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EFFECT OF NACA INJECTION IMPELLER AND DUCTED HEAD BAFFLES ON FLIGHT COOLING PERFORMANCE OF DOUBLE-ROW RADIAL ENGINE IN FOUR-ENGINE HEAVY BOMBER

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MEMORANDUM REPORT

for the

Army Air Forces, Air Technical Service Command

EFFECT OF NACA INJECTION IMPELLER AND DUCTED HEAD BAFFLES ON FLIGHT COOLING PERFORMANCE OF DOUBLE-ROW RADIAL ENGINE IN FOUR-ENGINE HEAVY BOMBER

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SUMMARY

In order to relieve the limitations imposed by improper engine cooling on the performance of a four-engine heavy bomber, the NACA has conducted a flight investigation to improve the cooling characteristics of the installation of a double-row radial engine. The tests reported herein concern the use of the NACA injection impeller and ducted head baffles in various combinations on both the port inboard and the port outboard engines. The performance of the modified installation was evaluated by comparing it with that of the standard engines.

It was found that use of the NACA injection impeller reduced the spread of fuel-air ratios among the cylinders to less than one-half its original value. As a result of improved mixture distribution, the maximum cylinder temperatures caused by poor mixture distribution were reduced and responded normally to enrichment cooling. The difference between the temperatures of the hottest and coldest cylinders was decreased. Ducted head baffles, designed to provide additional cooling air for the critical temperature regions of the rear-row cylinders, reduced the temperatures of the exhaust-valve seats approximately 50° F. Results of the flight cooling investigation were in substantial agreement with previously determined test-stand performance of the modified engine.

The NACA injection impeller in combination with ducted head baffles on a few of the hottest cylinders proved satisfactory for the particular engine tested. Because the same cylinders do not develop the highest temperature in all engines of the same type, the NACA injection impeller and ducted head baffles on all rear-row cylinders was found to be a more adaptable arrangement. An analysis

of the cooling data indicated that the use of these modifications reduced the pressure drop required to cool the exhaust-valve seat to one-half the original value. Consequently for all conditions at which cooling is possible with the standard engine installation, proper cooling of the exhaust-valve seat may be attained of the modified engine installation with a cowl-flap angle of less than 4°.

INTRODUCTION

Because inadequate engine cooling has limited the performance of the four-engine heavy bomber, the NACA has investigated means to improve the cooling of the double-row radial air-cooled engines installed in this airplane. Failure of the exhaust valve and exhaust-valve seat is one of the difficulties encountered most frequently. Single-cylinder tests have demonstrated that the failure develops progressively after warping of the exhaust-valve seat which apparently resulted from nonuniform heating. Large differences in the temperatures of various cylinders, which exist at nearly all flying conditions, make it difficult to maintain the temperature of each exhaust-valve seat below the value at which warping becomes dangerous. In order to prevent engine failures through overheating, it has been necessary to fly either with large cowl-flap angles or with very rich mixtures.

The differences between the exhaust-valve-seat temperatures of various cylinders may be resolved into the difference between the average temperatures of the two cylinder rows and the temperature variation between the cylinders of a given row. In the engines used in this investigation, the exhaust ports of the front-row cylinders face the front of the engine instead of the rear as do the cylinders in the rear row. Consequently the critical exhaust-valve-seat areas of the front-row cylinders are cooled more adequately and operate at a lower temperature level than the critical areas of the rear-row cylinders. The circumferential temperature variation, that is, the temperature variation between cylinders of one row, may be attributed to nonuniform charge-air and mixture distribution as well as to irregular cooling-air flow resulting from engine cowling characteristics and airplane flight attitude.

In order to improve the mixture distribution and to reduce the exhaust-valve-seat temperatures of the rear-row cylinders, the NACA injection impeller and special ducted head baffles were designed and adapted to the double-row radial engine. Test-cell investigations with this engine showed that remarkably uniform mixture distribution could be attained through use of the injection impeller (reference 1) and that ducted head baffles (reference 2), designed to conduct cool air over the exhaust-valve regions of the rear-row cylinders, were very effective in reducing the temperatures of the rear-row cylinders. Flight tests with the four-engine heavy bomber were therefore undertaken to substantiate these improvements under actual flight operation.

The present report discusses the effect of the NACA injection impeller and the ducted head baffles on the mixture distribution, the temperature distribution, and the cooling characteristics of the standard double-row radial engine determined in level-flight tests of the bomber. The investigation was conducted at the request of the Army Air Forces, Air Technical Service Command, at the Cleveland laboratory of the NACA.

APPARATUS AND INSTRUMENTATION

The airplane and engines. - The B-29 airplane (fig. 1) is a long-range, high-altitude bomber powered by four R-3350-23 engines. The airplane has a wing span of 143 feet, a wing area of approximately 1750 square feet, and a gross weight of between 80,000 and 140,000 pounds, depending on the fuel and bomb loads. Each of the double-row radial air-cooled engines has a normal rating of 2000 brake horsepower at 2400 rpm and a take-off rating of 2200 brake horsepower at 2600 rpm. In addition to the single-speed engine-stage supercharger, two turbosuperchargers operating in parallel are used in the installation of each of the four engines. The standard carburetors used during the flight tests were calibrated for air flow and were checked to assure correct metering characteristics. The fuel used conformed to AN-F-28 specifications, performance grade 130.

Cowl flaps 16 inches long and approximately 17 inches wide at the hinge are located around 300° of the circumference of each nacelle; no cowl flaps are provided at the bottom of the nacelle owing to the presence of the air-intake duct. The two flaps at the top of the cowl have a fixed opening of approximately 9° and all other flaps have a useful open range from 2° to 16°.

The NACA injection impeller. - The NACA injection impeller shown in figure 2 was designed (reference 1) for use with the double-row radial engine. The metered fuel from the carburetor is fed to a stationary nozzle ring and is delivered from the nozzle ring into the collector cup that rotates with the impeller. An air gap, which is provided between the nozzle ring and the rotating collector cup, was designed to prevent surging in the fuel system. The fuel thrown to the surface of the collector by the rotating vaned fuel inducer flows by centrifugal action through the collector cup and the impeller transfer passages to the fuel-distribution annulus. From the fuel-distribution annulus, the fuel is thrown by centrifugal action through radial holes into the air stream of the impeller passages. The installation of the injection impeller adds negligible weight to the engine.

Ducted head baffles. - Ducted head baffles (fig. 3) were adapted to the double-row radial engine as described in reference 2. The standard cylinder-head baffle for the rear-row cylinders of the engine was changed to accommodate a 3-inch-diameter duct extending over the head baffle and downward (fig. 3) at the rear of the cylinder. The exit furnishes the horizontal cooling fins adjacent to the exhaust port with a direct blast of cold air that has not previously contacted any hot surfaces. The lower end of the duct is fastened to the cylinder by means of a stud screwed into the thermocouple boss at the rear of the cylinder head. The baffle modifications increased the weight of the cylinder 0.90 pound.

Instrumentation. - All the tests were conducted on the port inboard and outboard engines of the bomber. The engine instrumentation was restricted to the minimum required to indicate the performance of the NACA injection impeller and ducted head baffles. Cylinder temperatures of the test engines were measured by thermocouples on the rear spark-plug gasket of all cylinders and by thermocouples embedded in the exhaust-valve seat of the rear-row cylinders. The fuel flow was measured by means of rotameters and the flow of charge air was calculated from the uncompensated carburetor metering pressure. The temperature and pressure of the charge air were measured by two thermocouples in the intercooler elbow and by impact tubes at the carburetor inlet. Torque noses installed on both test engines and the standard engine tachometers provided data for calculating the engine power.

Indicated airspeed was computed from readings of a standard NACA shielded total-pressure tube and swiveling static-pressure tube mounted on a boom extending 1 chord length ahead of the port wing tip. The pressure altitude was measured with a sensitive altimeter. The angle of the cowl-flap opening was observed through use of calibrated position transmitters and indicators.

TEST PROCEDURE AND METHOD OF ANALYSIS

In order to evaluate the effect of the engine modifications, the cooling characteristics of the standard double-row radial engine installation for the airplane were investigated in level-flight tests. These flight tests revealed the nature and severity of the cooling difficulties. Comparable tests were then made with various modified engine installations; each intended to correct or compensate for some factor contributing to improper cooling. Although the cooling problem was found to be more severe on the inboard engine than on the outboard engine, both port engines were used to test impeller injection and the baffle modifications in order to eliminate unnecessary changes of installation. The modifications were tested in the following combinations:

Inboard engine
  Injection impeller
  Injection impeller and ducted head baffles on five hottest rear-row cylinders
  Injection impeller and ducted head baffles on all rear-row cylinders

Outboard engine
  Ducted head baffles on all rear-row cylinders
  Injection impeller and ducted head baffles on all rear-row cylinders

The flight test of the standard engine and of the engines equipped with the NACA injection impeller and ducted head baffles on all rear-row cylinders were made over the complete range of engine powers, fuel-air ratios, and cowl-flap angles. The investigations of the intermediate modifications covered the complete range of mixture strengths but were usually restricted to 1450 and 1670 brake horsepower at a cowl-flap angle of 10°. The relation between engine speed and power was maintained according to a propeller-load curve based on rated engine conditions. All flight tests were made at a pressure altitude of 10,000 feet and with an airplane weight of approximately 95,000 pounds. Measurements of cylinder temperatures, fuel flow, charge-air flow, and usual engine variables were made for the port inboard and port outboard engines.

Because it was necessary to correct the cylinder-temperature readings for the variation of ambient-air temperature and because it was found desirable to interpolate between actual test values, the cooling data were correlated in the manner described in reference 3. Reasonable estimates and extrapolations of available data were substituted where the required measurements were not taken. The following table lists the data required for each test condition as well as the source or method used to obtain their values for the present tests:

Data required	Source or method of calculation
Cylinder temperatures	Measured at rear spark-plug gasket of all cylinders and at exhaust-valve seat of rear-row cylinders
Cooling-air temperature	Free-stream stagnation temperature
Carburetor inlet-air temperature	Measured at carburetor deck
Fuel-air ratio	Calculated from fuel flow and charge-air weight flow
Charge-air weight flow	Calculated from uncompensated metering pressure
Engine speed	Measured
Cooling-air pressure drop across engine	Estimated from results of unpublished wind-tunnel tests of the engine installation

Inasmuch as no engine pressure measurements were made during the flight tests, the cooling-air pressure drop was estimated from the free-stream dynamic pressure and the cowl-flap opening. Unpublished data from wind-tunnel tests provided the required relation between cowl-flap angle and the fraction of free-stream dynamic pressure available for cooling-air pressure drop. These values were corrected for tunnel wall interference by applying the correction described in reference 4 to the pressure downstream of the engine rather than to the pressure at the cowl-flap exit. Because the nacelle is not of circular cross section, the correction may have been slightly underestimated.

The cooling data taken at various engine conditions and cooling-air pressure drops were correlated by use of the relation

$$\frac{T_h - T_a}{T_g - T_h} = K\left(\frac{M_e^{n/m}}{\sigma\Delta p}\right)^m \qquad (1)$$

where

T_h cylinder-head temperature, °F

T_a free-stream stagnation temperature, °F

T_g	mean effective combustion-gas temperature corrected for carburetor-air temperature and blower temperature rise, °F
M_e	engine charge-air weight flow, pounds per second
Δp	approximate cooling-air pressure drop, inches of water
σ	ratio of ambient-air density to standard sea-level air density ρ/ρ_0, based on standard Army summer atmospheric conditions
m,n	empirical exponents
K	constant of proportionality depending on cylinder heat-transfer areas and heat-transfer coefficients

The data available from the flight tests were not sufficient to carry through the entire correlation procedure. The variation of T_g with fuel-air ratio, as well as the ratio of the exponents n/m, was taken as that determined in reference 5.

