Inactive [redacted] Copy
RM E50E01

NACA RM E50E01

NACA

RESEARCH MEMORANDUM

EVALUATION OF A DUCTED-FAN POWER PLANT DESIGNED FOR HIGH OUTPUT AND GOOD CRUISE FUEL ECONOMY

By M. Behun, F. E. Rom, and R. V. Hensley

Lewis Flight Propulsion Laboratory
Cleveland, Ohio

CLASSIFICATION CANCELLED

Authority NACA R7 2994 Date 5/10/53

By ... 5/12/56 See

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WASHINGTON
October 17, 1950

[redacted]

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

RESEARCH MEMORANDUM

EVALUATION OF A DUCTED-FAN POWER PLANT DESIGNED FOR HIGH OUTPUT AND GOOD CRUISE FUEL ECONOMY

By M. Behun, F. E. Rom, and R. V. Hensley

SUMMARY

A ducted-fan power plant was designed for both high-output, high-altitude operation at low supersonic Mach numbers and good fuel economy at lower flight speeds. Calculated performance of the power plant at take-off and at conditions representative of high-output and cruise operation at altitudes from 5000 to 50,000 feet are presented.

The performance of the ducted fan is compared with the performance (with and without tail-pipe burner) of two hypothetical turbojet engines, one representing current design practice and the other representing a more advanced design (rated compressor pressure ratio, 12:1). The comparison is made at take-off and at an altitude of 35,000 feet under high-output, climbing, and cruising modes of operation. The comparison indicates that at a flight Mach number of 1.1 the ducted fan has a propulsive thrust per unit of frontal area between the thrusts obtained by the turbojet engines without tail-pipe burners and the turbojet engines with tail-pipe burning. At cruise conditions the ducted-fan power plant obtains the lowest propulsive thrust specific fuel consumption.

For equal maximum propulsive thrust at low supersonic Mach numbers at high altitudes, the ducted fan obtains a cruising flight duration and range appreciably greater than the turbojet engines equipped with tail-pipe burners. The maximum cruising speed of the ducted fan with duct burner inoperative, however, is appreciably lower than the cruising speeds obtained by the turbojet engine if the configurations are designed for the same high-speed performance.

INTRODUCTION

The present trend in the performance required of military aircraft indicates a need for a power plant having high output at high

[redacted]

altitudes and low supersonic Mach numbers and also good fuel economy at lower flight speeds. In order to fulfill these requirements, the power plant must have the high-speed, high-output performance typical of a turbojet engine with tail-pipe burning and the cruising economy typical of a turbine-propeller engine. The ducted-fan power plant with its high air-handling capacity, ability to burn fuel in the duct for maximum power output, and ability to obtain better cruise economy than a turbojet engine may fulfill the requirements for such a power plant. The ducted fan has been the subject of several investigations (references 1 to 5). In general, these investigations have considered the design-point performance of optimized engines or have treated the off-design performance of power plants utilizing a turbojet engine having sea-level rated compressor pressure ratios of the order of 4 to 5. Inasmuch as the current turbine-propeller engine has a compressor pressure ratio higher than the existing turbojet engine and therefore nearer the optimum for the ducted fan (reference 5), a turbine-propeller engine was selected as the basic element of the ducted-fan power plant for this investigation.

1318

Theoretical analyses were made of the ducted-fan cycle for both maximum power output and cruising operation. With these analyses as a basis for a compromise of the thrust, the frontal area, and the specific fuel consumption, a ducted-fan power-plant design was selected. The high-output performance of this engine was determined for take-off and for flight Mach numbers of 0.5 and 1.1 at altitudes from 5000 to 50,000 feet. The cruising performance was calculated both for a flight Mach number of 0.5 at altitudes from 5000 to 50,000 feet and for flight Mach numbers of 0.3 to 0.7 at an altitude of 35,000 feet.

The performance of the ducted fan is compared with the performance (with and without a tail-pipe burner) of two hypothetical turbojet engines, one representing current design practice and the other representing a more advanced design (rated compressor pressure ratio, 12:1). The comparison is made at take-off and at an altitude of 35,000 feet under high-output, climbing, and cruising modes of operation. Cruising-flight duration and range of the engines were determined assuming drag characteristics for two types of aircraft. The comparison of the flight duration and range of the ducted fan (with duct burner inoperative) and the turbojet engines (with tail-pipe burners inoperative) was made assuming the engine in each configuration to be designed to give the same high-speed performance.

DESCRIPTION OF POWER PLANT

The ducted-fan power plant, in any of its possible configurations, is a propulsive system consisting of a primary engine
1318 driving a fan that forces a large mass flow of air through a duct. The duct may contain burners for considerable augmentation of the thrust of the primary engine. In the ducted-fan power plant designed for this investigation, part of the air handled by the fan enters the primary engine (modified turbine-propeller engine) and the remainder flows through the duct (equipped with burners) surrounding the engine. This particular configuration was chosen for its simplicity and ability to obtain a greater pressure at the primary-engine inlet and thereby give the primary engine an effective pressure ratio nearer the optimum for both maximum power and minimum specific fuel consumption. The arrangement of the component parts of the ducted-fan power plant investigated is illustrated in figure 1.

ANALYSIS OF DUCTED-FAN CYCLE

In general, the propulsive efficiency (for a given flight speed) increases with a decrease in jet velocity. Consequently, for a given power input to the jet, a high propulsive efficiency results from a large mass flow in the jet with an accompanying low pressure ratio and therefore a low jet velocity. The thrust produced by the ducted fan considered herein is the sum of the thrust produced by the jet issuing from the primary engine exhaust nozzle (primary cycle) and the thrust of the jet issuing from the duct exhaust nozzle (secondary cycle). For a high over-all propulsive efficiency, a low turbine-outlet pressure and a low fan pressure ratio are therefore indicated. For a given flight speed, engine speed,and propulsive efficiency, the thrust of the secondary cycle varies directly with the mass flow and therefore with the power input to the secondary cycle. For the ducted-fan configuration investigated, an increase in fan pressure ratio increases the over-all primary engine pressure ratio, and for pressure ratios below that yielding optimum power, results in higher primary cycle efficiency and greater power available to drive the fan. Consequently, for maximum thrust (with a given gas temperature) a high fan pressure ratio is indicated. Therefore, the selection of a fan pressure ratio for best over-all efficiency and performance of the ducted-fan power plant investigated necessitates a compromise between the low values of fan pressure ratio required for best propulsive efficiency and the high values necessary for maximum thrust.

In order to obtain a basis for a satisfactory compromise of the fan pressure ratio requirements, the effect of fan pressure ratio on thrust, power-plant frontal area, and specific fuel consumption of design-point power plants was determined for both maximum power and cruise operation assuming a primary engine corrected air flow of 11.5 pounds per second per square foot of frontal area. It was also assumed that for the conditions investigated the primary exhaust-nozzle area was adjusted to give a turbine-outlet total pressure equal to the fan-inlet total pressure. Inasmuch as the combustion temperature in the duct (for a given flight condition) affects the power obtainable from the ducted fan and turbine-inlet temperature affects the cruising specific fuel consumption, the high-output performance was determined for two values of duct gas temperature and the cruise performance for two values of turbine-inlet temperature. Calculations were made for the following conditions:

	Maximum power operation	Cruise operation
Flight Mach number	1.1	0.5
Altitude, ft	30,000	30,000
Fan pressure ratio	1.2 - 3.5	1.2 - 3.5
Compressor pressure ratio	5,7	5,7
Turbine-inlet temperature, $^{\circ}R$	2160	2160, 1730
Duct-inlet velocity, ft/sec	200	200
Duct gas temperature, $^{\circ}R$	3000 2000	Cold duct

Other conditions and assumptions used in the calculations were as follows:

Ram pressure recovery:	
Supersonic total-pressure ratio	0.95
Subsonic dynamic pressure recovery, percent	90
Fan adiabatic efficiency, percent	85
Compressor adiabatic efficiency, percent	82
Primary combustion-chamber pressure loss, percent	6
Primary engine combustion efficiency, percent	97
Turbine adiabatic efficiency, percent	84
Ratio of total-pressure loss across flame holder in cold duct to inlet dynamic pressure (incompressible)	2
Duct combustion efficiency, percent	90
Exhaust-nozzle velocity coefficient (duct and engine)	0.95

