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RESEARCH MEMORANDUM

MODIFIED TUBULAR COMBUSTORS AS HIGH-TEMPERATURE
GAS GENERATORS

By Robert Friedman and Eugene V. Zettle

Lewis Flight Propulsion Laboratory
Cleveland, Ohio

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RESEARCH MEMORANDUM

MODIFIED TUBULAR COMBUSTORS AS HIGH-TEMPERATURE GAS GENERATORS

By Robert Friedman and Eugene V. Zettle

SUMMARY

An investigation was conducted to determine the feasibility of using tubular, production-type combustion systems as gas generators to provide high turbine-inlet temperatures for turbine-cooling studies. A pair of combustors and transition liners in a quarter-annular, direct-connect combustor and turbine-inlet assembly was operated at turbine-inlet temperatures up to 2400° F.

Although these standard combustors and transition liners performed satisfactorily, the turbine casing warped after 6 hours of operation at temperatures up to 2400° F. Consequently, modified liners that provided greater cooling-air flow between the turbine casing and interior components were tested. With the modified liners in place, the engine components were operated without damage at turbine-inlet temperatures of 2000° F or above for 32 hours, 23 of which were at 2300° F. The liner modifications caused a moderate increase in radial-temperature gradients.

INTRODUCTION

Turbine cooling is of ever-increasing interest for high-specific-output turbojet-engine designs, where turbine-inlet temperatures are increased to above 2000° F. Turbine-cooling techniques are being studied at the NACA Lewis laboratory with full-scale rotating turbine wheels mounted in current, production-type engines. These engines are convenient research tools for investigating promising turbine-cooling techniques, even though the cooled turbine wheels are not intended for use with current engines. For such studies, combustion systems are required to operate at higher-than-rated temperatures. Results of tests to determine the feasibility of using one production-type combustor to supply turbine-inlet temperatures up to 2400° F are reported herein.

These studies were conducted with a combustor and turbine-inlet transition assembly mounted in a direct-connect installation. The performance of components of the combustor is reported in terms of wall temperatures, durability, and temperature profiles. Minor modifications are proposed that increase wall cooling to protect the outer turbine casing.

APPARATUS AND PROCEDURE

Installation

The combustor test section was mounted in a direct-connect installation shown schematically in figure 1. Combustion air was drawn from the laboratory air-supply system, preheated in a heat exchanger (supplied with hot exhaust gases from a gasoline-fired slave combustor), passed through the test unit, and then discharged into the altitude exhaust system. Combustor-inlet temperatures were controlled by the amount of inlet air that bypassed the heat exchanger. Air flow and combustion-chamber static pressure were regulated by remote-controlled valves with bypass lines for fine adjustments.

Combustor Test Section

Standard configuration. - In order to conserve air requirements, the combustor test section consisted of a one-quarter portion of an axial-flow turbojet engine in the 90- to 100-pound-per-second air-flow class. The standard production parts used were midframe, tubular combustors, transition pieces, aft frame without turbine-stator diaphragm, and turbine casing.

The test section thus included a pair of combustors and transition pieces and quarter-annular midframe, aft frame, and turbine-casing sectors. Enclosing side-walls and additional flanges were necessary to complete the assembly. The turbine casing was built with a flanged, removable outer section to permit the replacement of transition liners without disturbing the rest of the test section. The downstream end of the transition liners was extended to cover the part of the turbine casing ordinarily occupied by the stator blades.

Modified configuration. - For improved high-temperature durability, some alterations were made to the standard engine components. Principally, the changes were made to allow additional cooling air to flow between the outer-turbine casing and the interior engine components. The downstream end of the combustor liner was reduced in diameter to increase the annular passage between the liner and the combustor housing (fig. 2). The transition liners were altered to fit the modified combustor outlet. An Inconel sheet-metal shroud was built around the transition liners to control the cooling-air flow over the transition-liner surface and to prevent loss of cooling air into the large volume below the inner radius of the transition liners. The scalloped surfaces at the outlet ends of the transition liners were more deeply drawn for additional cooling area, and scallops were also formed on the inner radii of the liners. Photographs of the standard and modified transition pieces are shown for comparison in figure 3.

Fuel and Ignition Systems

Duplex fuel nozzles normally used with the engine were found to be adequate for the higher fuel flows used in these tests. The fuel used throughout the investigation was MIL-F-5624A, grade JP-4. Fuel-supply pressures were increased to as high as 500 pounds per square inch, a pressure somewhat higher than is normally used with this engine. Ignition was by a single spark plug connected to a 5000-volt, 60-cycle, 250-volt-ampere transformer.

Instrumentation

Gas-stream total temperatures and pressures were measured at the two stations indicated in figure 1. Combustor-inlet total temperatures and pressures were measured with four bare-junction iron-constantan thermocouples and nine total-pressure tubes at the combustor-inlet instrumentation plane (station 1 in fig. 1). Combustor-outlet temperature profiles were determined at the exhaust plane (station 2 in fig. 1) by four rakes of three platinum-13 percent rhodium - platinum thermocouples (fig. 4). These rakes were enclosed by faired metal walls that permitted water cooling of the rakes, leaving only the thermocouple junctions outside of the cooled walls. All instruments were located at approximate centers of equal areas. Static-pressure orifices were installed in the duct walls at both instrumentation stations.

Additional precautions were taken to protect the instrumented exhaust section from damage at high temperatures. This section had an inner metal liner for wall protection (fig. 4), and some of the original engine flanges in this section were increased in thickness.

Chromel-alumel thermocouples were also peened into the walls of the engine components to determine metal temperatures. These thermocouples were placed, as shown in figure 5, on the transition liner, transition-liner air-flow control shroud, and outer turbine casing. With the exception of the thermocouples on the air-flow control shroud, which is not part of the standard liners, instrumentation of the modified and standard transition liners was the same.