RESULTS AND DISCUSSION

Throughout the discussion the production double-row radial engine and the engine using the injection impeller, the ducted head baffles, or a combination of both will be denoted standard and modified engines. respectively. For the direct temperature comparisons, all cylinder temperatures have been corrected (reference 6) to a cooling-air temperature of 49° F, the temperature encountered during the test of the standard engines. Because similar improvements in cooling performance were indicated by tests at both 1450 and 1670 brake horsepower, only those for 1450 brake horsepower need be considered. The temperatures of the exhaust-valve seats are used as the basis of comparison and analysis.

Cooling Characteristics of the Standard Double-Row Radial Engine

Cylinder temperatures. - The results of the test-stand investigation (references 1 and 2) have established that, although the average temperatures of the rear spark-plug gasket of the front-row and the rear-row cylinders are nearly equal during all normal operating conditions, differences of approximately 80° F exist between the average temperatures of the front-row and the rear-row exhaust-valve seats. Temperature patterns (fig. 4), typical of those obtained for the port inboard and port outboard engines during the flight tests of the four-engine heavy bomber, show somewhat higher temperatures at the spark-plug gaskets for the rear-row cylinders than for the front-row cylinders. Consequently, although the temperatures of the exhaust-valve seats for the front-row cylinders were not measured, it appears that the temperatures of the rear-row exhaust-valve seats would be at least 80° F hotter than those of the front row. Because no consistent variations between the average fuel-air ratios of the two rows have been observed (reference 1), the temperature differences evidently result from variations of cooling-air flow and engine geometry. This difficulty may be overcome, to a large degree, by improvement in cooling-air flow over the critical regions of the hot cylinders (reference 2).

The temperature patterns (fig. 4) also indicate that differences between the temperatures of the exhaust-valve seats for a given row may exceed 80° F. Inasmuch as a part of the circumferential temperature variation results from the difference in fuel-air ratio among the cylinders of one row, improvement of mixture distribution may be expected to reduce this temperature variation.

Mixture distribution. - For a given power and cooling-air flow, the temperature of an air-cooled cylinder attains a maximum value at a fuel-air ratio of approximately 0.068. Likewise, the temperatures for different cylinders of a multicylinder engine would reach their maximum values at the same over-all fuel-air ratio only if the individual fuel-air ratios were equal to the over-all fuel-air ratio; that is, if the mixture distribution were uniform. Consequently, the difference between the values of over-all fuel-air ratio at which the maximum temperature of various cylinders occur may be used as an indication of the variation of fuel-air ratio among the cylinders.

From figure 5, in which the temperatures of the exhaust-valve seat of the rear-row cylinders are plotted against the over-all fuel-air ratio, it appears that the mixture distributions in both the standard inboard and the standard outboard engines are extremely nonuniform and that the outboard engine is considerably worse than the inboard engine. The variation of fuel-air ratio among cylinders is about 0.013 for the inboard engine and is in excess of 0.020 for the outboard engine. Because of this nonuniform mixture distribution, the cylinder temperatures do not respond in a normal manner to enrichment cooling; for example, the maximum cylinder temperature of the port outboard engine (fig. 5) increases as the over-all fuel-air ratio is increased.

Correlation of cooling data. - Because the ducted head baffles were installed on only the rear-row cylinders, the cooling data for each row were handled separately. The correlation of cooling data, based on the average temperatures of the rear spark-plug gasket, is shown in figure 6 for the front-row and the rear-row cylinders of the standard port inboard engine on which the highest cylinder temperatures were encountered. The relation between the cooling-air pressure-drop coefficient $\Delta p(1/2\ \rho V^2)$ and the cowl-flap angle used in estimating the cooling-air pressure drop, and the relation between effective combustion-gas temperature and fuel-air ratio at a carburetor-deck temperature of 0° F and at three engine speeds (reference 5) are shown in figures 7 and 8, respectively. When the curves of figure 8 are applied, the value of the effective combustion-gas temperature must be increased by 0.8 of the carburetor-deck temperature in °F.

The interpretation of figure 6(b) in terms of the temperature of the exhaust-valve seat necessitates relating the temperatures of the rear spark-plug gasket and the exhaust-valve seat for the rear-row cylinders. Because the valve seat and the rear spark-plug gasket are located inside and outside the cylinder, respectively, the valve seat is more responsive to power variations and less affected by variations in cooling-air flow. From figure 9, where the variation of the average exhaust-valve-seat temperature with the average rear spark-plug-gasket temperature is given for both constant power and constant cooling-air flow, it is apparent that no simple relation exists between the temperatures of the exhaust-valve seat and the rear spark-plug gasket. Consequently, in order to permit a general comparison of the temperatures of the exhaust-valve seat before and after modification of the engine, the cooling data were correlated (fig. 10) on the basis of the average exhaust-valve seat temperature of the rear-row cylinders. The data of figure 9 were used for approximating the required empirical exponents.

The appropriate constants for equation (1), when the cooling data are correlated on the basis of the average temperature of the rear spark-plug gaskets and of the exhaust-valve seats, are given in the following table:

Cylinder-head temperatures	K	m	n
Average rear spark-plug-gasket temperature of front-row cylinders	0.49	0.35	0.60
Average rear spark-plug-gasket temperature of rear-row cylinders	.53	.35	.60
Average exhaust-valve-seat temperature of rear-row cylinders	.67	.28	.66

The low value of the exponent m corresponding to the exhaust-valve seat indicates the ineffectiveness of air cooling on the critical internal regions of the cylinders.

Inasmuch as the cooling of the engine installation is limited by the hottest rear-row exhaust-valve seat instead of the average values used in equation (1) and correlated in figure 10, the approximate relation between the hottest and the average temperature of the rear-row exhaust-valve seat is given in figure 11 for the port inboard engine. Because temperature variations may result from small inconsistencies between engines or cylinders of the same type, the relation is not necessarily the same for other engines.

Cooling Characteristics of the Modified Double-Row Radial Engine

Effect of the NACA injection impeller on mixture distribution. - Improvement in the mixture distribution and reduction of the maximum cylinder temperatures (figs. 12 and 13) resulted from the installation of the NACA injection impeller on the port inboard engine of the four-engine heavy bomber. The variation in temperatures of the exhaust-valve seat with over-all fuel-air ratio (fig. 12) shows the mixture distribution for the modified installation to be considerably improved. The mixture distribution of the standard port inboard engine, as was previously noted, was relatively uniform and consequently the improvement is definite but not striking. The effect of the injection impeller is clarified further in figure 13(a), which shows the change in the cylinder temperature pattern resulting from the more uniform mixture distribution. The temperatures of relatively few cylinders were affected, but generally it was these cylinders that had been hot because of excessively lean operation. As a result, the maximum exhaust-valve-seat temperatures (fig. 13(b)), while not appreciably changed at lean mixtures, show significant reductions below that of the standard engine as the mixture is enriched. The temperature response of the hottest cylinder to mixture enrichment, which may be severely disrupted by poor mixture distribution, has been improved slightly. Use of the NACA injection impeller reduced the temperature spread, the difference between the temperatures of the hottest and coldest cylinders (fig. 13(c)), about 25° F for all but the leanest fuel-air ratios.

Effect of ducted head baffles on cylinder temperatures. - Ducted head baffles were installed on all rear-row cylinders of the port outboard engine and were tested at several values of engine power and over a range of fuel-air ratios. The resulting cylinder temperatures are compared in figure 14 with those taken at comparable conditions using the standard head baffles.

The temperature-distribution pattern (fig. 14(a)), although of the same general shape as that for the standard engine, was lowered more than 50° F for all cylinders by the addition of the ducted head baffles. These results compare favorably with those of the original test-stand tests (reference 2). The maximum cylinder temperature (fig. 14(b)) was reduced by approximately the same magnitude for all mixture strengths. The response of the maximum temperature to mixture enrichment was, of course, not affected by the addition of ducted head baffles. The temperature reduction appeared to be consistent for all engine powers tested. Because the baffle modification was similar for all rear-row cylinders, the temperature spread (fig. 14(c)) was unaffected by the ducted head baffles.

Combined effects of NACA injection impeller and ducted head baffles on cylinder temperatures. - Inasmuch as the ducted head baffles handle more air than the standard baffles and in this manner augment the momentum drag of the engine installation, it appeared desirable to use the fewest ducted head baffles consistent with proper cooling of the rear-row cylinders. Several problems arise in selecting the cylinders on which to install the ducted baffles. As indicated in figure 5(b), nonuniform mixture distribution may cause a complete interchange of hottest and coldest cylinders, depending on the over-all fuel-air ratio. This difficulty may largely be overcome by using the NACA injection impeller to improve the mixture distribution. Inherent differences between engines of the same type (fig. 4), however, present a definite and unpredictable obstacle. Consequently, only a limited number of tests were made with ducted head baffles on selected cylinders. Use of the injection impeller together with ducted head baffles on all rear-row cylinders was investigated thoroughly.

The cylinder temperature patterns (fig. 15) were greatly improved through use of the NACA injection impeller and ducted head baffles on cylinders 1, 3, 5, 7, and 17. Not only was the maximum cylinder temperature and the temperature spread reduced at the conditions of figure 15(a), but improvements of the same magnitude were present (figs. 15(b) and 15(c)) for the range of fuel-air ratios covered. Because the tests of the modified engine were conducted with a cowl-flap angle of 6° whereas those of the standard engine were made with a cowl-flap angle of 10°, the cylinder temperatures were actually reduced by a greater amount than is shown in figure 15. Because of this difference in the test conditions, the temperatures of the unaltered cylinders do not check between tests of the standard and the modified installation.

Results of tests using the NACA injection impeller in conjunction with ducted head baffles on all rear-row cylinders of the port outboard engine (fig. 16) show the combined effects of both modifications on the cylinder temperatures. A similar configuration was tested on the port inboard engine. In addition to the general reduction of cylinder temperatures that was observed with use of the ducted head baffles alone (fig. 14), the notable features are the improvement in temperature response to mixture enrichment (fig. 16(b)) and the reduction of the temperature spread at high fuel-air ratios (fig. 16(c)). The large values of temperature spread for the standard port outboard engine substantiate the observation that the mixture-distribution problem is more severe on the port outboard engine than on the port inboard engine. The improvement of mixture distribution through use of the injection impeller (fig. 16(c)) is shown more clearly by figure 17, where the temperature variation of the rear-row exhaust-valve seats with over-all fuel-air ratio is given. This comparison indicates that the difference between the fuel-air ratios of the richest and the leanest cylinders has been reduced to less than 0.010 from values in excess of 0.020. The general temperature reduction resulting from use of the ducted head baffles (fig. 17(b)) does not affect the comparison of fuel-air-ratio spreads.

Correlation of cooling data. - In order to complete the comparison between the standard double-row radial engine and the same engine using the NACA injection impeller and ducted head baffles on all rear-row cylinders, the cooling data were correlated using the cooling-air pressure-drop approximation of figure 7. The cooling performance of the standard and modified port inboard engines is compared in figure 18, where the average temperature of the exhaust-valve seat is used as the criterion of cooling. The following table gives the constants of the correlation equation for both the standard and the modified engines.

	K	n	m
Standard engine	0.67	0.66	0.28
Modified engine	.56	.66	.28

The relation between the average and maximum temperature of the rear-row exhaust-valve seat is given in figure 19 for the engine using both the NACA injection impeller and the ducted head baffles on all rear-row cylinders.