The effect of fan and compressor pressure ratios on the high-output performance of the ducted-fan power plant is presented in figure 2. For a given compressor pressure ratio, figure 2(a) indicates that the ratio of duct air flow to primary engine air flow decreases with an increase in fan pressure ratio. For a given compressor pressure ratio and duct gas temperature, the maximum net thrust per unit of power-plant air flow is obtained for fan pressure ratios between 1.6 and 2.7. Figure 2(a) indicates that for fan pressure ratios up to approximately 3.0, the net-thrust specific fuel consumption decreases with an increase in fan pressure ratio. For a given fan pressure ratio the net thrust per unit of power-plant air flow decreases with an increase in compressor pressure ratio; however, the decrease is relatively small in the lower range of fan pressure ratios. The compressor pressure ratio had no appreciable effect on the specific fuel consumption. The effect of fan and compressor pressure ratios on power-plant size and net thrust per unit of power-plant frontal area is presented in figure 2(b). For a given compressor pressure ratio the frontal area decreases and the net thrust per unit of frontal area increases with an increase in fan pressure ratio. Although the net thrust per unit of frontal area increases with an increase in fan pressure ratio, the power-plant frontal area decreases at a greater rate, which results in a decrease in net thrust. Inasmuch as the primary engine corrected air flow was assumed constant for the study of design-point performance, the net thrust per unit of primary engine corrected air flow also decreases with an increase in fan pressure ratio (fig. 2(b)). For a given fan pressure ratio the frontal area, the net thrust per unit of frontal area, and the net thrust per unit of primary engine corrected air flow decrease slightly with an increase in compressor pressure ratio.

1318

The effect of fan and compressor pressure ratios on the cruise performance of the ducted-fan power plant is shown in figure 3. The ratio of duct air flow to primary engine air flow is shown to decrease with an increase in fan pressure ratio (fig. 3(a)). Comparison of the air-flow ratios (turbine-inlet temperature, 2160° R) in figures 2(a) and 3(a) indicates that for a given fan pressure ratio the air-flow ratio is approximately 50 percent greater for the cruise condition than for the high-output condition. Figure 3(a) also shows that for a turbine-inlet temperature of 2160° R, the net thrust per unit of power-plant air flow increases with fan pressure ratio over the ranges of pressure ratios investigated. For the lower turbine-inlet temperature, 1730° R, maximum values of net thrust per unit of power-plant air flow are obtained at fan pressure ratios of about 2.5 to 3.0, depending on the compressor pressure ratio. The minimum specific fuel consumption for the compressor pressure ratios investigated occurs at fan pressure ratios of approximately 1.5 to 2.0. In this range of fan pressure ratios, specific fuel consumption decreases with an increase in compressor pressure ratio and turbine-inlet temperature. Increasing the fan pressure ratio decreases the ratio of power-plant frontal area to primary engine frontal area, increases the net thrust per unit of frontal area, and in the lower range of fan pressure ratios increases the net thrust per unit of primary engine corrected air flow (fig. 3(b)). Figure 3(b) also indicates that increasing the compressor pressure ratio tends to decrease these factors.

OFF-DESIGN PERFORMANCE STUDIES

<u>Selection of engine characteristics</u>. - The design-point studies (figs. 2 and 3) indicate that the high-output performance was relatively insensitive to compressor pressure ratios in the range of fan pressure ratios below approximately 2.0 and that minimum cruising specific fuel consumption was obtained with the highest compressor pressure ratio investigated. Consequently, a constant primary engine compressor pressure ratio of 7.0 was used for the off-design studies. The primary engine was assumed to have a frontal area of 2.4 square feet and the corrected mass flow - corrected engine speed characteristics shown in figure 4. The primary engine component efficiencies were assumed to be those used in the design-point studies and are pessimistic compared to those obtained in current gas-turbine engines. It was further assumed that the limiting turbine-inlet temperature was 2160° R for sustained operation and 2260° R for short duration operation (take-off). In order to simplify the control problem of the ducted-fan power plant, the primary engine was assumed to have a constant-area exhaust nozzle. To deliver as much power as possible to the fan without increasing the engine frontal area, the actual exhaust-nozzle area was assumed equal to the primary engine frontal area.

As a result of the design point studies, a fan pressure ratio of approximately 1.6 was considered to be a suitable compromise of the conflicting fan-pressure requirements of the primary and secondary cycles. The fan characteristics used in the analysis (fig. 5) are those of a fan having a pressure ratio of the order of 1.6. These characteristics were scaled from experimentally determined characteristics of a small compressor and are representative of the characteristics that would be obtained from a three- or four-stage axial-flow compressor operating over this range of pressure ratios.

Preliminary calculations indicated that in order to have favorable fan pressure ratios over the entire flight range at constant engine speed and constant turbine-inlet temperature, it was necessary to operate at a lowered fan pressure ratio at take-off conditions. A fan pressure ratio of 1.5 at take-off was therefore selected. In order to obtain the required variation in fan-pressure ratio, a variable-area exhaust nozzle was required on the duct. Calculations indicated that for a given duct cross-sectional area, the duct-inlet velocities would vary considerably under some flight conditions. In order that the duct-inlet velocity should not exceed approximately 230 feet per second under any operating conditions, a duct cross-sectional area 3.19 times the primary-engine frontal area was required. Consequently, the total power-plant frontal area was approximately 10 square feet.

Engine performance. - The performance of the ducted-fan power plant operating at rated speed is shown in figure 6. At sea-level take-off, the thrust is 780 pounds per unit of frontal area and the specific fuel consumption is 3.0 pounds of fuel per hour per pound of thrust. In general, the net thrust per unit of frontal area decreases with an increase in altitude and the specific fuel consumption is independent of altitude above 10,000 and 15,000 feet for flight Mach numbers of 0.5 and 1.1, respectively. The relatively poor performance at the lower altitudes is caused by unfavorable fan operating conditions discussed subsequently. For a flight Mach number of 1.1, the net thrust per unit of frontal area decreases from 960 to 194 pounds per square foot as the altitude is increased from 5000 to 50,000 feet. At this flight Mach number the specific fuel consumption decreases from 3.6 pounds of fuel per hour per pound of thrust at 5000 feet to 2.6 pounds of fuel per hour per pound of thrust at 15,000 feet and remains at this value for altitudes up to 50,000 feet. For altitudes below 10,000 feet and a flight Mach number of 0.5 the net thrust per unit of frontal area increases slightly with an increase in altitude. At the same flight Mach number above an altitude of 10,000 feet the net thrust per unit of frontal area decreases with an increase in altitude. For burning in the duct at a flight Mach number of 0.5 (representative climbing condition) the net thrust per unit of frontal area decreases from approximately 590 pounds per square foot at 10,000 feet to 120 pounds per square foot at 50,000 feet. For this flight Mach number and range of altitudes, the specific fuel consumption is approximately 2.8 pounds of fuel per hour per pound of thrust. For the duct burner inoperative at a flight Mach number of 0.5 (representative cruising condition) the net thrust per unit of frontal area decreases from a maximum of 147 pounds per square foot at 10,000 feet to 30 pounds per square foot at 50,000 feet. For this flight Mach number at altitudes above 10,000 feet the specific fuel consumption is approximately 1.0 pound of fuel per hour per pound of thrust.

The poor performance at the lower altitudes is caused by the low fan pressure ratio and efficiency necessitated by the limiting turbine-inlet temperature of 2160° R. The variation of turbine-inlet temperature, fan pressure ratio, and fan efficiency with flight conditions is shown in figure 7. Although the turbine-inlet 1318 temperature at the higher altitudes did not limit the operation of the power plant to a fan pressure ratio of 1.7, calculations indicated that, due to the characteristics of the fan, any improvement in performance that might be expected from use of higher pressure ratios was more than offset by the effect of the reduced mass flow accompanying the increase in pressure ratio. The variation of the duct exhaust-nozzle area, expressed as the ratio of this area to that of the primary engine exhaust nozzle, necessary to obtain the required fan pressure ratios and the resulting duct-inlet velocities are presented in figure 8.

More favorable fan operating conditions at low altitudes (at a given primary engine speed) could be obtained if provision were made for varying the ratio of fan mass flow to primary engine mass flow. Three possible methods of accomplishing this mass-flow variation are the use of a variable gearing ratio between the fan and the primary engine, a separate turbine to drive the fan, or variable-incidence inlet-guide vanes on the fan. As an example of the possible appreciation in performance, decreasing the ratio of the fan to compressor speeds by 8.5 percent at a low altitude and a low Mach number increases the thrust obtained with the duct burner inoperative by approximately 45 percent and the specific fuel consumption decreases by approximately 25 percent.