Test Conditions

Sea-level rated-engine conditions of combustor-inlet temperature and reference velocity were approximated in the duct. Because of facility limitations, the pressure was maintained at 85 inches of mercury absolute instead of the required 160 inches of mercury absolute. The combustor operating conditions investigated are shown in the following table.

Operating condition	Inlet total pressure, in. Hg abs	Inlet temperature, °F	Reference velocity, ft/sec (a)	Outlet temperature, °F
A	85	450	110	2000
B	85	450	110	2300
C	85	350	160	2000

^aBased upon maximum combustor cross-sectional area and inlet-air conditions.

RESULTS AND DISCUSSION

Total operating times of the combustor installations for each condition are shown in table I. The 12 gas thermocouples placed as shown in figure 4 measure the hottest portions of the exhaust-gas stream, and average readings of these thermocouples are recorded as average outlet-core temperatures in table I. The core temperatures represent the maximum gas temperatures rather than the average gas temperatures. If a combustion efficiency of 97 percent is assumed, approximate average temperatures can be calculated from heat balances across the combustor. These average temperatures are shown as approximate outlet temperatures in table I.

Wall Temperatures

The wall temperatures measured with the standard- and modified-combustor assemblies are shown in table II. The locations of the thermocouples are shown in figure 5. The ten thermocouples located on the walls of the modified liner configuration gave a representative, although admittedly incomplete, picture of liner-wall temperatures, but the number of thermocouples was limited because of the complexity of bringing the thermocouple lead wires through the walls of the shroud and turbine casing. The local hot spots on the combustor walls changed location slightly during the investigation. For some test runs, therefore, hot spots may have occurred closer to the thermocouple locations than in other runs. Thus, in comparing wall temperature data for different test runs, average values of the thermocouple readings must be used rather than any individual thermocouple indication.

Standard turbine transition liners. - Wall temperatures were as high as 1850° F on the inner-radius sides of the standard transition liners for runs 1 and 2 (table II). After about 6 hours of operation at the high outlet-temperature conditions of these runs, the turbine casing warped at

the upstream flange area, causing the flange to be pulled out of shape as shown in figure 6. In a cooled-turbine engine installation, the turbine stators may be cooled and the cooling air collected at the tip edge of the stator ring. This tends to protect the areas of the turbine casing that warped in the present tests. Although the transition liners operated without damage during the 6-hour test, the durability of the liners and the turbine casing is questionable at these temperature levels.

The wide differences in wall temperatures between the two combustors (table II) were caused by inequalities in air and fuel flow to the two combustors. With no external flow divider it was difficult to balance the fuel distribution to the two fuel nozzles. In an actual engine with a fuel-flow divider, this problem would be much less severe.

Modified turbine transition liners. - The turbine transition liners were modified by increasing the coolant-air-flow passages and installing a sheet-metal shroud for controlling the coolant flow. As shown in table II, the hottest area on the walls of the modified liner was approximately 300° to 400° F cooler than the corresponding area on the standard liners. Increasing the reference velocity from 110 (run 4) to 160 feet per second (run 3) resulted in a slight decrease in average liner-wall temperatures for the same outlet conditions, disregarding hot spots. While the higher exhaust-gas velocities increased the heat-transfer rate to the inside of the liner walls, the increased velocities in the cooling annulus apparently had a larger effect on heat transfer from the outside of the liner walls to the cooling air. The modified liners were operated for 9 hours at an average outlet-temperature of 2000° F, and 10 hours at an average outlet-temperature of 2300° F. There was no evidence of damage in the exhaust sections.

The modified turbine transition liners were also run without the air-flow control shroud in place at an average exhaust temperature of 2300° F for a period of 13 hours. This resulted in a total accumulated time of 32 hours of operation at high temperatures for the same liners. No warping or burning of parts was observed. Thus for the time duration tested at least, the air-flow control shrouds do not appear to be necessary, and the modification to the standard liners can possibly be simplified by omitting these shrouds.

The effect of metal fatigue was not included in this investigation. For the applications intended for these components and the short duration of running time required for the laboratory tests, fatigue may not be important.

Temperature Profiles

The effect of the liner modifications on the turbine-inlet temperature profile is shown in figure 7. At approximate over-all gas temperatures of 2000° and 2300° F and a reference velocity of 110 feet per

second, the modified liners increased the radial-temperature gradients moderately. Peak temperatures for the modified liners were recorded near the inner walls, and temperature decreased near the outer walls. As discussed previously, these are core-temperature profiles based on measurements at four circumferential positions. Values of average gas temperature cannot be obtained from these curves since the small number of thermocouples (12) was insufficient to obtain a true average. This, in turn, explains the discrepancy between the apparent over-all gas-temperature levels of the curves in figure 7.

Although the temperature profiles obtained in the connected-duct installation are highest near the inner wall (blade root), temperature profiles usually reported for the turbine-inlet section of the full-scale engine using the same combustors are relatively flat. There is some evidence that the shape of the gas passages through the stator and rotor sections in the engine may contribute to the change in temperature profile. A comparison of the temperature profiles obtained for the unmodified configuration with and without stator blades located at the transition liner exit are shown in figure 8. For this comparison standard transition liners without the downstream end extension were used, and a quarter sector of the turbine-stator ring was installed at the downstream end of the transition liners. There is a slight shift towards a flatter profile with stator blades in place. Work described in reference 1 leads to the conclusion that the actual spanwise turbine-blade temperature distribution for cooled blades varies little over a wide range of gas-profile variations. The moderate increases in temperature gradients resulting from using the modified transition liners will probably not be detrimental to turbine life when used in conjunction with cooled turbine blades.

Combustor Total-Pressure Loss

The total-pressure losses across the combustor were unaffected by using the modified turbine transition liners in place of the standard liners.

CONCLUDING REMARKS

This investigation was conducted to determine the feasibility of using standard tubular combustors as gas generators for supplying turbine-inlet temperatures up to 2400°F for turbine-cooling studies. As no difficulty was experienced in producing a temperature rise of 2000°F across the combustor with current production liners and fuel nozzles, the studies were directed mainly at improving component reliability.