The cooling-correlation curves for the standard engine and for the engine using both NACA injection impeller and ducted head baffles (fig. 18) indicate that for given engine conditions (values of M_e and T_g) and atmospheric conditions (values of σ and T_a), the cooling-air pressure drop required by the modified engine to attain a given exhaust-valve-seat temperature is only half that required by the standard engine. If the exhaust-valve seat is the limiting cylinder temperature, this reduction of cooling-air pressure requirement permits the use of smaller cowl-flap openings, which leads to greater airplane speeds and increased cruising economy. The allowable reduction of cowl-flap angle may, to a first approximation, be estimated from figure 7. Inasmuch as a cowl-flap angle of 16° is the maximum normally employed, cooling at any condition for which operation is possible with the standard installation may, when using the NACA injection impeller and ducted head baffles, be attained with a cowl-flap angle of less than 4°, that is, with half the cooling-air pressure drop. This result indicates that extreme operating conditions excluded by the cooling limitations of the standard engine may be employed successfully with the modified engine.

SUMMARY OF RESULTS

The following results were obtained from a flight investigation of the cooling performance of a double-row radial air-cooled engine installed in a four-engine heavy bomber and the same engine modified by using the NACA injection impeller and ducted head baffles:

1. The use of the NACA injection impeller reduced the fuel-air-ratio spread among cylinders to less than one-half its original value. This improvement in mixture distribution is of the same magnitude as was shown in a previous test-stand investigation.

2. The maximum exhaust-valve-seat temperature of the rear-row cylinders was reduced approximately 50° F by use of the ducted head baffles. This reduction is of the same order as that shown in the test-stand investigation.

3. When high cylinder temperature resulted from poor mixture distribution, use of the NACA injection impeller reduced the maximum cylinder temperatures as well as the temperature spread and provided normal enrichment cooling.

4. Limited tests demonstrated that the use of the NACA injection impeller and the ducted head baffles on a few selected rear-row cylinders reduced the maximum exhaust-valve-seat temperatures approximately 50° F and the temperature spread to less than 45° F.

5. Tests on the port inboard engine using the NACA injection impeller and the ducted head baffles on all rear-row cylinders showed that the cooling-air pressure drop required to cool the critical region around the exhaust-valve seat of the rear-row cylinders was reduced to half its normal value.

6. Because of the reduced pressure drop required for cooling the modified engine, tests indicated that for all conditions at which cooling of the rear-row exhaust-valve seats was possible with the standard engine installation, proper cooling can be attained for the modified engine with a cowl-flap angle of less than 4°.

Aircraft Engine Research Laboratory,
National Advisory Committee for Aeronautics,
Cleveland, Ohio, April 13, 1945.

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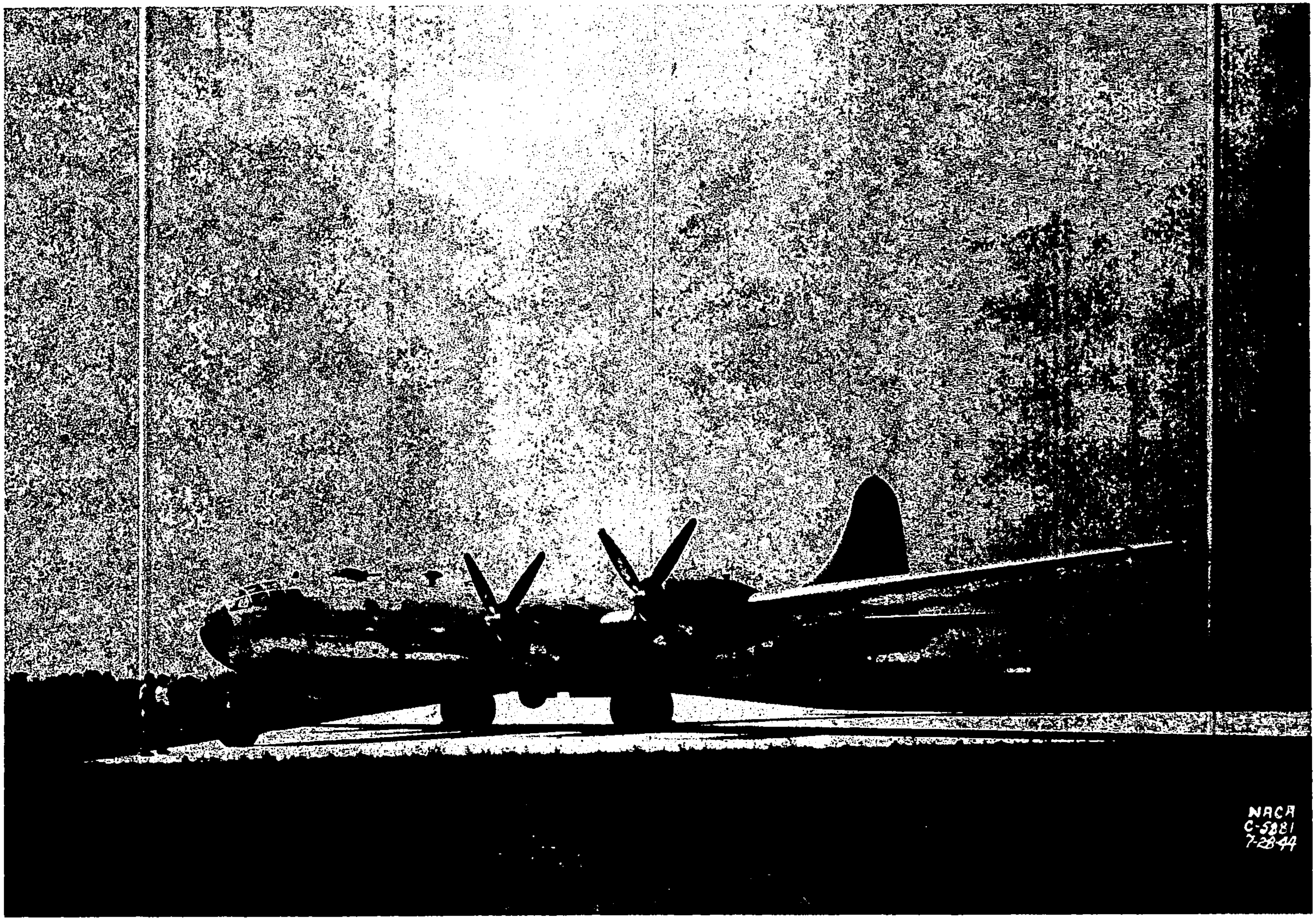

Figure 1. - Four-engine heavy bomber used in flight tests.

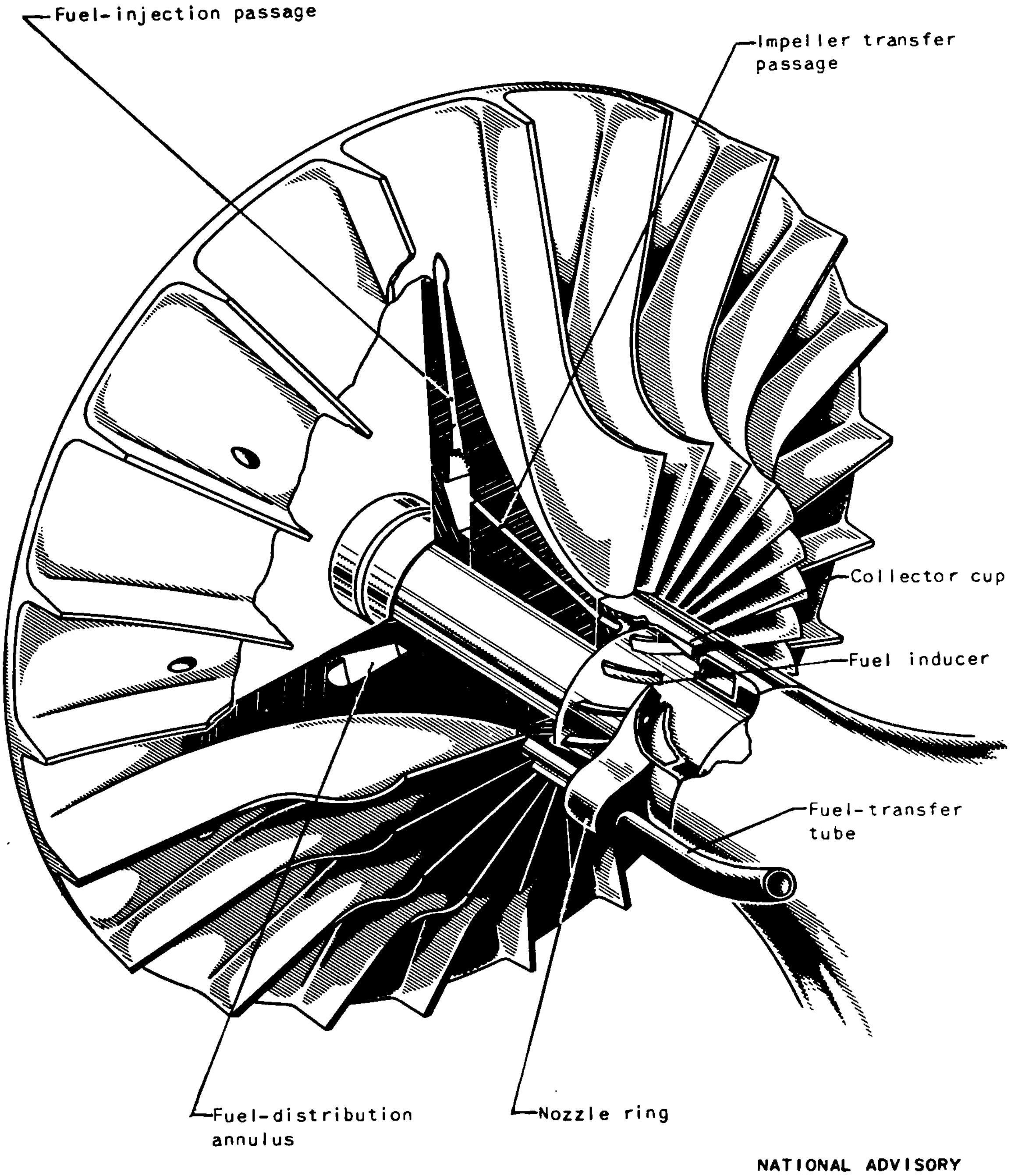

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Figure 2. - NACA injection impeller designed for installation on double-row radial engine.


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Figure 3. - Ducted head baffle for rear-row cylinders of double-row radial engine.

