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RESEARCH MEMORANDUM

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CALCULATED CONDENSER PERFORMANCE FOR A MERCURY-TURBINE POWER PLANT FOR AIRCRAFT

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

RESEARCH MEMORANDUM

CALCULATED CONDENSER PERFORMANCE FOR A MERCURY-TURBINE POWER PLANT FOR AIRCRAFT

By Ronald B. Doyle

SUMMARY

As part of an investigation of the application of nuclear energy to various types of power plants for aircraft, calculations have been made to determine the effect of several operating conditions on the performance of condensers for mercury-turbine power plants. The analysis covered a range of turbine-outlet pressures from 1 to 200 pounds per square inch absolute, turbine-inlet pressures from 300 to 700 pounds per square inch absolute, and a range of condenser cooling-air pressure drops, airplane flight speeds, and altitudes.

The maximum load-carrying capacity (available for the nuclear reactor, working fluid, and cargo) of a mercury-turbine powered aircraft would be about half the gross weight of the airplane at a flight speed of 500 miles per hour and an altitude of 30,000 feet. This maximum is obtained with specific condenser frontal areas of 0.0063 square foot per net thrust horsepower with the condenser in a nacelle and 0.0060 square foot per net thrust horsepower with the condenser submerged in the wings (no external condenser drag) for a turbine-inlet pressure of 500 pounds per square inch absolute, a turbine-outlet pressure of 10 pounds per square inch absolute, and a turbine-inlet temperature of 1600° F.

INTRODUCTION

Vapor cycle power plants offer a possibility for the application of nuclear energy to aircraft propulsion. The results of an analysis of the performance of a steam-turbine power plant for aircraft, with particular emphasis on the performance of the air-cooled condenser, were reported in reference 1.

The results of a similar analysis on the performance of a mercury-vapor power plant are reported herein. As with the steam plant, aside from the reactor, the condenser size was found to be a critical item of the power-plant installation, hence a large part of the study involves a determination of optimum condenser parameters. The analysis covers a range of turbine-inlet pressures, turbine-outlet pressures, cooling-air pressure drops, flight speeds, and altitudes.

An estimate of the power-plant specific weight, excluding the weight of the nuclear reactor and the working fluid, was made for one set of turbine operating conditions and two flight conditions and was used to calculate the percentage of the gross weight of the airplane that would be available for carrying the reactor and the cargo.

METHODS OF ANALYSIS

The power plant was considered to consist of a nuclear-reactor boiler, a mercury turbine, an air-cooled condenser, and the necessary pumps, valves, and piping. The boiler feed pump was assumed to be driven directly by the turbine and the net shaft power delivered to a propeller.

Calculations were made to determine the effect of turbine-inlet and turbine-outlet pressure, the ratio of cooling-air static-pressure drop to compressible dynamic pressure $\Delta p/q$, flight speed, and altitude on the condenser size and internal drag power. Turbine-outlet pressures from 1 to 200 pounds per square inch absolute were investigated at turbine-inlet pressures of 300, 500, and 700 pounds per square inch absolute for a value of $\Delta p/q$ of 0.30 at a flight speed of 500 miles per hour and an altitude of 30,000 feet. Values of $\Delta p/q$ from 0.10 to 0.75 were investigated for constant turbine operating conditions and flight conditions. Flight speeds of 100 to 500 miles per hour at altitudes of sea level, 15,000, and 30,000 feet were investigated for a constant condenser size and one set of turbine operating conditions. All cycle calculations were made for a constant turbine-inlet temperature of 1600° F. This inlet temperature corresponds to a superheated temperature of 509°, 404°, and 327° F at turbine-inlet pressures of 300, 500, and 700 pounds per square inch absolute, respectively.

Except for some small differences, the method of analysis is the same as the method given in detail in reference 1. For convenience, however, the method will be briefly outlined here.

For all calculations except those involving power-plant-weight estimates, the weight flow of mercury was adjusted to give 1000 net shaft horsepower from the turbine, which was assumed to have an adiabatic efficiency of 85 percent. The 1000 shaft horsepower was then delivered to a propeller having an assumed efficiency of 85 percent that resulted in 850 propeller thrust horsepower.

Condenser calculations were based on an aircraft fin-and-tube-type heat exchanger manufactured by the Harrison Radiator Division, General Motors Corporation. In reference 1 for condensing steam, an aluminum heat exchanger having a weight, including headers, of 15.4 pounds per square foot of frontal area was used; whereas in this analysis for condensing mercury vapor, a steel construction of the same configuration having a weight of 45 pounds per square foot of frontal area was used. Preliminary calculations based on the cooling-air-side and working-fluid-side film coefficients and the fin effectiveness indicated that the over-all heat-transfer coefficient for condensing mercury in a steel exchanger would be slightly greater than for condensing steam in an aluminum exchanger. These calculations assumed the addition of a wetting agent to the mercury so that the steel condenser tubes were completely wetted by the liquid mercury. On the basis of these preliminary calculations, the manufacturer's experimental steam-to-air heat-dissipation-rate charts for the aluminum exchanger were used in the calculation of condenser area. Cooling-air pressure drops were obtained from the manufacturer's charts modified to account for the effects of altitude and higher heat loading.

For a given heat rejection and cooling-air pressure drop, the required condenser frontal area and weight flow of cooling air were determined from the modified charts. The condenser weight was then the product of frontal area and the weight per unit frontal area (45 lb/sq ft). The internal drag power (sometimes thrust power) of the condenser was then calculated from the change in momentum of the cooling air. The net thrust power was taken as the algebraic difference between the propeller thrust power (product of turbine power and propeller efficiency) and the internal drag power of the condenser. Positive values of the difference between the net thrust power and 850 (propeller thrust power) represent condenser thrust power and negative values represent internal condenser drag power. Specific condenser weight and specific condenser frontal area in pounds and square feet per net thrust horsepower were then computed from the net thrust power and condenser weight and frontal area.

The calculations of the ratio of disposable load (load-carrying capacity available for reactor, working fluid, and cargo) to airplane gross weight W_d/W_g involved an estimation of the installed power-plant specific weight including propeller, reduction gearing, engine mountings, air ducting, and controls. The lift-to-drag ratio of the airplane without nacelles was assumed to be 18 and the structural weight of the airplane was assumed to be 40 percent of the airplane gross weight. Calculations were made for the cases of the condenser submerged in the wings so that no external condenser drag was involved and for the condenser enclosed in a nacelle. For the latter case it was necessary to calculate the external condenser drag power (nacelle drag power). The method and assumptions used in calculating the quantity W_d/W_g were the same as in reference 1.

The thermodynamic properties of the mercury vapor necessary for these calculations were obtained from the General Electric Company.

RESULTS AND DISCUSSION

Moisture in turbine exhaust. - The percentage of moisture in the turbine exhaust is shown in figure 1 for several combinations of turbine-inlet and turbine-outlet pressures for a turbine-inlet temperature of 1600° F and an adiabatic turbine efficiency of 0.85. As the turbine-outlet pressure is decreased and the turbine-inlet pressure is increased, the percentage of moisture in the turbine exhaust increases. If a moisture content in the turbine exhaust of 15 percent is considered to be the maximum allowable amount then for a turbine-inlet temperature of 1600° F the minimum turbine-outlet pressures allowable will be approximately 2.5, 8.0, and 14.0 pounds per square inch absolute for turbine-inlet pressures of 300, 500, and 700 pounds per square inch absolute, respectively.