The production-model combustor and turbine-inlet transition liners tested operated without damage for almost 6 hours at combustor-exit

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temperatures of 2000° F and 2400° F. However, the turbine casing warped, and the flange was distorted. It is not known if the casing would be warped if cooled stators were used, but since it is imperative to protect the cooled rotor blades from damage, the use of these standard components is hazardous at these temperature levels. A turbine transition-liner modification that consisted of an increased coolant passage between the liner and turbine casing and a shroud to control the coolant flow eliminated warping of the turbine casing in 32 hours of operation at average gas temperatures of 2000° to 2300° F. Turbine-inlet temperature profiles were only slightly distorted at the high combustor-exhaust temperatures when using the modified turbine transition liners. Total-pressure loss across the combustor was unaffected by the liner modifications.

Lewis Flight Propulsion Laboratory
National Advisory Committee for Aeronautics
Cleveland, Ohio, August 26, 1955

REFERENCE

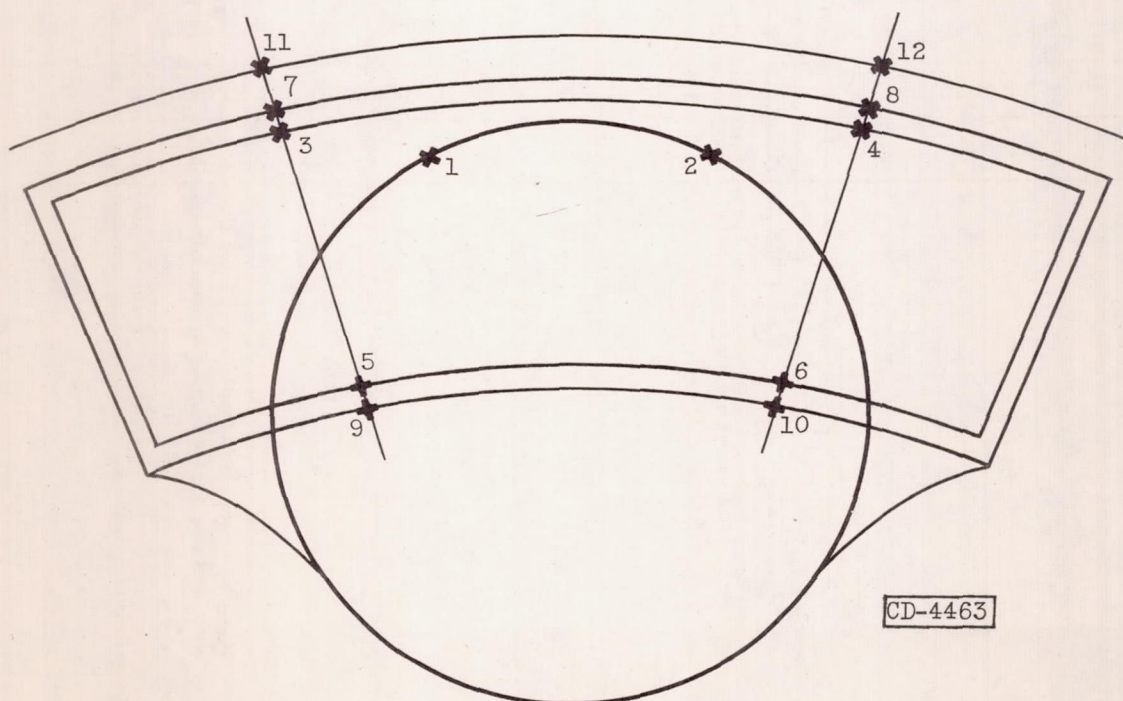
1. Hubbartt, James E., and Slone, Henry O.: Analytical Comparison of Convection-Cooled Turbine Blade Cooling-Air Requirements for Several Radial Gas-Temperature Profiles. NACA RM E55G14, 1955.

TABLE I. - COMBUSTOR TOTAL OPERATING TIME FOR EACH CONDITION

Run	Operating condition	Pressure, in. hg abs	Inlet temperature, °F	Average outlet-core temperature, °F	Approximate outlet temperature, °F	Air flow, lb/sec	Reference velocity, ft/sec	Operating time, hr
Standard turbine transition liners								
1	A	85	455	2190	2000	12.5	111	$2\frac{3}{4}$
2	B	85	450	2622	2400	12.8	114	3
Modified turbine transition liners								
3	C	85	350	2419	2000	17.7	158	$4\frac{1}{2}$
4	A	85	450	2332	2000	12.5	110	$4\frac{1}{2}$
5	B	85	450	2712	2300	12.5	110	10
Modified transition liners without air control shrouds								
6	B	85	450	----	2300	12.5	110	13

TABLE II. - WALL TEMPERATURES AT TURBINE TRANSITION SECTION, °F

Run	Operating condition	Com-bus-tor	Wall thermocouple locations as shown in fig. 5											
			1	2	3	4	5	6	7	8	9	10	11	12
Standard turbine transition liners														
1	A	1	680	620	1120	1085	1575	----	Not used				670	580
		2	715	705	1150	1165	1730	1125					770	710
2	B	1	700	710	1270	1335	1685	----					750	655
		2	745	740	1250	1285	1850	1260					825	715
Modified turbine transition liners														
3	C	1	----	400	1110	1090	1280	625	435	425	470	385	380	325
		2	350	---	1225	695	995	625	430	400	445	410	335	405
4	A	1	550	540	1455	1500	1295	815	615	565	595	510	---	---
		2	415	---	1035	715	1375	715	535	530	580	620	445	510
5	B	1	690	770	955	----	1315	1065	610	550	620	585	480	780
		2	565	---	935	1250	1475	630	540	555	1515	680	465	880
Modified turbine transition liners without air-control shrouds														
6	B	1	1590	570	630	1430	775	1460	Not used				525	645
		2	675	590	1725	1425	1585	1050					670	830