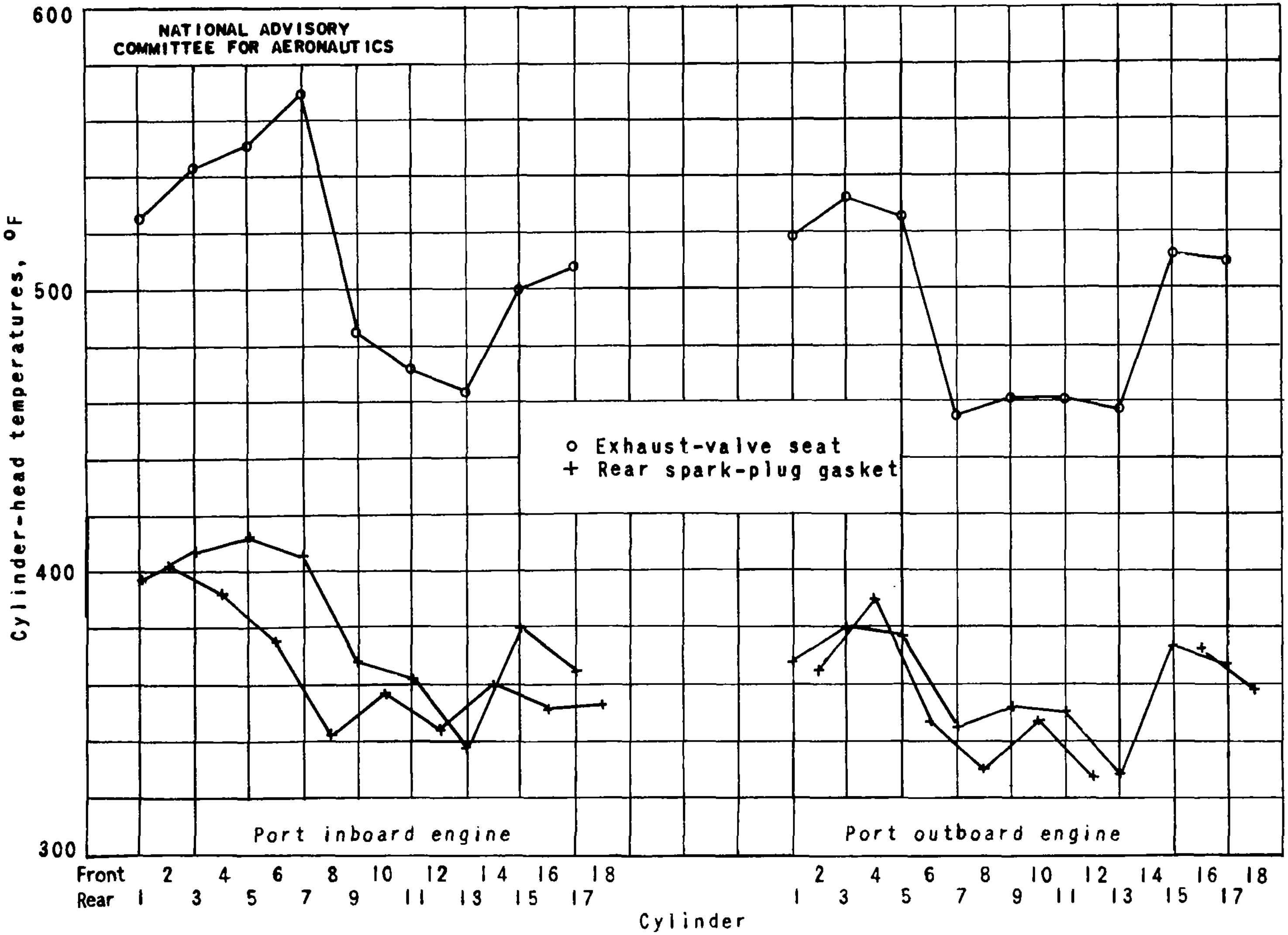
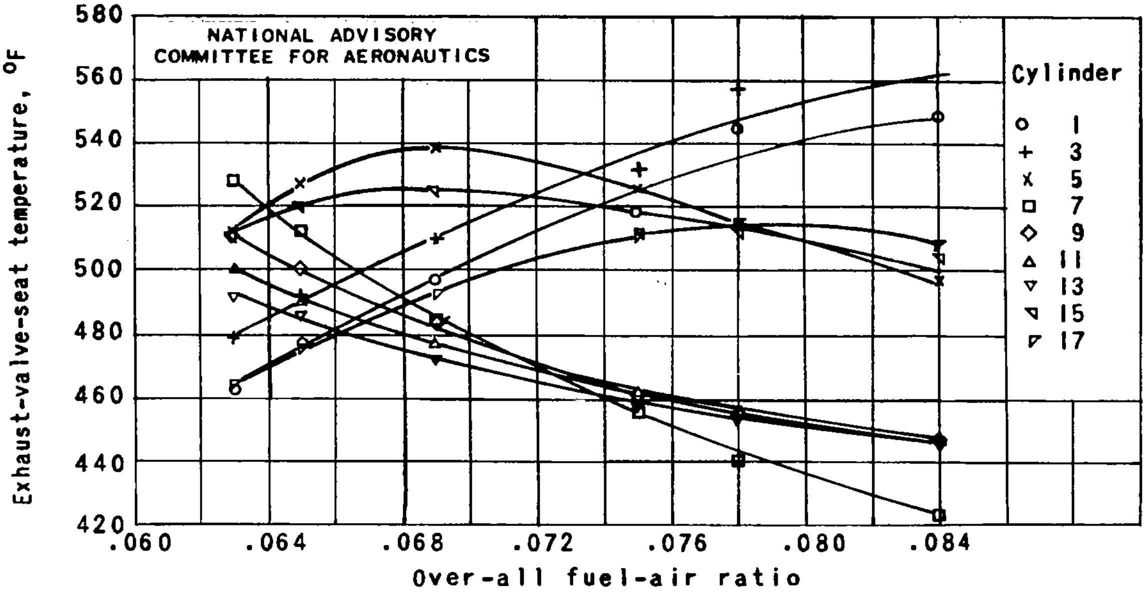
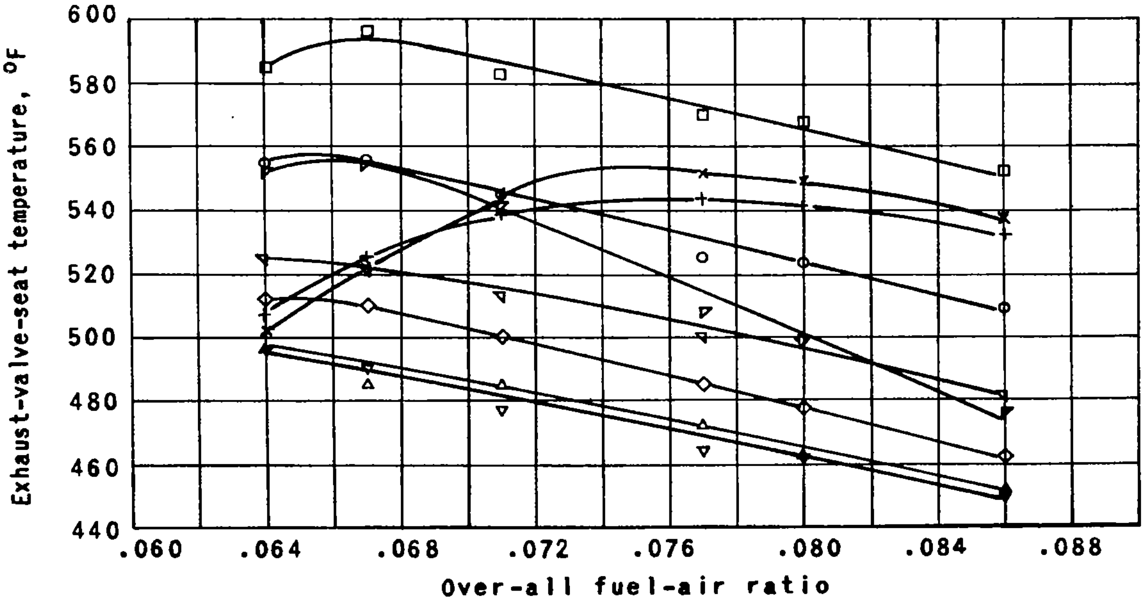


Figure 4. - Typical temperature-distribution patterns for standard double-row radial engine obtained during flight tests. Brake horsepower, 1450; engine speed, 2150 rpm; air temperature, 49° F; approximate fuel-air ratio, 0.076.

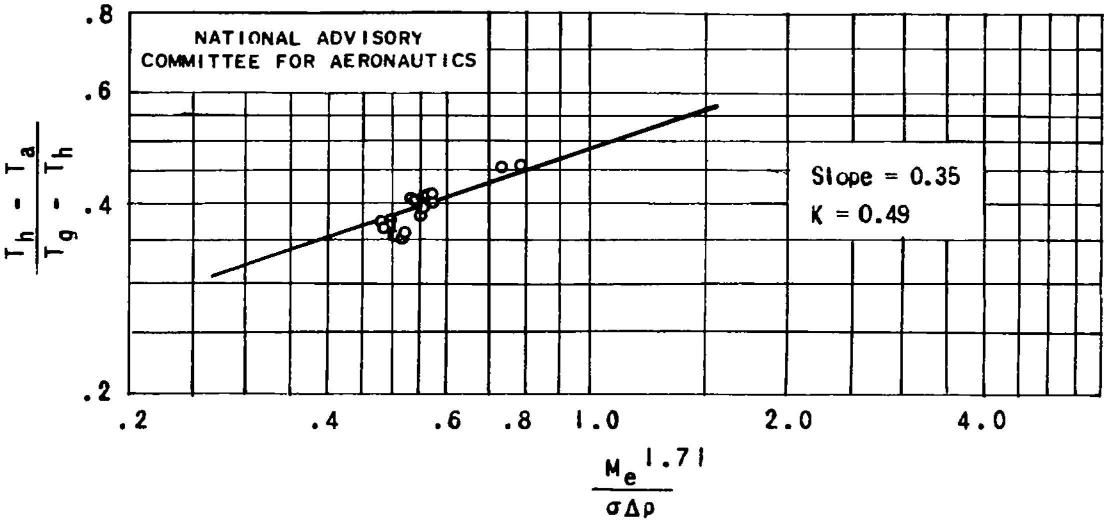


(a) Port outboard engine.

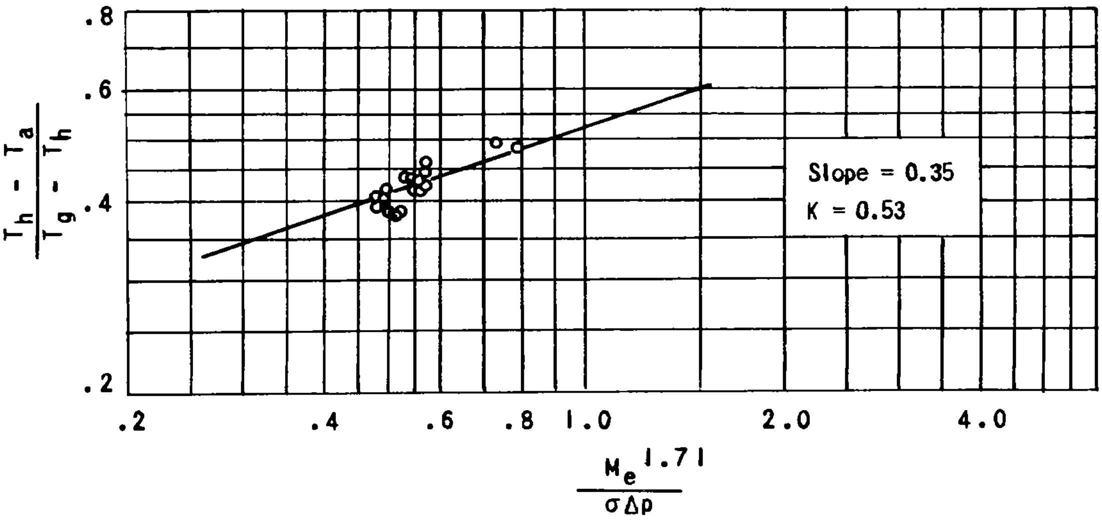


(b) Port inboard engine.

Figure 5. – Variation of exhaust-valve-seat temperatures of rear-row cylinders with over-all fuel-air ratio in standard double-row radial engine. Brake horsepower, 1450; engine speed, 2150 rpm; air temperature, 49° F.



(a) Based on average temperature of rear spark-plug gaskets of front-row cylinders.



(b) Based on average temperature of rear spark-plug gaskets of rear-row cylinders.

Figure 6. - Correlation of cooling data for standard double-row radial engine in port inboard nacelle of four-engine heavy bomber.

