NACA

RESEARCH MEMORANDUM

AXIAL-SLOT AIR ADMISSION FOR CONTROLLING PERFORMANCE OF A ONE-QUARTER-ANNULUS TURBOJET COMBUSTOR AND COMPARISON WITH COMPLETE ENGINE

By Herman Mark and Eugene V. Zettle

Lewis Flight Propulsion Laboratory
Cleveland, Ohio

NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS

WASHINGTON

March 24, 1952
Declassified May 29, 1959

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

RESEARCH MEMORANDUM

AXIAL-SLOT AIR ADMISSION FOR CONTROLLING PERFORMANCE OF A ONE-QUARTER-ANNULUS TURBOJET COMBUSTOR AND COMPARISON WITH COMPLETE ENGINE

By Herman Mark and Eugene V. Zettle

SUMMARY

An investigation of a single-annulus turbojet combustor design with slot-type air admission was conducted to demonstrate the application of certain design principles to the control of the gas-temperature distributions at the combustor outlet. Comparisons of the performance of a one-quarter-annulus combustor (obtained in laboratory duct-type installation) and a full-annulus combustor (obtained in a full-scale turbojet engine mounted in an altitude test chamber) are presented to indicate the general applicability of results obtained from combustion studies conducted in laboratory duct-type installations. Combustion efficiency, altitude operational limits, and exhaust-gas temperature-distribution data were obtained for the one-quarter-annulus combustor; similar data were obtained for the full-annulus combustor.

The radial gas-temperature distribution at the combustor outlet was controlled (for an amenable slot-type opening upstream design) primarily by providing for longitudinal partitioning of the gases in the secondary zone of the combustor. A reasonable correlation existed between the performance of the one-quarter-annulus and the full-annulus combustors except for temperature distribution. Although actual correlation of radial temperature distribution was not established, sufficient trends did exist which made it possible to predict a given temperature distribution for the engine. A radial temperature distribution similar to the optimum distribution obtained from calculation was obtained in a given engine using a one-quarter-annulus laboratory duct-type test setup to predict the results.

INTRODUCTION

Research at the NACA Lewis laboratory on designs for annular combustors for turbojet engines (references 1 to 3) has indicated specific measures which give improved altitude performance. The combustor-design program applying some of the general design principles outlined in references 2 and 3 is presented in this report. Research was conducted in a one-quarter-annulus duct installation and in an actual jet engine installed in an altitude test chamber. A comparison of the performance of a one-quarter-annulus combustor, as determined in the duct, with the performance of the full-annulus counterpart, as determined in an actual engine, is made herein. This program was primarily intended to determine the applicability of design principles that improve combustor performance in laboratory duct-type installations to the design of combustors in the actual engine.

The turbine of the engine in which the research on the full-annulus combustor was conducted had specific radial-temperature-distribution requirements which were met by developing a combustor for a given temperature distribution in a one-quarter-annulus duct and subsequently testing the same design in the actual engine. Six combustor-design modifications were tested, first in the one-quarter-annulus duct and then in the full annulus as a component of the engine, before the turbine radial-temperature-distribution requirements of the engine were met. The results of the program are herein discussed and compared.

APPARATUS

Installation

A schematic diagram of the one-quarter-annulus combustor installation is shown in figure 1. Air of desired quantity, pressure, and temperature was drawn from the laboratory air-supply system and exhausted into the altitude exhaust system, which permitted operation in the test chamber at pressures as low as 5 inches of mercury absolute. Combustor-inlet temperatures were controlled by using a gasoline-fired preheater located in a bypass upstream of the combustor. The quantity of air flowing through the bypass, the total air flow, and the combustion-chamber static pressure were regulated by three remote-control valves. Two observation windows were installed in the test section in order to permit visual observation of the combustion process. A pictorial representation of the turbojet engine installed in an altitude test chamber (fig. 2) illustrates the equipment installation used for evaluating the full-annulus combustor.

Instrumentation

Total temperature and pressure were measured in the one-quarter-annulus combustor at the three stations indicated in figure 1. The position of the instruments in each of the three planes is shown in figure 3. Combustor-inlet total temperatures were measured with three bare-junction unshielded iron-constantan thermocouples at station 1, as shown in figure 3(a). Slightly upstream of station 1 were located twelve total-pressure tubes, three in each of four rakes as shown in figure 3(a). Combustor-outlet total temperatures were measured with thirty bare-junction unshielded chromel-alumel thermocouples; five thermocouples in each of six rakes were located across the duct at station 2, as shown in figure 3(b). At station 3 were located fifteen total-pressure tubes in three rakes of five pressure tubes each (fig. 3(c)). All instruments were located at approximate centers of equal areas. Static-pressure taps were installed at the walls, as shown in figure 3.

Instrument construction details are shown in figure 4. Fuel flow was metered through calibrated rotameters and air flow, through a concentric-hole sharp-edged orifice.

Combustors

The one-quarter-annulus combustor consisted of a one-quarter sector (90°) of a single-annulus combustor designed to fit into a one-quarter sector of an annular combustion-chamber housing. The outer diameter of the housing was $25\frac{1}{2}$ inches, the inner diameter, $10\frac{5}{8}$ inches, and the distance in the assembled unit from fuel nozzles to combustor outlet was approximately 23 inches. A three-quarter view illustrating the combustor as it was located in the housing is shown in figure 5. Fuel is injected downstream by means of ten fixed-orifice pressure-atomizing nozzles. Air passes from behind a partition near the upstream face of the combustor into the combustion zone through two rows of small rectangular openings located in the partition plate at the combustor walls and through the annular clearances between the fuel nozzle and the plate. Figures 5 and 6 illustrate the geometric relation between the fuel nozzles and the partition plate. Most of the combustion air enters the combustion zone through the slotted openings in the walls of the combustor. A series of six air-admission configurations on the inner and outer walls were investigated and hereinafter will be designated models 1 to 6. Sketches of these six configurations are shown in figure 7. For discussion, the first one-half length of the combustor is called the primary zone and the second one-half length of the combustor, the secondary zone. The configurations used in evaluating the full-annulus combustor in a turbojet engine were the same as those shown in figure 7, except that the combustor was a full (360°) annulus. A photograph of one configuration is shown in figure 8.

PROCEDURE

The general procedure was to develop a single-annulus combustor patterned after that of reference 3, but with a specific exhaust-gas radial temperature distribution which would meet the specifications for a given engine. The altitude performance characteristics were evaluated in a one-quarter-annulus duct setup.

The corresponding full-annulus combustor was then installed in a turbojet engine and its altitude performance as obtained in an altitude test chamber compared with the performance obtained in the one-quarter-annulus duct test setup. Altitude performance was determined for both the one-quarter-annulus and the full-annulus combustor with MIL-F-5624 (JP-3) fuel.

One-quarter annulus. - The combustor-inlet air conditions and the values of the estimated combustor-outlet temperatures required to operate a turbojet engine having a pressure ratio of 4 were calculated from data obtained in an altitude-wind-tunnel investigation of the complete engine equipped with the standard combustor for that engine. Conditions were chosen for a simulated flight Mach number of 0.24 and an engine jet-exhaust-nozzle cross-sectional area of approximately 171 square inches. Curves for combustor-inlet conditions and for estimated values of turbine-inlet gas temperatures are given in figure 9. The performance of the one-quarter-annulus combustor was determined by using these curves as the basis for simulating engine operating conditions in the test combustor. The methods outlined in reference 3 for obtaining combustor performance were followed.

Full-annulus. - The performance of the full-annulus combustor as a component of a turbojet engine was determined in another investigation in an altitude test chamber by operating the engine over a range of engine speeds at predetermined values of altitude and flight Mach number. Performance data for comparison with the one-quarter-annulus combustor were obtained at a simulated flight Mach number of 0.30. The low-speed altitude limit was determined with the engine speed and flight Mach number held constant and the altitude increased until combustor blow-out occurred. The high-speed limit was dictated by a temperature limit based on the stresses induced on the turbine by gas and dynamic loading and by the reduction in allowable stresses in the blade material at the higher temperatures. The high-speed limit was considered to have been reached when the turbine radial-temperature-distribution curve became tangent to the calculated limiting temperature curve at any point.

It was necessary to increase the jet-exhaust-nozzle area from the original 171 square inches for the standard engine combustor configuration to approximately 194 square inches to make possible the operation of the engine with this modified combustor design over the required engine-speed range.

RESULTS AND DISCUSSION

Combustor Design Features

Previous research at this laboratory has indicated an advantage in considering the entire combustor length for obtaining radial-temperature-distribution control at the combustor outlet. First an environment amenable to control should be established in the primary zone, that is, a consistent temperature pattern should be obtained at the primary-zone exit (approximately one-half of the combustor length for current design). Control of the outlet radial temperature distribution can then be accomplished with variations in the air-admission opening in the secondary zone of the combustor; however, the dilution should be introduced over as long a path as possible to allow more time for mixing of the hot and the cold gases. The results of the investigations of references 2 and 3 showed the advantage of axial slots for the air-admission geometry in the primary-zone walls to maintain the desired condition discussed previously. Excess air could be admitted into the primary zone in this manner without reducing the primary-zone effectiveness. This method of air admission made better use of the available volume by initiating the dilution mixing process somewhere in the primary zone. In addition, introducing the primary air through axial-slot openings tends to produce alternate longitudinal sectors of fuel-rich and air-rich regions, resulting in a continuous path of optimum fuel-air concentration in the interfaces of the alternate sectors.

Application of Design Features

By applying the principles outlined previously and demonstrated in references 2 and 3, a single-annulus combustor similar to that of reference 3 was investigated in a one-quarter-annulus test rig to obtain a specific radial gas temperature distribution for a preselected compressor-turbine combination. After the basic air-admission arrangement on the primary-zone walls had been developed, the radial gas-temperature distribution at the combustor outlet was controlled primarily with variations in air-admission geometry of the secondary zones of the combustor. Variations in the air-admission geometry in one area will necessarily affect a given flow balance along the length of the combustor because of a resultant change in flow resistance. Alterations were thus necessary in other portions of the combustor to stabilize performance, other than temperature distribution, at satisfactory levels.

The air-admission design provided for longitudinal partitioning of gases in the upstream part of the secondary zone on both the inner and the outer walls. Louvers, providing for air entry with little penetration in the downstream part of the secondary zone, were located in the outer wall. The dilution air-admission geometry was so designed that alternate zones within the combustor would remain relatively undisturbed by incoming cooling air, and corridors of hot flowing gases would continue uninterrupted for the length of the combustor. Physically, this geometry should produce alternate sheets of hot and cold gases. Variations in the exhaust radial temperature distribution were obtained by changing the penetration and mixing of the cold air with the hot gases, which was in turn accomplished by varying the width and the length of the corridors. Combustor model 1 (figs. 5 and 7(a)) was thus developed and evaluated.

The discharge velocity flow profile for the compressor of the preselected compressor-turbine combination varied with compressor speed but, in general, tended toward high velocities near the outer wall. Typical compressor discharge velocity profiles for this compressor are shown in figure 10. The performance of combustor model 1 was therefore evaluated with an inlet velocity profile disturbed in the manner shown by the dashed curve in figure 10, which was considered a compromise inlet condition for the actual compressor characteristic.

Model 1

One-quarter annulus. - The altitude performance of model 1 obtained in the one-quarter-annulus test setup is shown in figures 10 to 12. The altitude operating limits are shown in figure 11. Low-speed limits occurred at approximately 54,000 feet for a simulated condition of 70 percent of rated engine speed and at 48,000 feet for 63 percent of rated engine speed. High-speed limits are fictitious with respect to the engine because the limits in the high-speed region are usually imposed by the temperature limits of the turbine rather than by the performance of the combustor.

In order to indicate the performance of this combustor irrespective of requirements that might be imposed by a particular turbojet engine, the combustor was operated over a range of air flows per square foot of combustor maximum cross section at an inlet-air pressure and temperature combination typical of current engine operation. Combustion efficiency is shown as a function of the mass flow through the combustor over a range of combustor temperature rise in figure 12. At each temperature rise ratio the combustion efficiency increases to a maximum value and then decreases with increasing air flows through the combustor. Maximum combustion efficiency is obtained at successively lower air flows as the temperature rise through the combustor increases. Shown in this figure is the approximate range of air flows corresponding to a combustor-inlet pressure of 10 pounds per square inch absolute over which the combustor would be required to operate as a component of the engine considered. The primary zone of the combustor was so designed that the most favorable portion of the performance curves falls within this range of air flows.

This design was accomplished by variations of the dimensions and arrangement of the slots that admit air. In this manner the design was molded into a combustor containing the required combinations of stability, combustion efficiency, and temperature-rise characteristics. A typical combustor-outlet radial temperature distribution is shown in figure 13 for simulated engine conditions at an altitude of 50,000 feet and a corrected engine speed of 13,000 rpm. The solid curve shown is the average curve for data obtained at four circumferential positions. The dashed curve represents the calculated optimum temperature distribution for the turbine employed.

Comparison of one-quarter and full annulus. - The comparison of the performance of the one-quarter- and the full-annulus combustors (model 1) is presented in figure 14. The altitude operating limits for the two combustors are presented in figure 14(a). In the low-speed region the full-annulus combustor showed slightly higher limits than the one-quarter-annulus combustor; however, the curves intersect at an altitude of about 50,000 feet and 65 percent of rated engine speed. The high-speed limitation, as mentioned previously, cannot be compared directly because the engine is limited by the temperature limitations of the turbine. The small difference in simulated flight Mach number (0.24 for the one-quarter-annulus combustor and 0.30 for the full-annulus combustor) would create a small variation in the combustor-inlet conditions for the two combustors; however, this was considered not to affect the comparison seriously. The variation of combustion efficiency with engine speed for two altitudes is presented in figure 14(b). The limited data for the one-quarter-annulus combustor indicate a reasonable correlation of combustion efficiency with the data of the full-annulus combustor. Figure 14(c) presents a comparison of radial gas-temperature distributions at the turbine section with the calculated optimum distribution. Temperature level is plotted as a function of radial distance at the plane of instrumentation. The full-annulus-combustor temperature data were recorded downstream of the turbine; whereas the one-quarter-annulus-combustor data were obtained at a section in the duct corresponding to a point upstream of the turbine in the engine. An adjustment was made in the temperature level of the one-quarter-annulus data to simplify comparison at turbine-exit temperature levels. The temperatures for the full-annulus combustor were much higher at the blade root and much lower at the blade tip positions than those for the one-quarter-annulus combustor and, as a result, the temperature distribution at the turbine in the engine was far from matching the calculated optimum curve. Design changes were therefore made in an attempt to improve this condition without affecting other performance characteristics.

Model 2

One-quarter annulus. - It appeared possible that the provision in combustor model 1 for wide corridors of hot flowing gases and deep penetration of the cooling air from the inner wall of the secondary zone had been overdesigned. As a result, these provisions (fig. 7(a)) were almost entirely eliminated in an effort to reduce the temperatures at the turbine root with respect to those at the tip. Because the resulting decrease in flow resistance in the inner wall of the secondary zone would result in reduced flow into the primary zone, the areas of the large louvers in the outer wall of the downstream part of the combustor were reduced to compensate for this effect on primary air flow. This variation of model 1 resulted in model 2.

The compressor-outlet velocity characteristics were considered a possible cause for the lack of correlation of the temperature distribution between the one-quarter- and the full-annulus configurations. The effect of variation of inlet velocity distribution on radial temperature distribution at the combustor outlet was therefore determined for the three velocity distributions shown in figure 15. The slope of the curve producing a high velocity at the outer wall is approximately the same as that obtained in the engine at simulated conditions of an altitude of 40,000 feet and engine speeds above 11,000 rpm. The variation in inlet velocity represented in figure 15 is much greater than that encountered in engine operation. The radial temperature distributions as obtained with model 2 for the three inlet velocity distributions at a simulated altitude of 50,000 feet and 13,000 rpm are shown in figure 16. Slightly lower turbine-tip temperatures resulted from a high inlet velocity on the inner wall. In general, however, the temperature distribution at the combustor outlet was very similar for all three inlet velocity distributions. All subsequent combustor modifications discussed were therefore evaluated with a uniform velocity distribution at the combustor inlet. The moderately high pressure drop across the combustor (about 9 percent of the inlet total pressure) could be a contributing factor in diminishing an effect of inlet velocity profile on the combustor-outlet radial temperature distribution.

Comparison of one-quarter and full annulus. - Figure 17(a) compares the radial temperature distributions obtained with model 2 in the full-annulus combustor and in the one-quarter-annulus combustor. The curve shown for the full-annulus combustor was obtained at simulated altitude operating conditions of 40,000 feet and that shown for the one-quarter-annulus combustor, at simulated altitude operating conditions of 50,000 feet. In another investigation, these differences were shown to have little or no effect on the shape of the exhaust-gas radial temperature distribution of the slot-type combustor. The shapes of the two curves are in good agreement, with the exception that the gas temperatures near the outer wall decreased more rapidly in the one-quarter-annulus setup than in the full-annulus engine runs. This could indicate an unaccountable difference between the one-quarter-annulus runs and the full-annulus engine runs. The gas temperatures at the turbine-blade root were reduced over those of model 1 and those at the turbine-blade tip were increased; however, comparison with the calculated optimum curve indicates that now the root temperatures are much too low, and the tip temperatures, too high.