The calculations were terminated at turbine-outlet pressures of 75 and 170 pounds per square inch absolute for turbine-inlet pressures of 300 and 500 pounds per square inch absolute, respectively, inasmuch as turbine-outlet pressures above these values result in superheated vapor at the turbine exhaust.

Cycle performance. - The effect of turbine-outlet pressure on cycle efficiency and mercury-flow rate is shown in figure 2 for turbine-inlet pressures of 300, 500, and 700 pounds per square inch absolute and a turbine-inlet temperature of 1600° F. The turbine power output is 1000 horsepower and the turbine efficiency is 0.85. The dashed lines in figures 2, 3, 4, and 7 indicate the combinations of turbine-inlet and turbine-outlet pressures that result in 15-percent moisture at the turbine outlet.

As the turbine-outlet pressure increases and the turbine-inlet pressure decreases, the cycle efficiency decreases and in order to maintain a constant turbine-power output the mercury-flow rate must increase.

The variation of reactor-heat input and heat rejected by the condenser with turbine-outlet pressure is shown in figure 3 for

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turbine-inlet pressures of 300, 500, and 700 pounds per square inch absolute and a turbine-inlet temperature of 1600° F. Also shown in this figure is the variation of turbine-outlet temperature (saturation temperature) with turbine-outlet pressure. The turbine power and efficiency are the same as in figure 2. The reactor-heat input and the heat rejected by the condenser increase with increasing turbine-outlet pressure and decreasing turbine-inlet pressure. These heat quantities are the products of the heat per pound of fluid and the mercury-flow rate and inasmuch as the heat per unit weight of fluid is nearly constant, the increases with turbine-outlet pressure shown in figure 3 are due to the increasing mercury-flow rate, which in turn is due to the decreasing cycle efficiency.

The turbine-outlet temperature (temperature of the condensing mercury vapor) increases as the turbine-outlet pressure increases. Inasmuch as the expansion in every case was to or below the saturation line the turbine-outlet temperature is a function of the turbine-outlet pressure only. This temperature varies from about 640° to 1020° F for a change in turbine-outlet pressure from 10 to 200 pounds per square inch absolute (fig. 3). For the same change in turbine-outlet pressure, the temperature of condensing steam varies from about 190° to 390° F.

A range of turbine-inlet temperatures was not investigated inasmuch as 1600° F represents approximately the maximum allowable value with respect to turbine strength and lower temperatures would only result in lower cycle efficiencies and larger condenser sizes. The final choice of a turbine-inlet temperature will primarily depend on reactor considerations.

Effect of turbine-outlet pressure on condenser performance. - The effect of turbine-outlet pressure on net thrust horsepower, condenser weight and frontal area, and specific condenser weight and frontal area is shown in figure 4 for turbine-inlet pressures of 300, 500, and 700 pounds per square inch absolute, a value of $\Delta p/q$ of 0.30, a flight speed of 500 miles per hour, and an altitude of 30,000 feet.

The condenser weight and frontal area increase as the turbine-outlet pressure increases and as the turbine-inlet pressure decreases for the range investigated. This increase in condenser weight and frontal area is due to the decrease in cycle efficiency and consequent increase in heat rejection shown in figures 2 and 3, respectively. Although the initial temperature difference (between the entering cooling-air and the condensing mercury) increases with increasing turbine-outlet pressure, tending to decrease the condenser size, the effect is offset by the increased heat rejection.

The net thrust power (propeller thrust power less internal condenser drag power or plus condenser thrust power) increases with increasing turbine-outlet pressure and decreasing turbine-inlet pressure. At this value of $\Delta p/q$ (0.30) thrust was obtained from the condenser in every case. For a constant cooling-air pressure drop, the increase in condenser frontal area discussed in the preceding paragraph results in an increase in total cooling-air flow and therefore an increase in net thrust power. The increases in net thrust power with turbine-outlet pressure are also due, in part, to an increase in the cooling-air exit temperatures resulting from higher mercury condensing temperatures.

Specific condenser weight and frontal area also increase with increasing turbine-outlet pressure and decreasing turbine-inlet pressure, inasmuch as the increases in net thrust power are small compared to the increases in condenser weight and frontal area.

In the analysis of reference 1 on the steam plant the combination of the effects of initial temperature difference, condenser heat rejection, and condenser drag power resulted in a minimum point on the curve of specific condenser size against turbine-outlet pressure at pressures between 50 and 100 pounds per square inch absolute, which indicates that a compromise must be made between conditions that represent high cycle efficiency and those that represent low condenser size and drag power. For the mercury system, however, minimum specific condenser size and maximum cycle efficiency are both obtained at the low turbine-outlet pressures. For the inlet pressures and inlet temperature considered here, however, minimum turbine-outlet pressures are limited by excessive moisture in the turbine exhaust as indicated in figure 1.

Turbine-inlet pressures higher than 700 pounds per square inch absolute would be desirable with respect to specific condenser size, however, higher inlet pressure were not investigated in this analysis because of a lack of thermodynamic data.

Effect of cooling-air pressure drop on condenser performance. - The variation of net thrust horsepower, condenser weight and frontal area, and specific condenser weight and frontal area with $\Delta p/q$ is shown in figure 5 for a turbine-inlet pressure of 500 pounds per square inch absolute, a turbine-outlet pressure of 10 pounds per square inch absolute, a flight speed of 500 miles per hour, and altitude of 30,000 feet.

The net thrust horsepower and the condenser weight and frontal area decrease with increasing $\Delta p/q$. As the cooling-air pressure drop increases, the internal drag power increases with a consequent reduction in net thrust power. Also, as the pressure drop increases, the cooling-air flow per unit cross-section area increases so that progressively smaller condenser sizes are required to reject a given amount of heat. As a result of the decreasing net thrust power and condenser size, the specific condenser weight and frontal area reach minimum points of 0.225 pound per net thrust horsepower and 0.005 square foot per net horsepower, respectively, at a $\Delta p/q$ of about 0.55 at the flight speed and altitude shown. The optimum $\Delta p/q$ will vary somewhat with flight speed and altitude as was shown in reference 1.

Effect of flight speed and altitude on the performance of a given condenser. - The effect of flight speed on net thrust horsepower and specific condenser weight and frontal area is shown in figure 6 for altitudes of sea level, 15,000, and 30,000 feet; a turbine-inlet pressure of 500 pounds per square inch absolute; and a turbine-outlet pressure of 10 pounds per square inch absolute. These curves are for a condenser having a weight of 225 pounds and a frontal area of 5 square feet, which is close to the size for minimum specific weight and frontal area at a flight speed of 500 miles per hour and an altitude of 30,000 feet for the same turbine operating conditions.

The dashed lines of required pressure drop equal to maximum available pressure drop mark the limiting flight speeds at each altitude below which this size condenser will not dissipate the required amount of heat.

The net thrust horsepower increases as the flight speed increases and as the altitude decreases. The effect of flight speed on net thrust power is less at the low altitudes. Inasmuch as these curves are for a constant condenser size and a specific set of cycle conditions, the variation of specific condenser weight and frontal area is only a reflection of the variation of net thrust power, hence, internal drag power with flight speed and altitude.