The performance at cruise conditions (duct burner inoperative) at a given altitude is very sensitive to changes in flight Mach number. The effect of flight Mach number on the cruise performance at rated engine speed and an altitude of 35,000 feet is presented in figure 9. Inasmuch as the performance of the primary engine in the range of cruising speeds investigated is essentially that of a constant-power engine, the thrust increases from 48 to 78 pounds per unit of frontal area and the specific fuel consumption decreases from 1.25 to 0.68 pound of fuel per hour per pound of thrust with a decrease in flight Mach number from 0.7 to 0.3.

Comparison of Performance

Net thrust. - The performance of the ducted fan is compared with the performance (with and without a tail-pipe burner) of two hypothetical turbojet engines, one representing current design practice and the other representing a more advanced design (rated compressor pressure ratio, 12:1). For the comparison, the current and future turbojet engines were assumed to have corrected mass flow-corrected engine speed characteristics similar to existing engines, rated corrected mass flows of 13 and 16 pounds per second per square foot of frontal area, and rated compressor pressure ratios of 5 and 12, respectively. In order to provide an equitable comparison, the same component efficiencies (polytropic for compressor and turbine) and limiting turbine-inlet temperature were assumed for all engines considered. Rated engine speed and a tail-pipe-burner outlet temperature of 3800° R were assumed for the high-output condition of the turbojet engines equipped with a tail-pipe burner. For cruise conditions, the turbojet engines were assumed to operate at 95 percent of rated engine speed with a turbine-inlet temperature of 1730° R. The performance of the turbojet engines was computed by the methods of reference 6. Performance comparisons are presented in terms of net thrust per unit of frontal area and net-thrust specific fuel consumption in table I.

The comparison of the performance of the power plants at a flight Mach number of 1.1 indicates that the ducted fan has a net thrust per unit of frontal area between that obtained by the turbojet engines without tail-pipe burners and the turbojet engines with tail-pipe burning. At this flight condition the ducted fan has the highest net-thrust specific fuel consumption. Comparison of the cruise performance indicates that the ducted fan has a net thrust per unit of frontal area of about 30 to 40 percent of that obtained by the turbojet engines. At these conditions the net-thrust specific fuel consumption of the ducted fan is appreciably below that obtained by the turbojet engines.

An appreciable improvement in component performance over that assumed in the preceding calculations would improve the performance of all the engines considered. The improvement in performance of the ducted fan, due to the inherent characteristics of this type of power plant, would be greater than that realized by the turbojet engines.

Propulsive thrust. - For configurations in which the engine is completely buried in the fuselage or wing roots, net thrust may be used as a basis for an equitable comparison of engine performance. If the power plant tends to increase the frontal area of the air frame or if the engines must be mounted in nacelles, propulsive thrust (net thrust minus nacelle drag) is to be preferred as a basis for a comparison of engine performance at high flight speeds. Nacelle drag for subsonic flight was determined assuming an over-all drag coefficient of 0.04. For supersonic conditions the nacelle drag was considered as the sum of the wave drag (5° flow deflection) and the

skin-friction drag (skin-friction coefficient, 0.0025). The results
of the drag calculations indicate that at low supersonic Mach numbers
the total nacelle drag of the ducted fan of this investigation is
greater than that of the turbojet engines; however, its drag per
unit of frontal area (because of the greater mass flow per unit of 1318
frontal area) is less than that of the turbojet engines. The per-
formance of the ducted-fan power plant and the turbojet engines in
terms of propulsive thrust per unit of frontal area and specific fuel
consumption based on propulsive thrust are presented in table II.

The comparison of the performance of the ducted-fan power plant and the turbojet engines with tail-pipe burning at a flight Mach number of 1.1 at an altitude of 35,000 feet (table II) indicates that the current turbojet engine with tail-pipe burning gives a propulsive thrust per unit of frontal area approximately 36 percent greater and a specific fuel consumption slightly lower than the ducted-fan power plant. The future turbojet engine with tail-pipe burning gives a propulsive thrust per unit of frontal area approximately 86 percent greater and a specific fuel consumption approximately 10 percent lower than the ducted-fan. Therefore, if the turbojet engines with tail-pipe burning and the ducted fan are to provide the same propulsive thrust at this flight condition, the ducted-fan power plant would have to be approximately 1.36 and 1.86 times the size of the current and future turbojet engines, respectively. Consequently, the take-off thrust of the ducted fan will be only slightly lower than the thrusts of the current and future turbojet engines with tail-pipe burning, because the difference in power-plant sizes almost compensates for the lower value of the take-off thrust per unit of frontal area of the ducted fan (table II). In addition, if all the engines are designed to give the same thrust at a Mach number of 1.1 at an altitude of 35,000 feet, the propulsive thrust of the ducted fan under cruising conditions is about one-half that of either the current or future turbojet engine, although the cruising thrusts per unit of frontal area (table II) show a considerably greater difference.

In order to determine the relative weights of the engines giving the same propulsive thrust at a flight Mach number of 1.1 and an altitude of 35,000 feet, the weight of the ducted fan was estimated. For this estimate the primary engine weight was assumed equal to 65 percent of the dry weight of a typical turbine-propeller engine, and the weight of the fan, the gear reduction unit, and the other components was scaled from similar elements of other engines. Results of the weight estimation are in fair agreement with references 3 to 5 and indicate that the weight per unit of frontal area of the ducted fan investigated is approximately 35 and 48 percent lower than that of the current and future turbojet engines equipped with tail-pipe burners, respectively. Consequently, the weights of the engines giving the same propulsive thrust at the flight condition considered are approximately equal because the difference in the weight per unit of frontal area of the engines very nearly compensates for the difference in power-plant sizes.

Duration and range. - For the comparison of the cruising-flight duration and range of the ducted-fan power plant and turbojet engines with tail-pipe burners, it was assumed that the power plants were installed in identical airplanes and gave the same propulsive thrust at a flight Mach number of 1.1 and an altitude of 35,000 feet. It was also assumed that each configuration carried an equal weight of fuel at the start of cruise operation at this altitude. The cruising speed of each configuration is therefore determined by the propulsive thrust and drag characteristics of the engine and airplane, respectively. The airplane drag characteristics assumed for the comparison are based on drag characteristics presented in references 4, 7, and 8, and are considered to be representative of aircraft designed for the type of service considered. The propulsive thrust of the engines and the drag of two types of airplane at an altitude of 35,000 feet are expressed in figure 10 as a ratio of the propulsive thrust (or drag) at different flight Mach numbers to the propulsive thrust (or drag) at a flight Mach number of 1.1. The results presented in figure 10 indicate that the ducted-fan configurations have the lowest cruising speed (flight Mach numbers of 0.38 and 0.60) and the airplanes propelled by the current turbojet engine have the highest cruising speed (flight Mach numbers of 0.83 and 0.92). The relatively low cruising speed of the ducted-fan configurations is due to the low propulsive thrust per unit of frontal area obtained by the ducted fan with duct burner inoperative. Figure 10 also indicates that the operable range of flight speeds of the turbojet engines with tail-pipe burners inoperative is much greater than that of the ducted fan operating with no burning in the duct. In order to operate the ducted fan over this greater range of cruising flight speeds, it is necessary to burn fuel in the duct; however, the attendant greater fuel consumption will result in a considerable reduction in flight duration and range.

The calculated performance of the airplane-A configurations indicates that the ducted fan (cruising flight Mach number, 0.38) has a specific fuel consumption of 0.78 pound of fuel per hour per pound of thrust compared with 1.21 and 1.45 pounds of fuel per hour per pound of thrust obtained by the future turbojet (cruising flight Mach number, 0.73) and current turbojet (cruising flight Mach number, 0.83) engines, respectively. These data indicate that the ducted-fan power plant obtains a flight duration approximately

260 and 140 percent greater than the current and future turbojet engines, respectively. For the conditions considered, the ducted fan obtains a range approximately 65 and 25 percent greater than the current and future turbojet engines, respectively. In order 1318
to determine the effect of flight Mach number on the relative cruise performance, the cruising speed of the turbojet configurations was lowered by operating the engines at reduced power levels. The performance of the turbojet configurations was determined assuming each turbojet engine to have a constant specific fuel consumption in the range of cruising speeds investigated. The effect of flight Mach number on the relative cruise performance of the airplane-A configurations, expressed as the ratio of flight duration (or range) of the ducted fan cruising at a flight Mach number of 0.38 to the flight duration (or range) of the turbojet engines cruising at different flight Mach numbers (relative duration or relative range), is presented in figure 11. Also shown are the relative flight duration and range of the airplane-B configurations (ducted fan cruising flight Mach number, 0.60). The data indicate that for the airplane characteristics considered the flight duration and range obtained by the ducted fan are at least 15 percent greater than those obtained by the turbojet engines.