Model 3

Apparently the radial partitioning of the gases in the secondary zone, which was almost entirely eliminated in model 2, should at least be partly replaced. The combustor was therefore modified by reducing the air-slot width by a factor of one-half for a length of 4 inches in the inner wall of the upstream part of the secondary zone. The air-admission-geometry arrangement is shown in figure 7(c). The accompanying change in air-slot pitch was for the purpose of increasing the tendency for the formation of corridors of hot flowing gases in this region. The open areas of the air louvers on the outer wall at the downstream part of the combustor were increased to aid in the reduction of temperatures at the extreme blade tip.

Comparison of one-quarter and full annulus. - Combustor model 3 produced temperature-distribution curves as shown in figure 17(b) for the one-quarter-annulus and the full-annulus combustors. The turbine-blade-root temperatures were increased just slightly over those of model 2 and the point of peak temperatures was shifted farther away from the outer wall. It was evident from these data that the modifications to increase the turbine-blade-root temperatures were insufficient.

Models 4 and 5

Combustor models 4 and 5 were obtained by providing wide corridors for predetermined lengths in the inner wall of the secondary zone of model 3. This was accomplished by blocking every third air-admission slot in the inner wall of the secondary zone, as is shown in figures 7(d) and 7(e). Again, in order to compensate for the shift in resistance to air flow created by this modification, the air-admission area in the outer wall of the primary zone was also reduced.

Comparison of one-quarter and full annulus. - The turbine-blade-root temperatures were increased and the peak temperature point was shifted toward the outer wall for model 4 as shown in figure 17(c). The turbine-blade-root temperatures in the one-quarter-annulus combustor have increased over the previous models more than those in the full-annulus combustor as evaluated in the engine. Temperature-distribution curves obtained with the two (model 5) combustors are shown in figure 17(d). The root temperatures in the one-quarter-annulus combustor have increased over the previous models much more than those in the full-annulus combustor for model 5; however, the tip temperatures for the one-quarter-annulus combustor decreased rather sharply.

Model 6

A further increase in the length of the corridors of hot flowing gases was indicated by the data; yet if this were achieved by further blocking of the air-admission slots, a condition similar to that obtained in model 1 would result; that is, a complete shift in temperature distribution would occur. The cold-air penetration from the inner to the outer wall would be increased sufficiently with a simultaneous shift in the air flow toward the outer wall (because of the blockage required to extend the corridors the full remaining length of the combustor) to cause the major shift in temperature distribution. In an attempt to obtain the benefits of the extension of the corridors and not to accept the shift in distribution, 13 "fingers" were installed at the downstream ends of the existing corridors of model 5, which allowed air to enter but not to penetrate. Figure 6 illustrates the installation of the fingers on the combustor wall.

Comparison of one-quarter and full annulus. - The full-annulus combustor for model 6 produced a temperature distribution very close to the calculated optimum curve (fig. 17(e)). The one-quarter-annulus combustor produced turbine-blade-root temperatures much higher than those of the calculated optimum design. This result is consistent with the trends noted for models 2 to 5.

Thus, altitude operating limits, combustion efficiency, and pressure drop with the full-annulus combustor model 6 were evaluated and these performance levels compared with those obtained for model 1 in the full-annulus combustor. Performance comparison for the two configurations is shown in figure 18. The intention of the combustor configuration changes from model 1 to model 6 was to effect a change in the radial temperature distribution of the gases while maintaining other performance criteria constant. It can be seen from figure 18 that this goal was successfully achieved with the exception of the increase in total-pressure drop $\Delta P_T/P_T$ that occurred (fig. 18(c)). These performance levels, along with the temperature distribution produced with model 6, were considered satisfactory. Although actual correlation of radial temperature distribution between the one-quarter and the full annulus was not established, trends did exist from model 1 to model 6 which made it possible to develop a given temperature distribution for the engine using a one-quarter-annulus laboratory duct-type setup to predict results.

SUMMARY OF RESULTS

The following results were obtained from an investigation of a one-quarter-annulus combustor design with slot-type air admission conducted in a laboratory duct-type setup and from a comparison with an investigation of the full-annulus counterpart conducted in a full-scale jet engine:

1. The radial gas-temperature distribution at the combustor outlet was controlled primarily with variations in air-admission geometry in the secondary zone of the combustor. This was accomplished by providing for longitudinal partitioning of gases in the upstream part of the secondary zone in such a way that alternate corridors within the combustor would remain relatively undisturbed by incoming cooling air, and corridors of hot flowing gases would continue uninterrupted for the length of the combustor. Variations in the exhaust radial temperature distribution were obtained by controlling the penetration and mixing of the cold air with the hot gases.

2. A reasonable correlation existed between the one-quarter-annulus and the full-annulus combustor for combustion efficiency and altitude operating limits. Although actual correlation of radial temperature distribution was not established, sufficient trends did exist which made it possible to develop a given temperature distribution for the engine using a one-quarter-annulus laboratory duct-type test setup for the development.

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

REFERENCES

1. Olson, Walter T., and Schroeter, Thomas T.: Effect of Distribution of Basket-Hole Area on Simulated Altitude Performance of $25\frac{1}{2}$-Inch-Diameter Annular-Type Turbojet Combustor. NACA RM E8A02, 1948.

2. Mark, Herman, and Zettle, Eugene V.: Effect of Air Distribution on Radial Temperature Distribution in One-Sixth Sector of Annular Turbojet Combustor. NACA RM E9I22, 1949.

3. Zettle, Eugene V., and Mark, Herman: Simulated Altitude Performance of Two Annular Combustors with Continuous Axial Openings for Admission of Primary Air. NACA RM E50E18a, 1950.

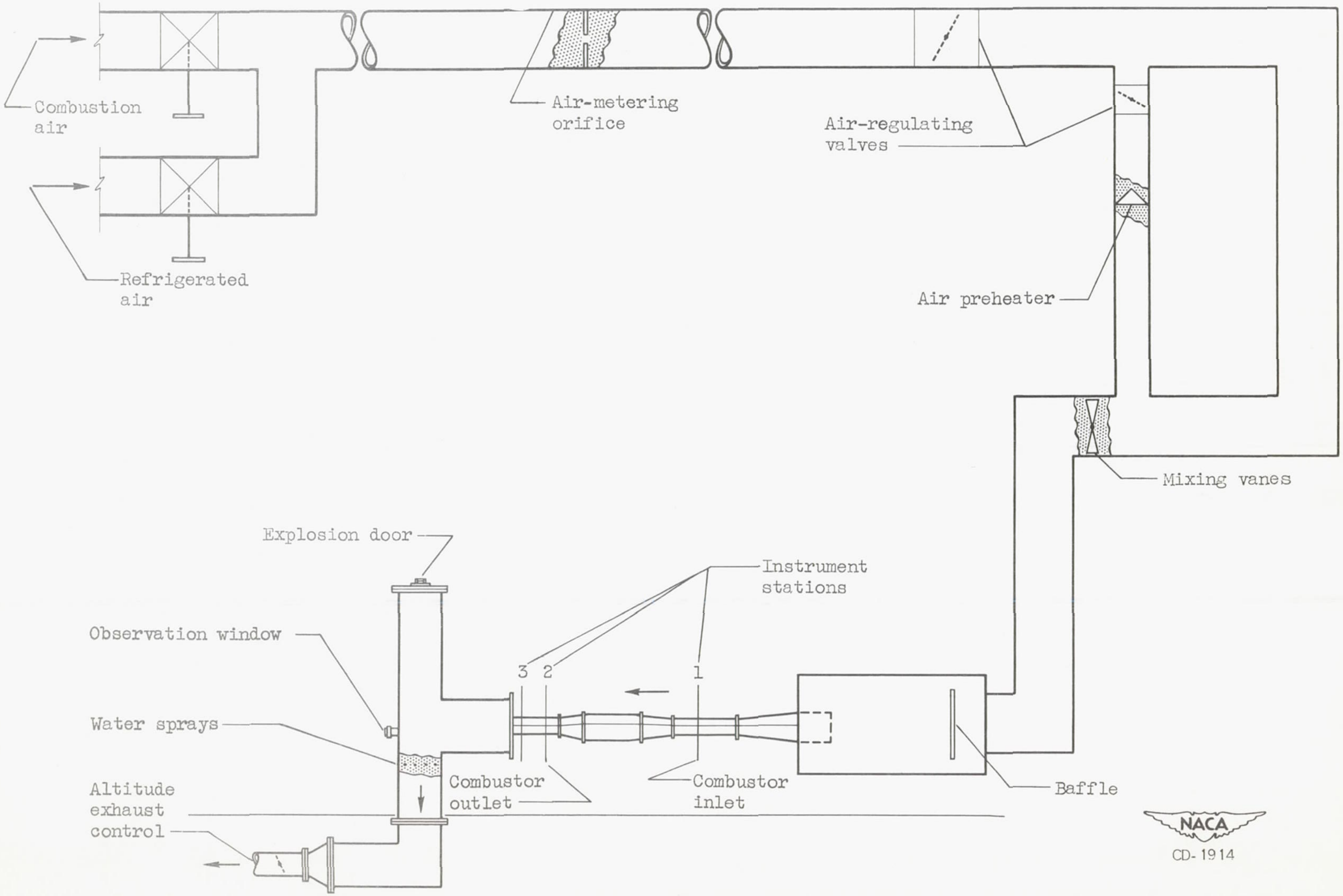


Figure 1. - Arrangement of one-quarter sector of $25\frac{1}{2}$-inch-diameter annular-combustor setup.

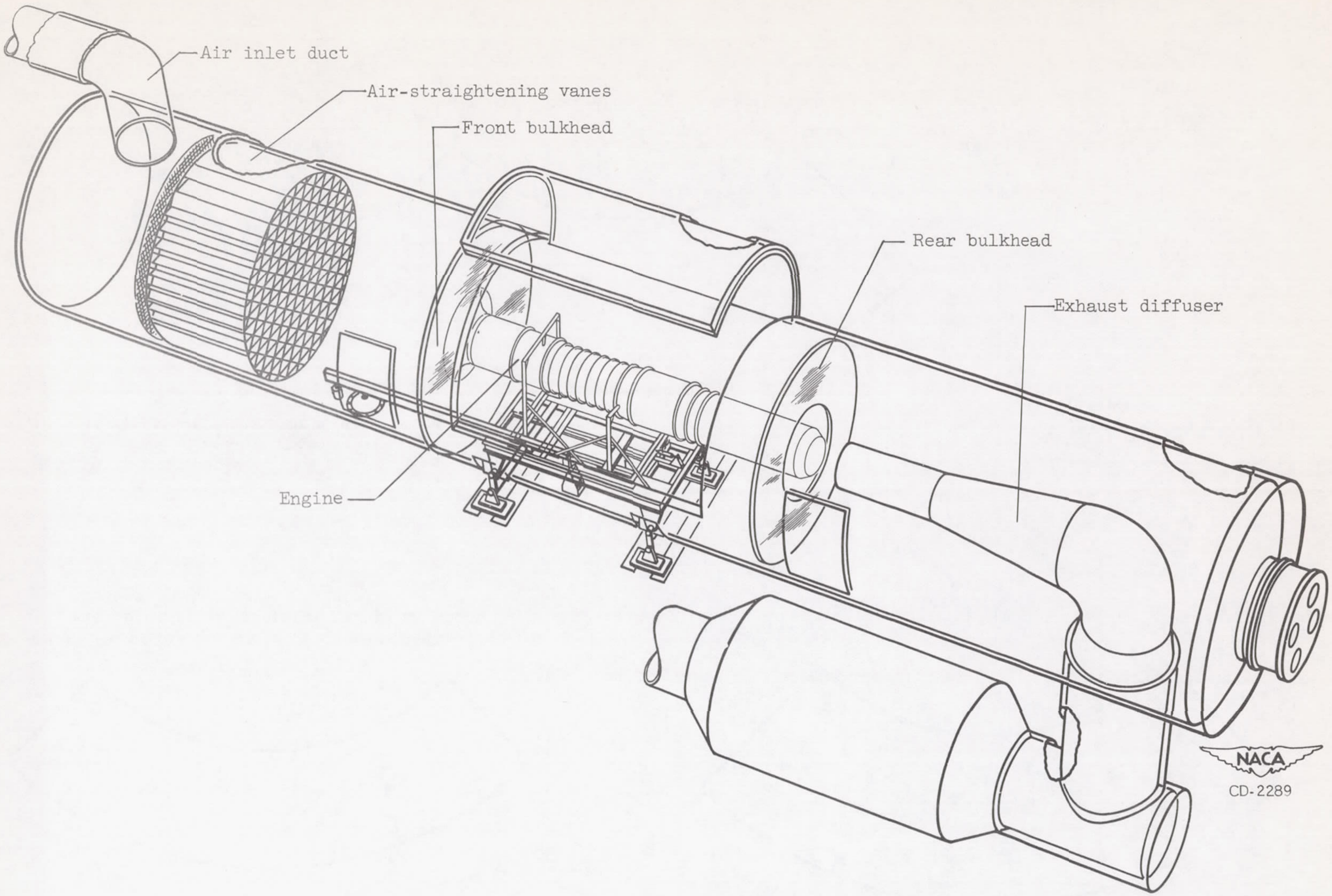
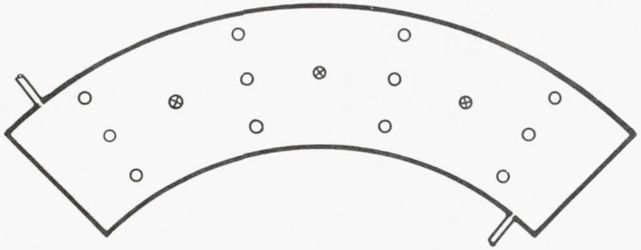
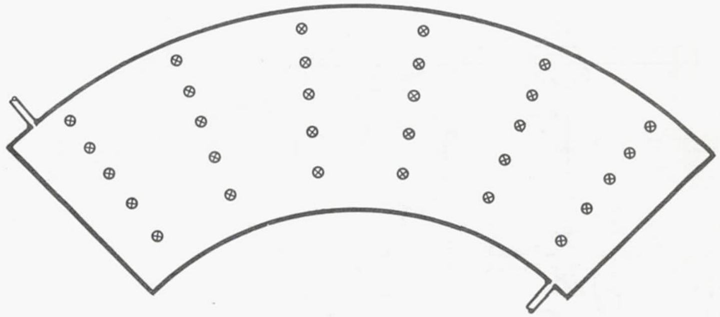


Figure 2. - Altitude chamber with engine installed.



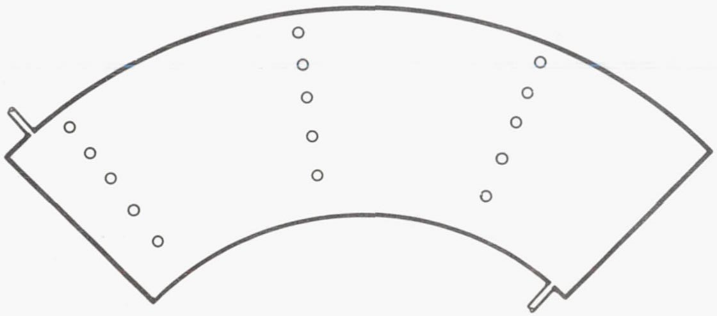
(a) Inlet thermocouples (iron-constantan) and inlet total-pressure rakes in plane at station 1.



(b) Outlet thermocouples (chromel-alumel) in plane at station 2.

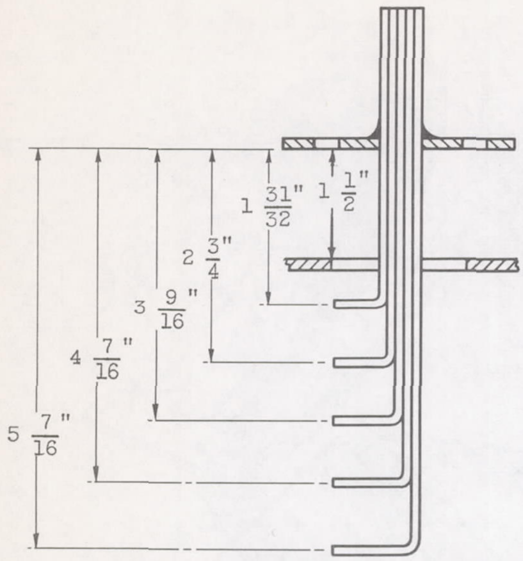
⊗ Thermocouple
○ Total-pressure rake
⅃L Static-pressure orifice

CD-1915

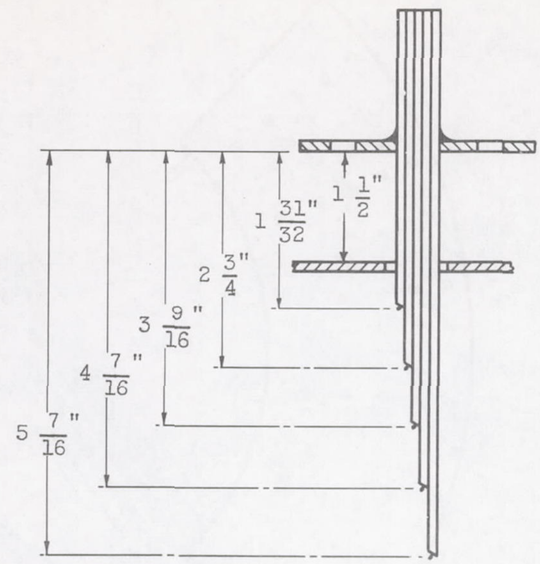


(c) Outlet total-pressure rakes in plane at station 3.

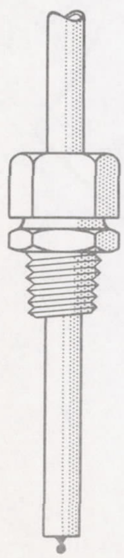
Figure 3. - Instrumentation.



