maximum combustor exit average temperature of 2368° F (1571 K), the hottest thermocouple was at only 1300° F (978 K). Tests with temperature-sensitive paint verified the thermocouple data, within the limits of the technique. Although no liner skin temperature data were available for the reference combustor, some unpublished data from an earlier model of that combustor were available. The perforated sheet film-cooled liner appeared to be at least as effective as the conventional liner.

Effect on Combustion Efficiency

Combustion efficiency as a function of fuel-air ratio for runs 1 to 7, inclusive, is compared with data from the reference combustor in figure 6. The curves for the two combustors are very similar. While there is no ready explanation for the difference of approximately 5 percent in combustion efficiency for the two combustors, it is clear that the perforated sheet film-cooled liner had no adverse effect on combustion efficiency.

Effect on Total Pressure Loss

The ratio of isothermal total pressure loss to inlet total pressure ($\Delta P/P$) is plotted against combustor inlet Mach number in figure 7, and compared with isothermal data for the reference combustor. The curves are similar, with the perforated sheet film-cooled liner giving a slightly lower pressure drop at higher inlet Mach numbers.

Effect on Combustor Exit Radial Temperature Profile

In figure 8, the combustor exit radial temperature profile for run 3 is compared with data for the reference combustor under similar conditions, except that the combustor exit average temperature was approximately 300° F (167 K) higher in the reference combustor. The profile would not be expected to change significantly at the lower temperature level. There is little difference in the results for the two combustors. The perforated sheet film-cooled liner provided slightly more cooling air at the hub.

SUMMARY OF RESULTS

The perforated sheet film-cooled liner performed well. Outer skin temperature reached only 1300° F (978 K) at its hottest area when combustor exit average temperature was 2368° F (1571 K). Combustion efficiency, total pressure loss, and exit radial temperature profile data compared favorably with data for the reference combustor, which had a conventional stepped continuous slot film-cooled liner.

REFERENCES

1. Goldstein, R.; Eckert, E. R. G.; and Ramsey, J. W.: Film Cooling with Injection Through Holes-Adiabatic Wall Temperatures Downstream of a Circular Hole. ASME paper 68-GT-19, American Society of Mechanical Engineers, March, 1968.

2. Humenik, Francis M.: Performance of a Short Length Turbojet Combustor Insensitive to Radial Distortion of Inlet Airflow. NASA TN D-5570, 1969.

TABLE I. - COMBUSTOR PERFORMANCE DATA - NOMINAL PRESSURE: ONE ATMOSPHERE

Run	Inlet air temperature		Air flow		Nominal reference velocity		Fuel-air ratio	Combustor average exit temperature		Combustion efficiency, percent	Combustor inlet Mach number	Combustor pressure loss, $\Delta P/P$, percent
	^{o}F	K	lb/sec	kg/sec	ft/sec	m/sec		^{o}F	K			
1	604	591	4.43	2.01	100	30.5	0.0084	1118	876	86.8		
2	604	591	4.45	2.02			.0139	1492	1084	94.4		
3	596	586	4.43	2.01			.0197	1887	1304	100.3		
4	602	590	4.43	2.01			.0250	2097	1421	94.0		
5	600	589	3.39	1.54	77	23.5	.0303	2368	1571	94.0		
6	602	590	3.39	1.54	77	23.5	.0217	1957	1343	96.5		
7	600	589	3.39	1.54	77	23.5	.0155	1558	1121	91.4		
8	66	292	1.47	0.67				Isothermal			0.085	0.51
9			1.97	.89							.115	.97
10			2.47	1.12							.143	1.47
11			2.97	1.35							.172	2.04
12			3.43	1.56							.198	2.71
13			3.93	1.78							.226	3.39
14			4.40	2.00							.253	4.29
15			4.88	2.21							.279	5.16

TABLE II. - PERFORATED SHEET FILM COOLING LINER

OUTER SKIN TEMPERATURES

Run	Combustor average exit temperature		Liner skin temperatures							
			T/C # 1		T/C # 2		T/C # 3		T/C # 4	
	^{o}F	K	^{o}F	K	^{o}F	K	^{o}F	K	^{o}F	K
1	1118	876	860	733	610	594	670	628	700	644
2	1492	1084	1000	811	650	616	700	644	740	666
3	1887	1304	1090	861	690	639	720	655	770	683
4	2097	1421	1200	922	730	661	750	672	860	733
5	2368	1571	1300	978	810	705	820	710	900	755
6	1957	1343	1160	900	720	655	730	661	790	694
7	1558	1121	1090	861	670	627	700	644	750	672