CONCLUDING REMARKS

For the same maximum propulsive thrust at low supersonic Mach numbers at high altitudes, the frontal area of the ducted fan is appreciably larger than that of the turbojet engines equipped with tail-pipe burner but the weights of the engines are approximately equal. If the engines have the same high-speed performance, the ducted fan has a cruising-flight duration and range appreciably greater than the turbojet engines equipped with tail-pipe burner. The greater duration and range, however, are obtained at flight speeds appreciably lower than those normally obtained with turbojet engines. The cruising flight speed of the ducted-fan power plant may be increased by burning fuel in the duct but the attendant reduction in flight duration and range is relatively great.

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

1318

REFERENCES

1. Anon: Metro-Vick Gas Turbine. Flight, vol. XLIX, no. 1948, April 25, 1946, pp. 420-423.

2. Keenan, Joseph H., Kaye, Joseph, and Riecke, Carol A.: The Calculated Performance of a Jet Propulsion Device, Systems CHT, PCHTJ, CchtJ, CHTX. NACA ACR 5B02, 1945.

3. Chew, B. B.: A Study of Ducted Fan Power Plants. Rep. R-110, The Rand Corp., Aug. 5, 1948. (Proj. Rand, USAF Proj. MX-791.)

4. Bruckman, B. W., Kappus, P. G., and Huber, F. J.: The Dual-Cycle Jet Engine. Tech. Rep. No. F-TR-2200-ND, Air Material Command, July 1948. (ATI No. 23805.)

5. Parisen, Richard B., Armstrong, John C., and Huntley, Sidney C.: Theoretical Evaluation of Ducted-Fan Turbojet Engine. NACA TN 1745, 1948.

6. Bohanon, H. R., and Wilcox, E. C.: Theoretical Investigation of Thrust Augmentation of Turbojet Engines by Tail-Pipe Burning. NACA RM E6L02, 1947.

7. Spearman, M. Leroy: Longitudinal Stability and Control Characteristics at Transonic Speeds of a Semispan Airplane Model Having a 45° Sweptback Wing and Tail as Obtained by the Transonic-Bump Method. NACA RM L8C11, 1948.

8. Wetmore, J. W.: A Review of Recent Information Relating to the Drag Rise of Airplanes. NACA RM L8A28d, 1948.

TABLE I

COMPARISON OF ENGINE PERFORMANCE BASED ON NET THRUST PER UNIT OF FRONTAL AREA

Flight condition	Net thrust per unit frontal area (lb/sq ft)					Specific fuel consumption (lb/(hr)(lb thrust))				
	Ducted fan	Current turbojet		Future turbojet		Ducted fan	Current turbojet		Future turbojet	
		Without tail-pipe burner	With tail-pipe burner	Without tail-pipe burner	With tail-pipe burner		Without tail-pipe burner	With tail-pipe burner	Without tail-pipe burner	With tail-pipe burner
Sea-level static (take-off)	780	820	1144	992	1485	3.0	1.1	2.3	.92	2.3
Mach number 1.1 at 35,000 feet (high power and high altitude)	400	324	565	365	717	2.5	1.4	2.3	1.2	2.3
Mach number 0.5 at 35,000 feet (climb)	255	252	387	302	509	2.8	1.2	2.2	1.0	2.0
Mach number 0.5 at 35,000 feet (cruise)	60[a]	187	176[b]	216	203[b]	.91[a]	1.17	1.24[b]	.96	1.02[b]
Mach number 0.3 at 35,000 feet (cruise)	78[a]	188	178[b]	215	203[b]	.68[a]	1.07	1.13[b]	.90	.96[b]

NACA

[a]Duct burner inoperative

[b]Tail-pipe burner inoperative

Error

An error occurred while processing this page. See the system log for more details.

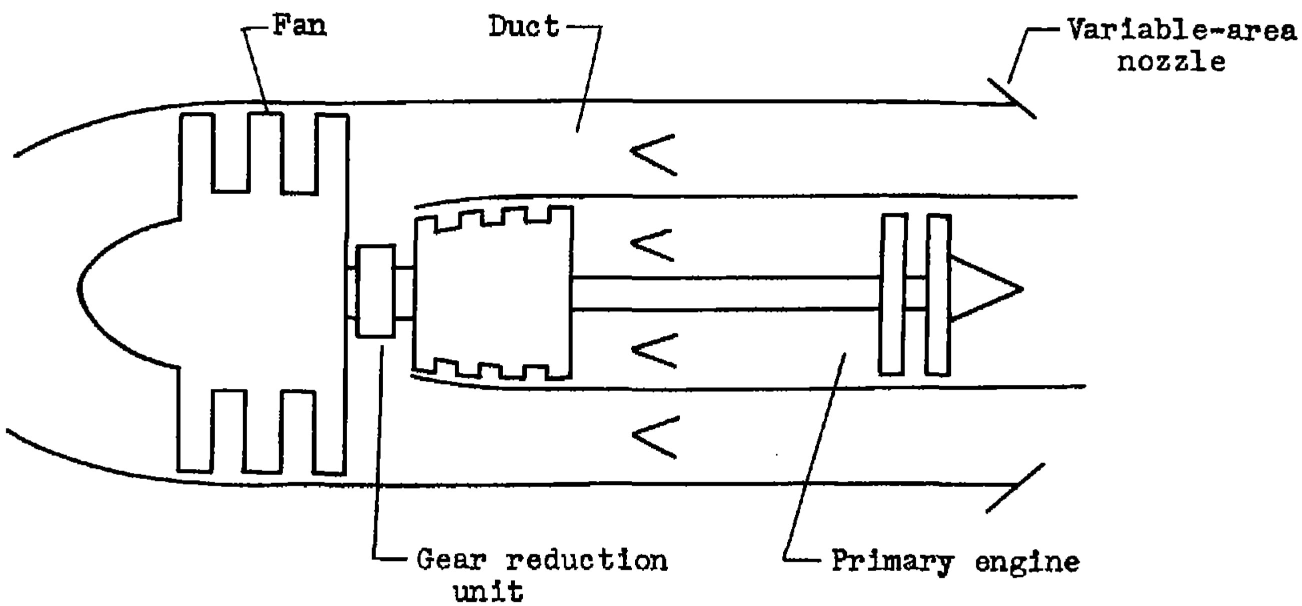
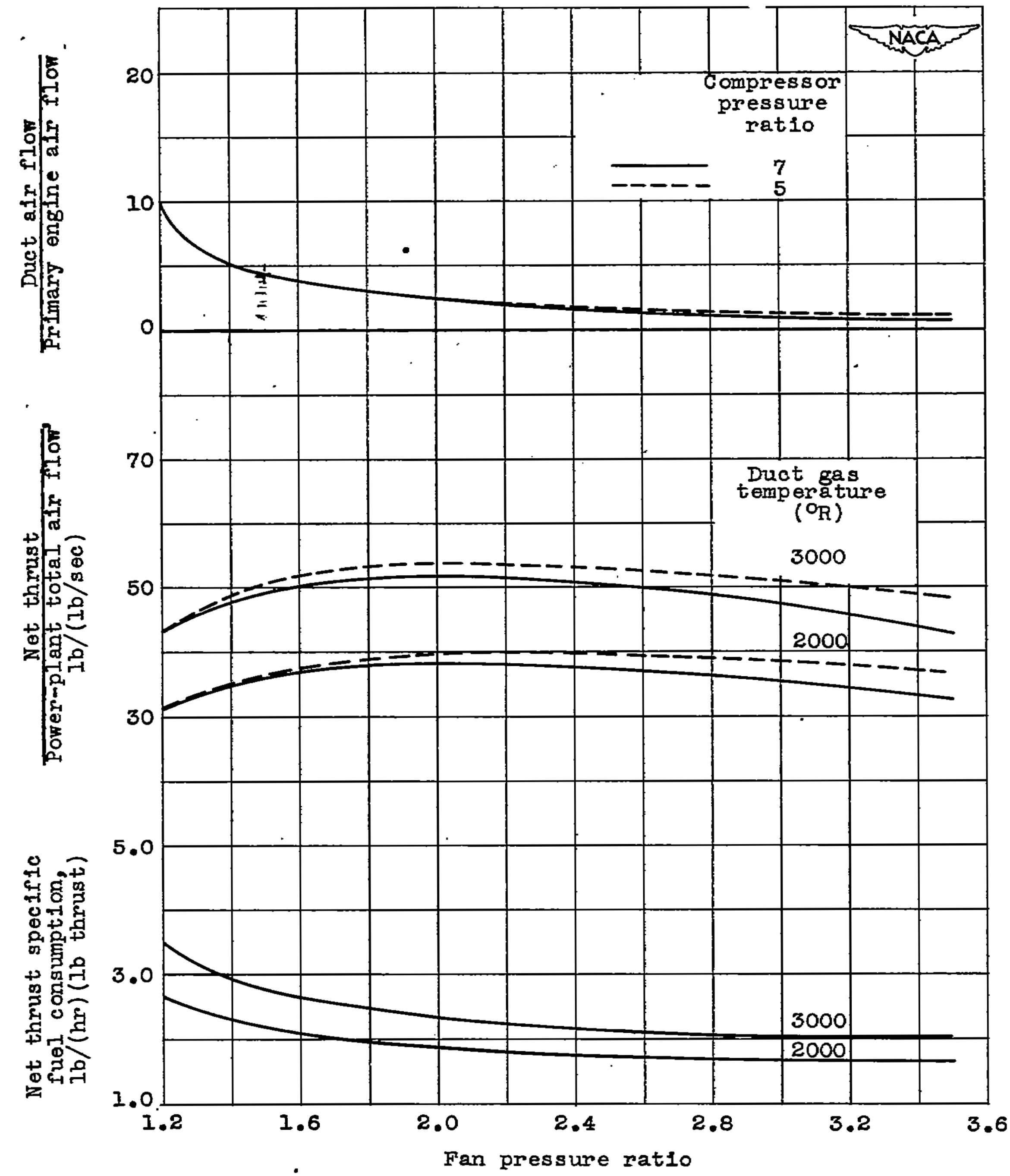