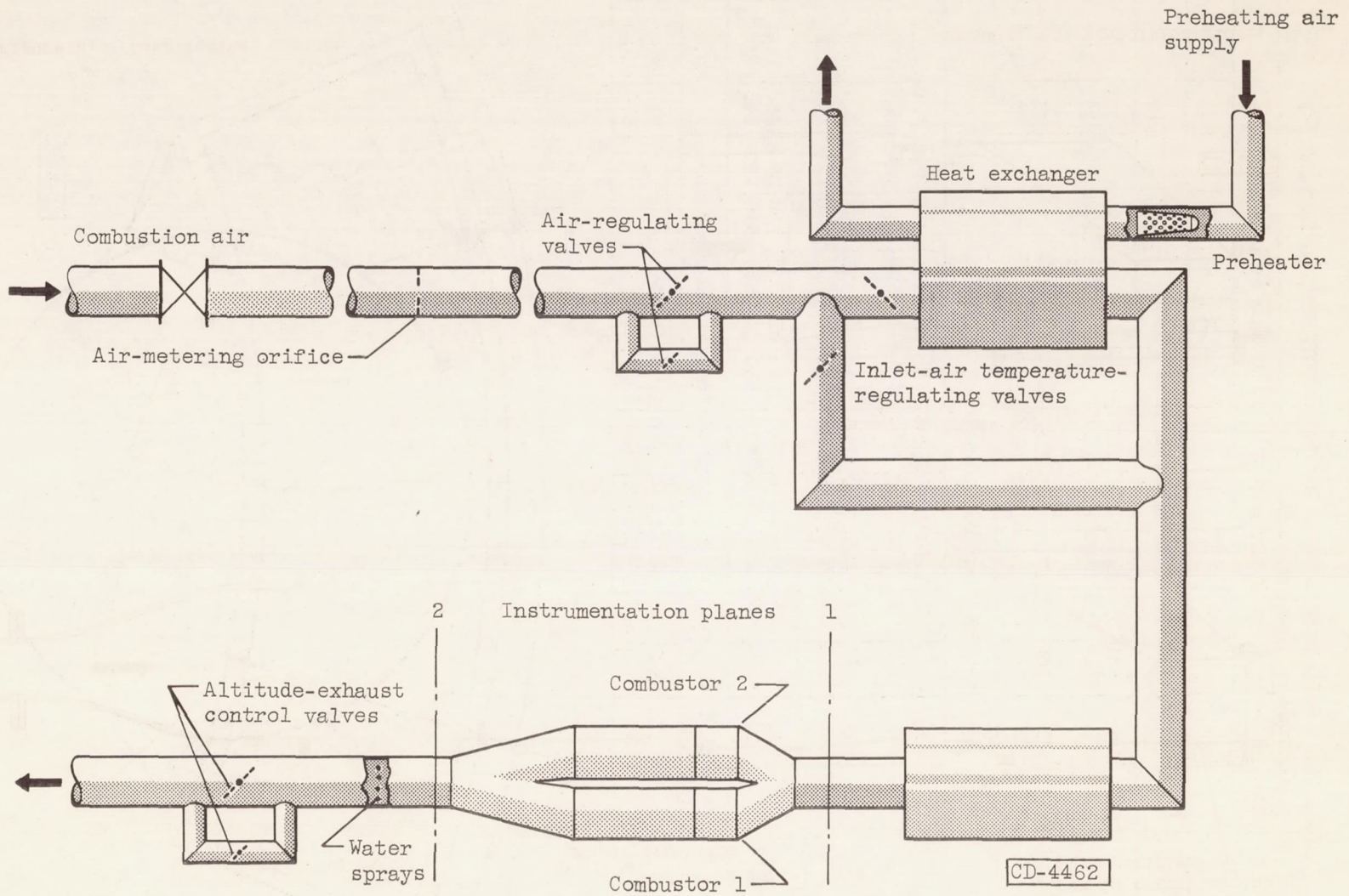


Figure 1. - Installation of combustor test section.