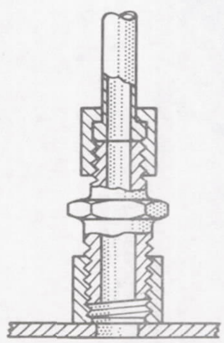
(a) Outlet total-pressure rake.



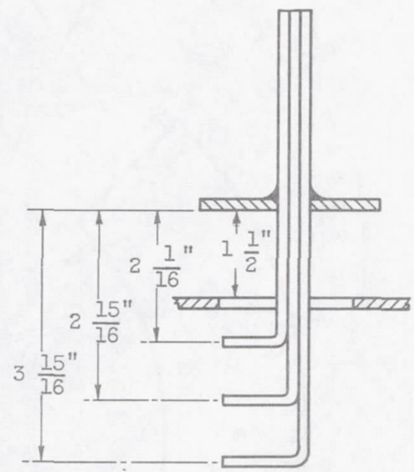
(b) Outlet thermocouple rake.



(c) Inlet thermocouple.



(d) Static-pressure orifice.



(e) Inlet total-pressure rake.

CD-1912

Figure 4. - Details of instrumentation.

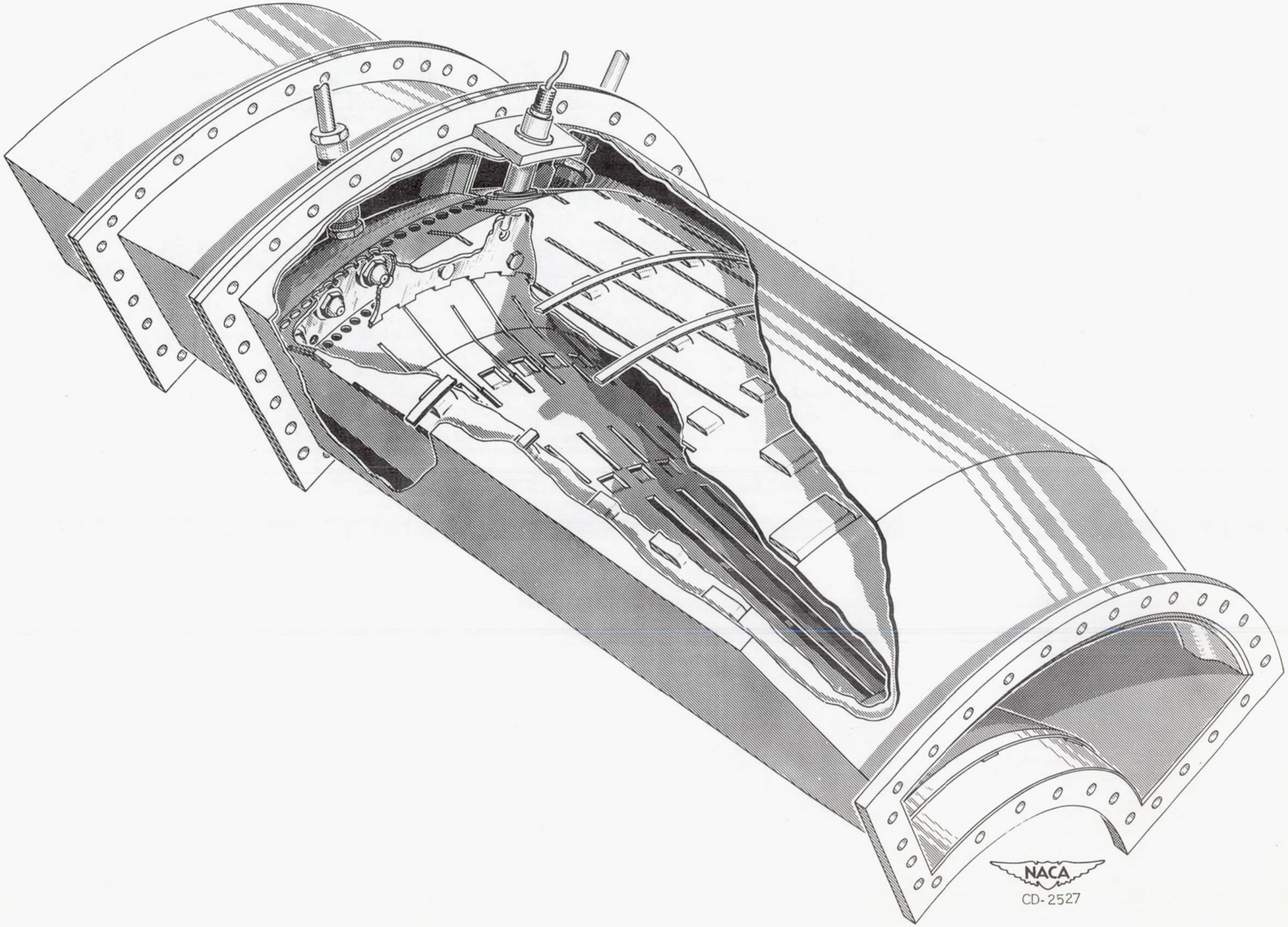


Figure 5. - One-quarter-annulus combustor as assembled in test ducting. Model 1.

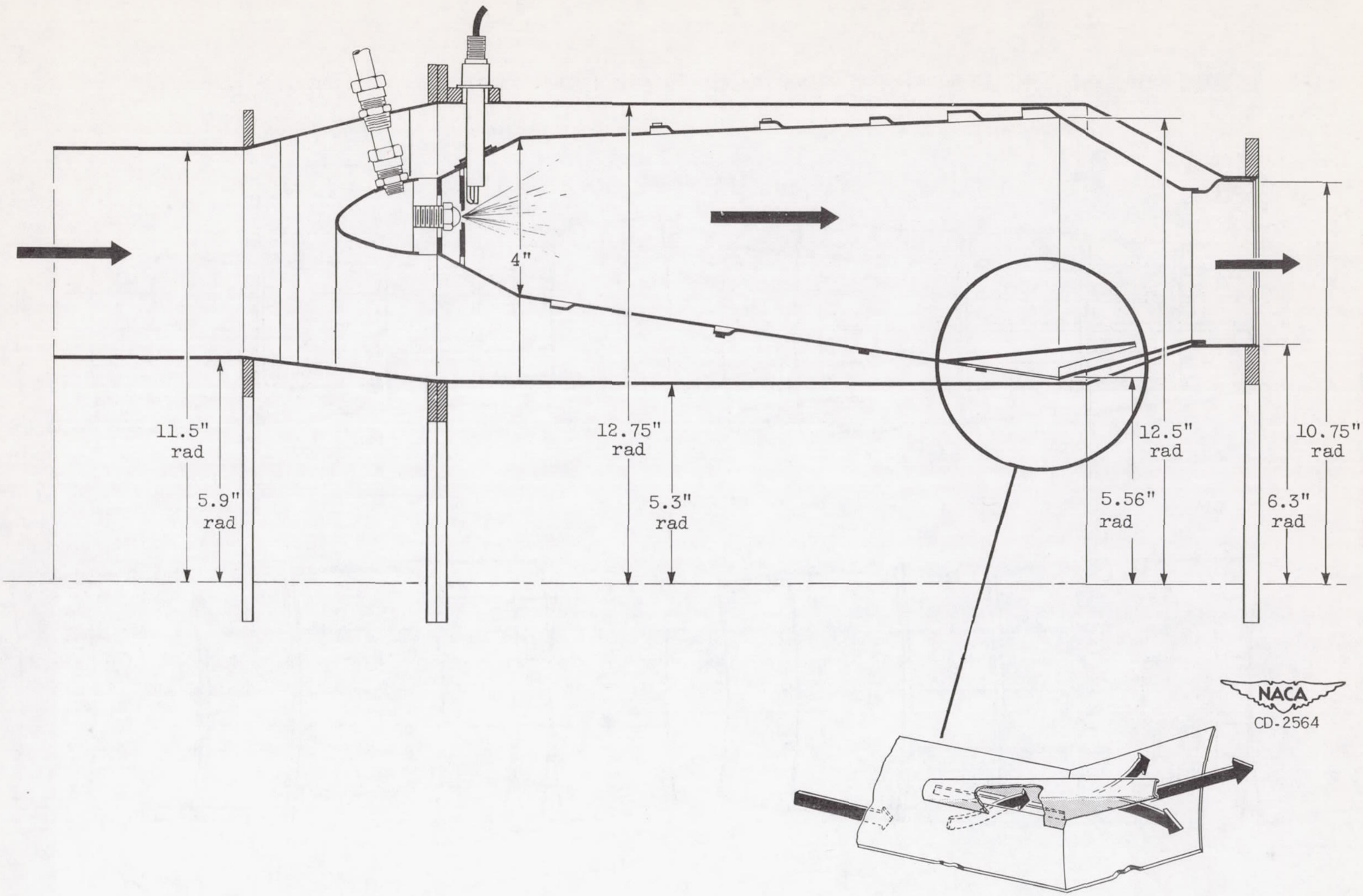
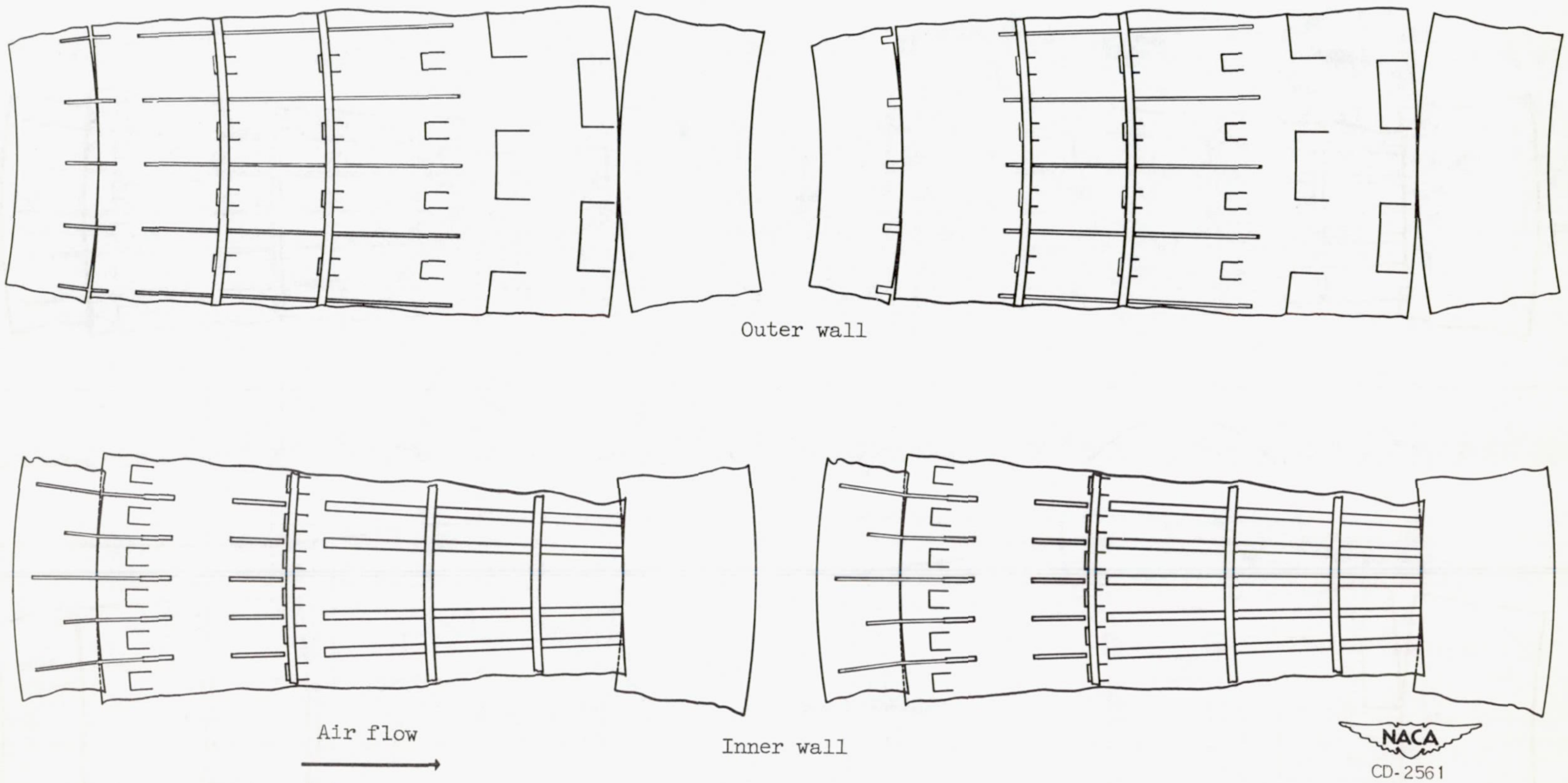


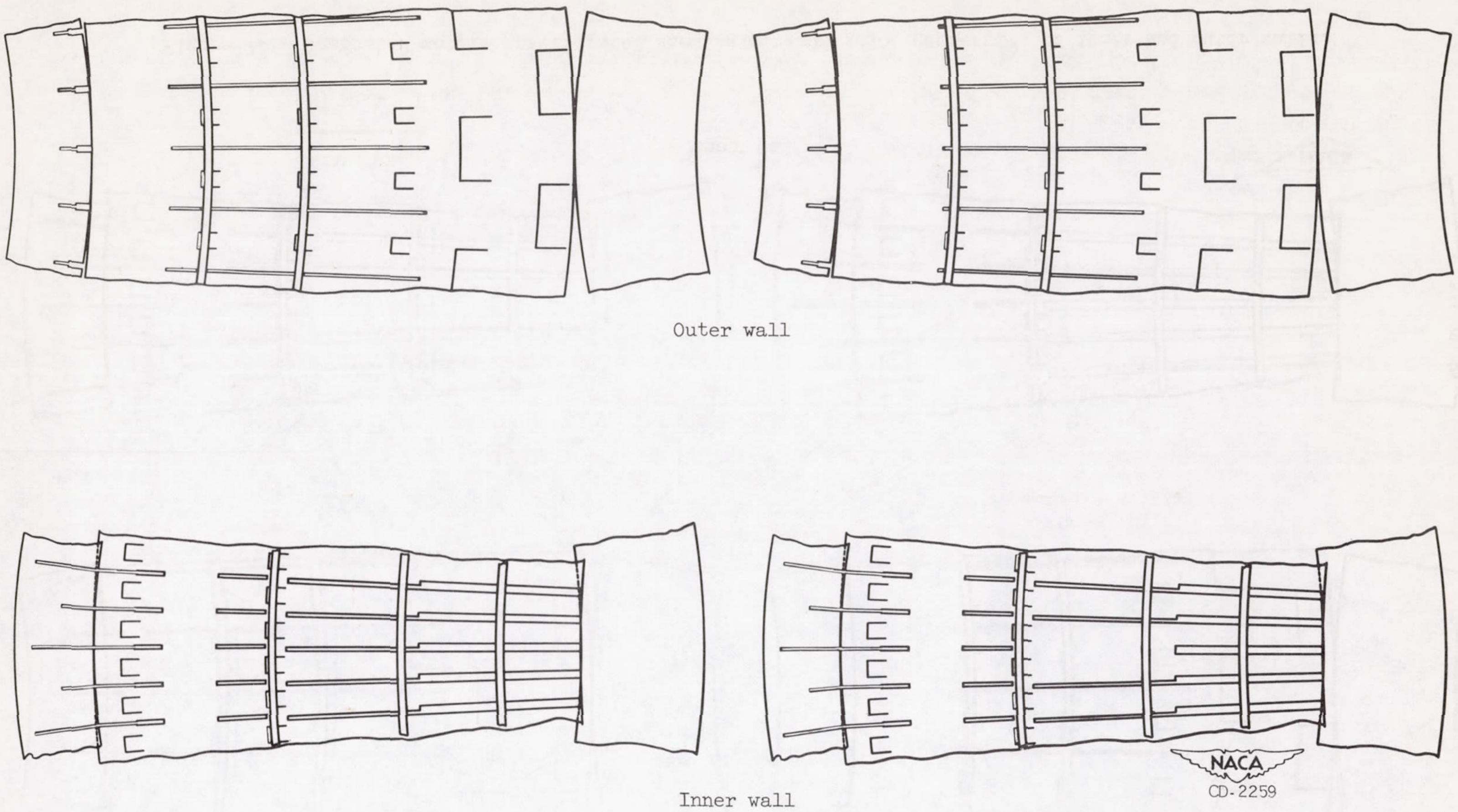
Figure 6. - Assembled arrangement of combustor and housing for one-quarter-annulus setup showing detail of "finger".



(a) Model 1.