Comparison of condensers for mercury and steam power plants. - The preceding curves have shown that the condensers for a mercury-vapor power plant may have a specific frontal area as low as 0.005 square foot per net thrust horsepower and a specific weight of about 0.225 pound per net thrust horsepower for a turbine-inlet pressure of 500 pounds per square inch absolute, a turbine-outlet pressure of 10 pounds per square inch absolute, and a turbine-inlet temperature of 1600° F (fig. 6). This specific condenser frontal area is about one-third the area required for a steam plant operating at a turbine-inlet pressure of 1400 pounds per square inch absolute, a turbine-outlet pressure of 100 pounds per square inch absolute, and a turbine-inlet temperature of 866° F as indicated in reference 1. Although the mercury condensers have a smaller frontal area and volume for these conditions the assumption of a steel construction results in their weight being about the same as that for the larger aluminum steam condensers. The difference in specific frontal areas between the mercury and steam plants is due primarily to the following two effects: (1) mercury condenses at a higher temperature, hence the initial temperature difference between the condensing vapor and the cooling air is greater making the required area less, and (2) the higher condensing temperature causes a higher temperature rise of the cooling air resulting in lower condenser internal drag powers (higher condenser thrust power).

Effect of turbine-outlet pressure on over-all efficiency. - Inasmuch as the reactor weight is the principal consideration in a nuclear-energy power plant the attainment of a maximum thrust power per unit weight of the reactor is of greater importance than the attainment of a maximum thrust per unit weight of condenser (minimum condenser size). Over-all efficiency, defined as the dimensionless ratio of net thrust power minus nacelle drag power to the reactor-heat input, is an approximate measure of the thrust power per unit weight of the reactor and, therefore, with the reactor operating at its maximum heat-release rate, maximum net thrust power per unit weight of the system will be obtained at maximum over-all efficiency.

The variation of over-all efficiency with turbine-outlet pressure is shown in figure 7 for turbine-inlet pressures of 300, 500, and 700 pounds per square inch absolute, a $\Delta p/q$ of 0.30, a flight speed of 500 miles per hour, and an altitude of 30,000 feet. Over-all efficiency decreases as the turbine-outlet pressure increases and as the turbine-inlet pressure decreases for the range of pressures investigated. These curves follow the same trend as the cycle efficiency curves of figure 2 although the decrease in over-all efficiency with increasing turbine-outlet pressure is not as rapid as the decrease in cycle efficiency. For a nuclear-energy mercury power plant, then, maximum cycle efficiency, minimum specific condenser size, and maximum over-all efficiency all occur at the lowest turbine-outlet pressure and highest turbine-inlet pressure investigated.

Submerging the condenser in the wing so as to eliminate the external nacelle drag power would not affect the general shape of the curves in figure 7, but the increase in over-all efficiency with decreasing turbine-outlet pressure would not be so rapid.

Effect of $\Delta p/q$ on over-all efficiency. - The effect of $\Delta p/q$ on over-all efficiency is shown in figure 8 for a turbine-inlet pressure of 500 pounds per square inch absolute, a turbine-outlet pressure of 10 pounds per square inch absolute, a flight speed of 500 miles per hour, and an altitude of 30,000 feet. Over-all efficiency increases with $\Delta p/q$ and reaches a maximum at a value of $\Delta p/q$ of about 0.20 and then decreases throughout the remainder of the range. As $\Delta p/q$ decreases the net thrust power (propeller thrust power less internal drag power) increases; however, the condenser frontal area and hence nacelle drag power also increase. (See fig. 5.) Below a value of $\Delta p/q$ of 0.20 the nacelle drag power increases more rapidly with decreasing $\Delta p/q$ than the net thrust power so that the over-all efficiency must decrease when the reactor-heat input is constant.

The position of the maximum point in the curve of figure 8 would vary with flight speed and altitude shifting to the left (toward low $\Delta p/q$ values and large condenser frontal areas) with decreasing flight speed where the nacelle drag power is low and to the right (toward high $\Delta p/q$ values and small condenser frontal areas) with decreasing altitude where the nacelle drag power is high. The condenser frontal area for maximum over-all efficiency will therefore be larger for the submerged installation than for the case of the condenser enclosed in a nacelle. For the conditions shown in figure 8 for the case of the condenser enclosed in a nacelle, maximum over-all efficiency will be obtained with a condenser having a specific frontal area of 0.0068 square feet per net thrust horsepower ($\Delta p/q$ of 0.30). For the submerged installation, the condenser frontal area for maximum over-all efficiency will be the maximum amount that can be submerged.

Load-carrying capacity. - The variation of the ratio of disposable load (load-carrying capacity) to airplane gross weight W_d/W_g with condenser frontal area is shown in figure 9 for the cases of the condenser enclosed in a nacelle and the condenser submerged in the wings (no external condenser drag). The quantity W_d/W_g represents the fraction of the gross weight of the airplane that will be available for carrying the nuclear reactor, working fluid, and cargo. The maximum value of this quantity will establish the optimum condenser size. The calculations for these curves are based on an estimate of the specific power-plant weight for a mercury-turbine power plant operating at a turbine-inlet pressure of 500 pounds per square inch absolute, a turbine-outlet pressure of 10 pounds per square inch absolute, a turbine-inlet temperature of 1600° F, a turbine-power output of 5000 shaft horsepower, a flight speed of 500 miles per hour, and an altitude of 30,000 feet.

The quantity W_d/W_g (load-carrying capacity) increases to a maximum of 0.480 for the condenser in a nacelle and to 0.493 for the condenser submerged in the wings at condenser frontal areas of 25 and 27 square feet, respectively. For the case of the condenser in a nacelle, increasing the frontal area above about 25 square feet increases the external condenser drag and the condenser weight sufficiently to cause a decrease in load-carrying capacity (reactor, working fluid, and cargo). For the case of the condenser submerged in the wings (no external condenser drag), increasing the condenser frontal area above about 27 square feet increases the condenser weight sufficiently to cause a decrease in W_d/W_g despite the fact that the net thrust power (propeller thrust power less internal condenser drag power) continues to increase with increasing condenser size. The curves of figure 9 are for a turbine output of 5000 shaft horsepower, however, if the assumption is made that specific power-plant weight is independent of power level the results are applicable to any power level. For example, a 50,000 shaft horsepower unit operating at the same flight conditions and turbine operating conditions as indicated in figure 9 would have a maximum value of W_d/W_g of approximately 0.493 (condenser submerged) with a condenser frontal area of 270 square feet.

The condenser frontal areas of 25 and 27 square feet for maximum load-carrying capacity correspond to specific frontal areas of 0.0063 and 0.0060 square foot per net thrust horsepower. These values correspond to minimum specific engine (including condenser) weight and are somewhat higher than the value (0.005 sq ft/net thrust hp) corresponding to minimum specific condenser weight indicated in figure 5.

The total installed weight of a power plant having a condenser with a frontal area of 25 square feet and operating at a flight speed of 500 miles per hour and an altitude of 30,000 feet was estimated to be 6445 pounds. This weight excludes the reactor and working fluid but includes the propeller, reduction gearing, engine mountings, and the necessary pumps, piping, and controls and corresponds to specific weights of 1.29 pounds per turbine horsepower, 1.44 pounds per net thrust horsepower with the condenser submerged in the wings, and 1.62 pounds per net thrust horsepower with the condenser in a nacelle.

For the same turbine operating conditions and condenser size but at a flight speed of 300 miles per hour and an altitude of 15,000 feet the values of W_d/W_g would be 0.525 for the condenser in a nacelle and 0.520 for the condenser submerged in the wings.

The power-plant weight would be 6855 pounds (owing to a heavier propeller) and the corresponding specific weights would be 1.37, 1.63, and 1.69 pounds per horsepower, respectively.