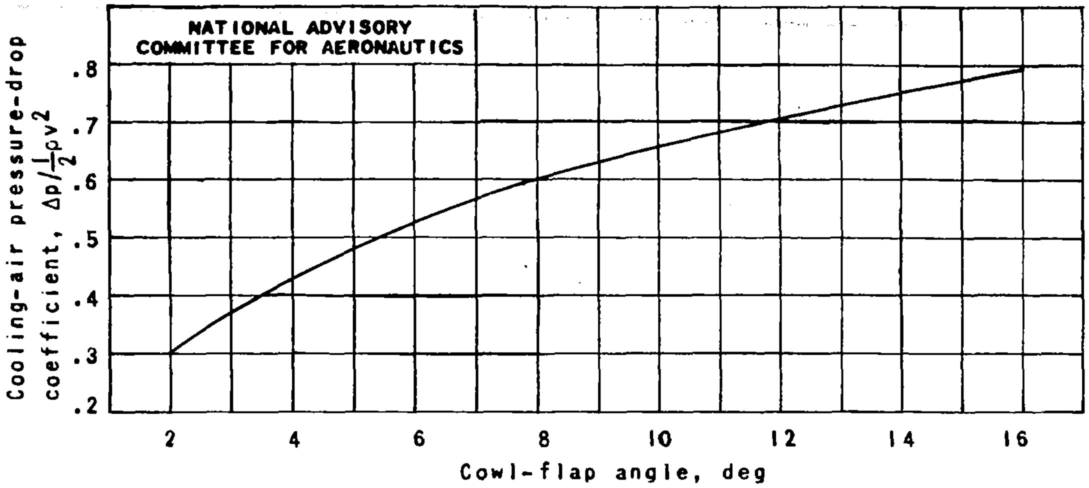


Figure 7. - Variation of cooling-air pressure-drop coefficient with cowl-flap angle. (Unpublished data from altitude-wind-tunnel tests, corrected for wind-tunnel wall interference.)

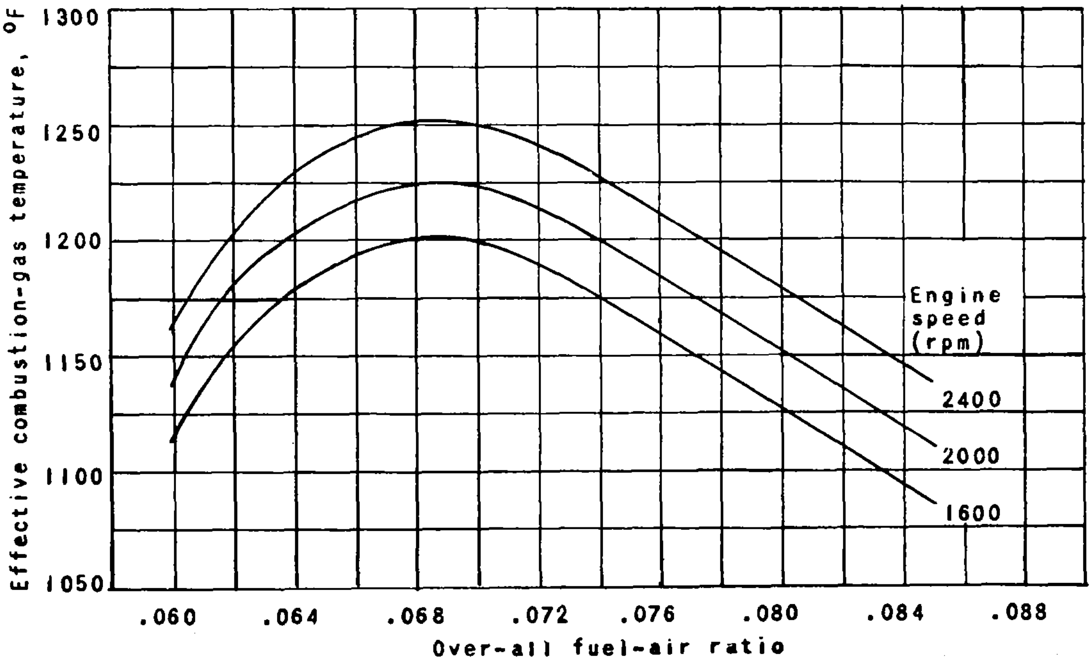


Figure 8. - Relation of effective combustion-gas temperature to over-all fuel-air ratio for standard double-row radial engine. Carburetor-deck temperature, 0° F. (Data from reference 5.)

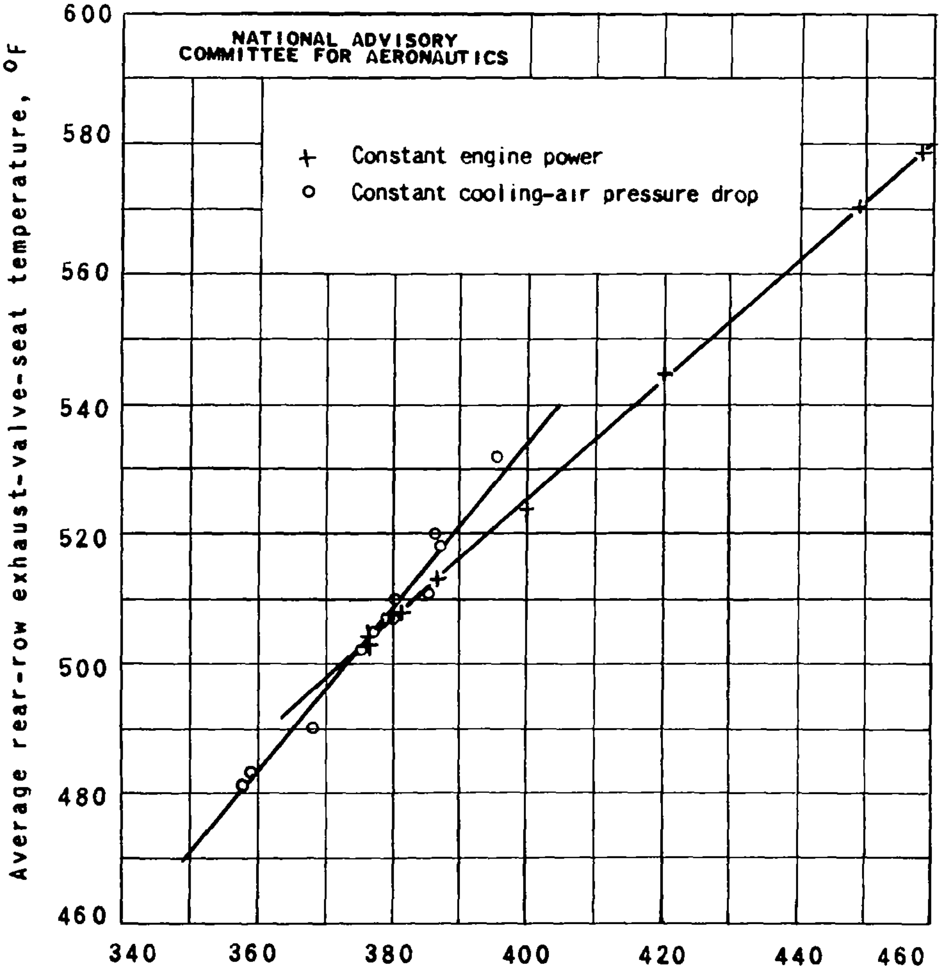


Figure 9. - Relation between temperatures of exhaust-valve seat and rear spark-plug gasket for rear-row cylinders of standard double-row radial engine in port inboard nacelle of four-engine heavy bomber.

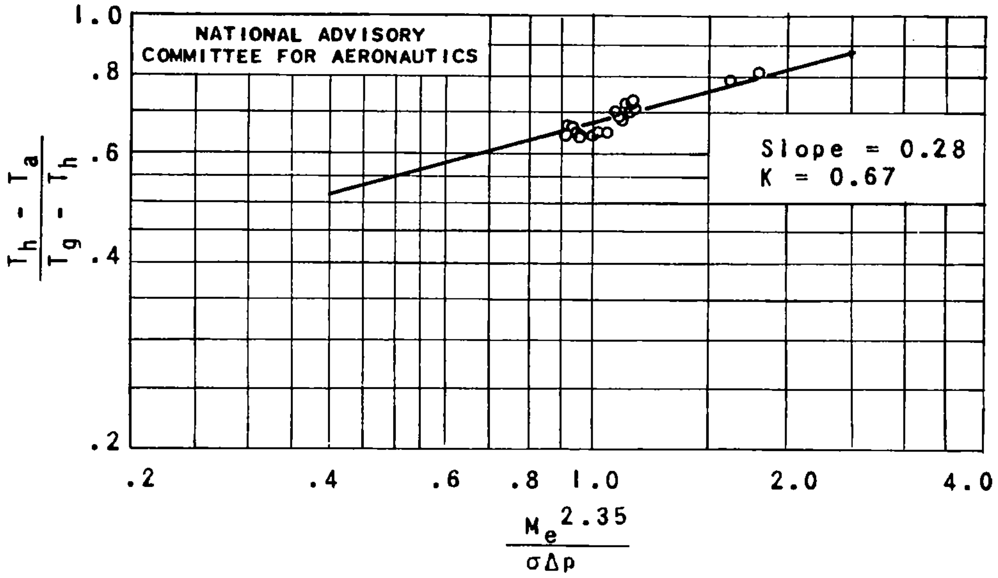


Figure 10. - Correlation of cooling data for standard double-row radial engine in port inboard nacelle of four-engine heavy bomber based on average temperature of exhaust-valve seats of rear-row cylinders.