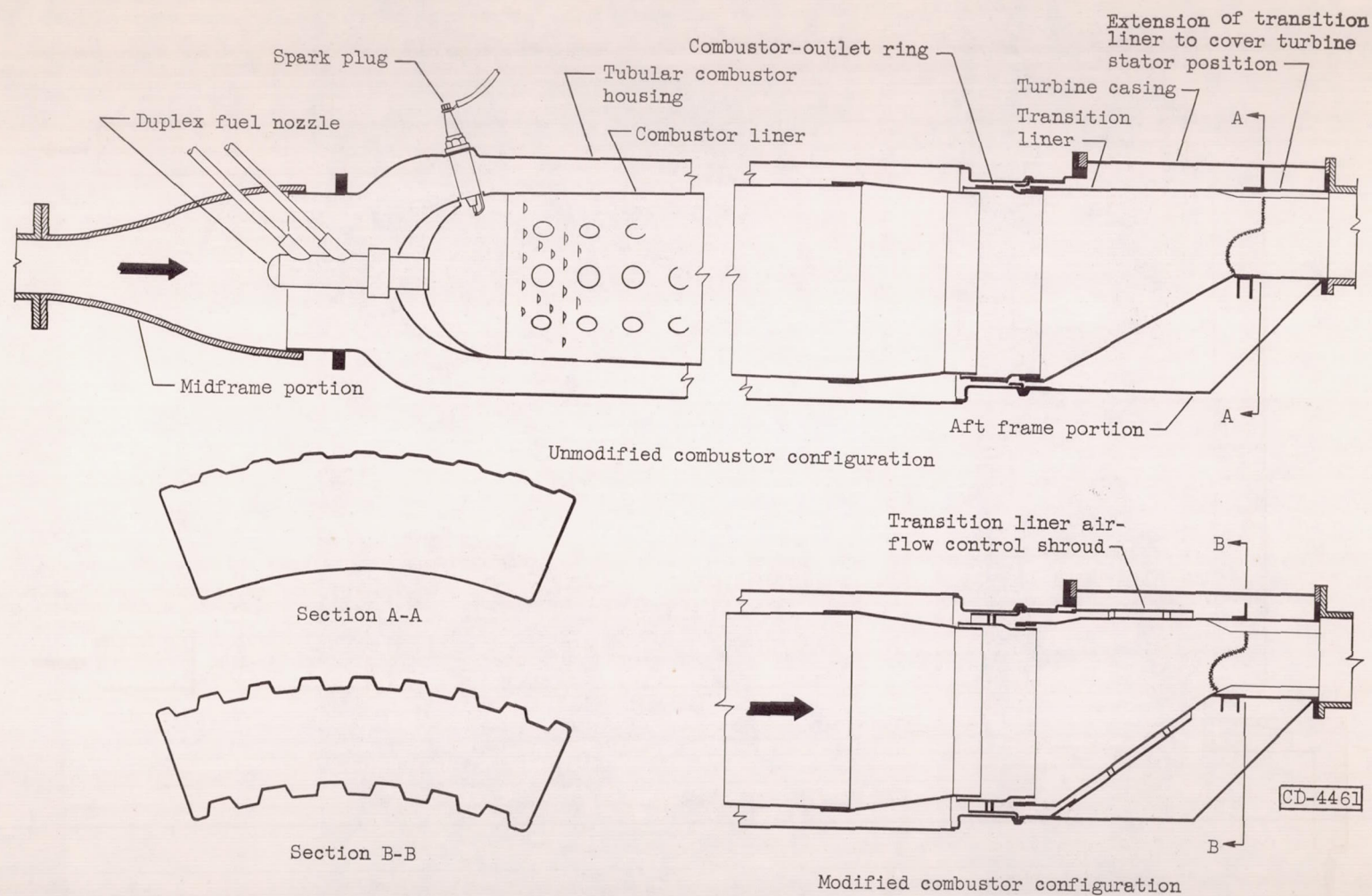


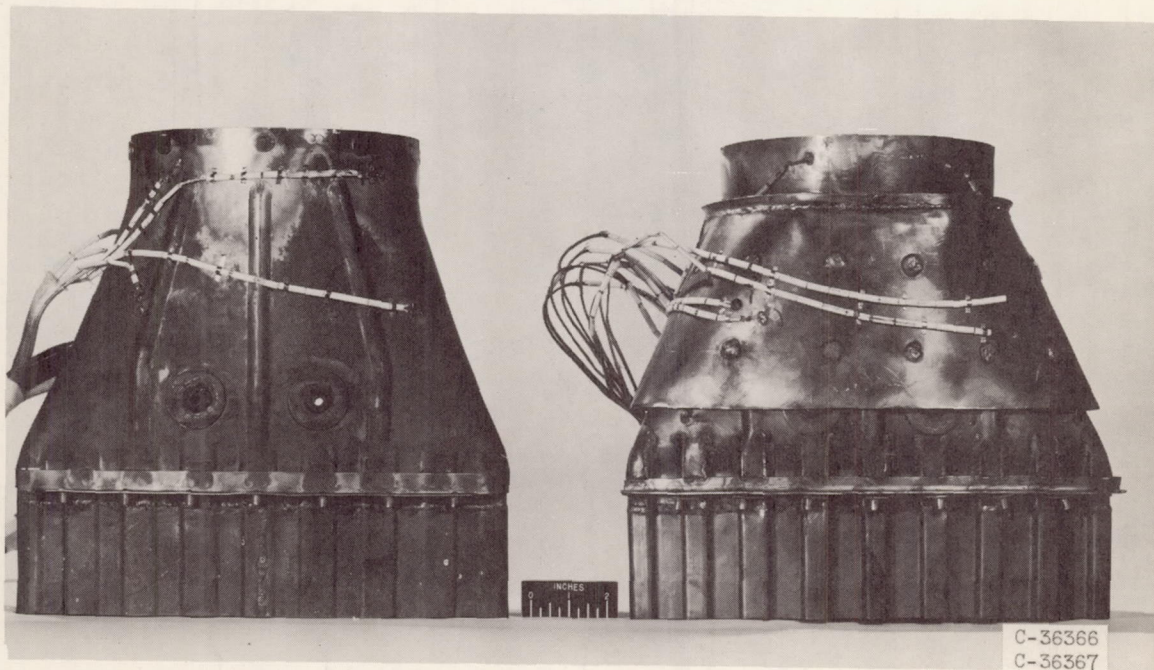
Figure 2. - Longitudinal section view showing modification to production-type tubular combustor and transition liner.

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(a) Unmodified liner; view looking upstream.

(b) Modified liner; view looking upstream.



(c) Unmodified liner; top view.

(d) Modified liner; top view.

Figure 3. - Modified and unmodified turbine transition liners.