These values of W_d/W_g at the two flight conditions indicate that a load-carrying capacity equal to approximately half the gross weight of the airplane would be available for the nuclear reactor, working fluid, and cargo, or conversely, the gross weight of an airplane powered with a nuclear-energy mercury-turbine power plant would be about twice the weight of the nuclear reactor, working fluid, and cargo.

For flight speeds up to 500 miles per hour only small percentage gains (1 to 3 percent) in load-carrying capacity are obtained with the mercury powered airplane by submerging the condenser in the wing to eliminate the external drag power. The values of the ratio W_d/W_g calculated for the steam powered airplane in reference 1 for the same flight conditions compare very closely with the values given here except for the case of the condenser in the nacelle at the high flight speed (500 mph) where the large frontal area steam condenser results in excessive external drag power with consequent lowering of the load-carrying capacity (reactor plus cargo). The part of the load-carrying capacity of either system available for cargo will depend upon the size reactor required. Consideration of the heat transfer and nuclear aspects of reactors is necessary before the relative merits of these two systems can be properly evaluated.

SUMMARY OF RESULTS

The results of calculations on the performance of a nuclear-energy mercury-turbine power plant for aircraft may be summarized as follows:

1. For the range of turbine-outlet pressures investigated (1 to 200 lb/sq in. absolute) specific condenser weight and specific condenser frontal area decrease as the turbine-outlet pressure decreases for turbine-inlet pressures of 300, 500, and 700 pounds per square inch absolute.

2. At a turbine-inlet pressure of 500 pounds per square inch absolute, a turbine-outlet pressure of 10 pounds per square inch absolute, a turbine-inlet temperature of 1600° F, a flight speed of 500 miles per hour, and an altitude of 30,000 feet the minimum specific condenser weight is 0.225 pound per net thrust horsepower and the minimum specific condenser frontal area is 0.005 square foot per net thrust horsepower.

3. At a turbine-inlet pressure of 500 pounds per square inch absolute, a turbine-outlet pressure of 10 pounds per square inch absolute, a turbine-inlet temperature of 1600° F, a flight speed of 500 miles per hour, and an altitude of 30,000 feet, the maximum load-carrying capacity of a mercury-turbine powered aircraft available for the nuclear reactor, working fluid, and cargo would be approximately half of the gross weight of the airplane. This maximum value is obtained with specific condenser frontal areas of 0.0063 square foot per net thrust horsepower with the condenser in a nacelle and 0.0060 square foot per net thrust horsepower with the condenser submerged in the wings (no external condenser drag). The estimated specific weights of the installed power plant for the above conditions would be 1.29 pounds per turbine horsepower, 1.44 pounds per net thrust horsepower with the condenser submerged in the wings, and 1.62 pounds per net thrust horsepower with the condenser enclosed in a nacelle. 952

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National Advisory Committee for Aeronautics,
Cleveland, Ohio.

REFERENCE

1. Humble, Leroy V., and Doyle, Ronald B.: Calculated Condenser Performance for a Steam-Turbine Power Plant for Aircraft. NACA RM No. E7J01, 1947.

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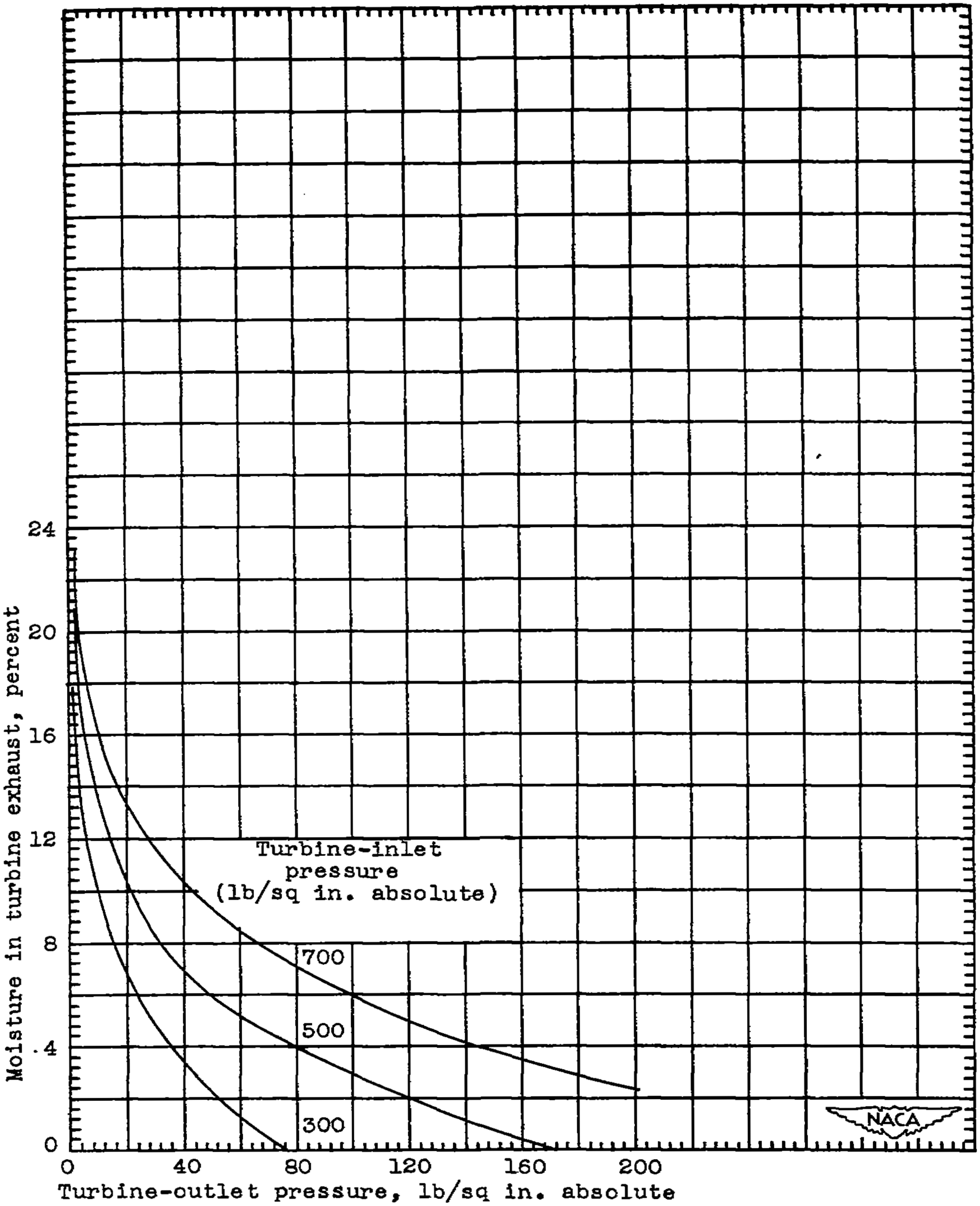

Figure 1. - Variation of percentage of moisture in turbine exhaust with turbine-outlet pressure for turbine-inlet pressures of 300, 500, and 700 pounds per square inch absolute. Turbine-inlet temperature, 1600° F; turbine efficiency, 0.85.