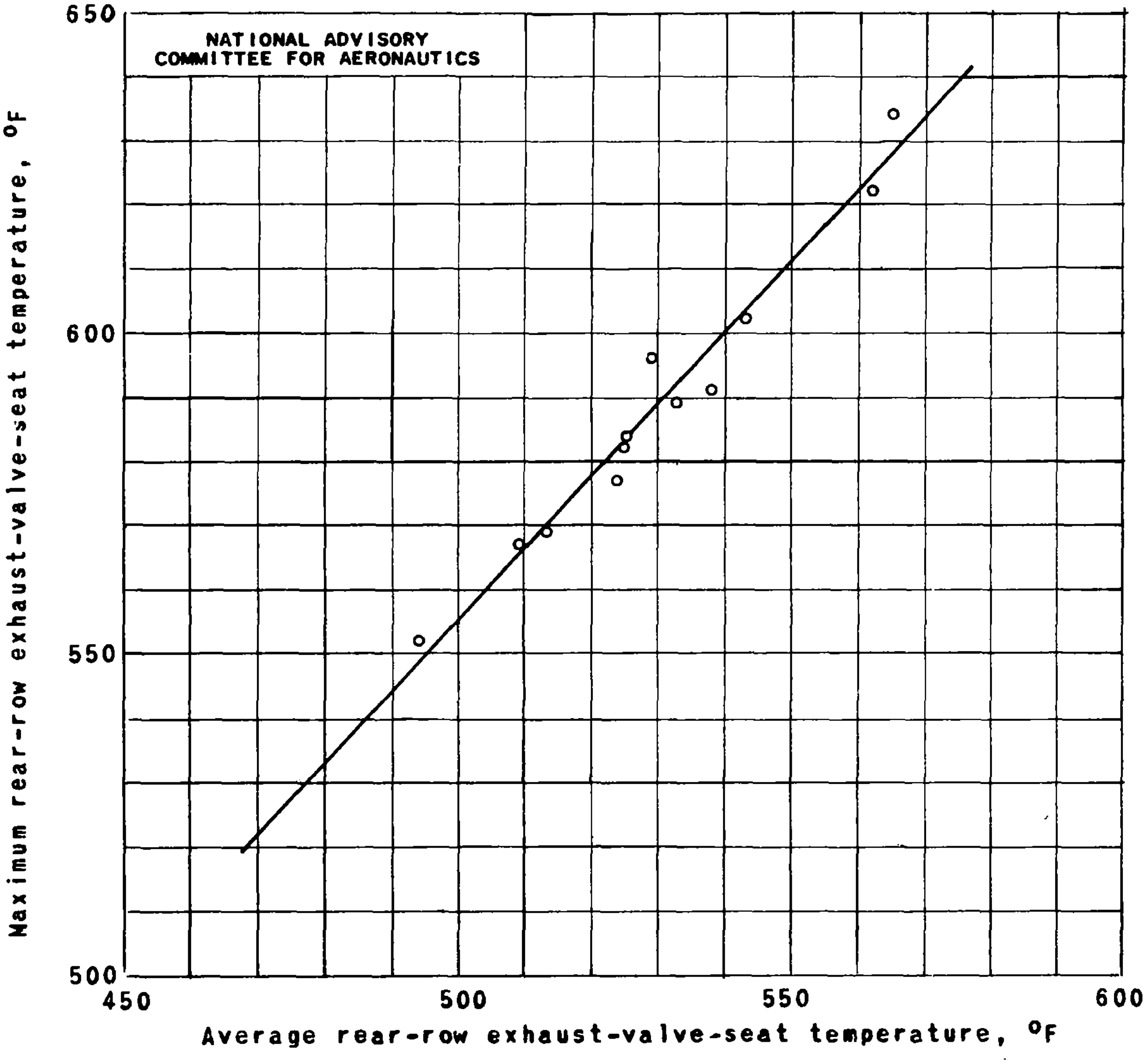
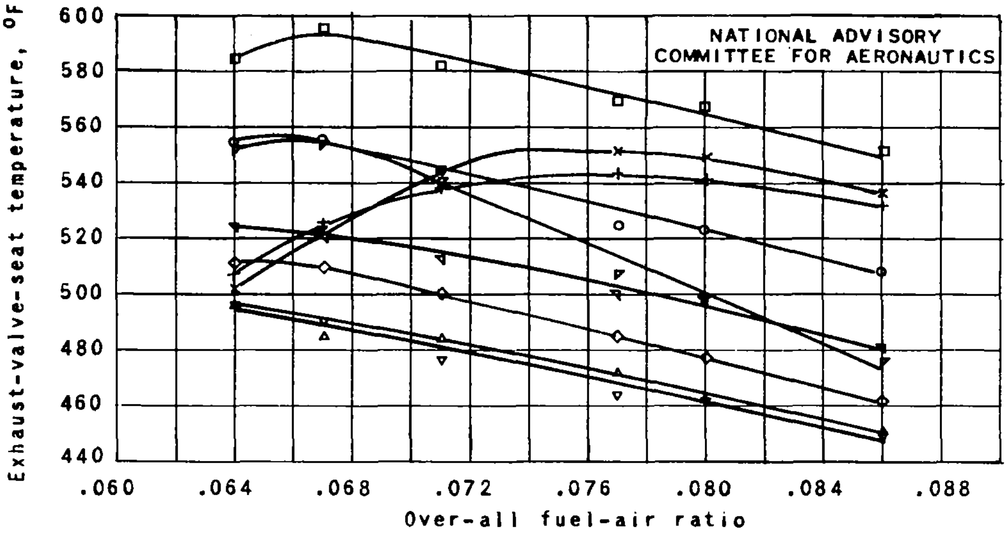
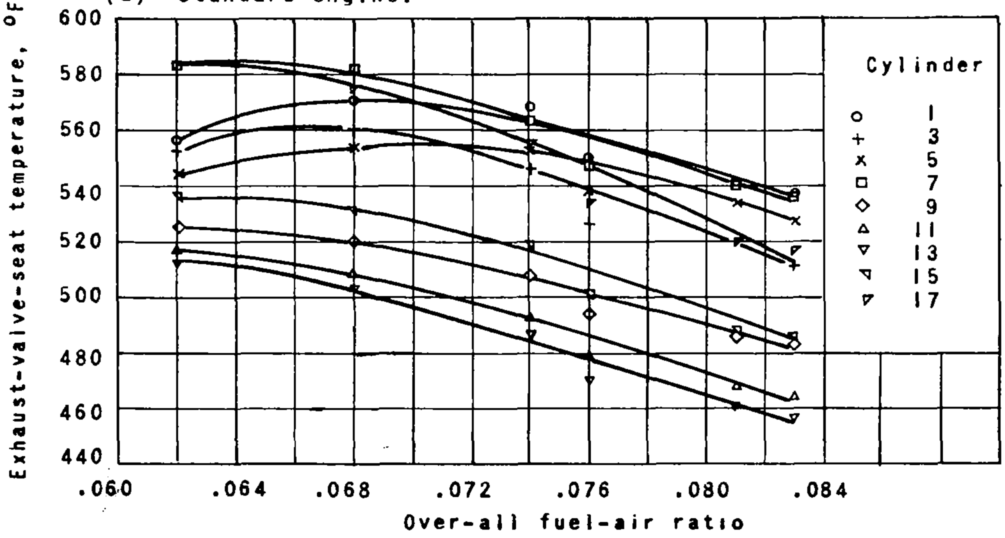


Figure 11. – Relation between maximum and average rear-row exhaust-valve-seat temperatures for standard double-row radial engine in port inboard nacelle of four-engine heavy bomber.

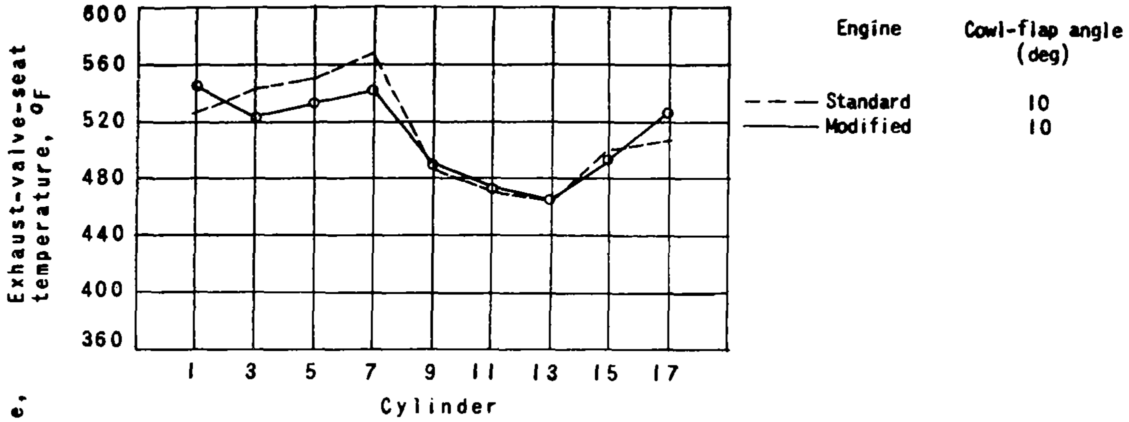


(a) Standard engine.

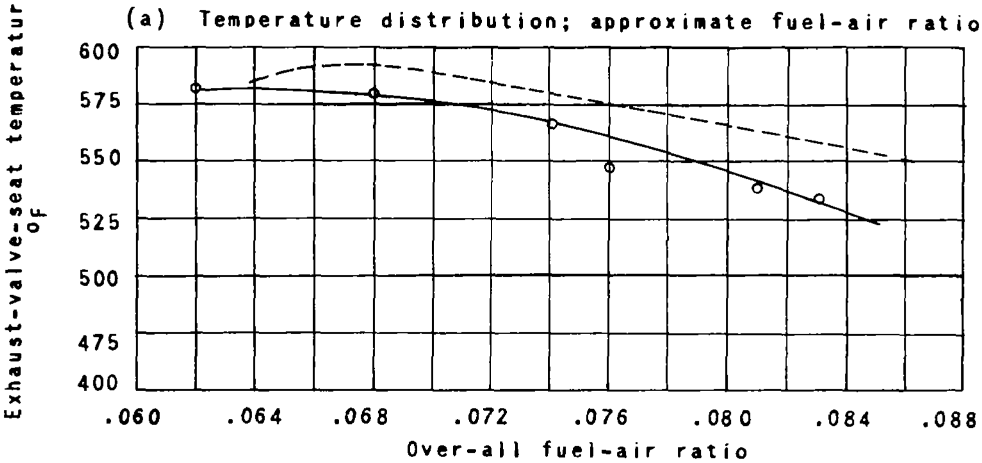


(b) Engine with NACA injection impeller.

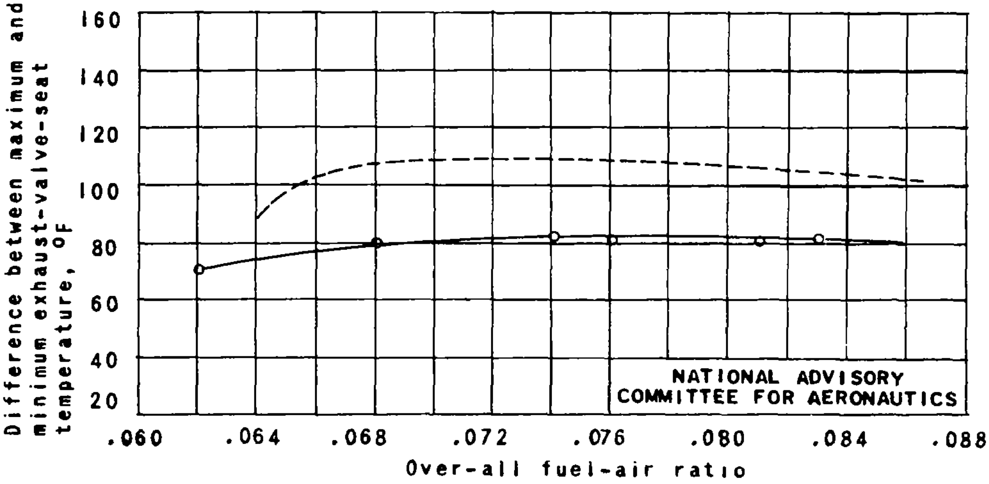
Figure 12. - Effect of NACA injection impeller on mixture distribution of double-row radial engine in port inboard nacelle of four-engine heavy bomber as indicated by the variation of cylinder temperature with over-all fuel-air ratio. Brake horsepower, 1450; engine speed, 2150 rpm; cylinder temperatures corrected to air temperature of 49° F.



(a) Temperature distribution; approximate fuel-air ratio, 0.076.

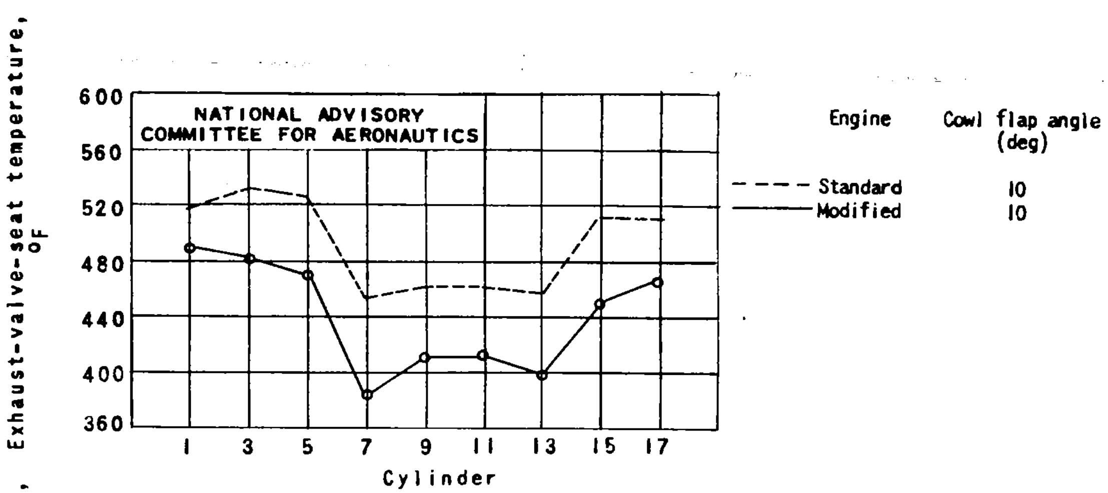


(b) Maximum cylinder temperature.