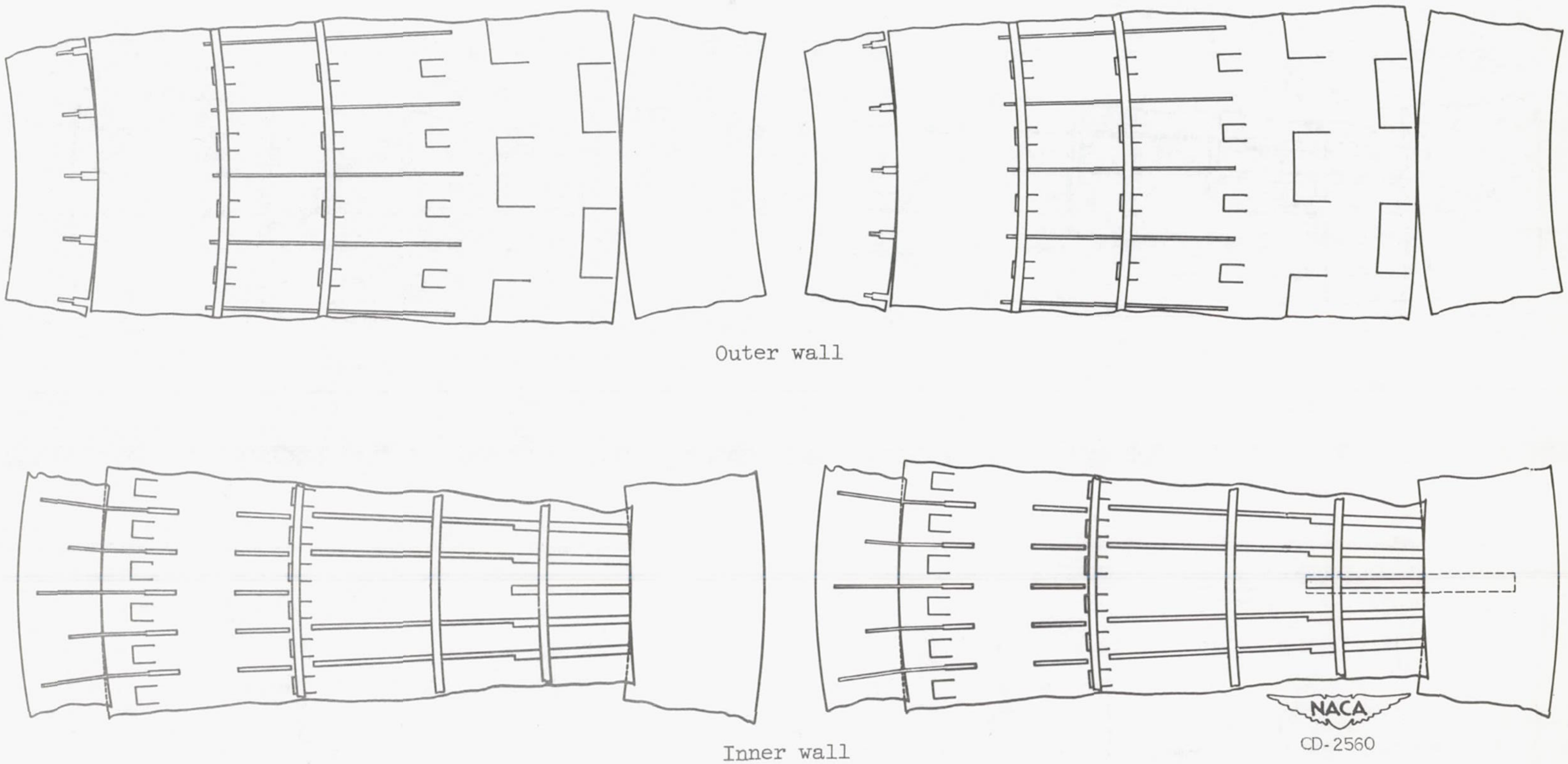
(b) Model 2.

Figure 7. - Combustor models investigated showing air-admission geometries of inner and outer walls.



(c) Model 3. (d) Model 4.

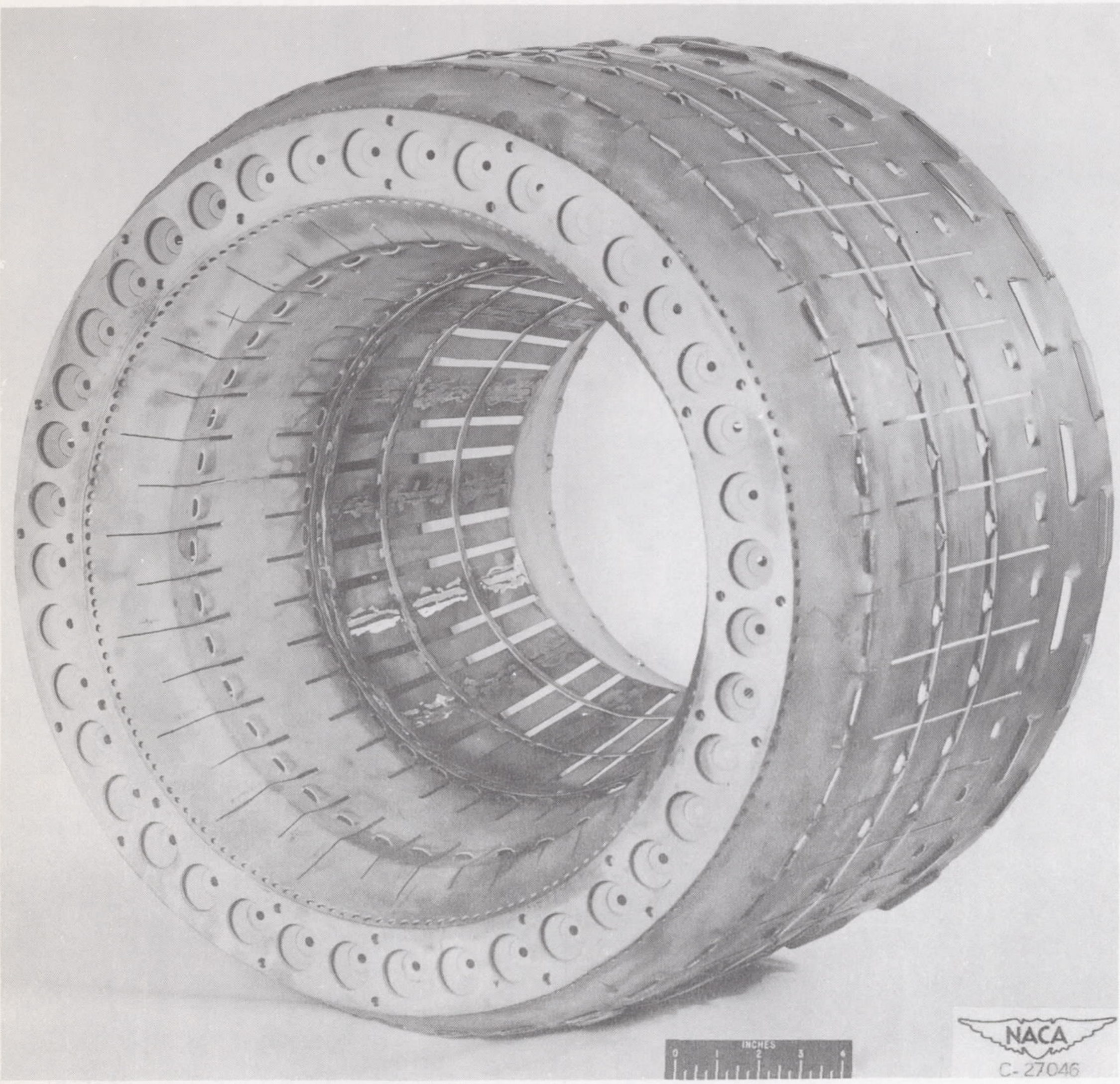
Figure 7. - Continued. Combustor models investigated showing air-admission geometries of inner and outer walls.



(e) Model 5.

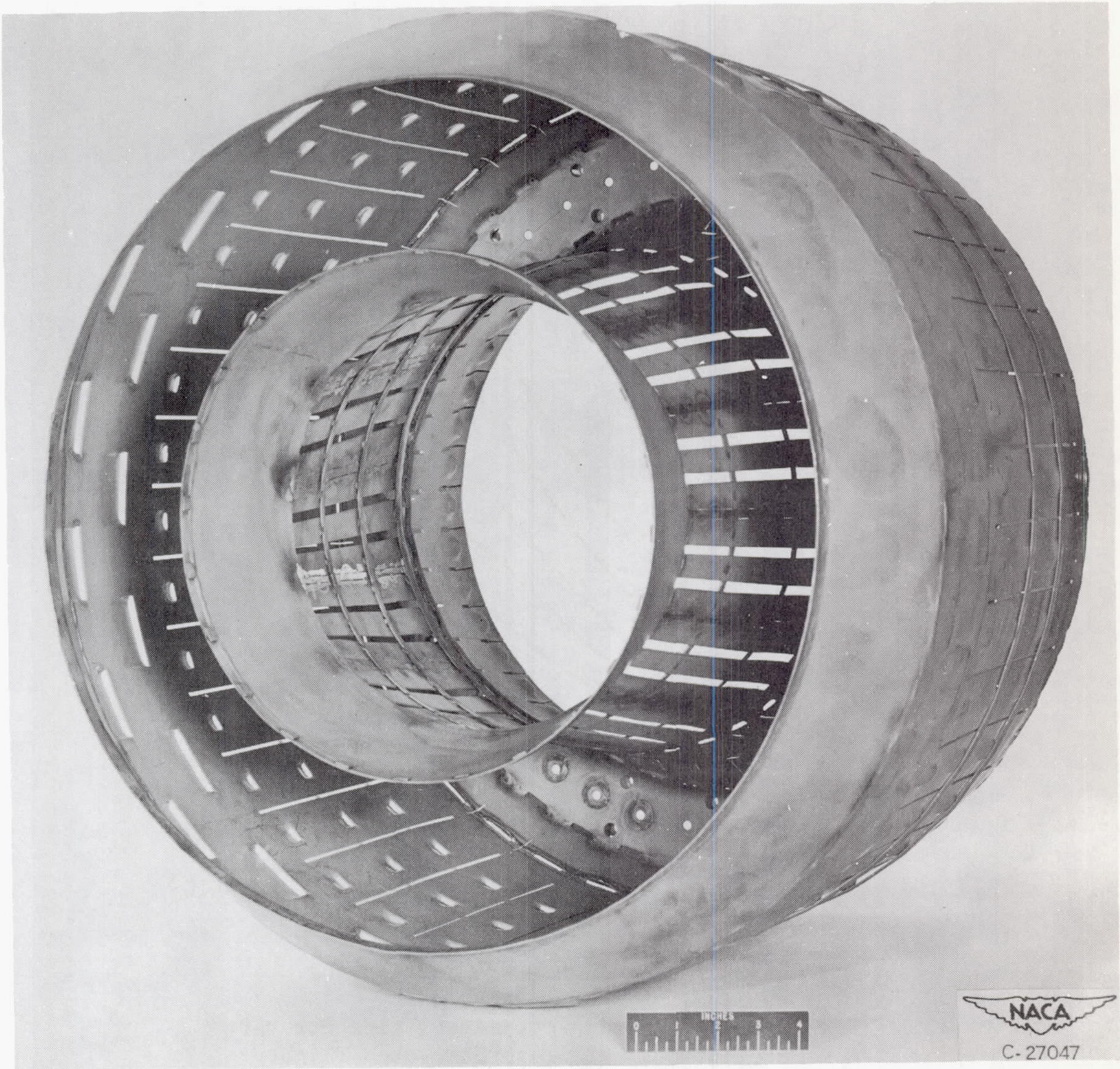
(f) Model 6.

Figure 7. - Concluded. Combustor models investigated showing air-admission geometries of inner and outer walls.



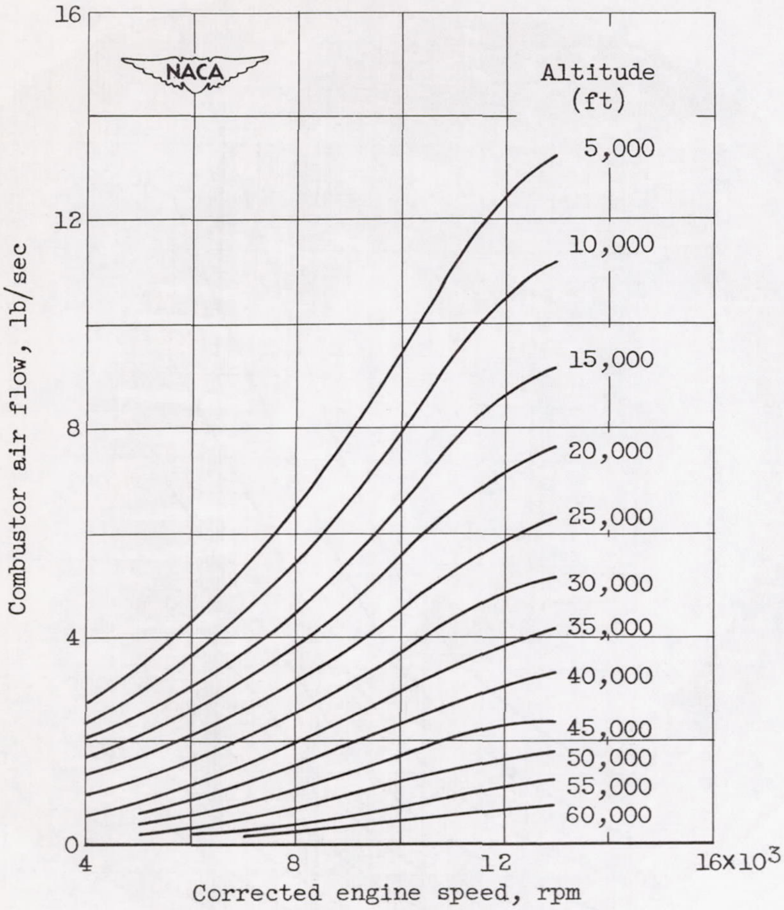
(a) One-quarter view of inlet.

Figure 8. - Full-annulus combustor.



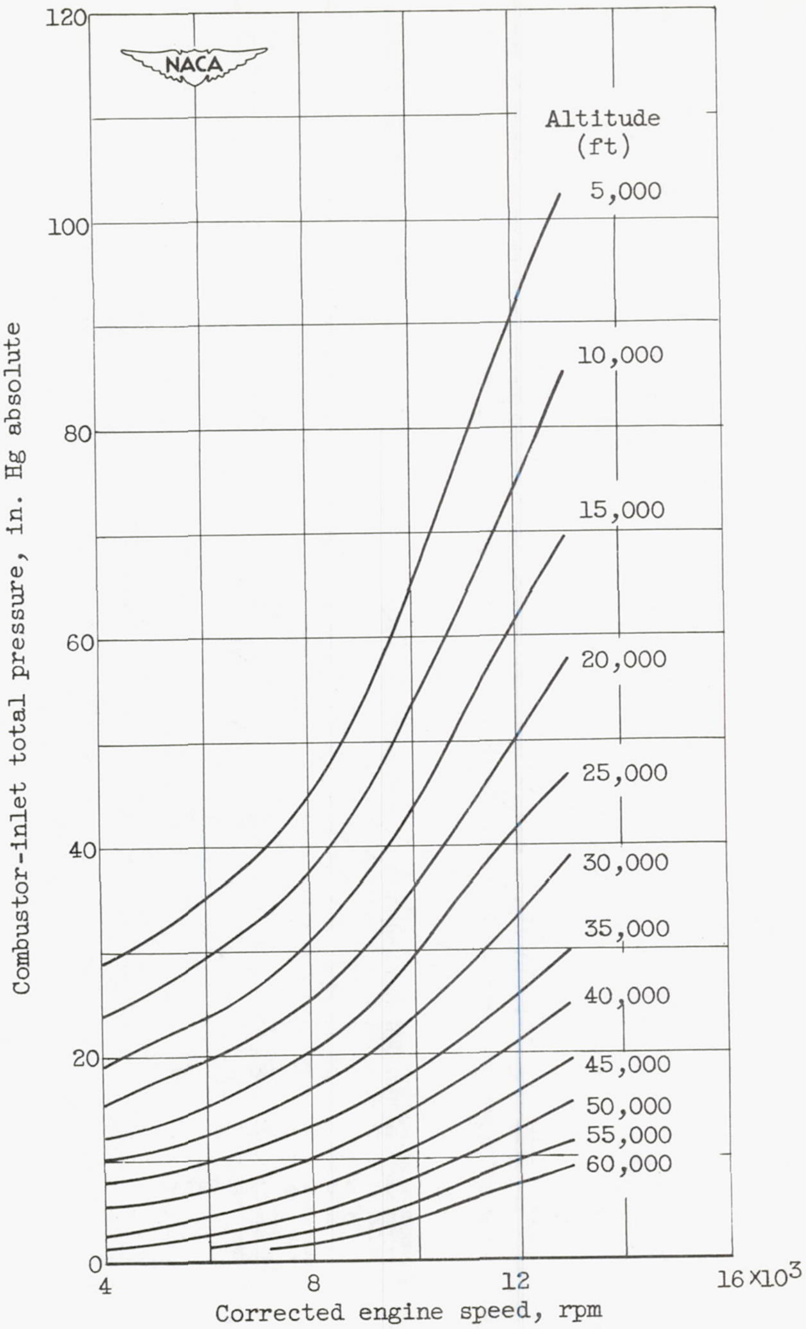
(b) One-quarter view of outlet.

Figure 8. - Concluded. Full-annulus combustor.