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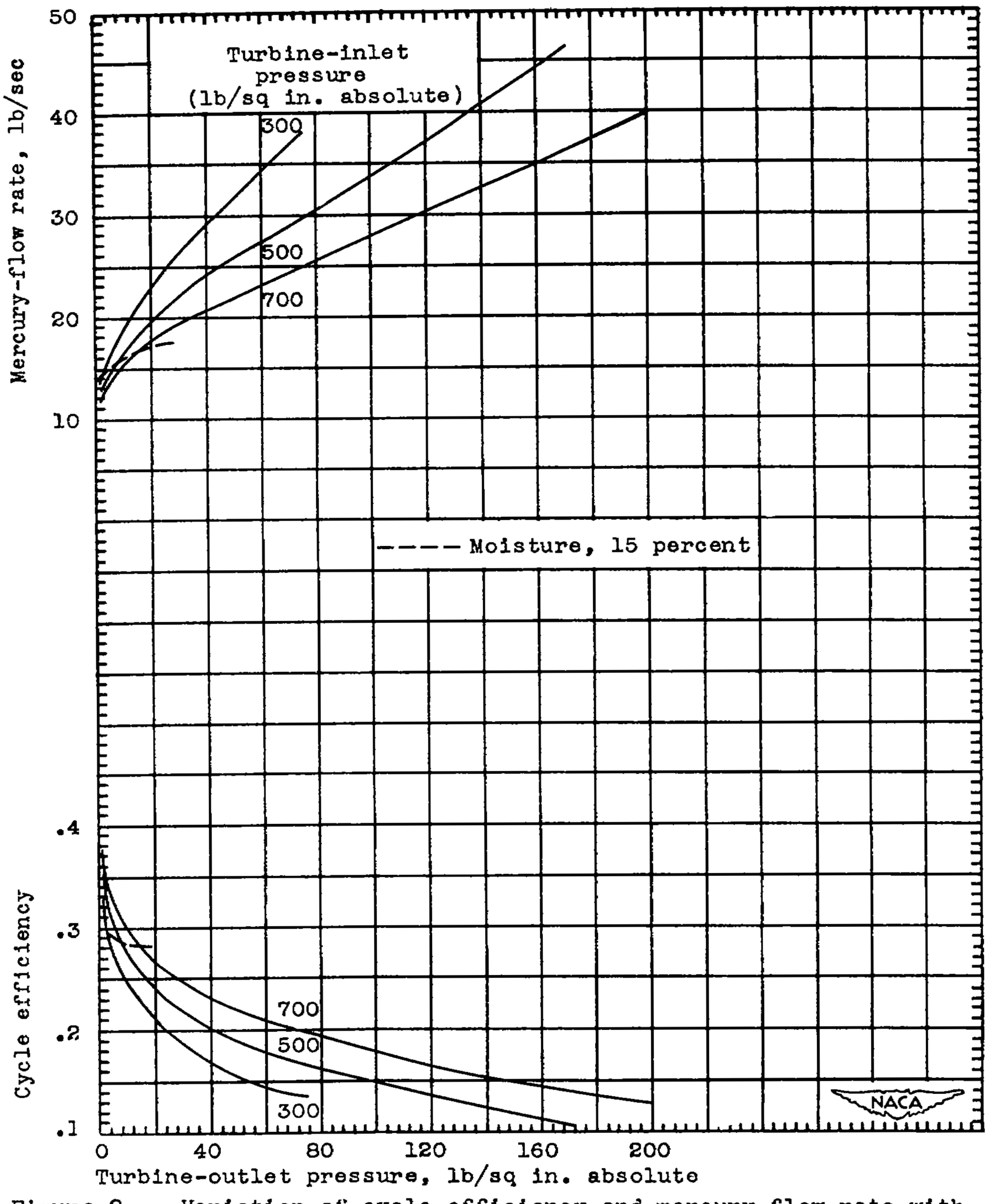

Figure 2. - Variation of cycle efficiency and mercury-flow rate with turbine-outlet pressure for turbine-inlet pressures of 300, 500, and 700 pounds per square inch absolute. Turbine-inlet temperature, 1600° F; turbine power, 1000 horsepower; turbine efficiency, 0.85.

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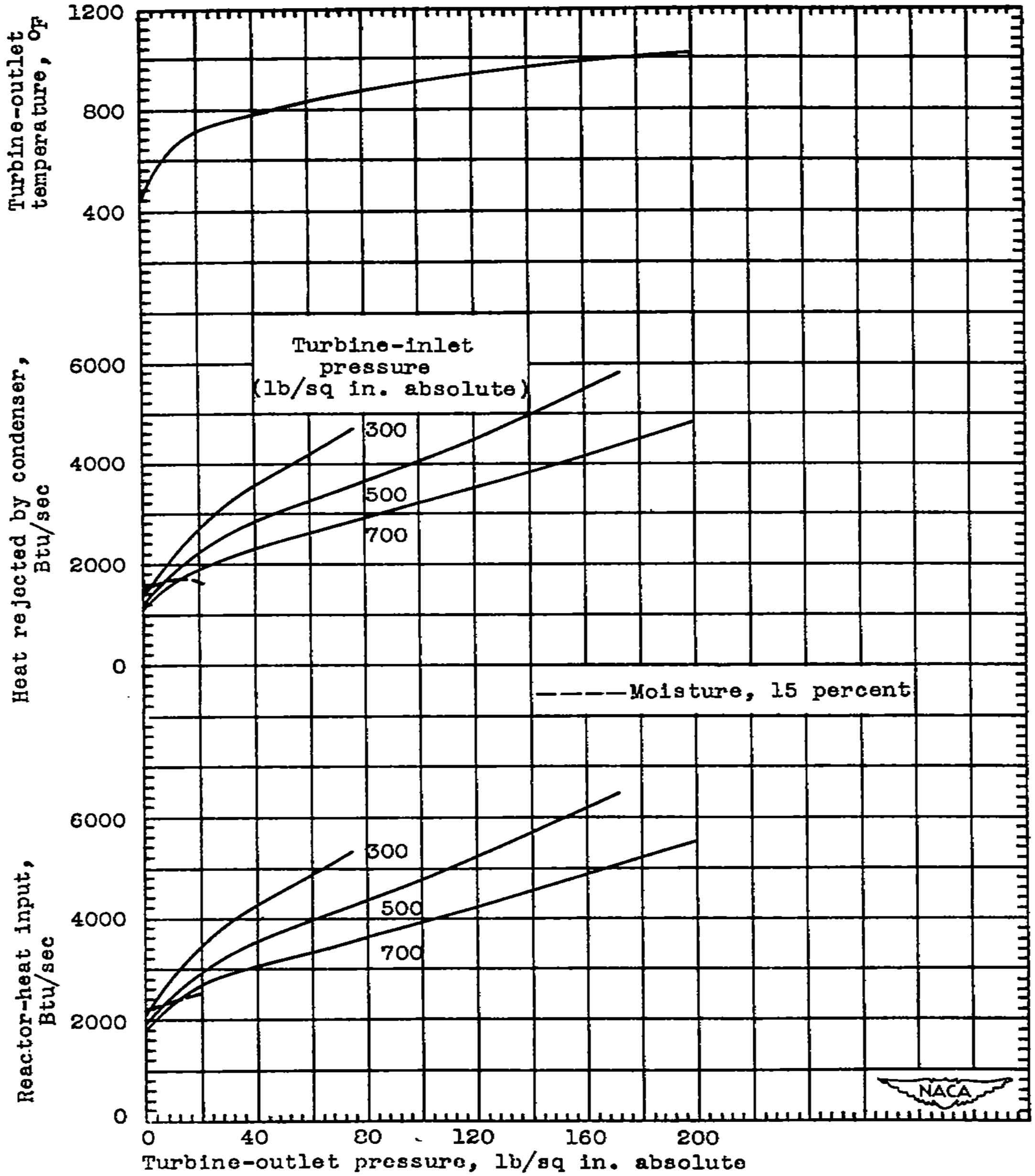

Figure 3. - Variation of reactor-heat input, heat rejected by condenser, and turbine-outlet temperature with turbine-outlet pressure for turbine-inlet pressures of 300, 500, and 700 pounds per square inch absolute. Turbine-inlet temperature, 1600° F; turbine power, 1000 horsepower; turbine efficiency, 0.85.