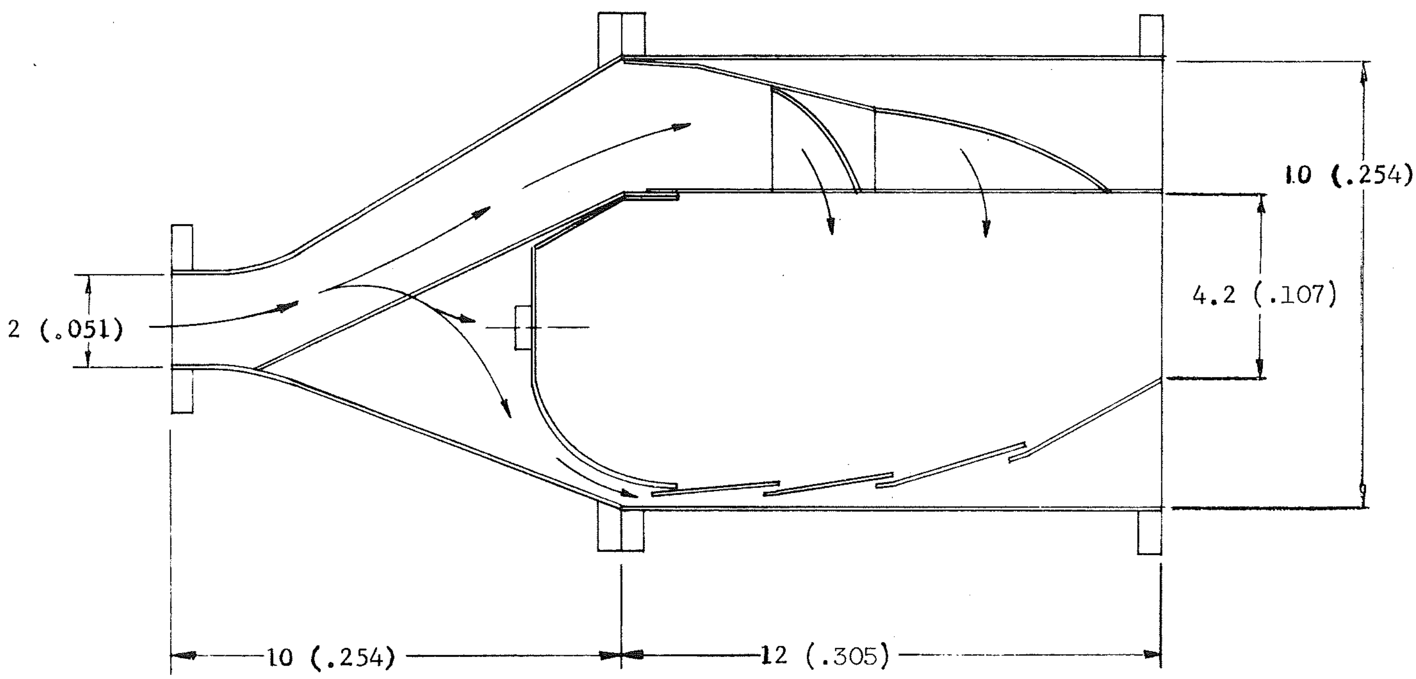

FIGURE 1. - Reference Combustor With One-Sided Air Entry and Stepped Film Cooling Liner. (Dimensions are in inches (m).)