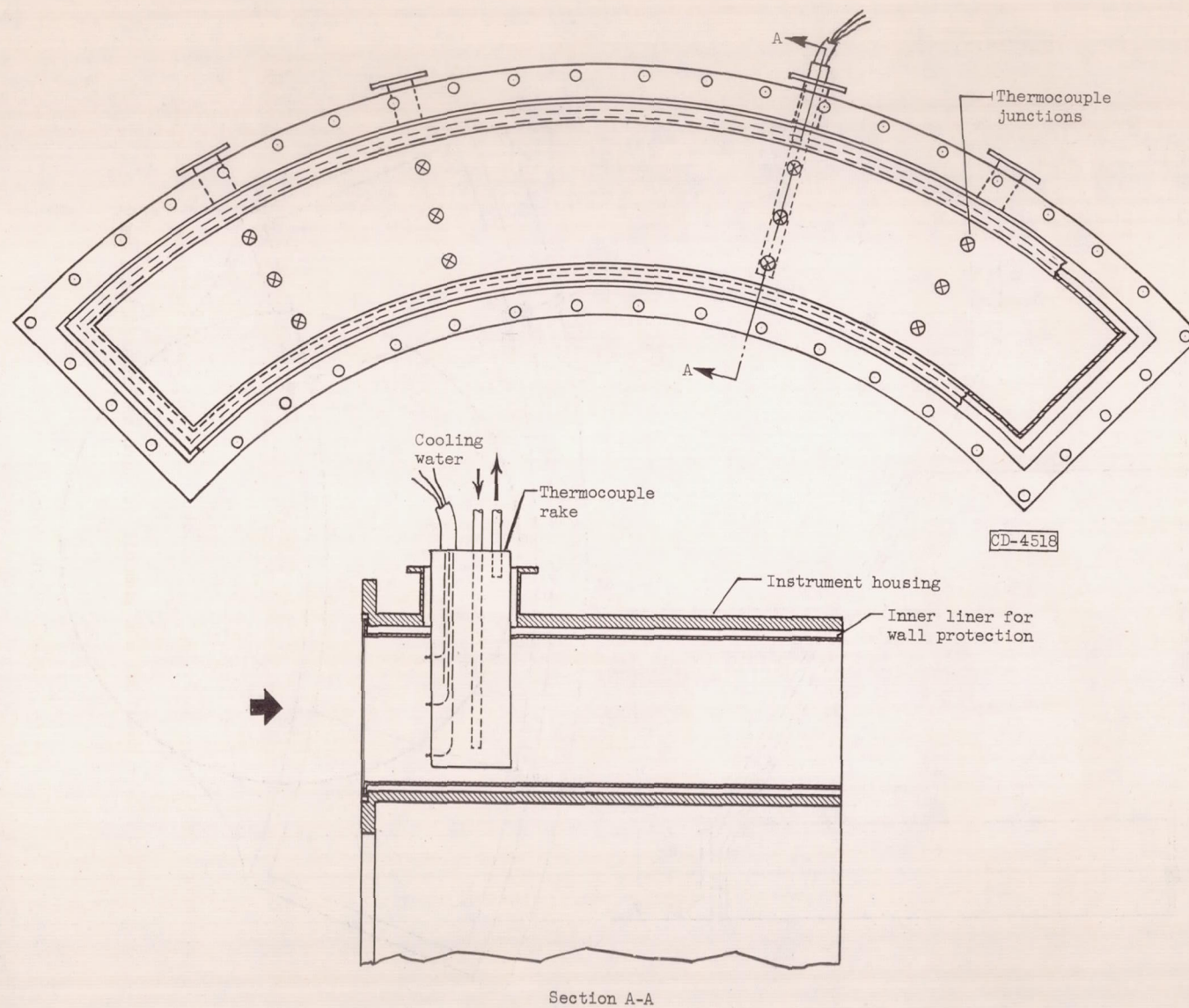


Figure 4. - Exhaust instrument housing with inner liner and thermocouple rakes.