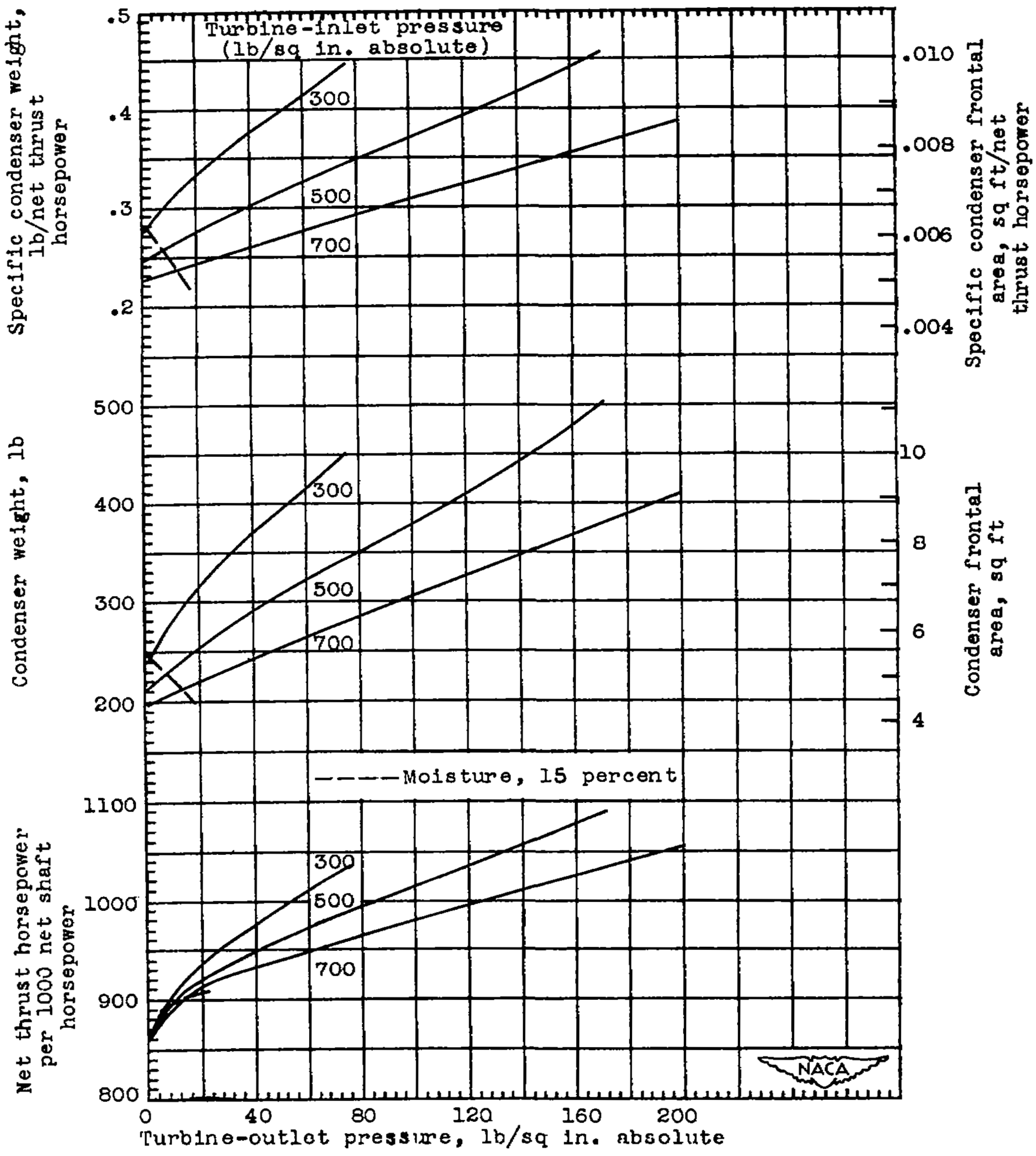

Figure 4. - Variation of net thrust horsepower, condenser weight and frontal area, and specific condenser weight and frontal area with turbine-outlet pressure for three turbine-inlet pressures. Turbine-inlet temperature, 1600° F; Δp/q, 0.30; flight speed, 500 miles per hour; altitude, 30,000 feet; turbine power, 1000 horsepower; turbine and propeller efficiencies, 0.85.

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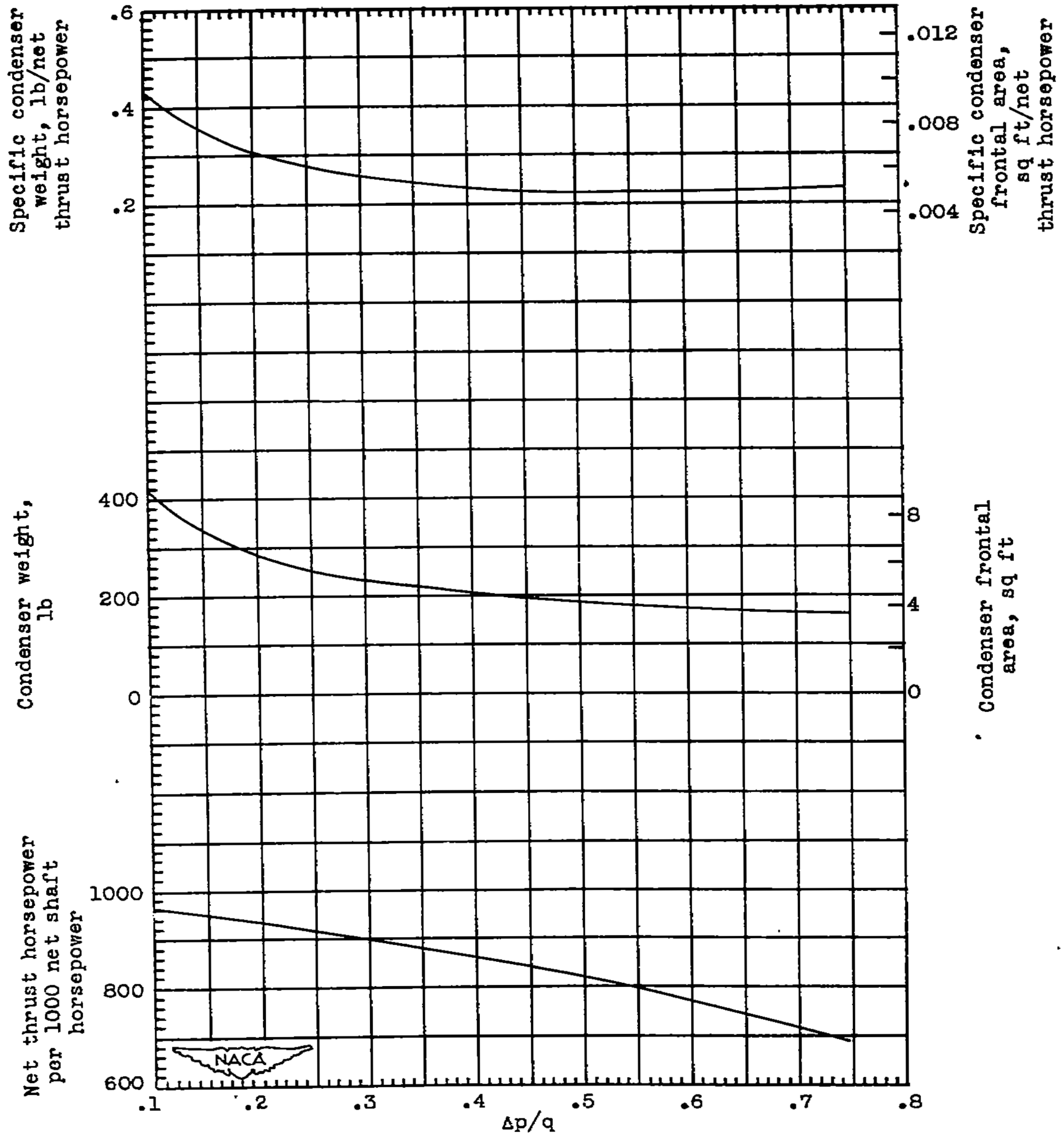