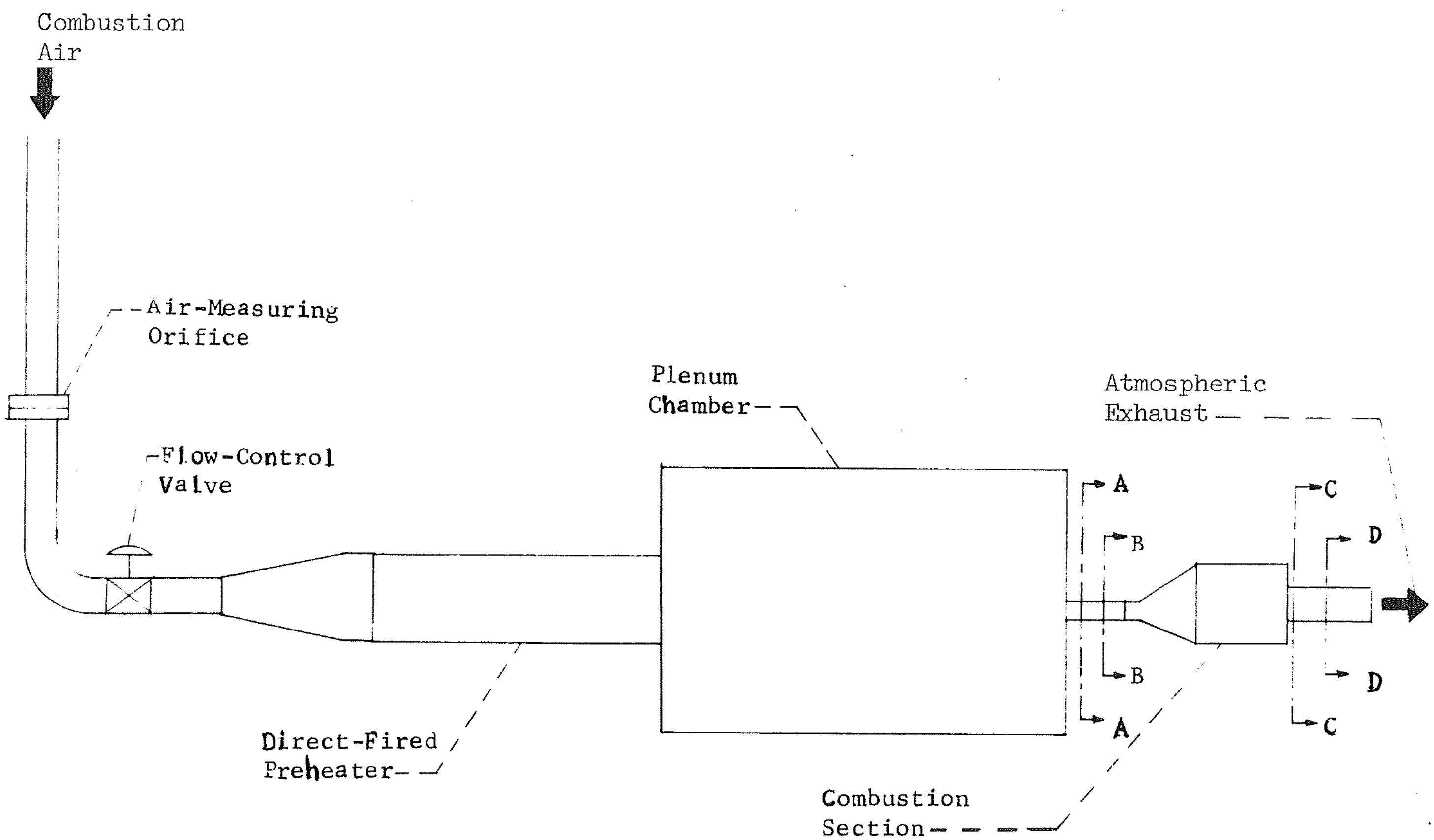

FIGURE 2. - Combustor Installation and Auxiliary Equipment.