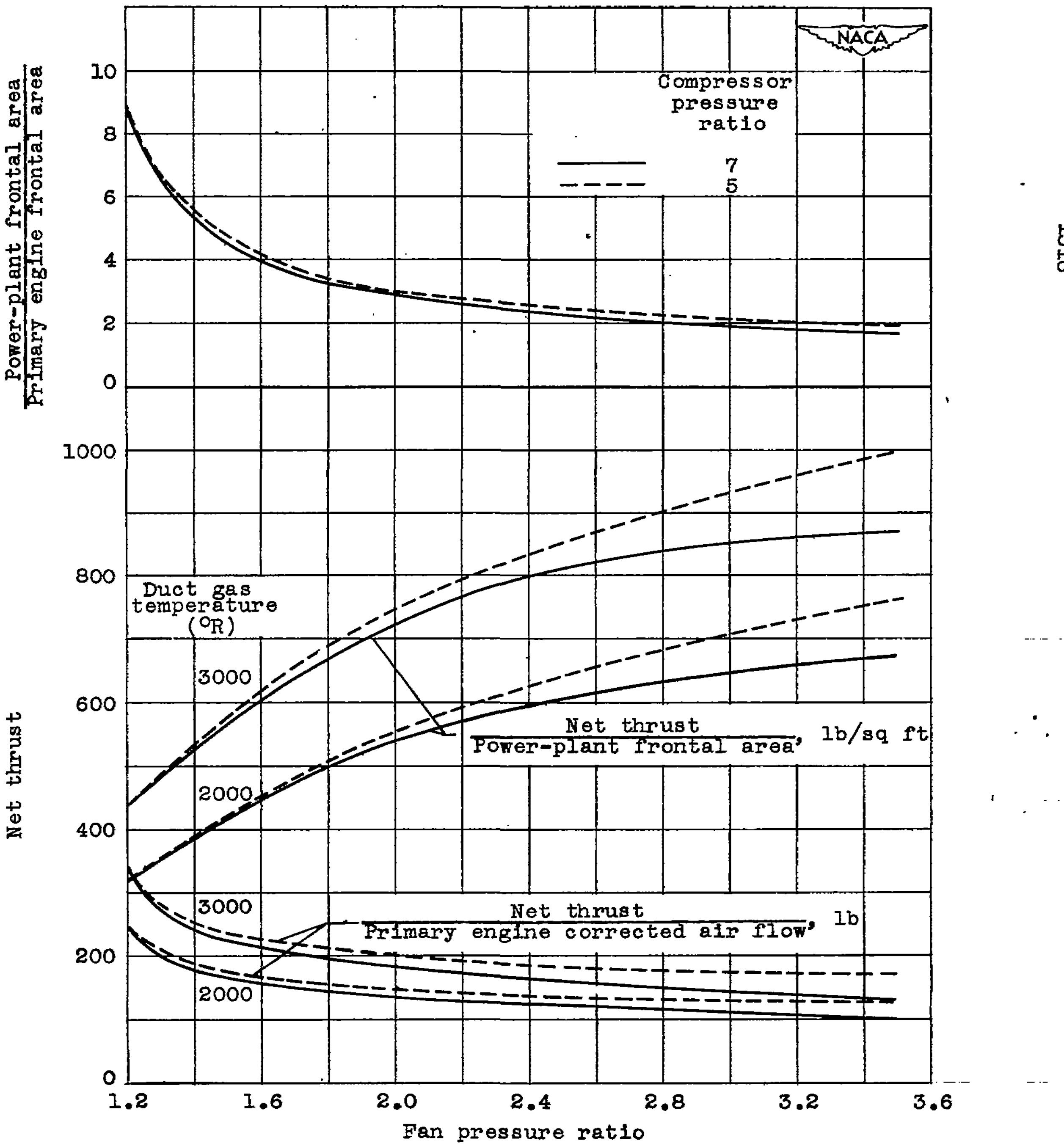
Figure 1. - Schematic diagram of ducted-fan power plant.



(a) Air-flow ratio, thrust per unit air flow, and specific fuel consumption.

Figure 2. - Characteristics of ducted-fan cycle with burning in duct. Mach number, 1.1; altitude, 30,000 feet.

[redacted]