Figure 5. - Variation of net thrust horsepower, condenser weight and frontal area, and specific condenser weight and frontal area with $\Delta p/q$. Turbine-inlet pressure, 500 pounds per square inch absolute; turbine-outlet pressure, 10 pounds per square inch absolute; turbine-inlet temperature, 1600° F; flight speed, 500 miles per hour; altitude, 30,000 feet; turbine power, 1000 horsepower; turbine and propeller efficiencies, 0.85.

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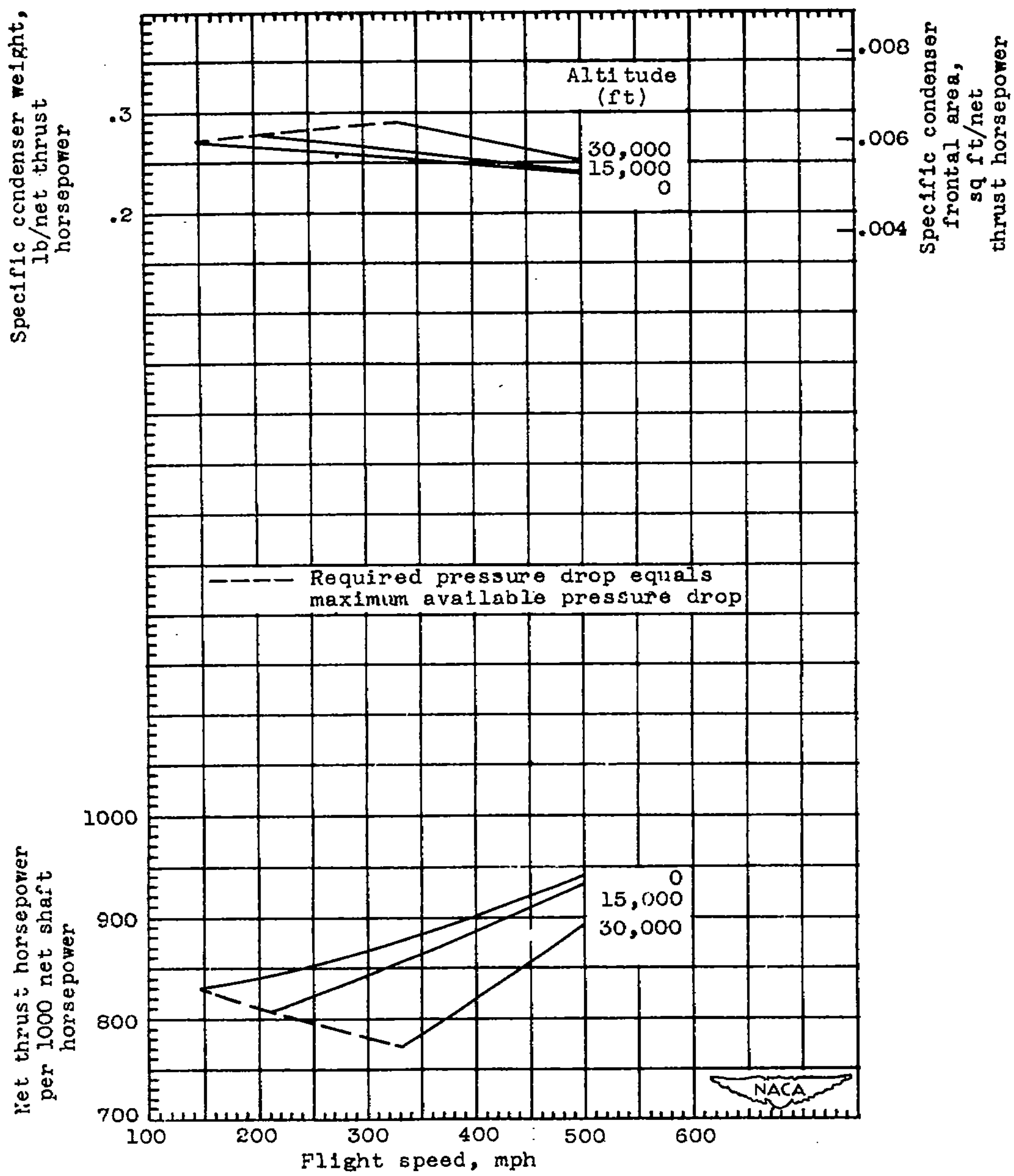

Figure 6. - Variation of net thrust horsepower and specific condenser weight and frontal area with flight speed for altitudes of sea level, 15,000, and 30,000 feet. Condenser weight, 225 pounds; condenser frontal area, 5 square feet; turbine-inlet pressure, 500 pounds per square inch absolute; turbine-outlet pressure, 10 pounds per square inch absolute; turbine-inlet temperature, 1600° F; turbine power, 1000 horsepower; turbine and propeller efficiencies, 0.85.

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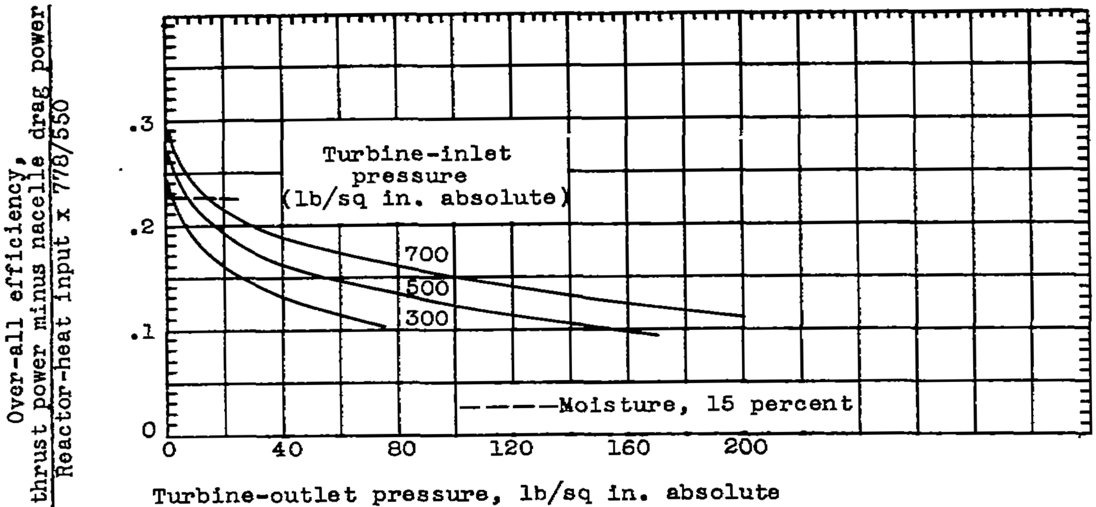

Figure 7. - Variation of over-all efficiency with turbine-outlet pressure for three turbine-inlet pressures. Turbine-inlet temperature, 1600° F; Δp/q, 0.3; flight speed, 500 miles per hour; altitude, 30,000 feet; turbine power, 1000 horsepower; turbine and propeller efficiencies, 0.85.