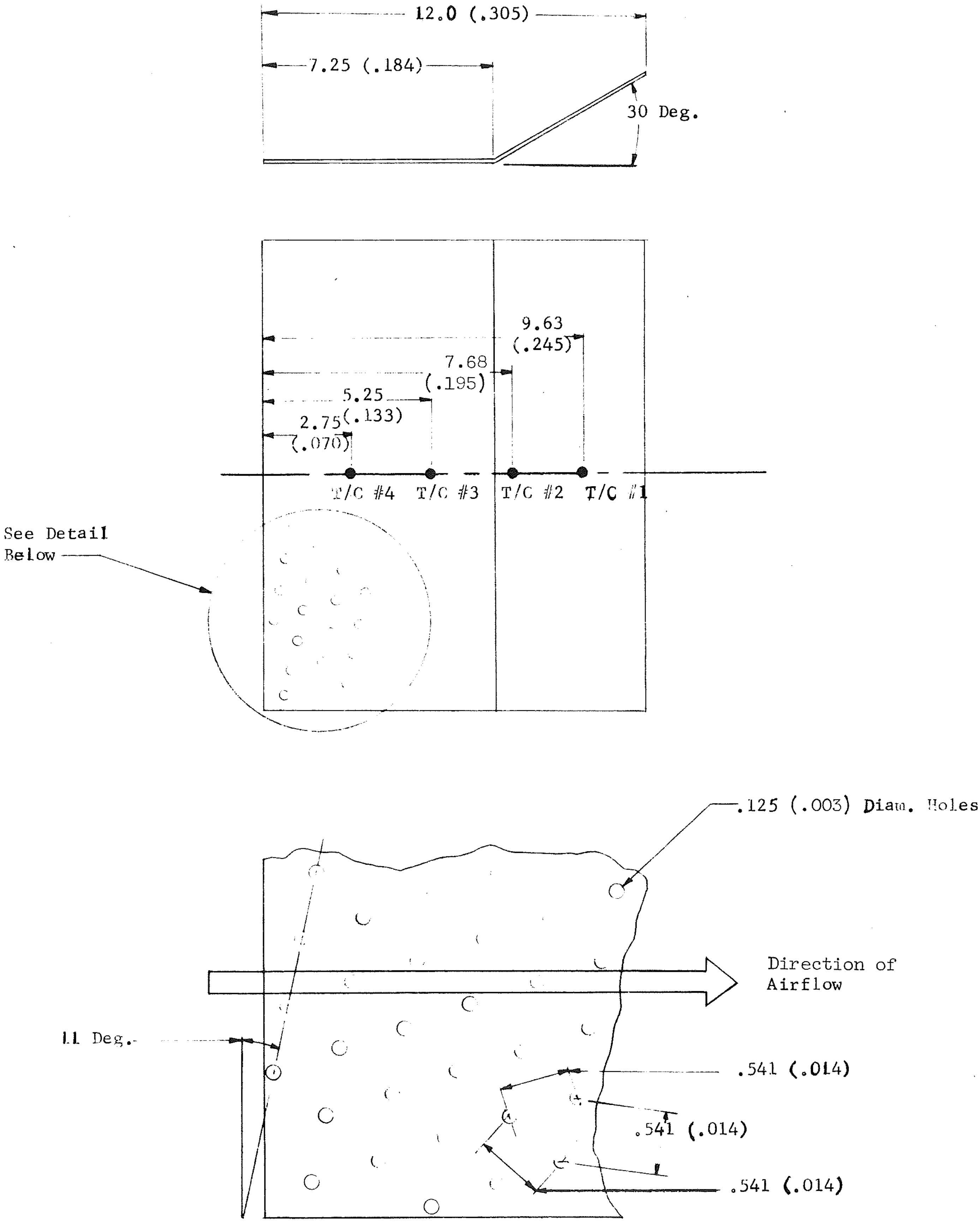

FIGURE 3. - Perforated Sheet Film Cooling Liner. (Dimensions are in inches (m).)