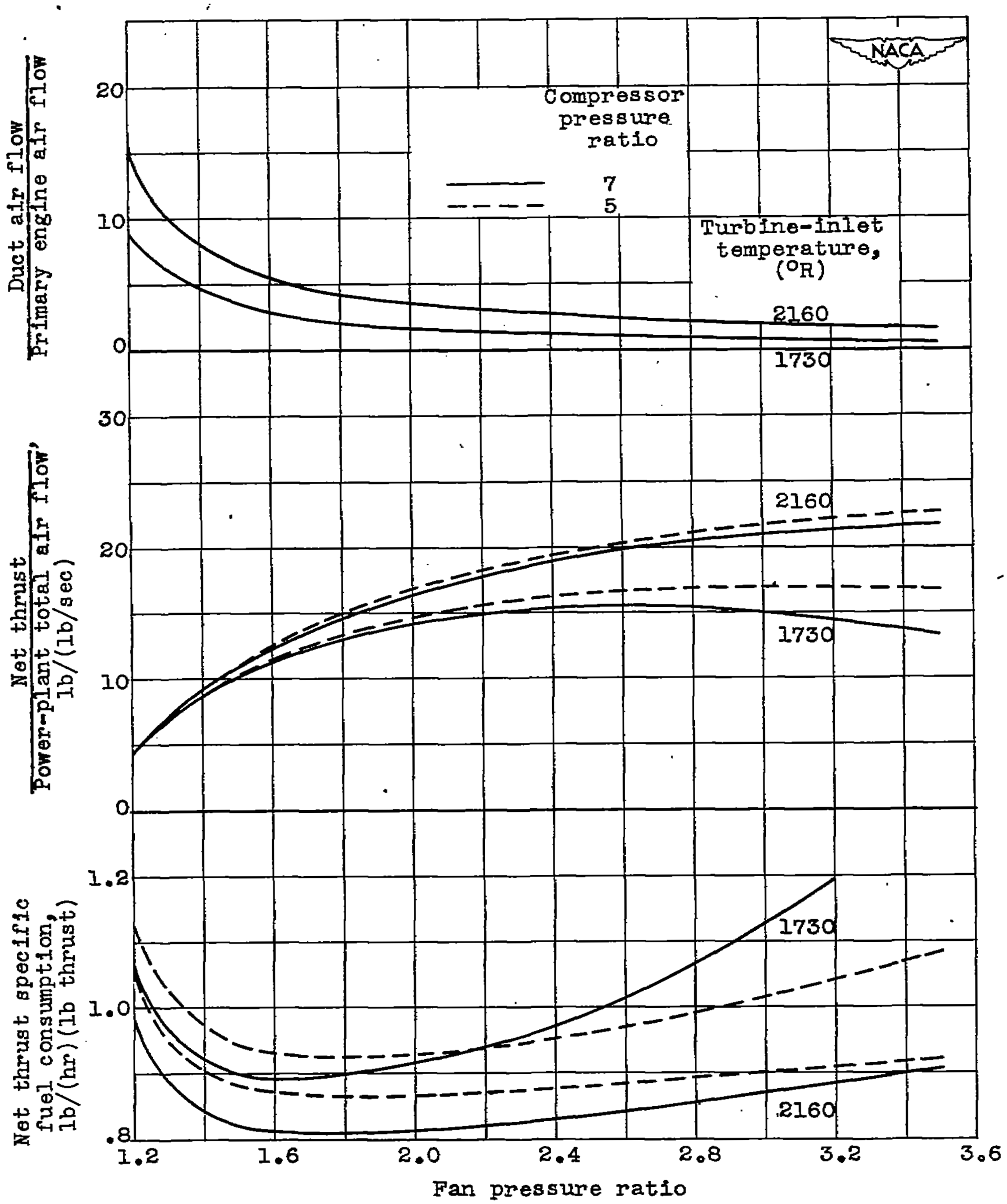


(b) Frontal area, thrust per unit area, and thrust.

Figure 2. - Concluded. Characteristics of ducted-fan cycle with burning in duct. Mach number, 1.1; altitude, 30,000 feet.

[redacted]

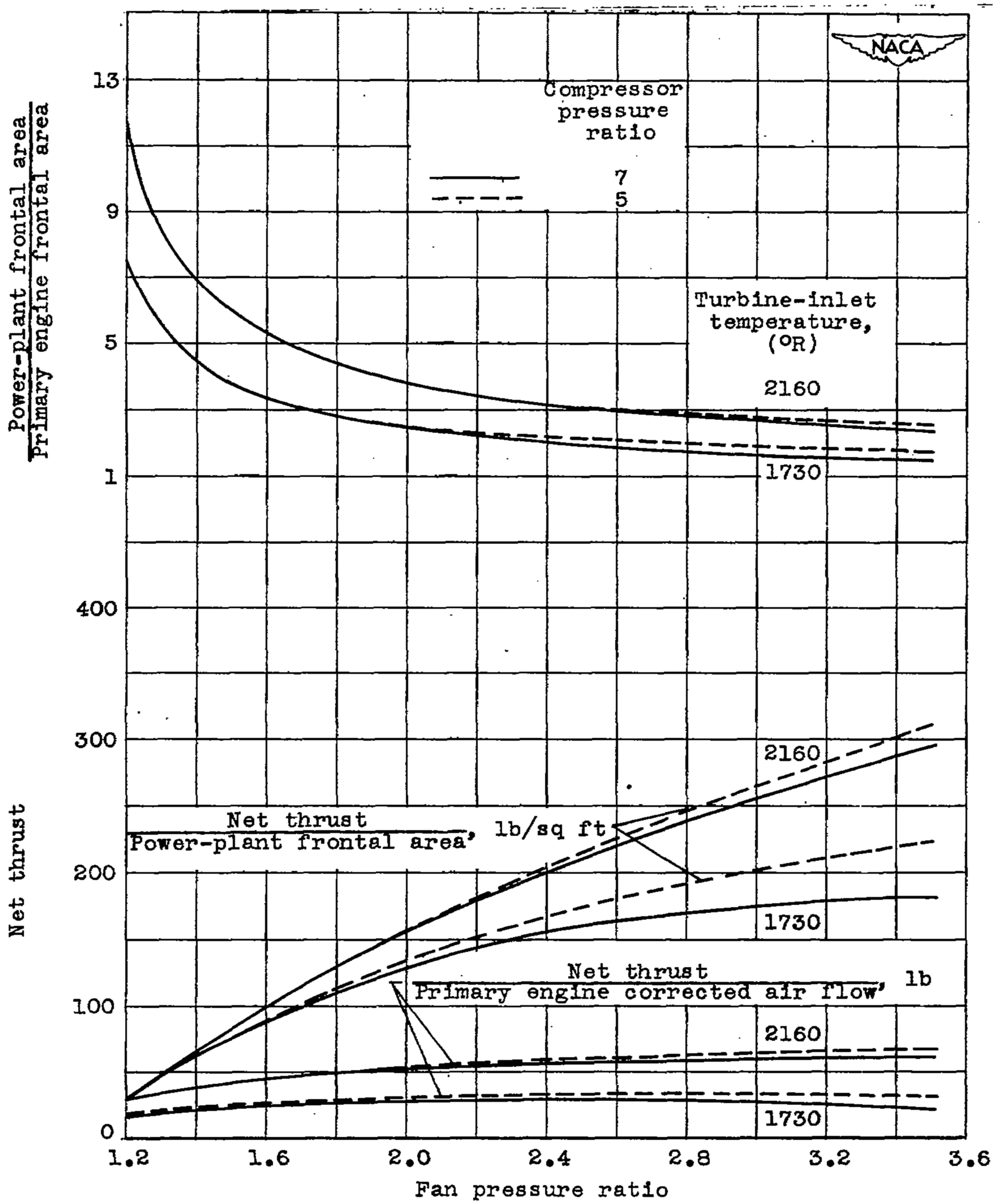
1318



(a) Air-flow ratio, thrust per unit air flow, and specific fuel consumption.

Figure 3. - Characteristics of a ducted-fan cycle with no burning in duct. Mach number, 0.5; altitude, 30,000 feet.

[redacted]



(b) Frontal area, thrust per unit area, and thrust.

Figure 3. - Concluded. Characteristics of ducted-fan cycle with no burning in duct. Mach number, 0.5; altitude, 30,000 feet.

1318

1518

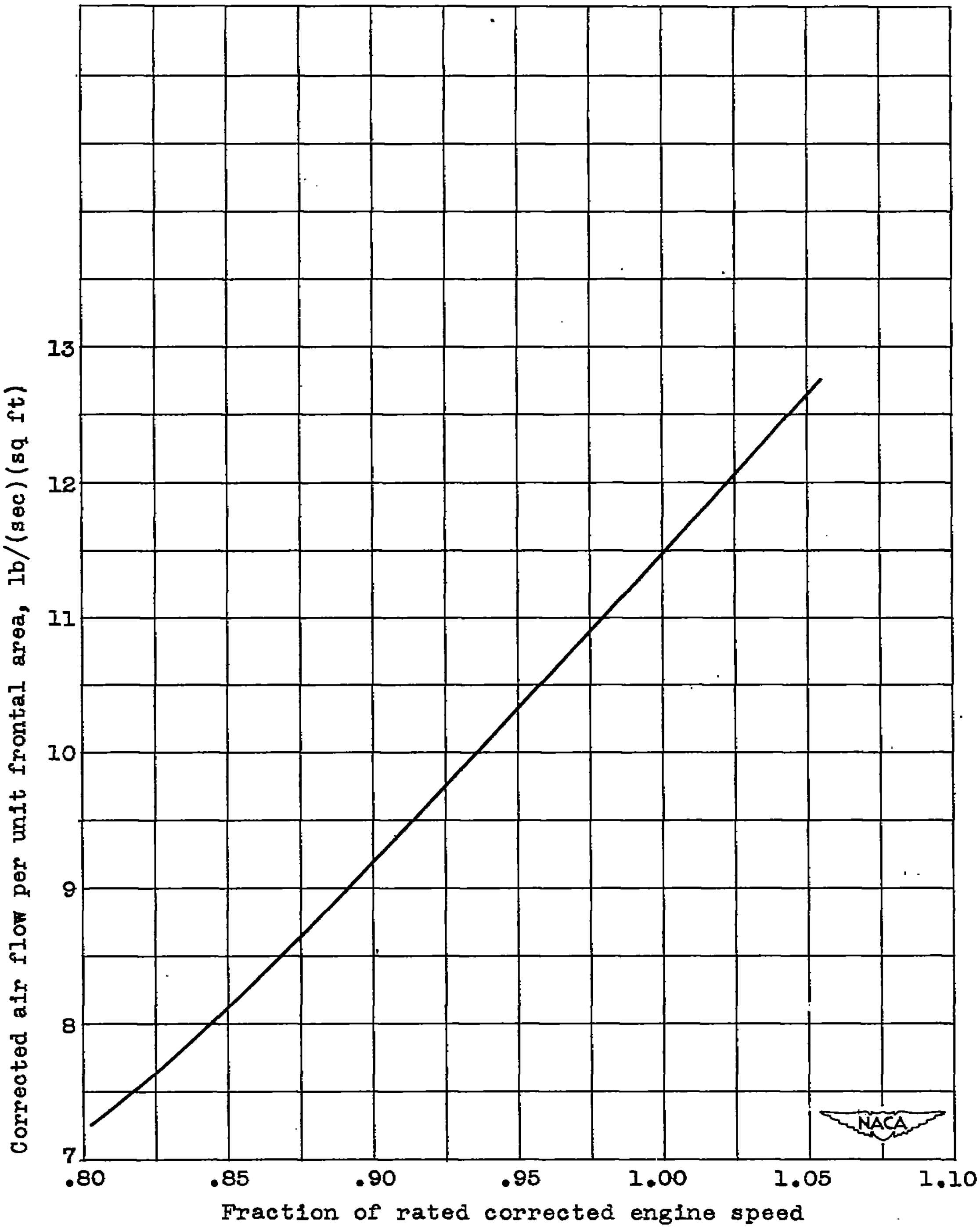


Figure 4. - Air flow - engine speed characteristics of primary engine.