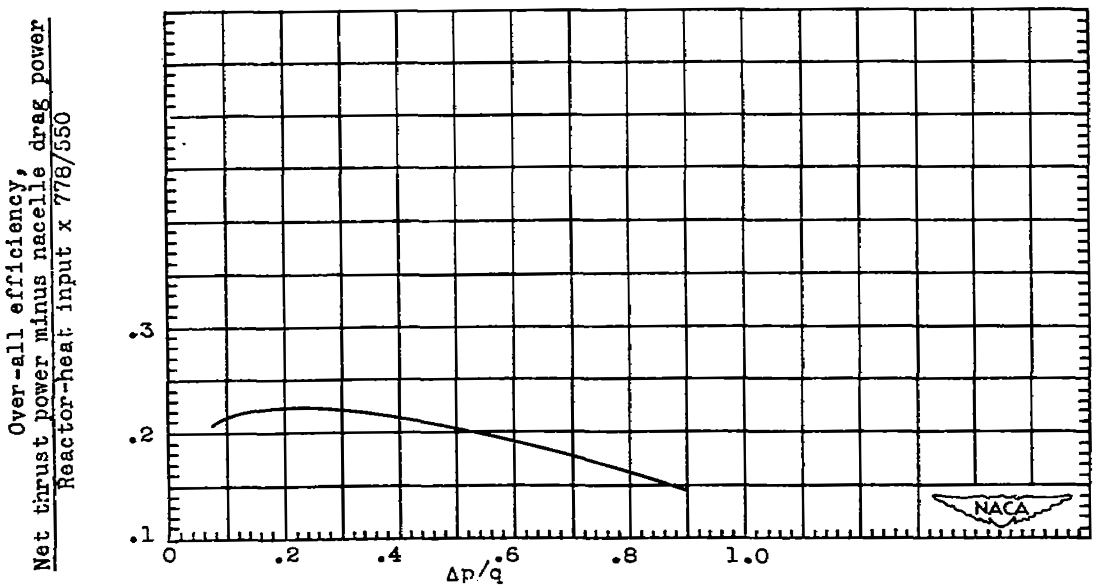

Figure 8. - Variation of over-all efficiency with Δp/q. Turbine-inlet pressure, 500 pounds per square inch absolute; turbine-outlet pressure, 10 pounds per square inch absolute; turbine-inlet temperature, 1600° F; flight speed, 500 miles per hour; altitude, 30,000 feet; turbine power, 1000 horsepower; turbine and propeller efficiencies, 0.85.

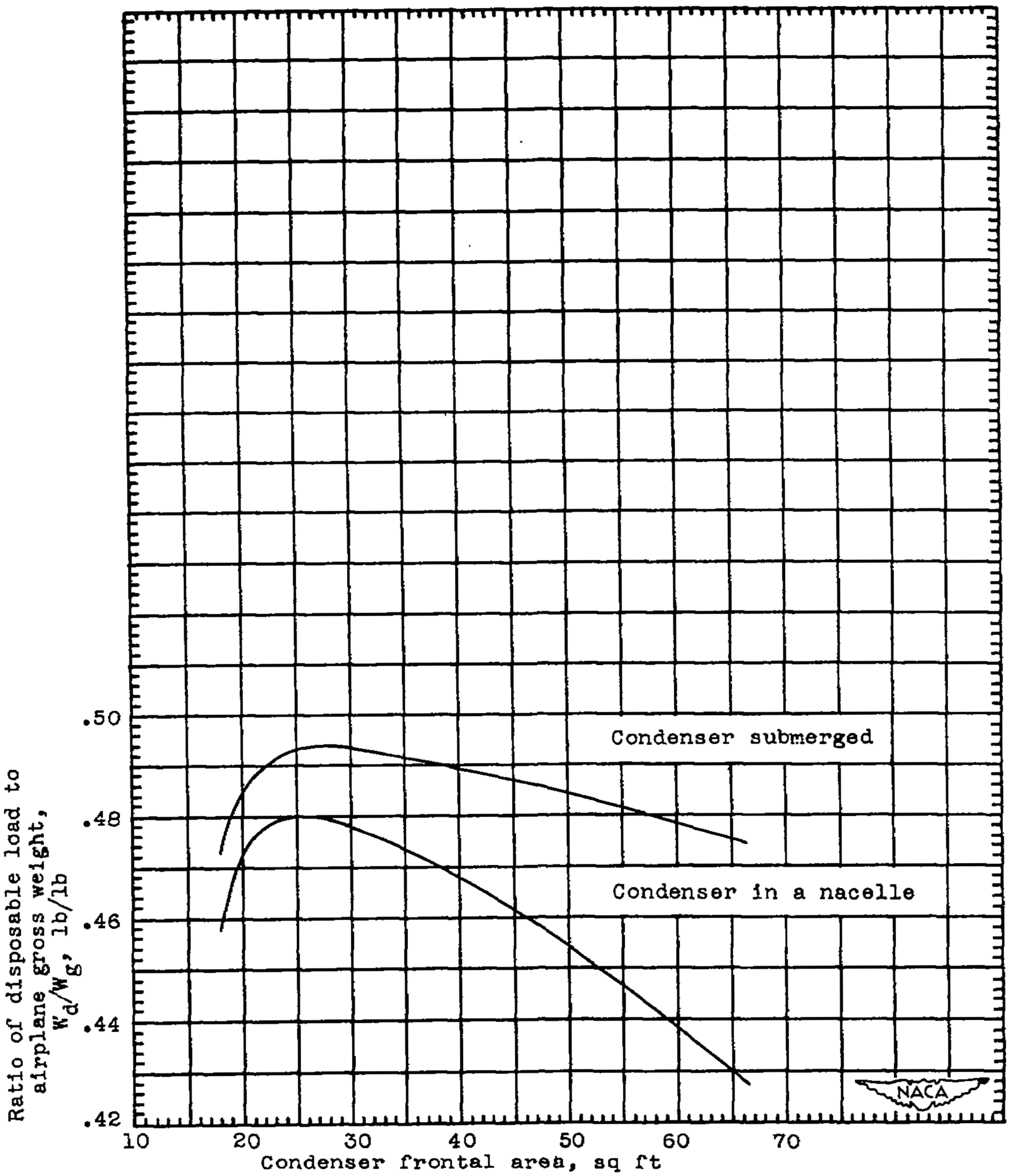

Figure 9. - Variation of the ratio of disposable load to airplane gross weight with condenser frontal area. Turbine-inlet pressure, 500 pounds per square inch absolute; turbine-outlet pressure, 10 pounds per square inch absolute; turbine-inlet temperature, 1600° F; flight speed, 500 miles per hour; altitude, 30,000 feet; turbine power, 5000 horsepower; turbine and propeller efficiencies, 0.85.