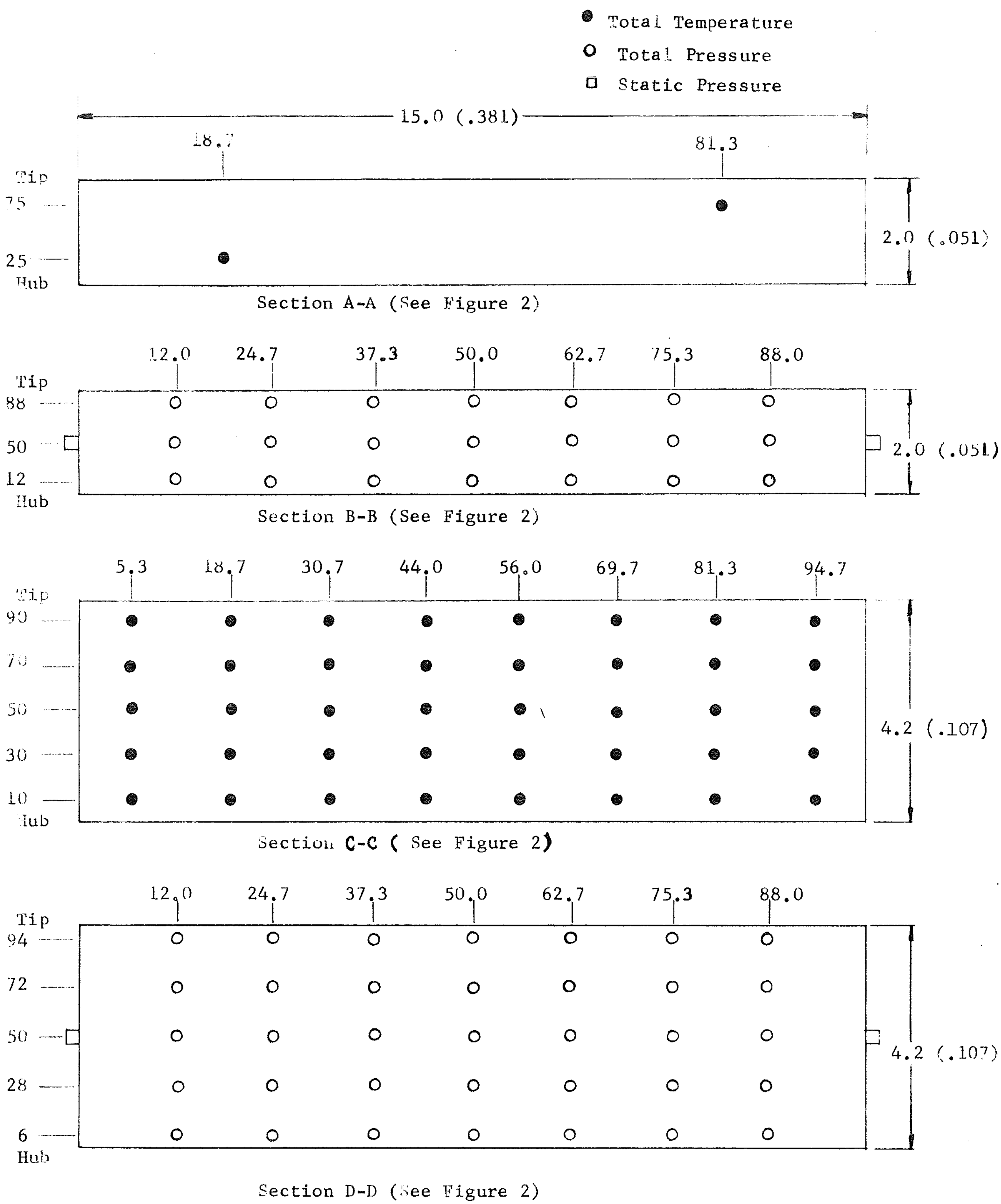

FIGURE 4. - Location of Temperature and Pressure Probes In Percentage of Duct Height and Width. (Dimensions are in inches (m).)