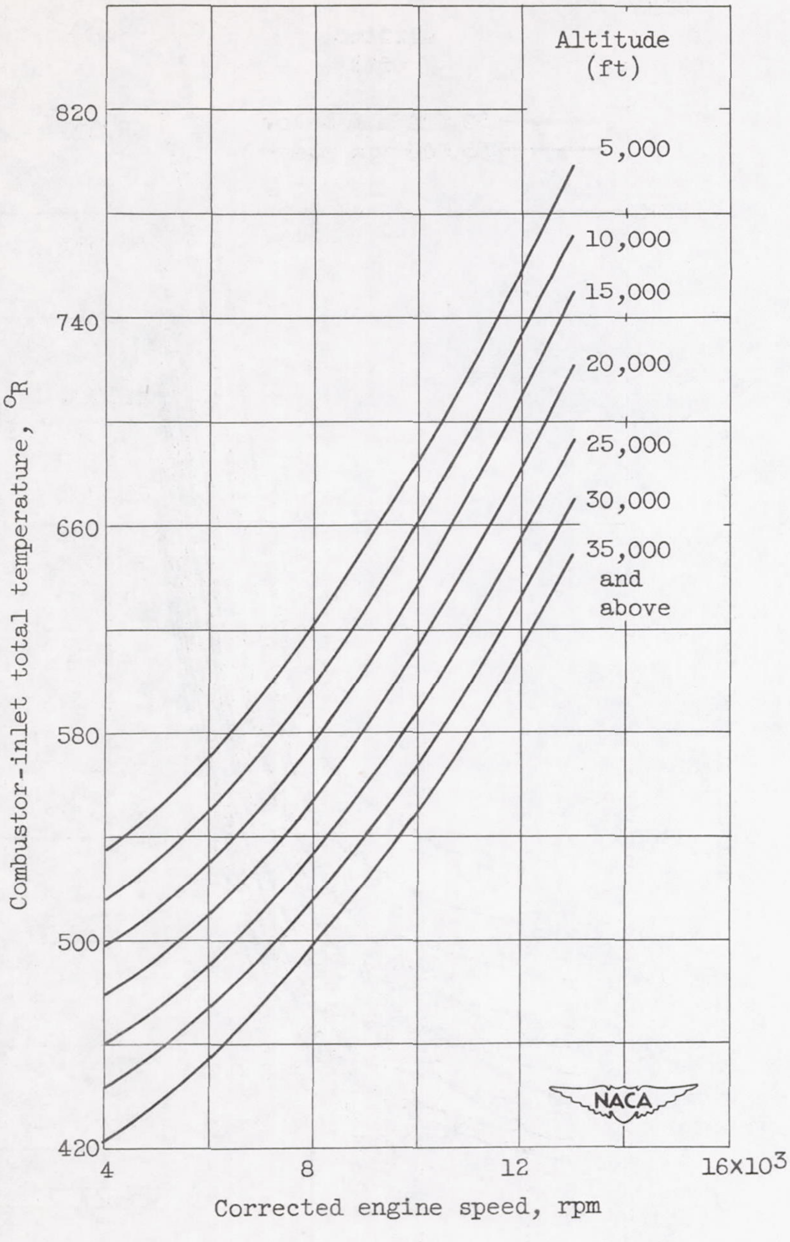
(a) Air flow for one-quarter sector.

Figure 9. - Operating characteristics for reference turbojet engine. Simulated flight Mach number, 0.24.



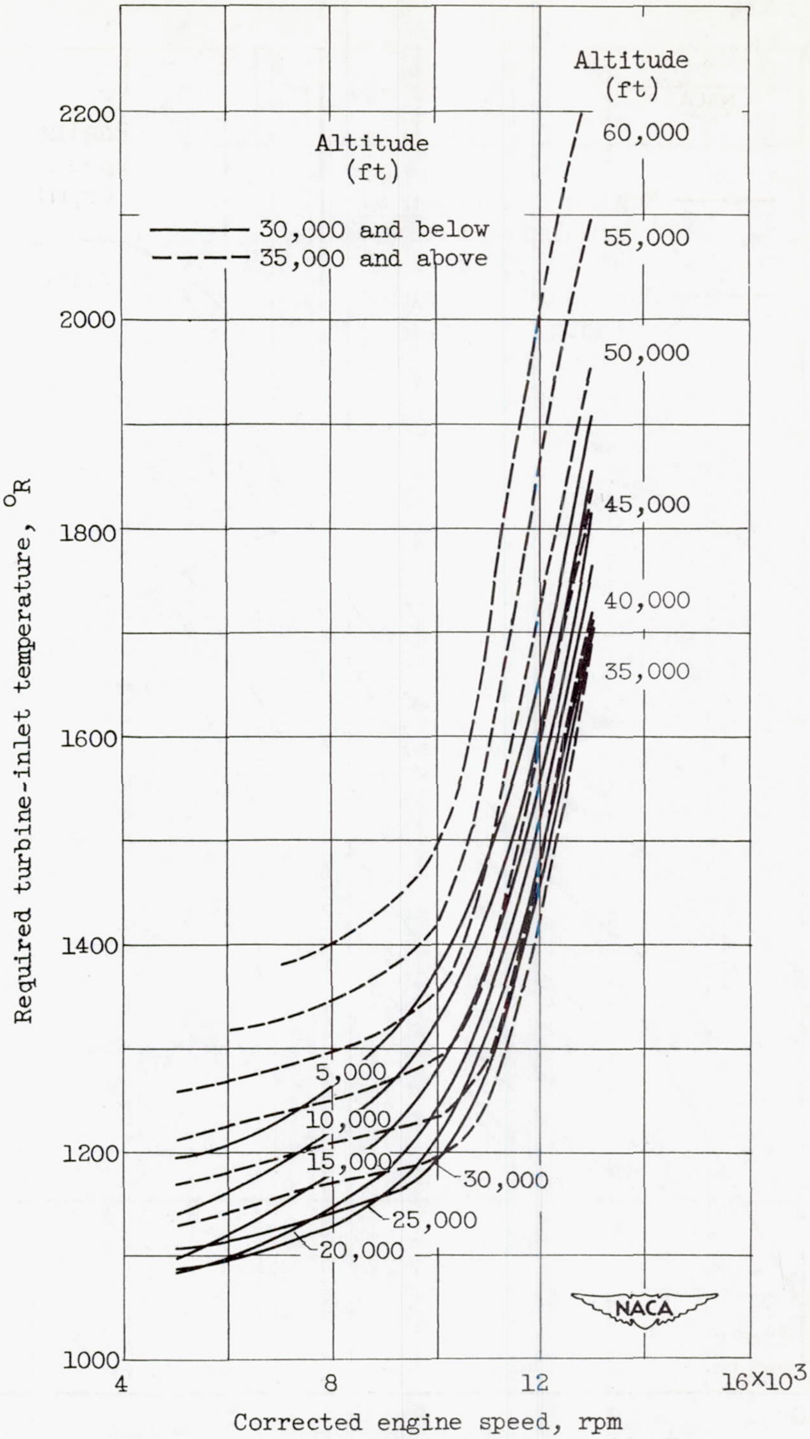
(b) Combustor-inlet air pressure.

Figure 9. - Continued. Operating characteristics for reference turbojet engine. Simulated flight Mach number, 0.24.



(c) Combustor-inlet air temperature.

Figure 9. - Continued. Operating characteristics for reference turbojet engine. Simulated flight Mach number, 0.24.



(d) Required turbine-inlet temperature.

Figure 9. - Concluded. Operating characteristics for reference turbojet engine. Simulated flight Mach number, 0.24.

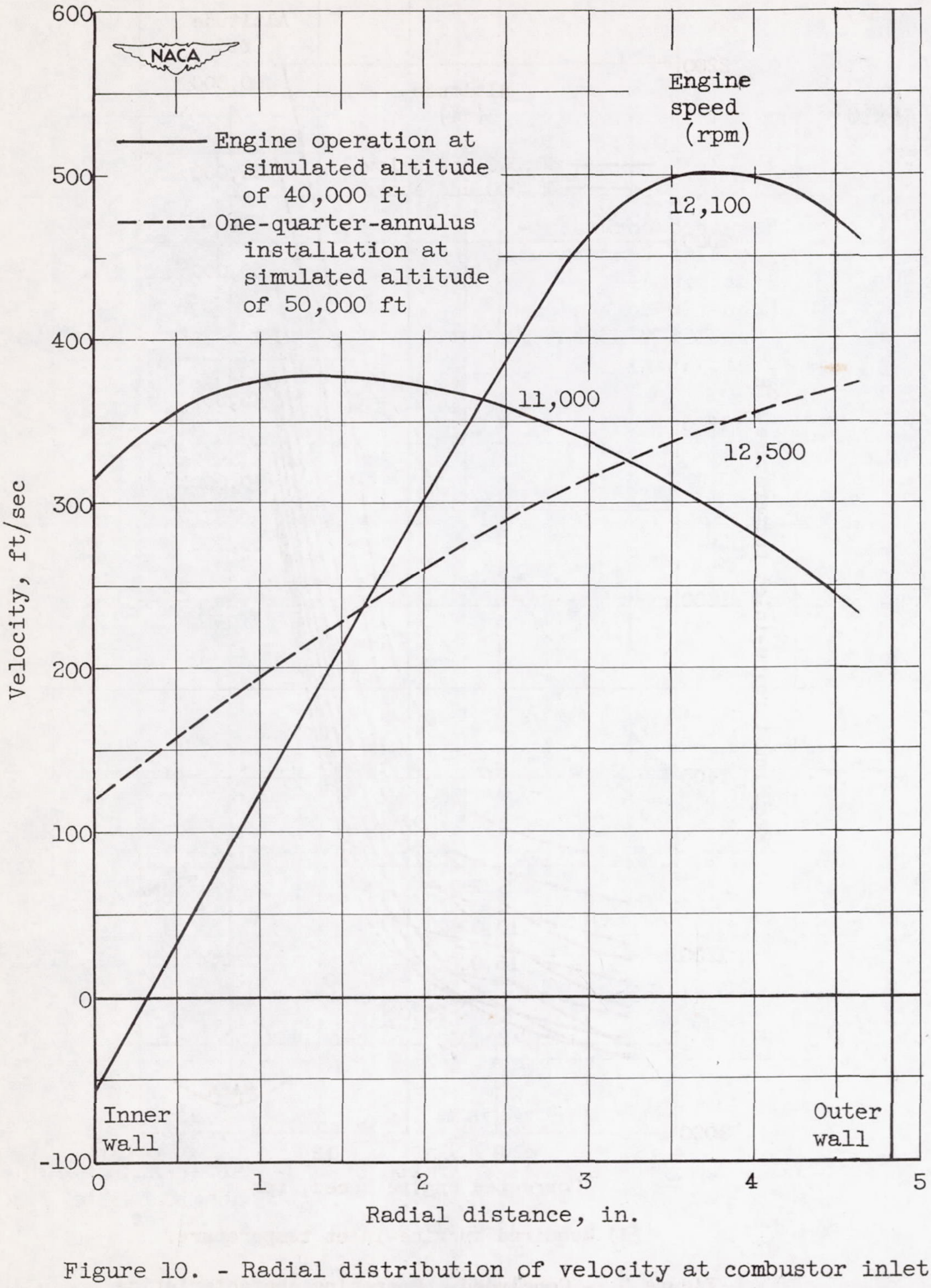


Figure 10. - Radial distribution of velocity at combustor inlet. Model 1.

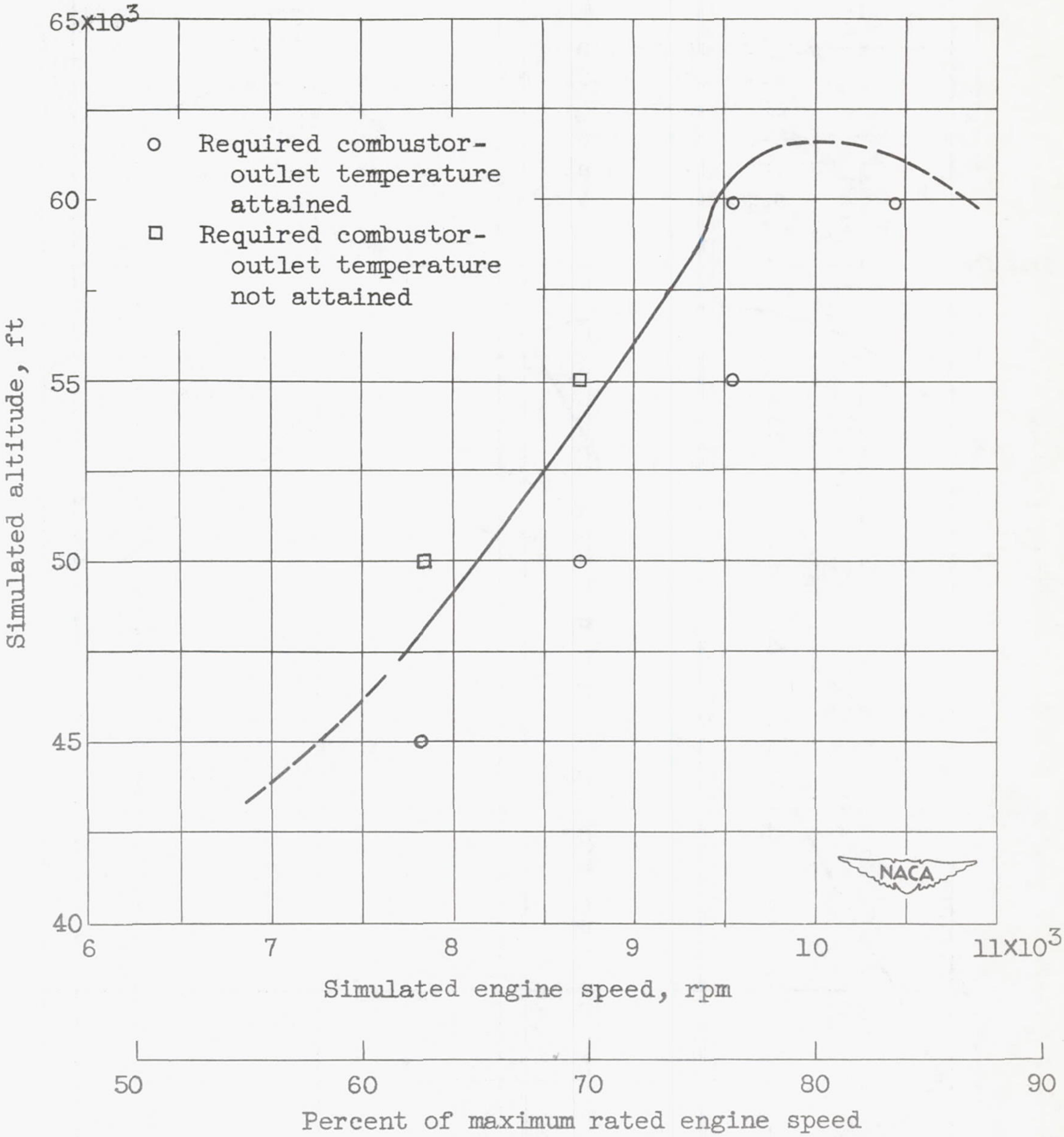


Figure 11. - Altitude operating limits of one-quarter annulus of single-annulus turbojet combustor for flight Mach number of 0.24. Combustor model 1; fuel, MIL-F-5624.

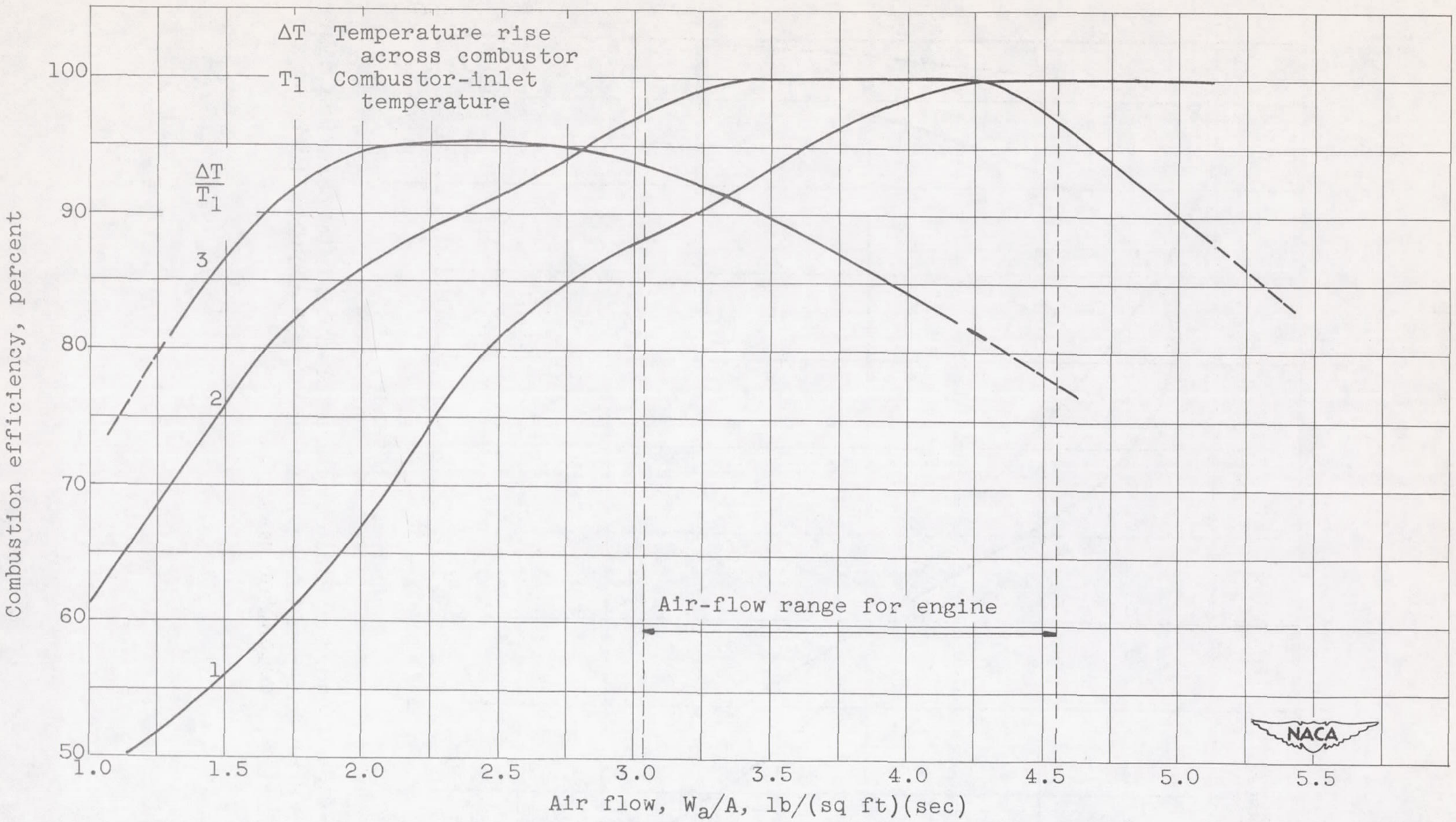


Figure 12. - Variation of combustion efficiency with air flow over range of combustor-outlet temperature levels for one-quarter annulus of single-annulus turbojet combustor. Combustor model 1; combustor-inlet pressure, 10 pounds per square inch absolute; combustor-inlet temperature 532° R.