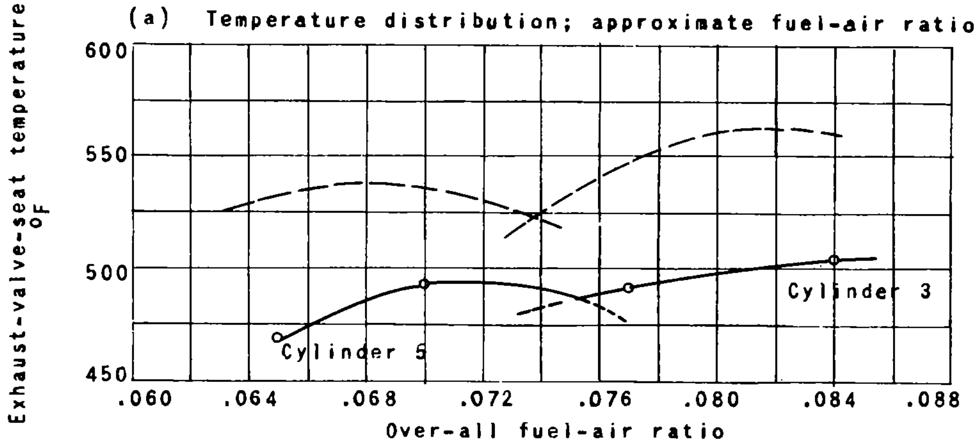


(c) Temperature spread.

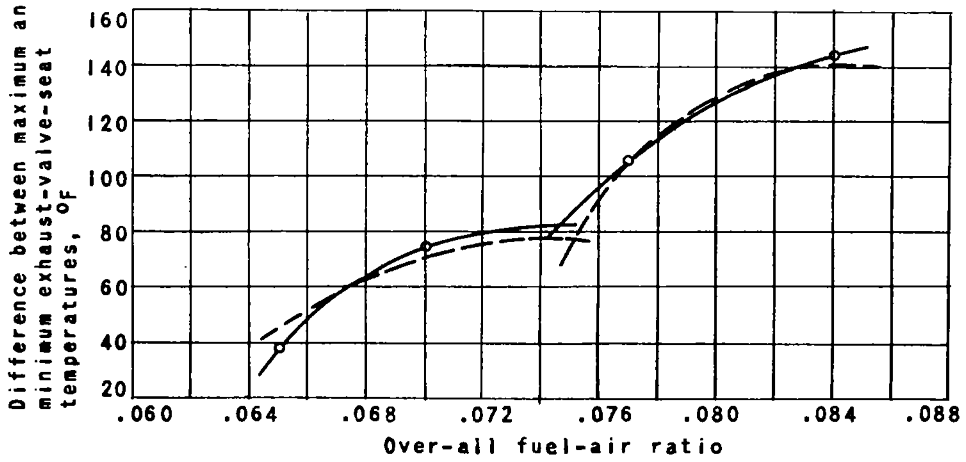
Figure 13. - Effect of NACA injection impeller on temperatures of double-row radial engine in port inboard nacelle of four-engine heavy bomber. Brake horsepower, 1450; engine speed, 2150 rpm; cylinder temperatures corrected to air temperature of 49° F.



(a) Temperature distribution; approximate fuel-air ratio, 0.076.

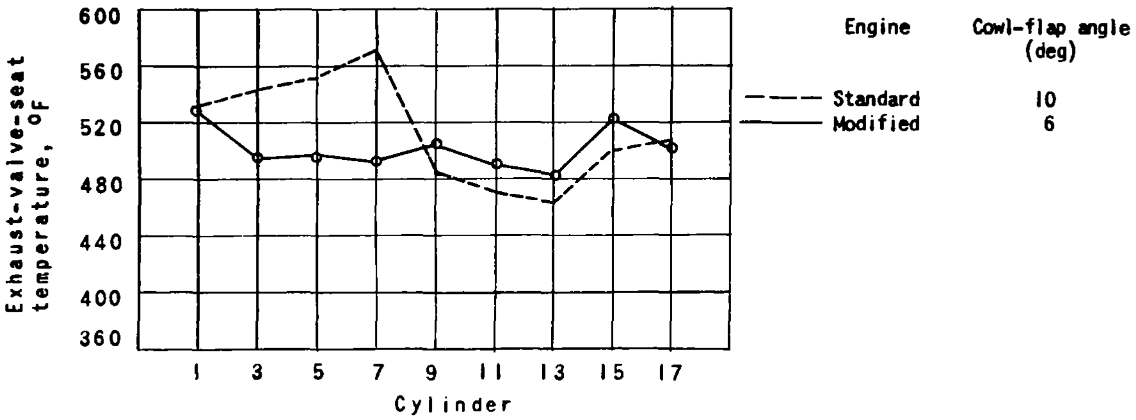


(b) Maximum cylinder temperature.

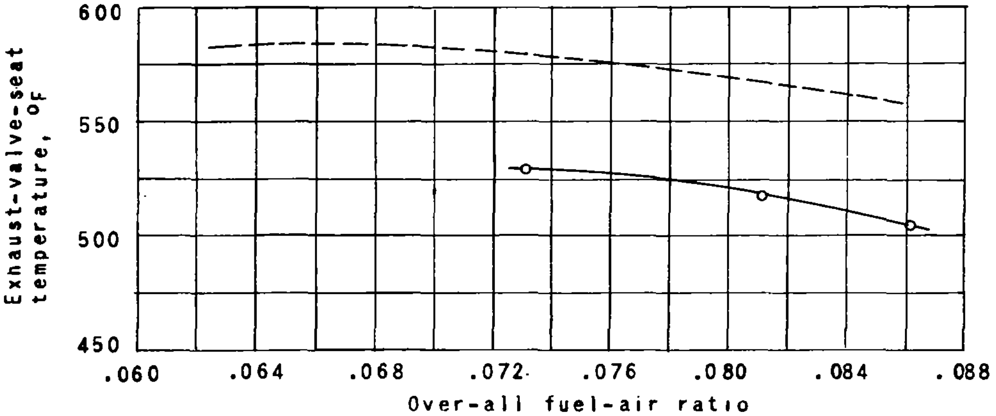


(c) Temperature spread.

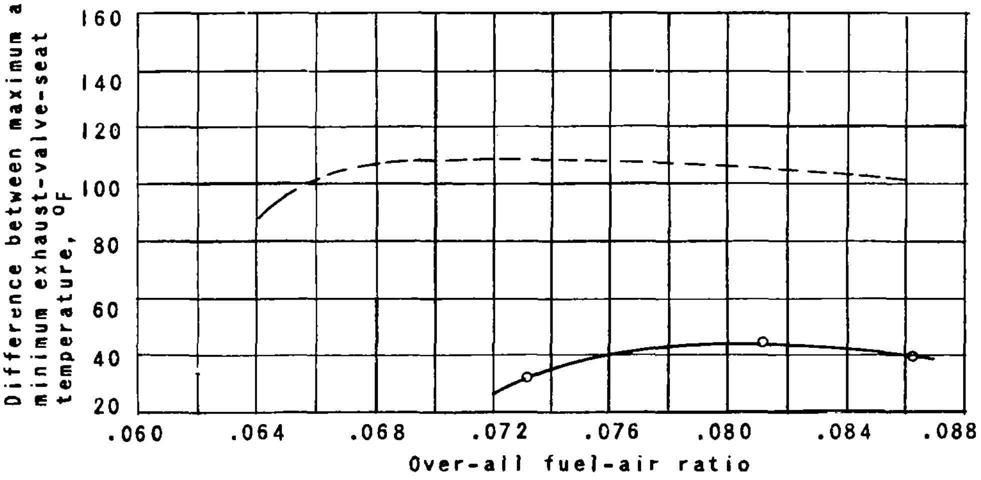
Figure 14. - Effect of ducted head baffles on temperatures of double-row radial engine in port outboard nacelle of four-engine heavy bomber. Brake horsepower; 1450; engine speed, 2150 rpm; cylinder temperatures corrected to air temperature of 49° F.



(a) Temperature distribution; approximate fuel-air ratio, 0.076.



(b) Maximum cylinder temperature.



(c) Temperature spread.

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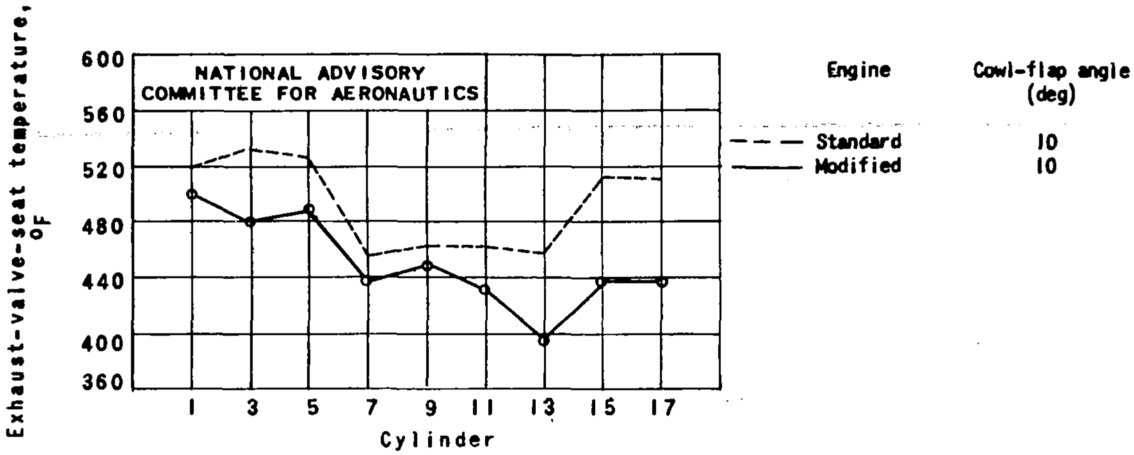
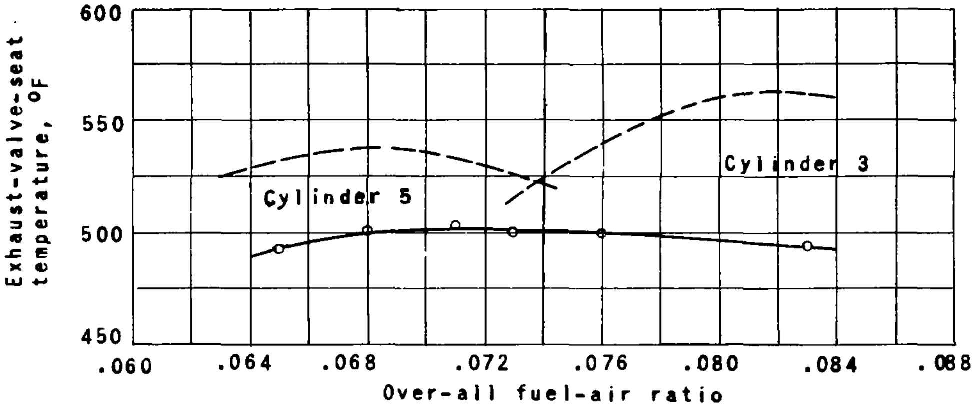
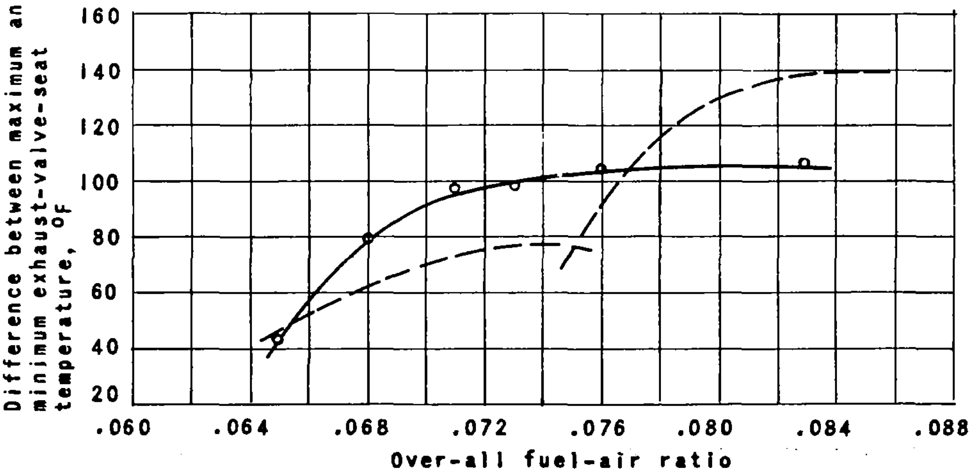
Figure 15. - Effect of NACA injection impeller and five ducted head baffles on the temperatures of double-row radial engine in port inboard nacelle of four-engine heavy bomber. Brake horsepower, 1450; engine speed, 2150 rpm; cylinder temperatures corrected to air temperature of 49° F.