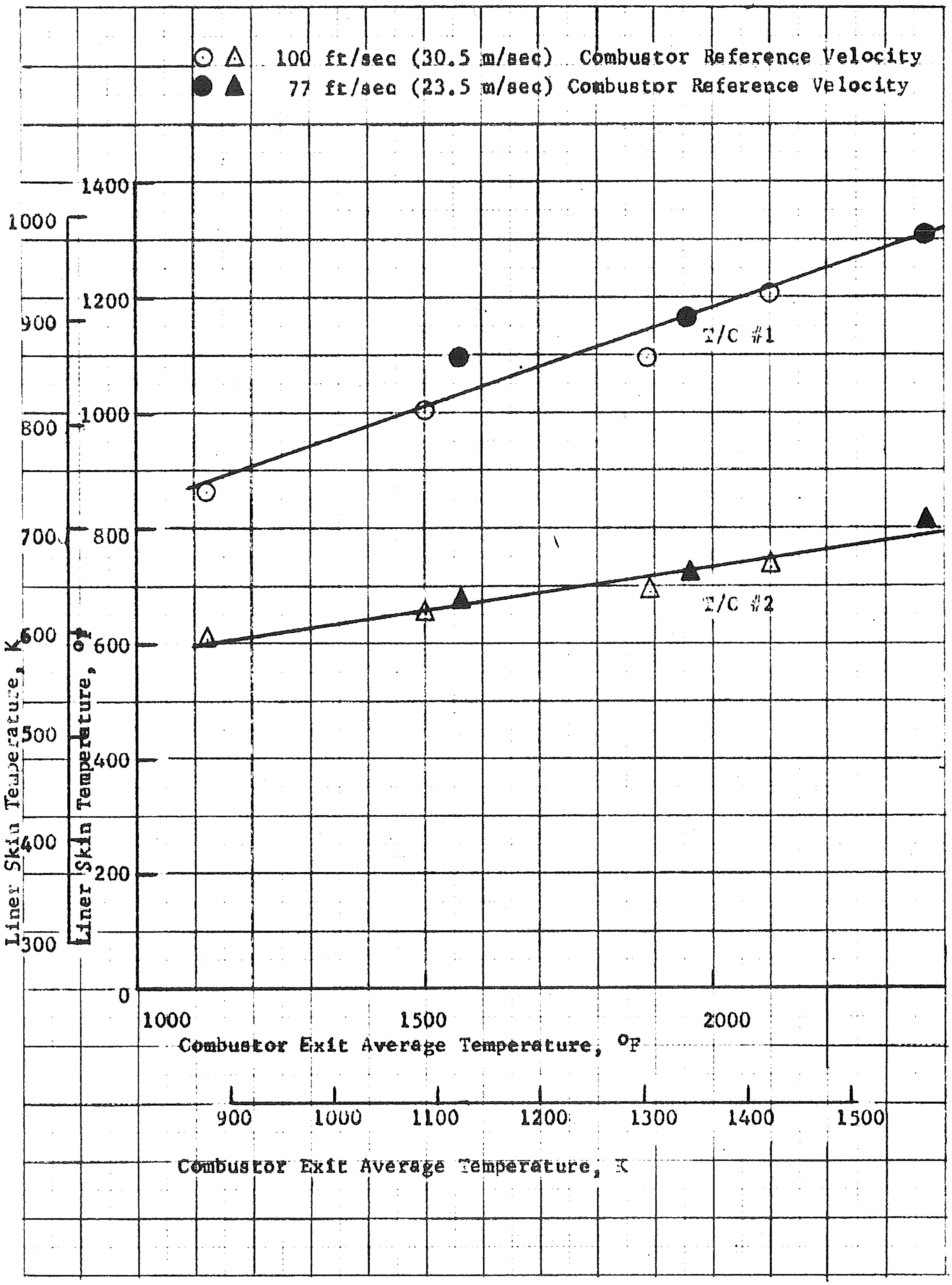

FIGURE 5. - Perforated Liner Outer Skin Temperature at Two Locations.