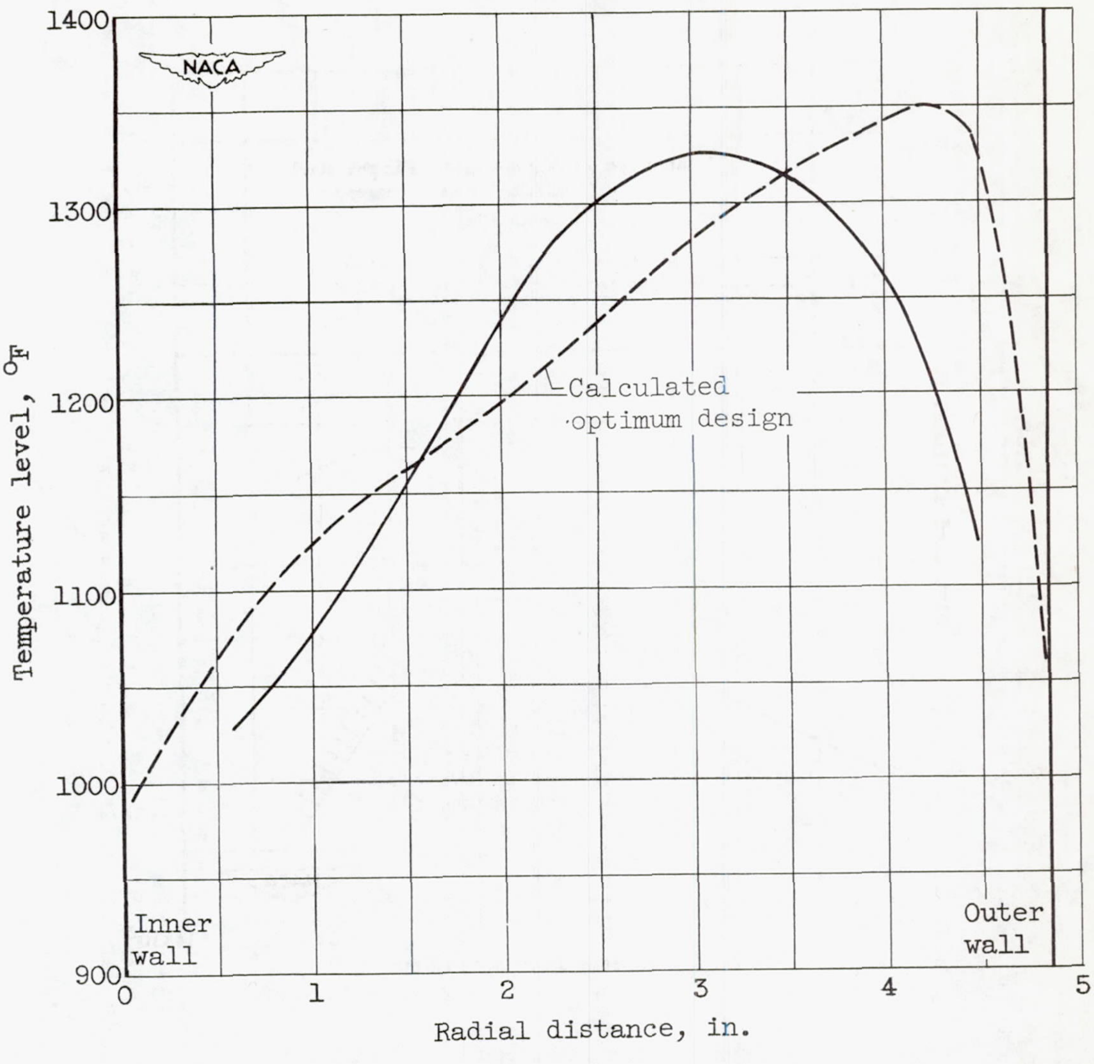
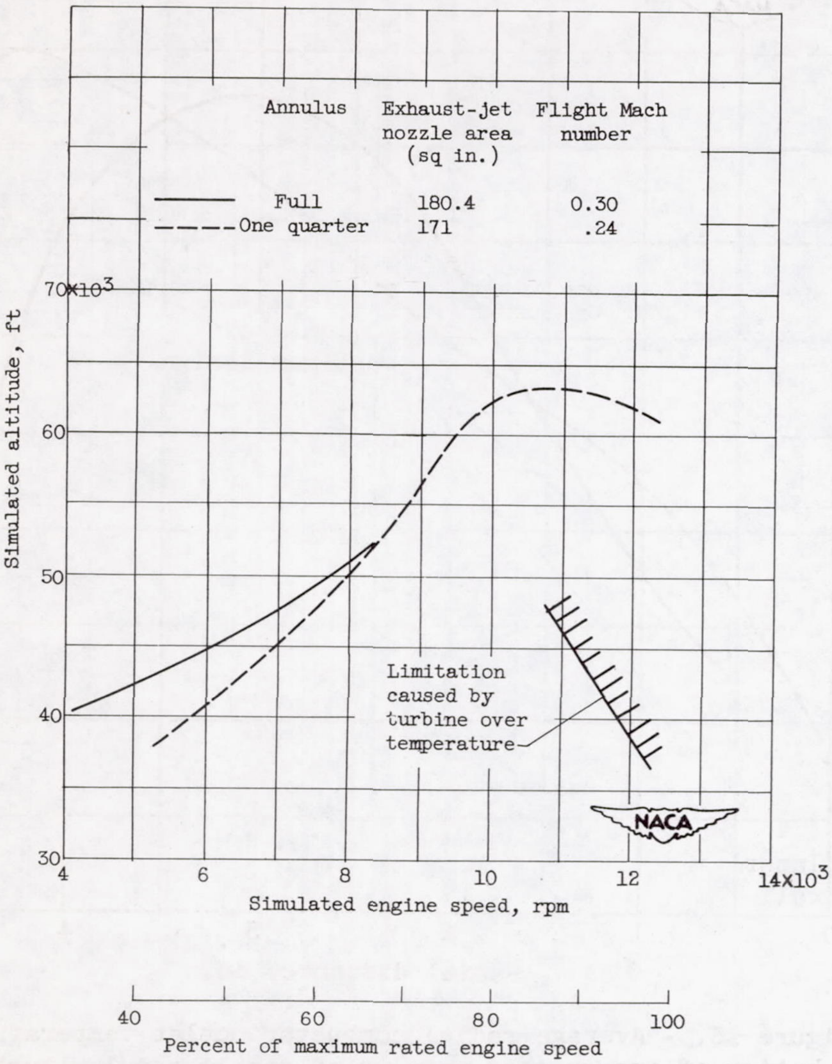
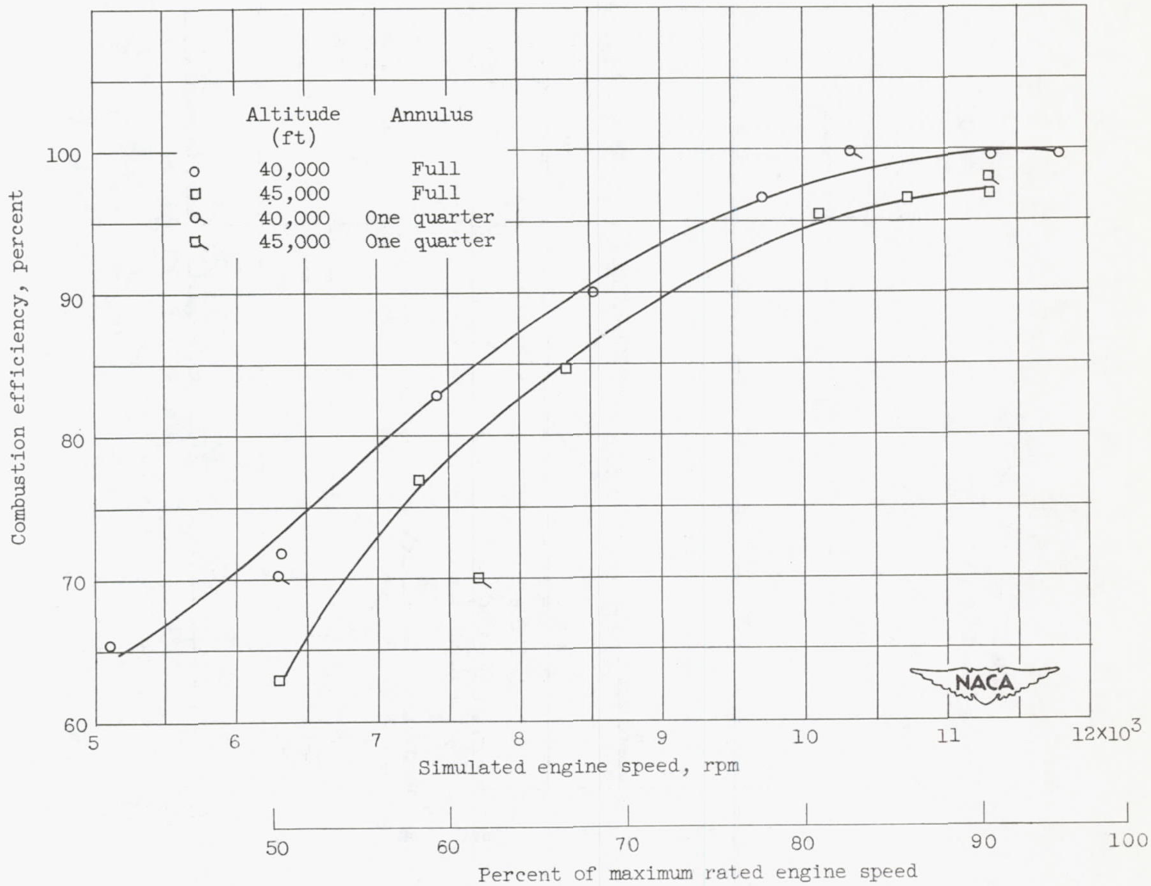


Figure 13. - Average radial combustor-outlet temperature distribution of one-quarter annulus of single-annulus turbojet combustor. Combustor model 1.



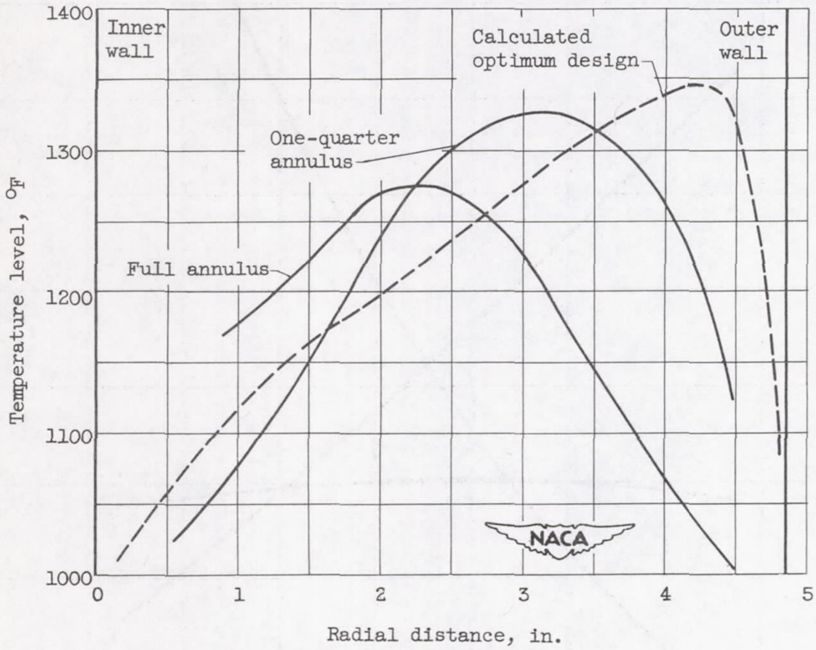
(a) Altitude operating limits.

Figure 14. - Comparison of operating characteristics of one-quarter-annulus and full-annulus turbojet combustors. Combustor model 1; fuel, MIL-F-5624.



(b) Combustion efficiency.

Figure 14. - Continued. Comparison of operating characteristics of one-quarter-annulus and full-annulus turbojet combustors. Combustor model 1; fuel, MIL-F-5624.



(c) Exhaust-gas radial temperature distribution.

Figure 14. - Concluded. Comparison of operating characteristics of one-quarter-annulus and full-annulus turbojet combustors. Combustor model 1; fuel, MIL-F-5624.

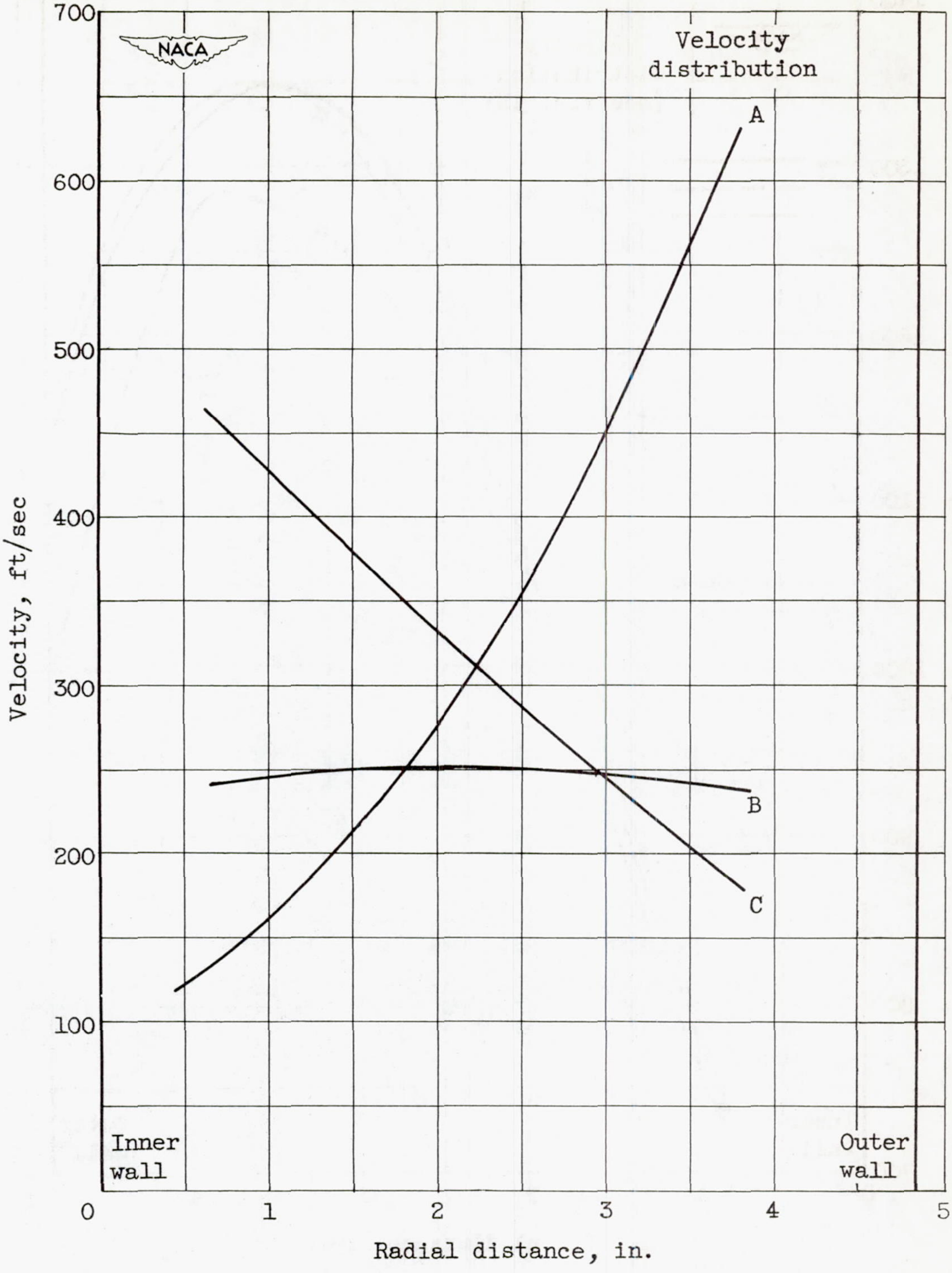


Figure 15. - Combustor-inlet radial velocity distributions imposed on one-quarter-annulus combustor at simulated pressure altitude of 50,000 feet and rated engine speed. Flight Mach number, 0.24.