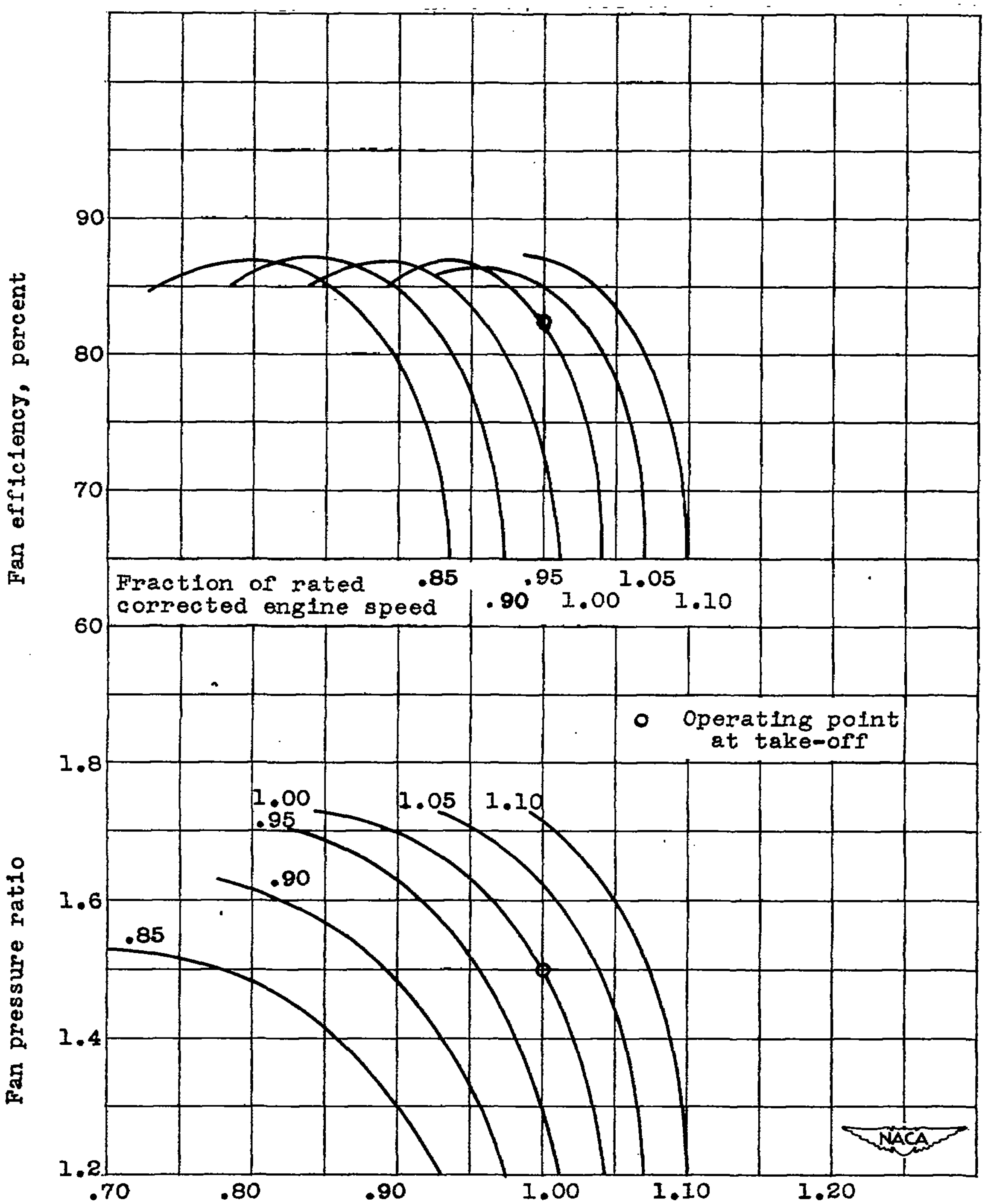


Figure 5. - Fan characteristics.

1318

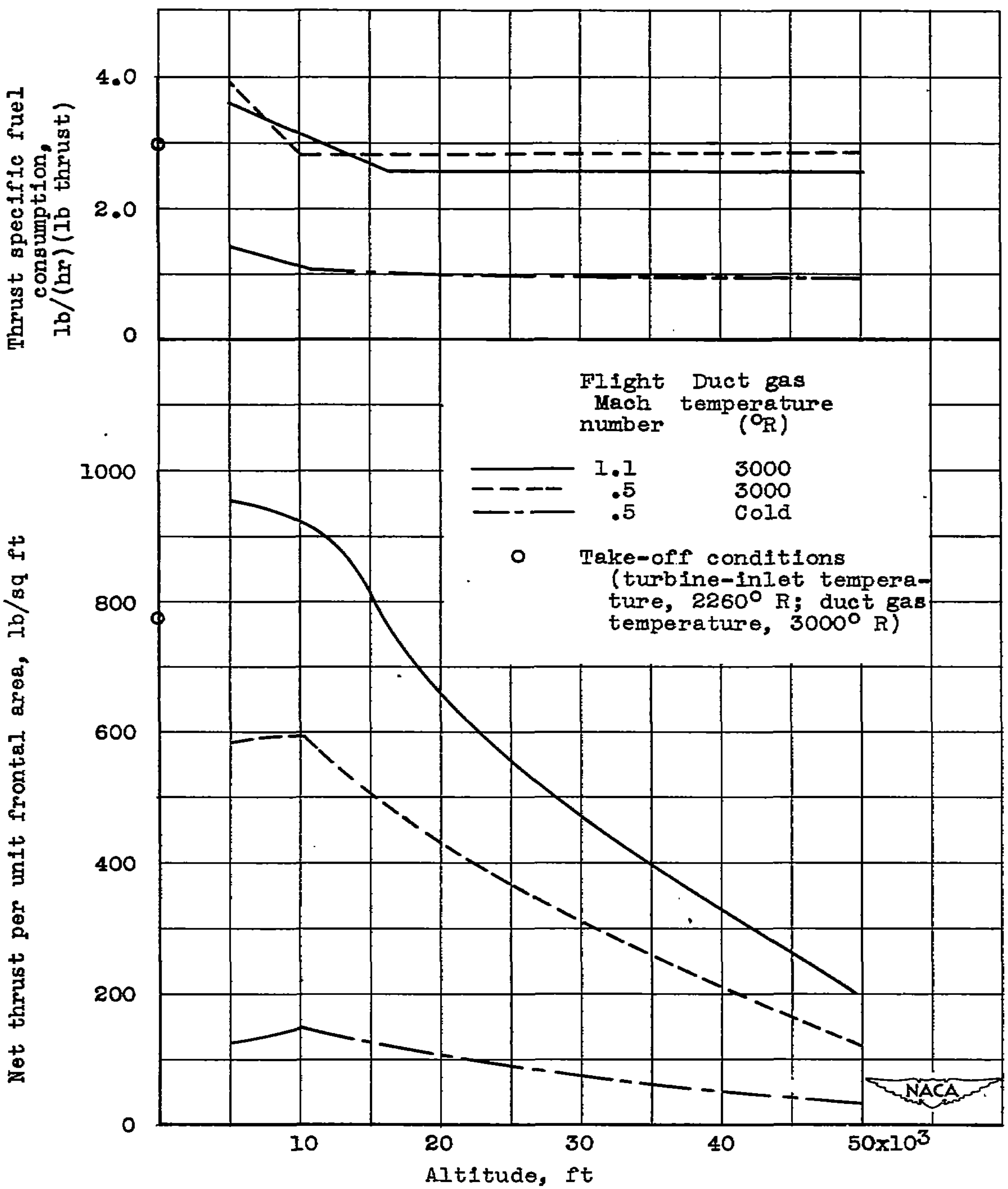


Figure 6. - Effect of Mach number and altitude on performance of ducted-fan engine at rated speed. Engine frontal area, 10 square feet.