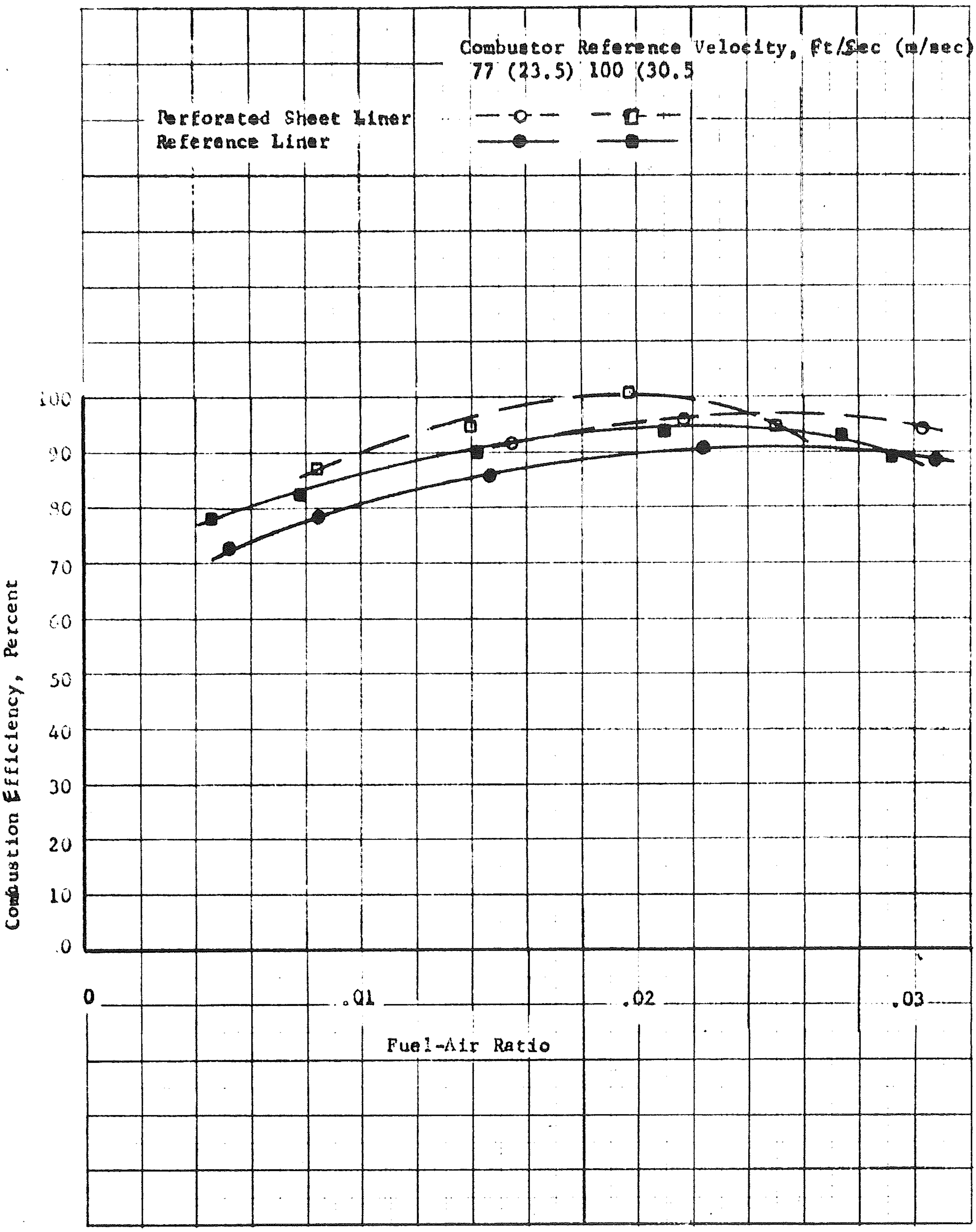

FIGURE 6. - Combustion Efficiency.

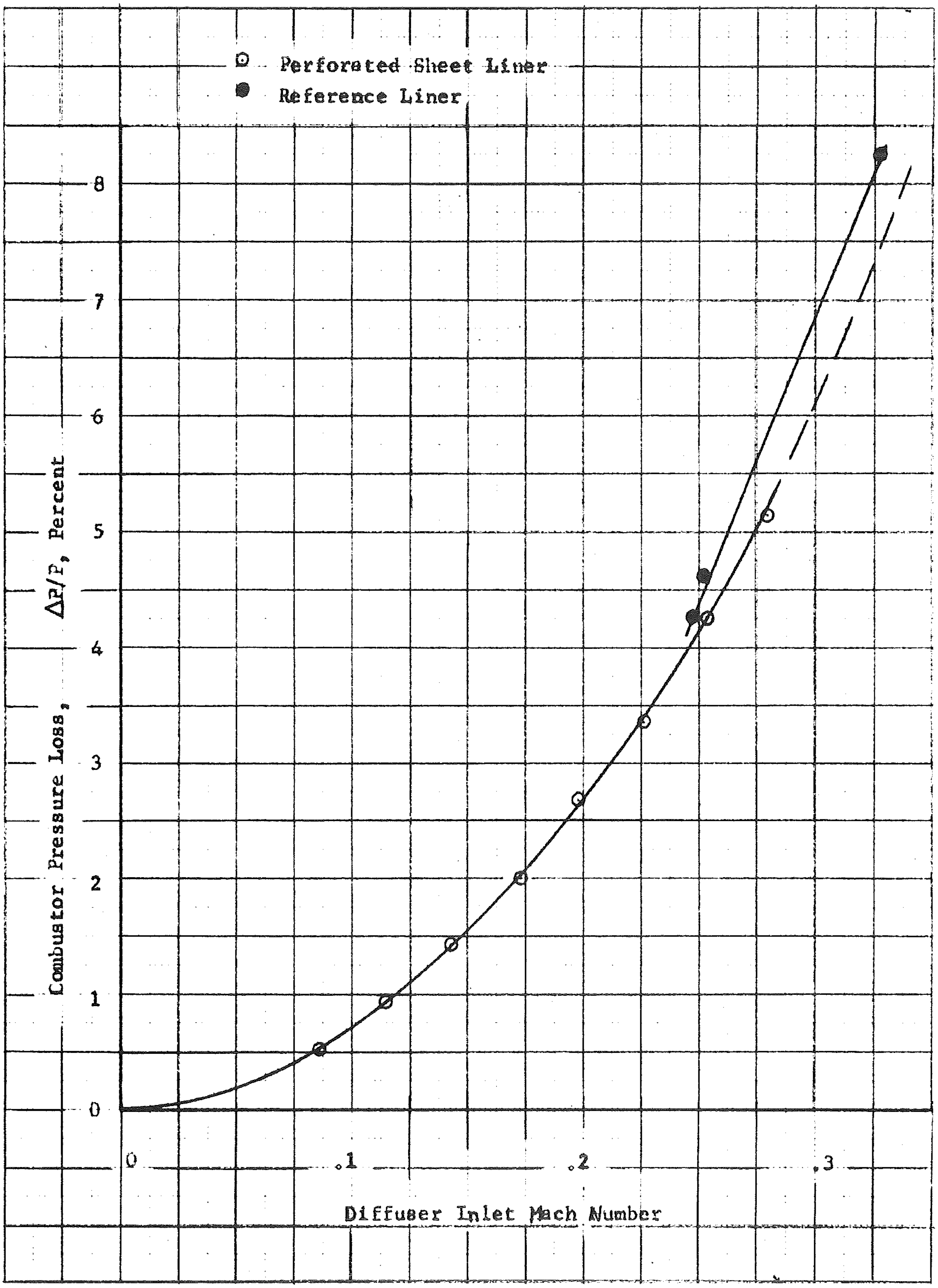

FIGURE 7. - Combustor Isothermal Pressure Loss.