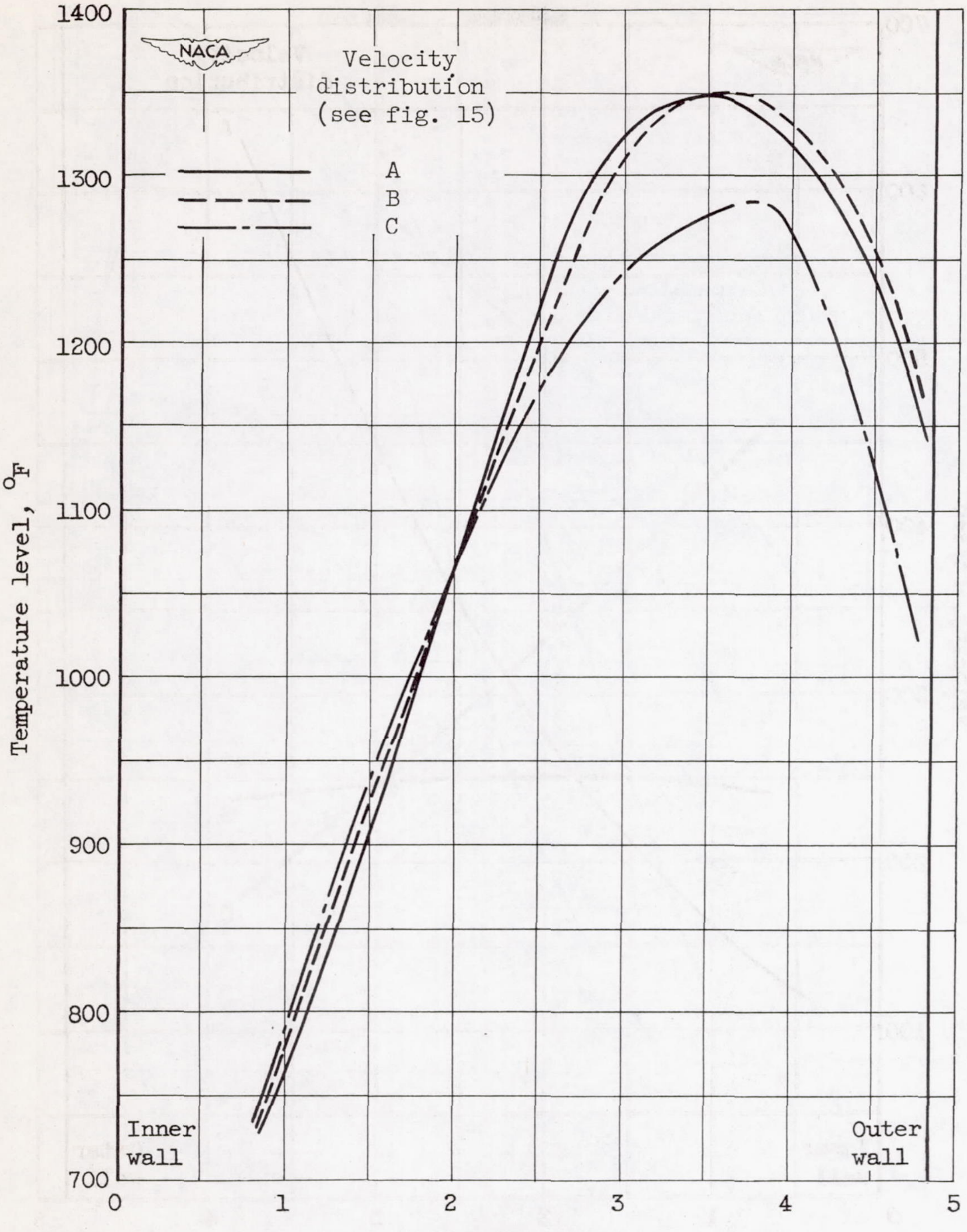
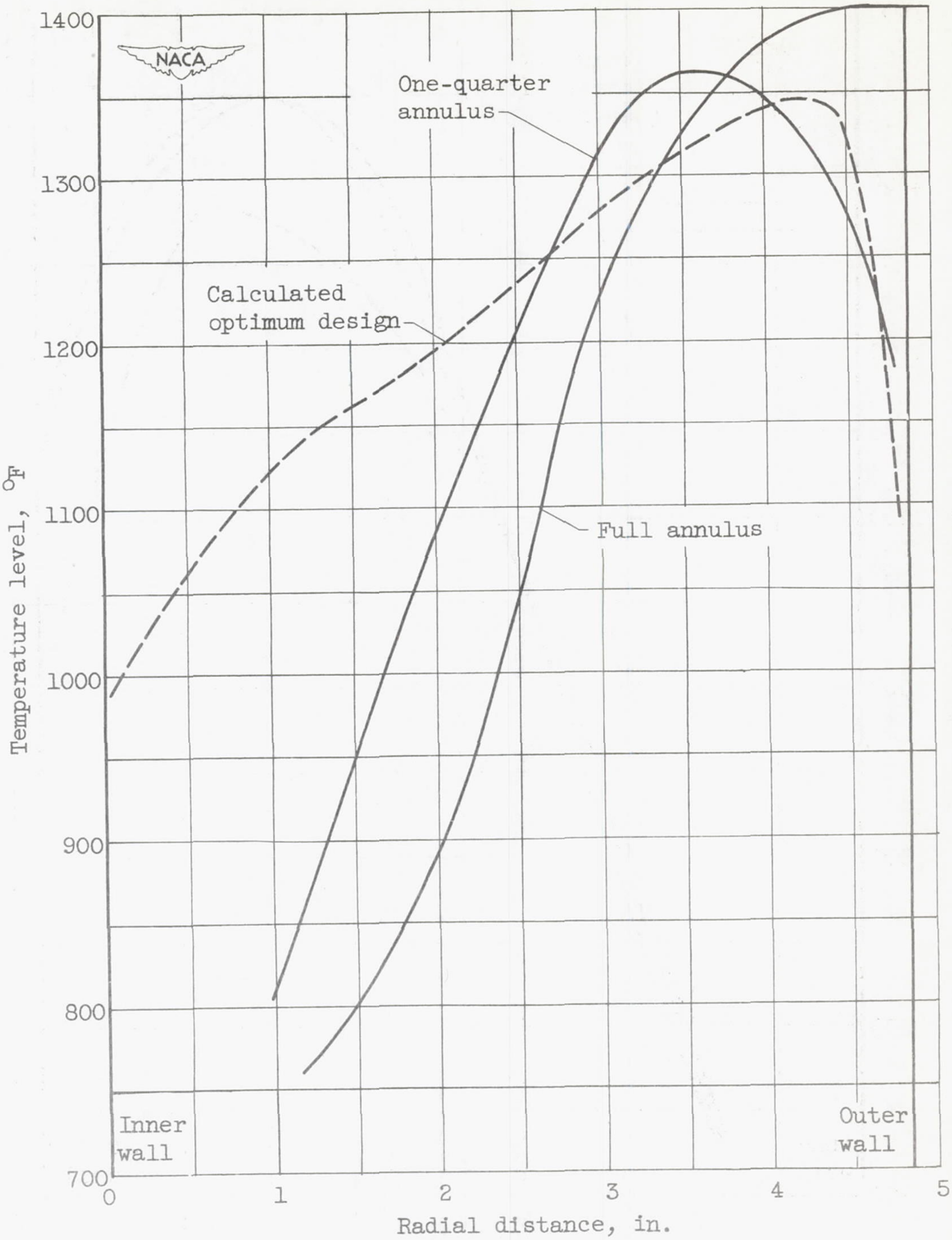
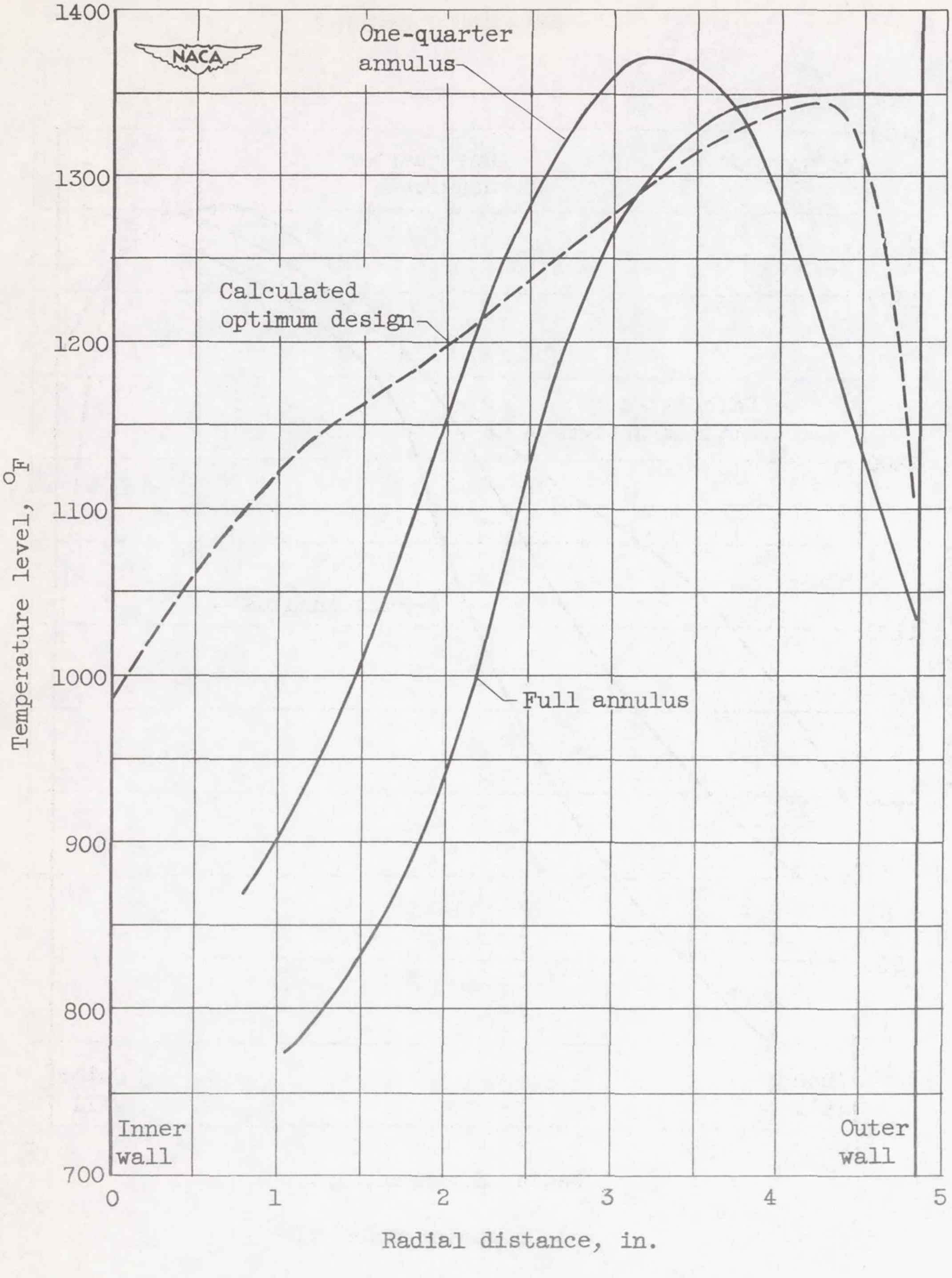


Figure 16. - Effect of imposed combustor-inlet velocity distribution on exhaust-gas radial temperature distribution at simulated pressure altitude of 50,000 feet and rated engine speed. Combustor model 2. Flight Mach number, 0.24.



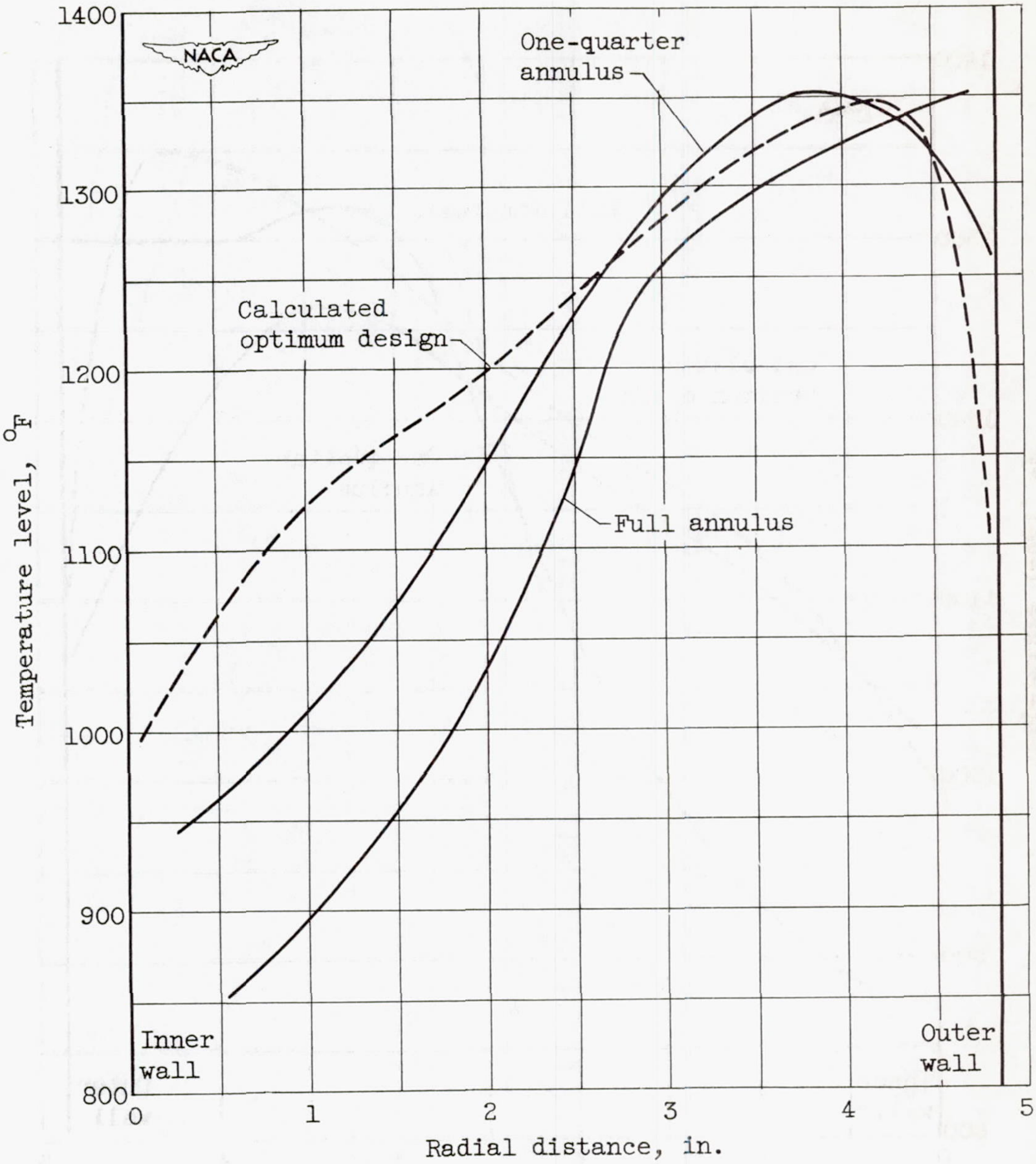
(a) Combustor model 2.

Figure 17. - Comparison of exhaust-gas radial temperature distribution of one-quarter-annulus and full-annulus turbojet combustors. Fuel, MIL-F-5624.