(a) Temperature distribution; approximate fuel-air ratio, 0.076.

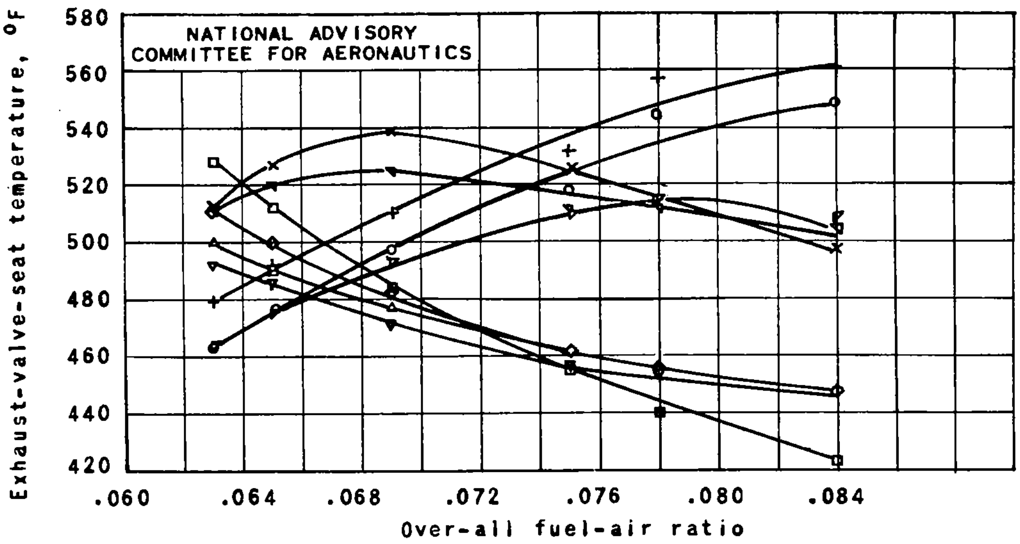


(b) Maximum cylinder temperature.

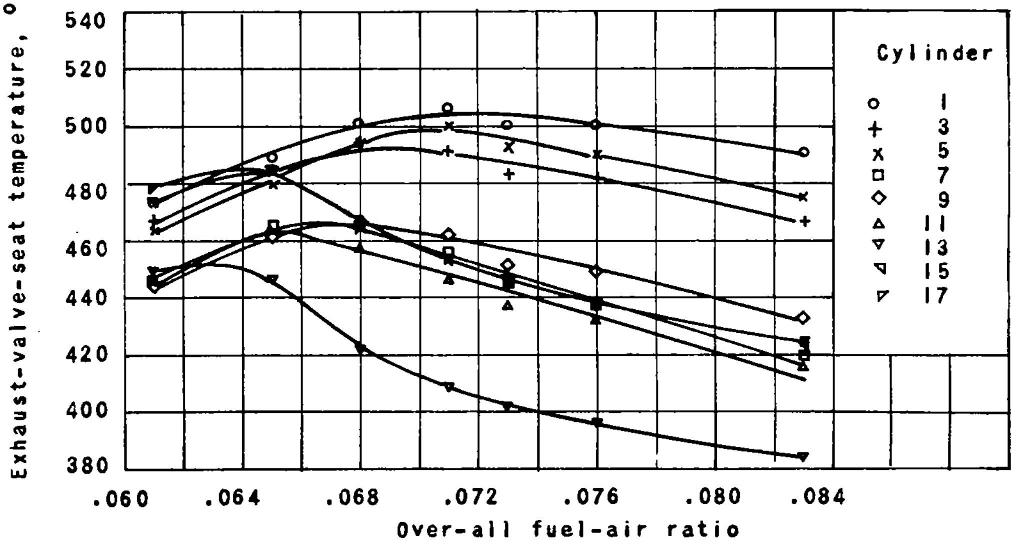


(c) Temperature spread.

Figure 16. - Effect of NACA injection impeller and ducted head baffles on all rear-row cylinders on the temperatures of double-row radial engine in port outboard nacelle of four-engine heavy bomber. Brake horsepower, 1450; engine speed, 2150 rpm; cylinder temperatures corrected to air temperature of 49° F.



(a) Standard engine.



(b) Engine with NACA injection impeller and ducted head baffles on all rear-row cylinders.

Figure 17. - Effect of NACA injection impeller and ducted head baffles on all rear-row cylinders on mixture distribution of double-row radial engine in port outboard nacelle of four-engine heavy bomber as indicated by the variation of cylinder temperatures with over-all fuel-air ratio. Brake horsepower, 1450; engine speed, 2150 rpm; cylinder temperatures corrected to air temperature of 49° F.

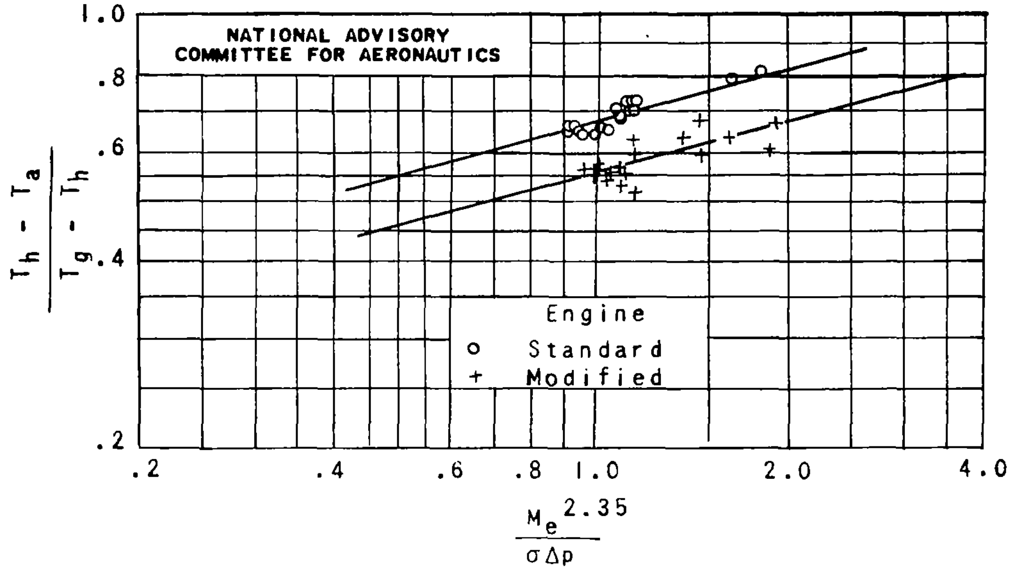


Figure 18. - Comparison between correlations of cooling data for standard and modified double-row radial engine in port inboard nacelle of four-engine heavy bomber. Modified engine equipped with NACA injection impeller and ducted head baffles on all rear-row cylinders.

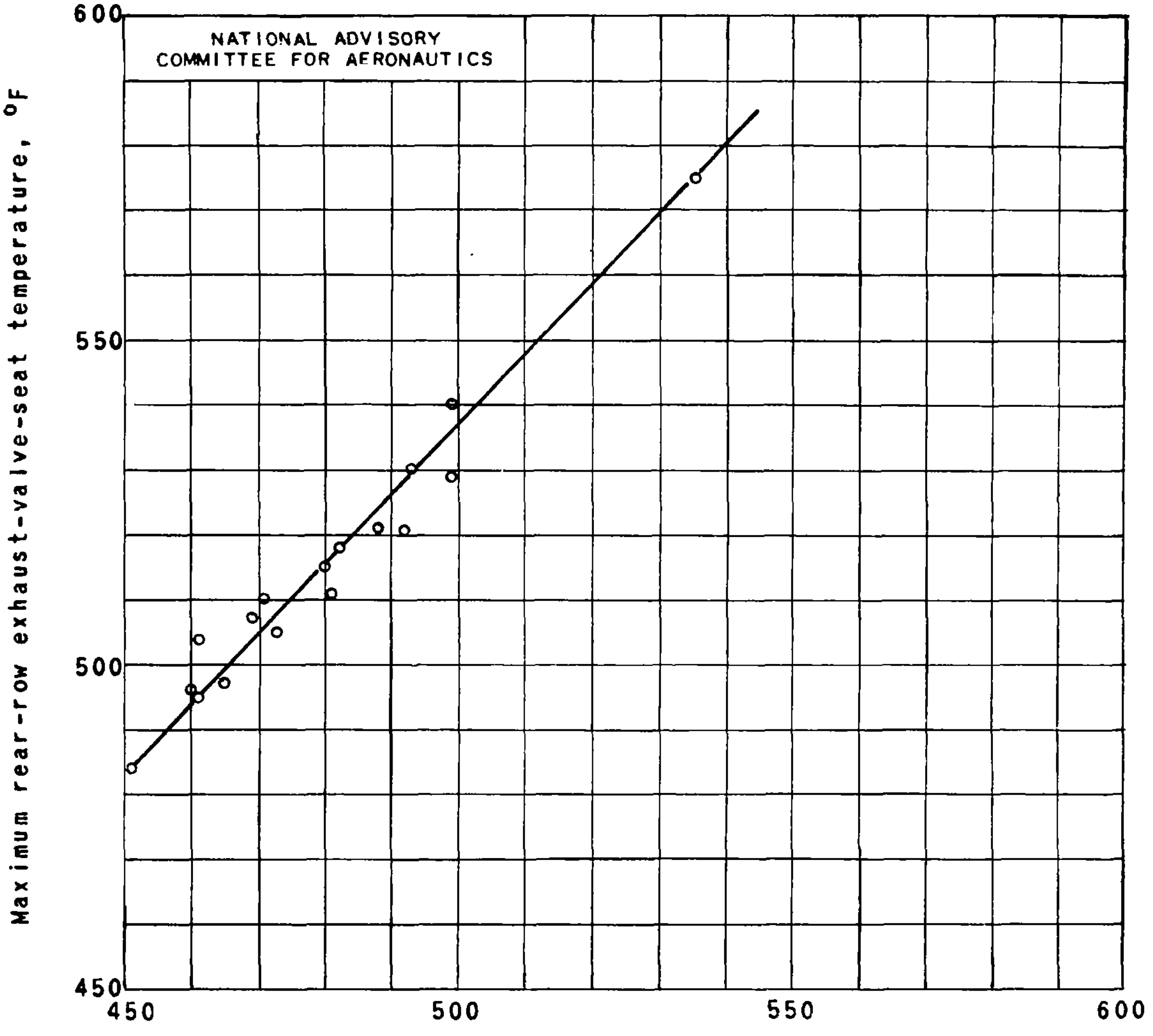


Figure 19. - Relation between average and maximum rear-row exhaust-valve-seat temperatures for modified double-row radial engine in port inboard nacelle of four-engine heavy bomber. Modified engine equipped with NACA injection impeller and ducted head baffles on all rear-row cylinders.