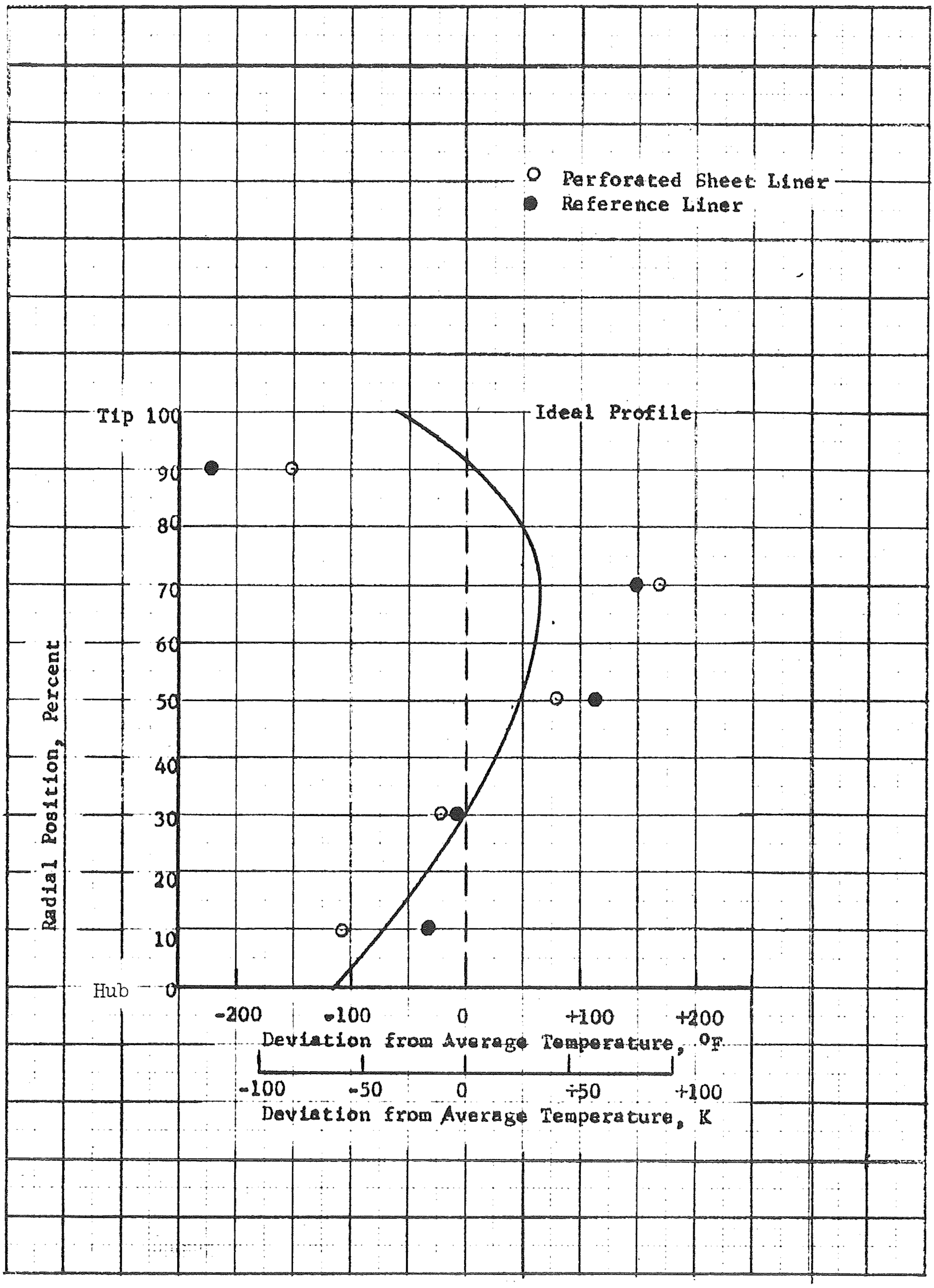

FIGURE 8. - Radial Temperature Profile Combustor Reference Velocity, 100 ft/sec (30.5 m/sec). Average Exit Temperature: Perforated Sheet Liner, 1887° F (1304 K); Reference Liner, 2223° F (1490 K).