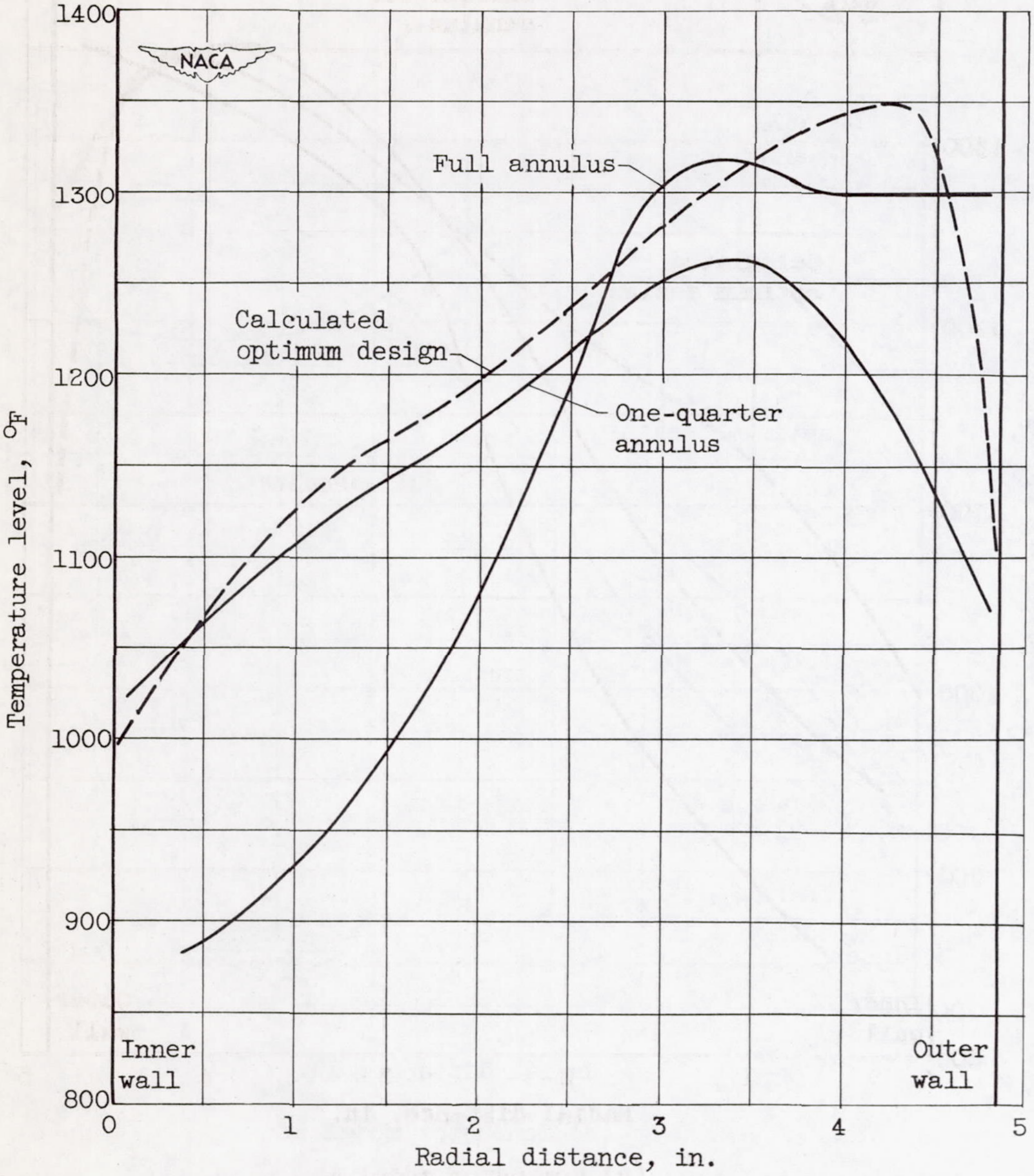
(b) Combustor model 3.

Figure 17. - Continued. Comparison of exhaust-gas radial temperature distribution of one-quarter-annulus and full-annulus turbojet combustors. Fuel, MIL-F-5624.



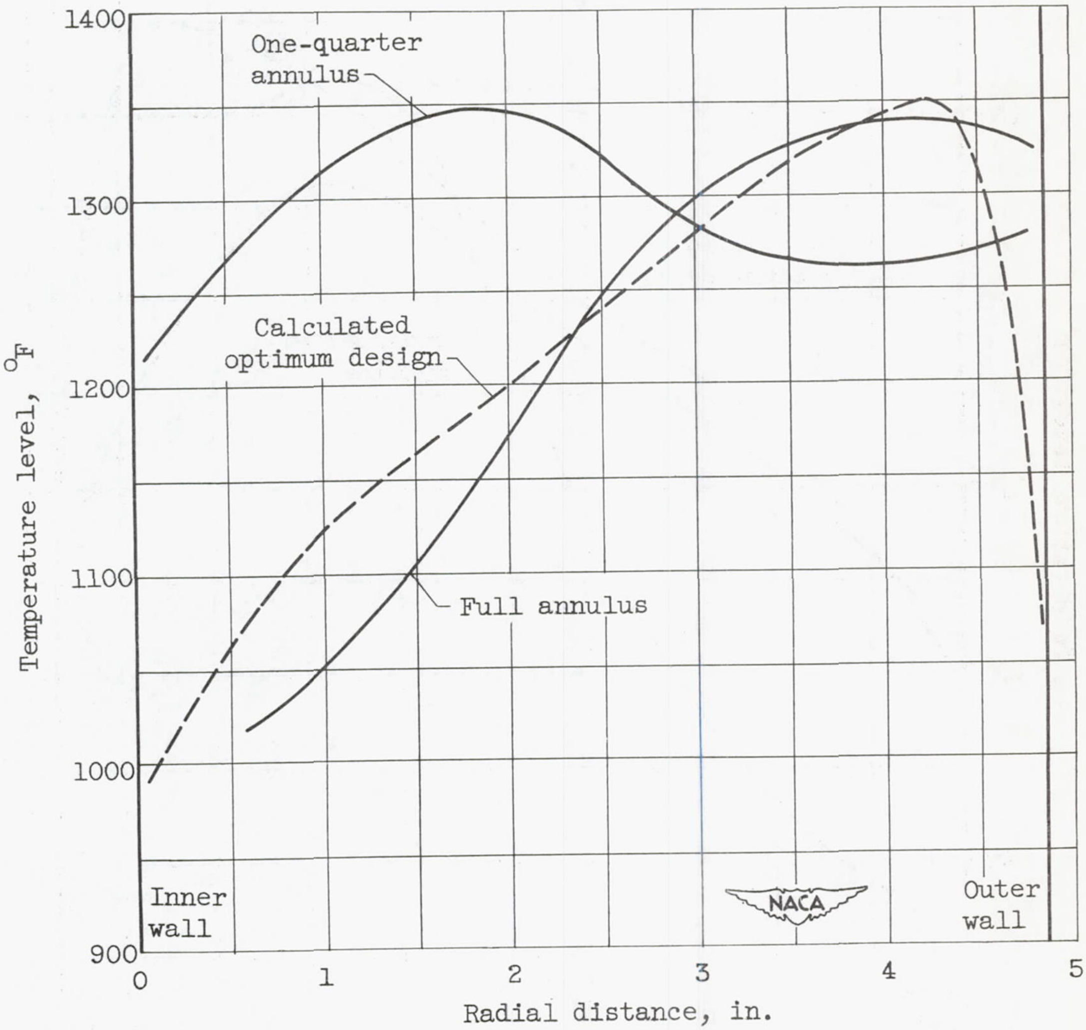
(c) Combustor model 4.

Figure 17. - Continued. Comparison of exhaust-gas radial temperature distribution of one-quarter-annulus and full-annulus turbojet combustors. Fuel, MIL-F-5624.



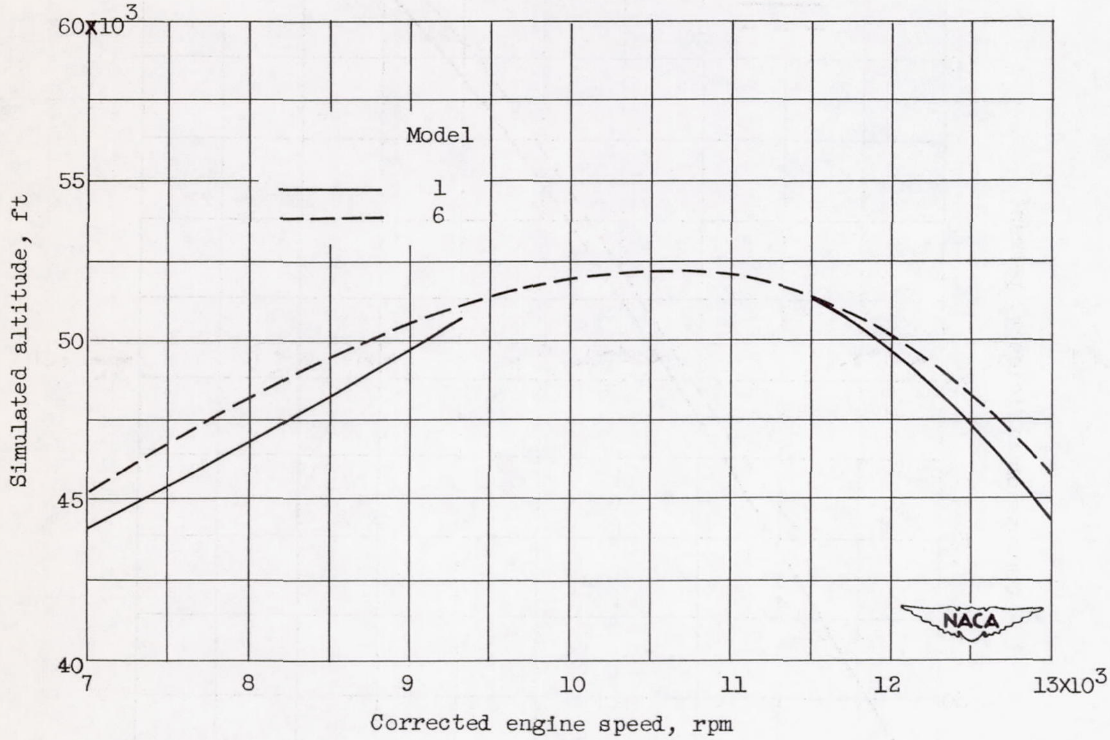
(d) Combustor model 5.

Figure 17. - Continued. Comparison of exhaust-gas radial temperature distribution of one-quarter-annulus and full-annulus turbojet combustors. Fuel, MIL-F-5624.



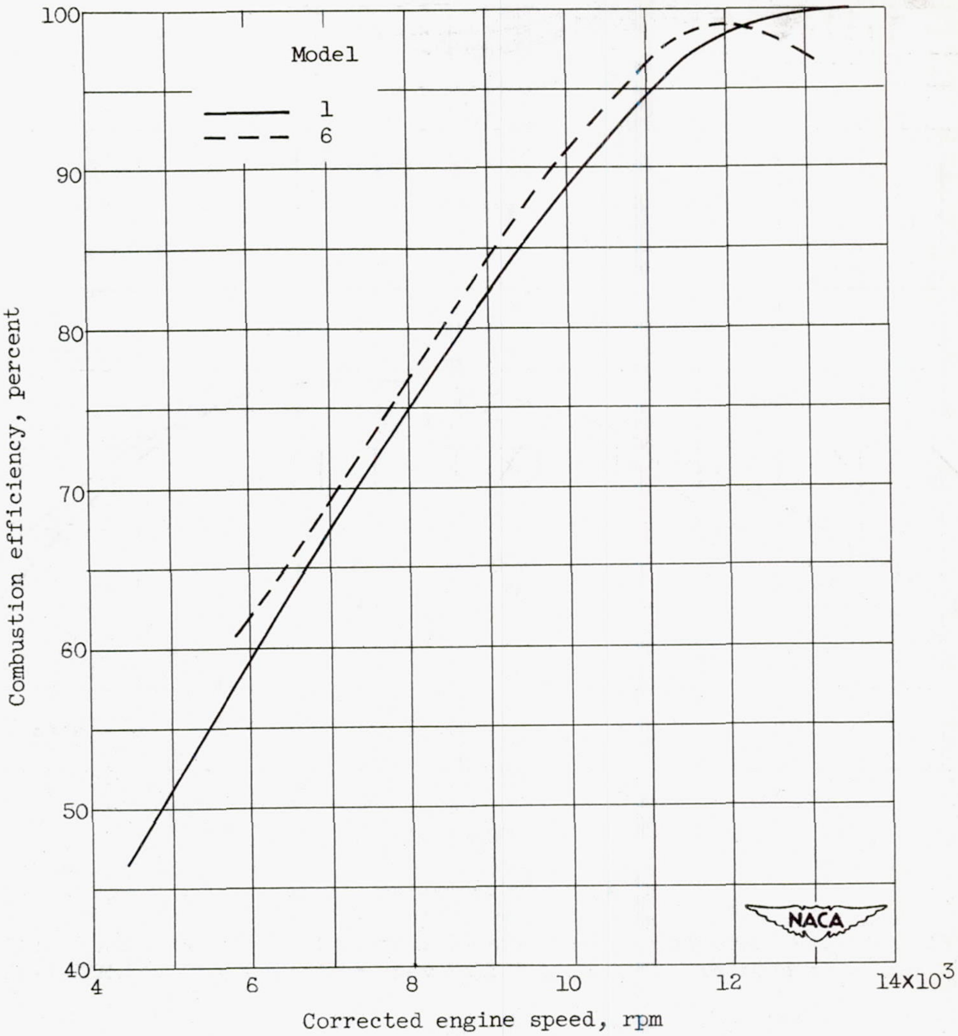
(e) Combustor model 6.

Figure 17. - Concluded. Comparison of exhaust-gas radial temperature distribution of one-quarter-annulus and full-annulus turbojet combustors. Fuel, MIL-F-5624.



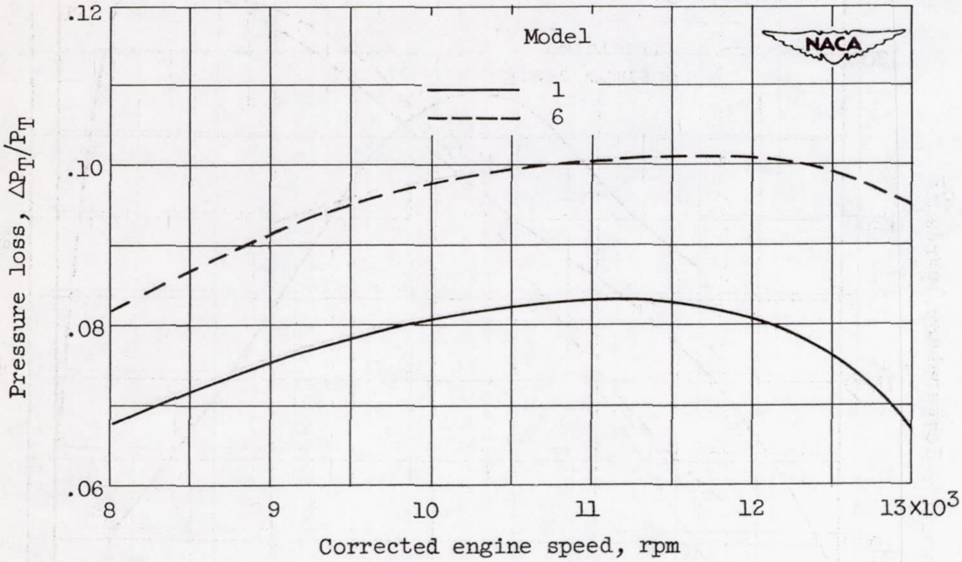
(a) Altitude operating limits.

Figure 18. - Comparison of performance between model 1 and model 6 in full-annulus combustor. Simulated flight Mach number, 0.30; fuel MIL-F-5624.



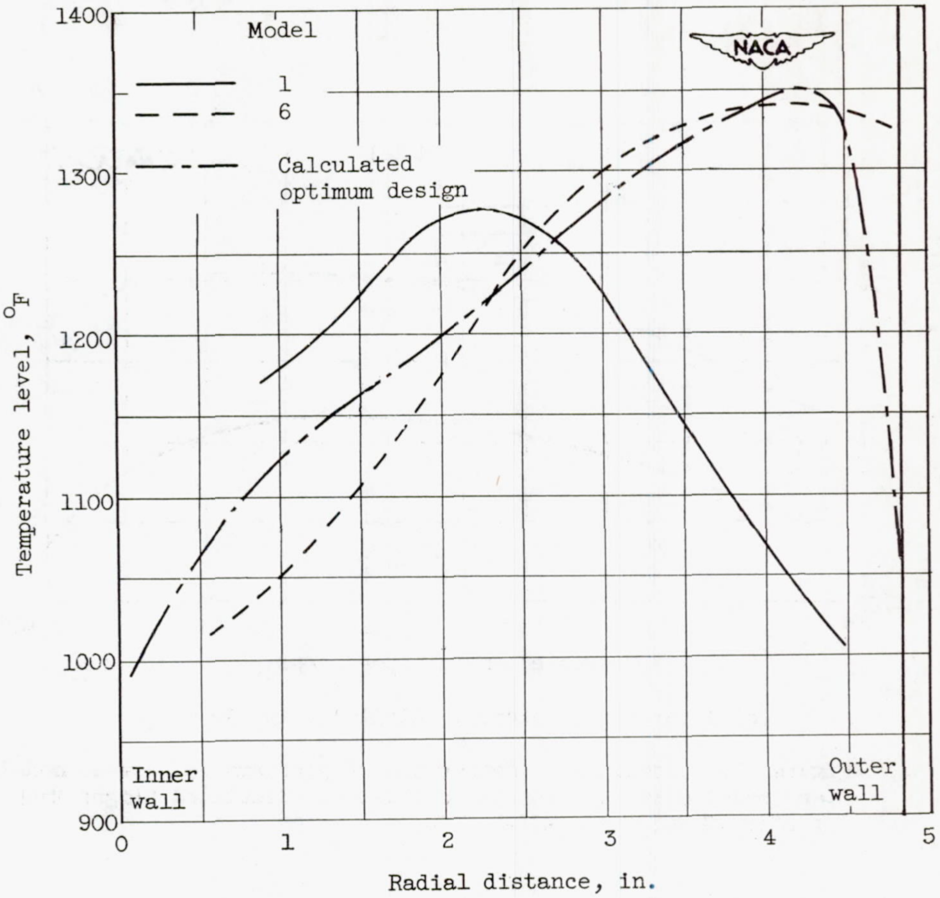
(b) Combustion efficiency. Altitude, 40,000 feet.

Figure 18. - Continued. Comparison of performance between model 1 and model 6 in full-annulus combustor. Simulated flight Mach number, 0.30; fuel, MIL-F-5624.



(c) Total-pressure drop. Altitude, 40,000 feet.

Figure 18. - Continued. Comparison of performance between model 1 and model 6 in full-annulus combustor. Simulated flight Mach number, 0.30; fuel, MIL-F-5624.



(d) Radial temperature distribution.

Figure 18. - Concluded. Comparison of performance between model 1 and model 6 in full-annulus combustor. Simulated flight Mach number, 0.30; fuel, MIL-F-5624.

NACA-Langley - 3-24-52 - 350