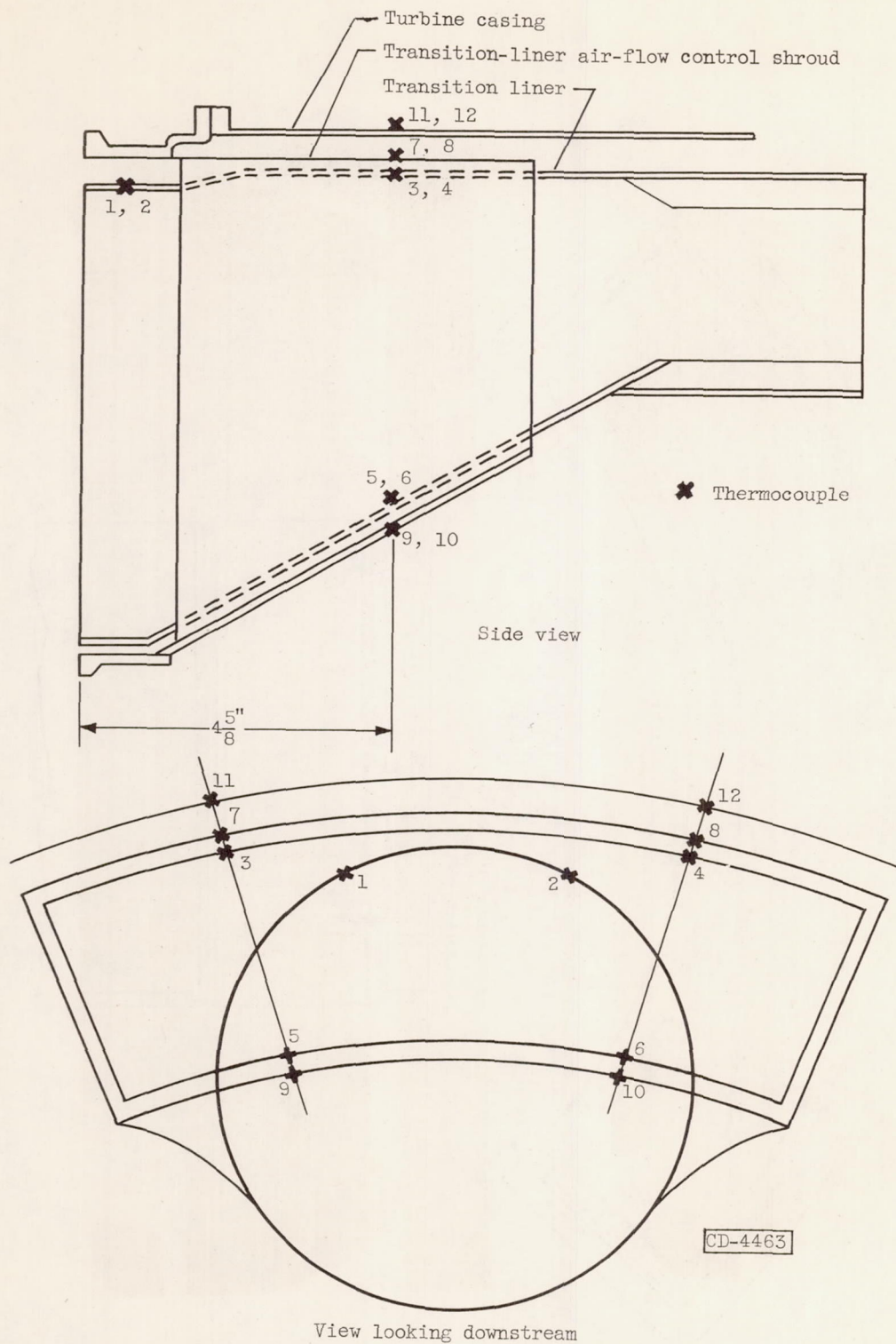
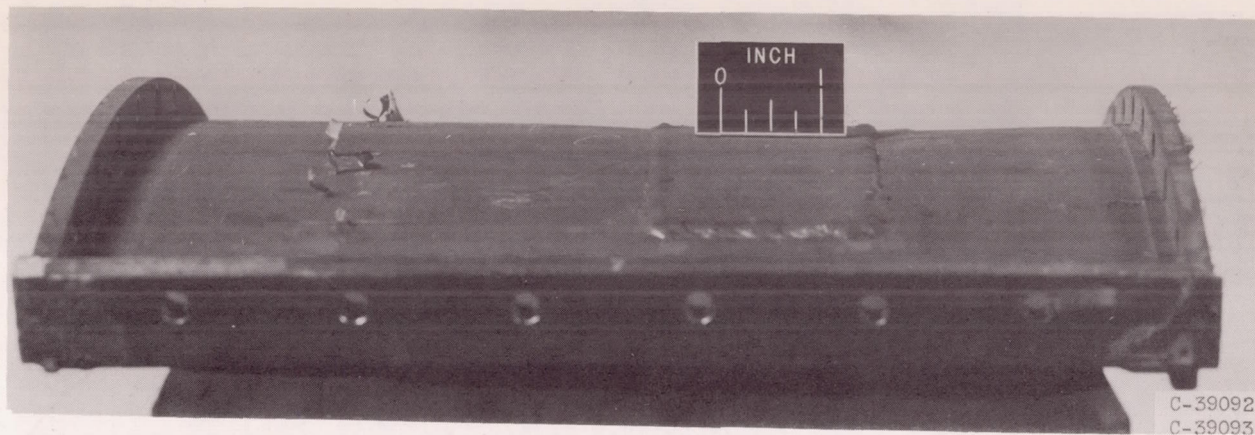
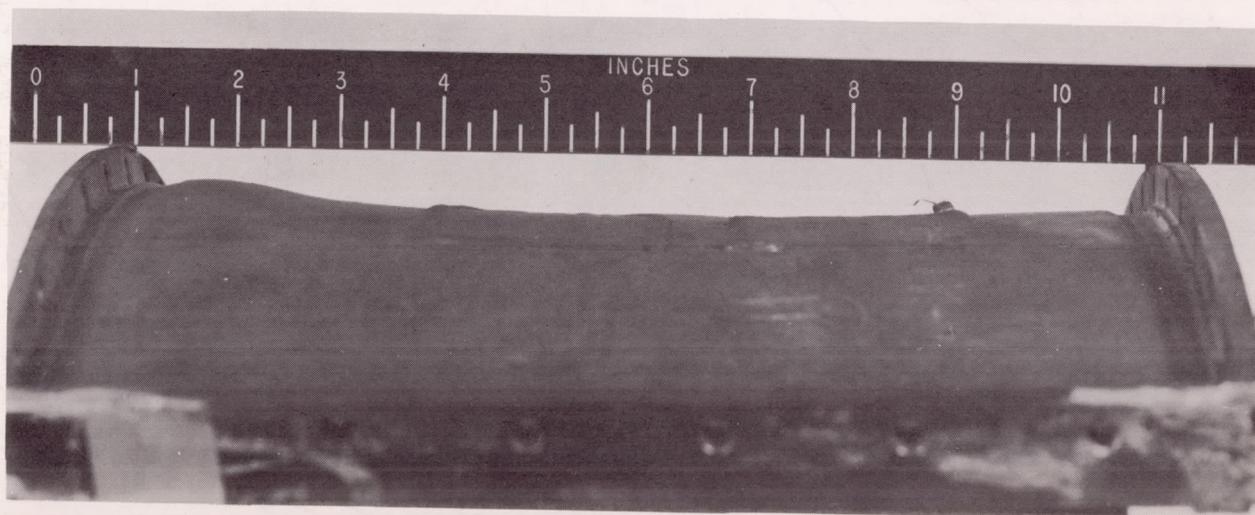


Figure 5. - Location of wall thermocouples on turbine transition liners and turbine casing. Combustors 1 and 2 were identically instrumented.



(a) Before operation.



(b) After 6 hours of operation.

Figure 6. - Turbine casing, showing warping of upstream flange area.

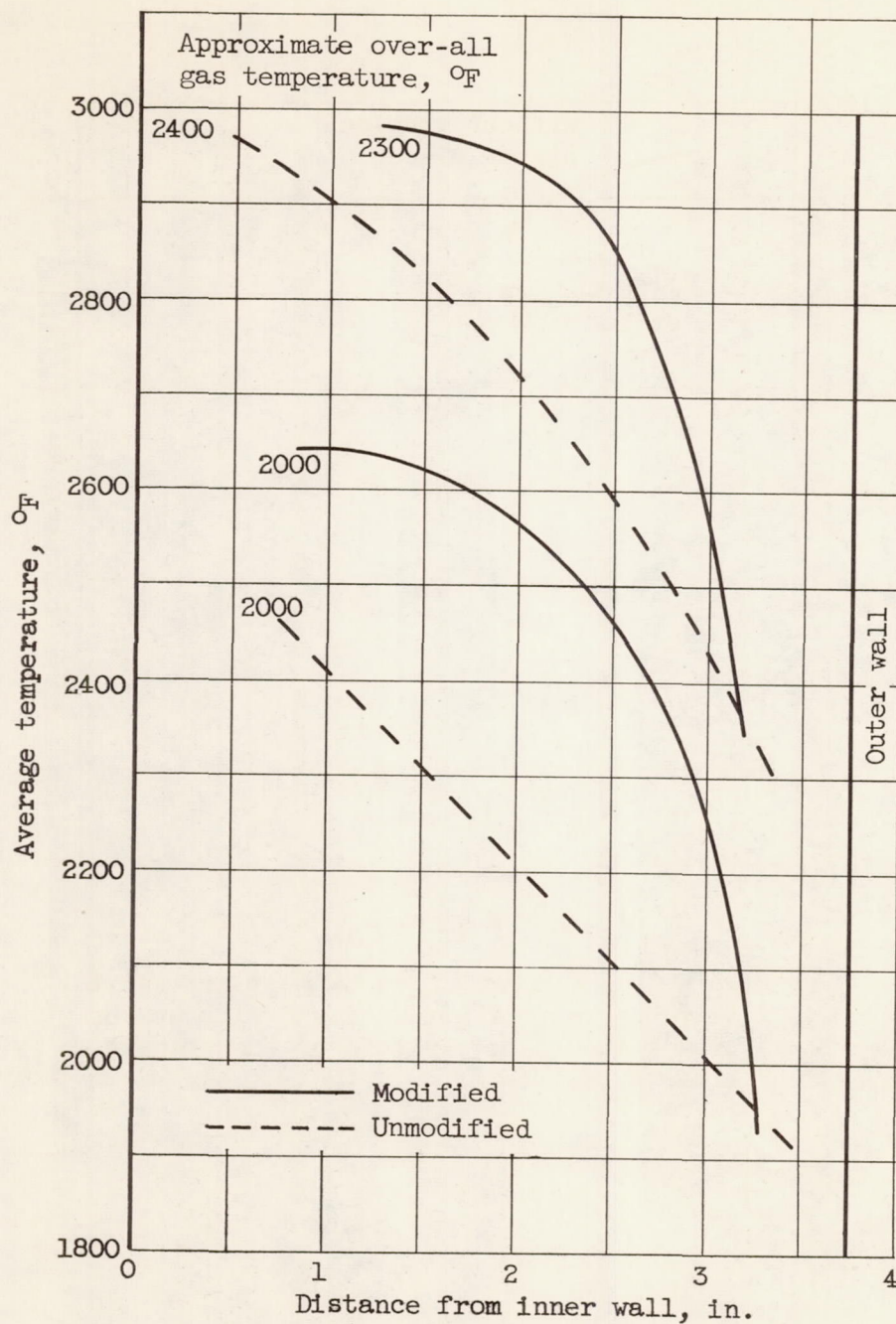


Figure 7. - Exhaust-gas radial-temperature profiles for the modified and unmodified configurations. Reference velocity, 110 feet per second.

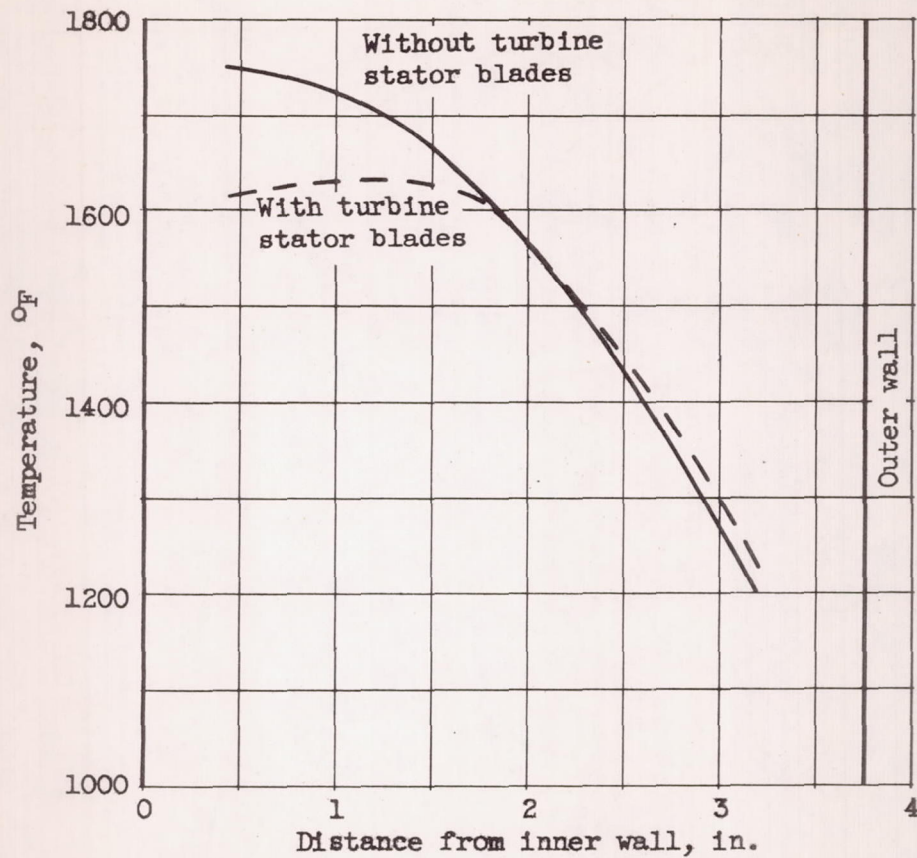


Figure 8. - Comparison of exhaust-gas radial-temperature profiles with and without turbine stator blades placed at the transition liner exit.

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