1318

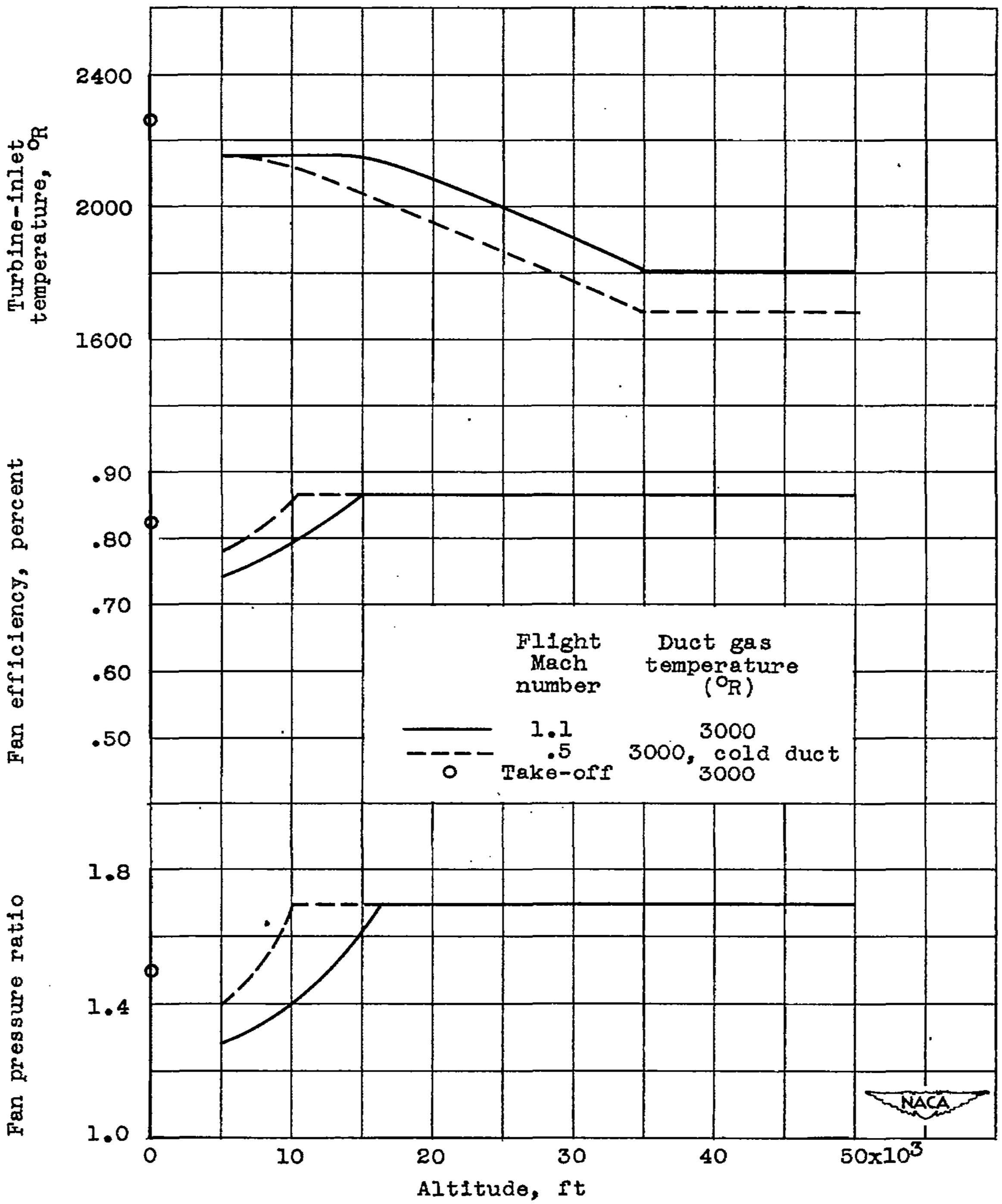


Figure 7. - Effect of flight conditions on turbine-inlet temperature, fan efficiency, and fan pressure ratio. Engine speed, rated.

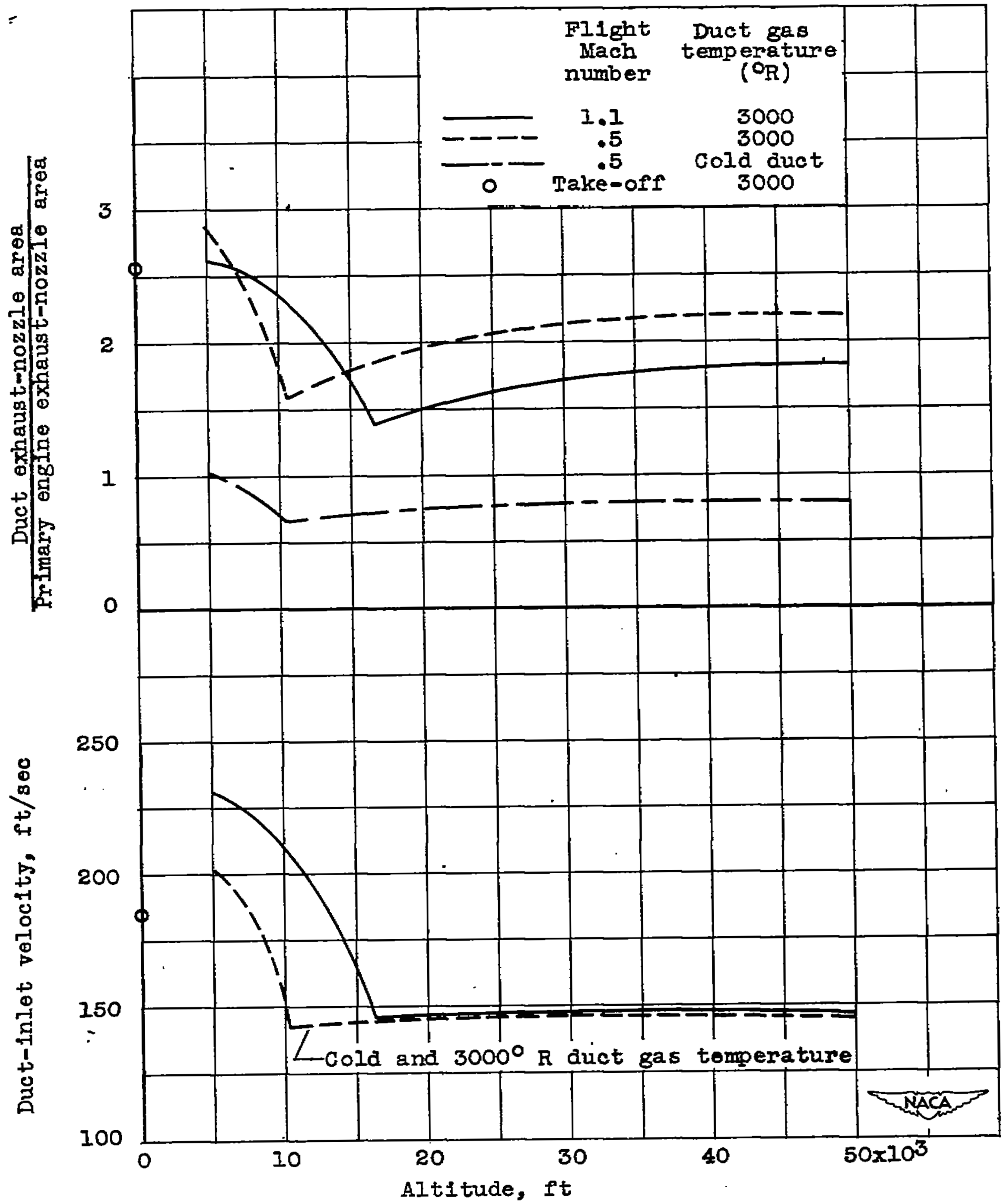


Figure 8. - Effect of flight conditions on duct exhaust-nozzle area and duct-inlet velocity. Primary engine exhaust-nozzle area, 2.4 square feet; engine speed, rated.

[redacted]

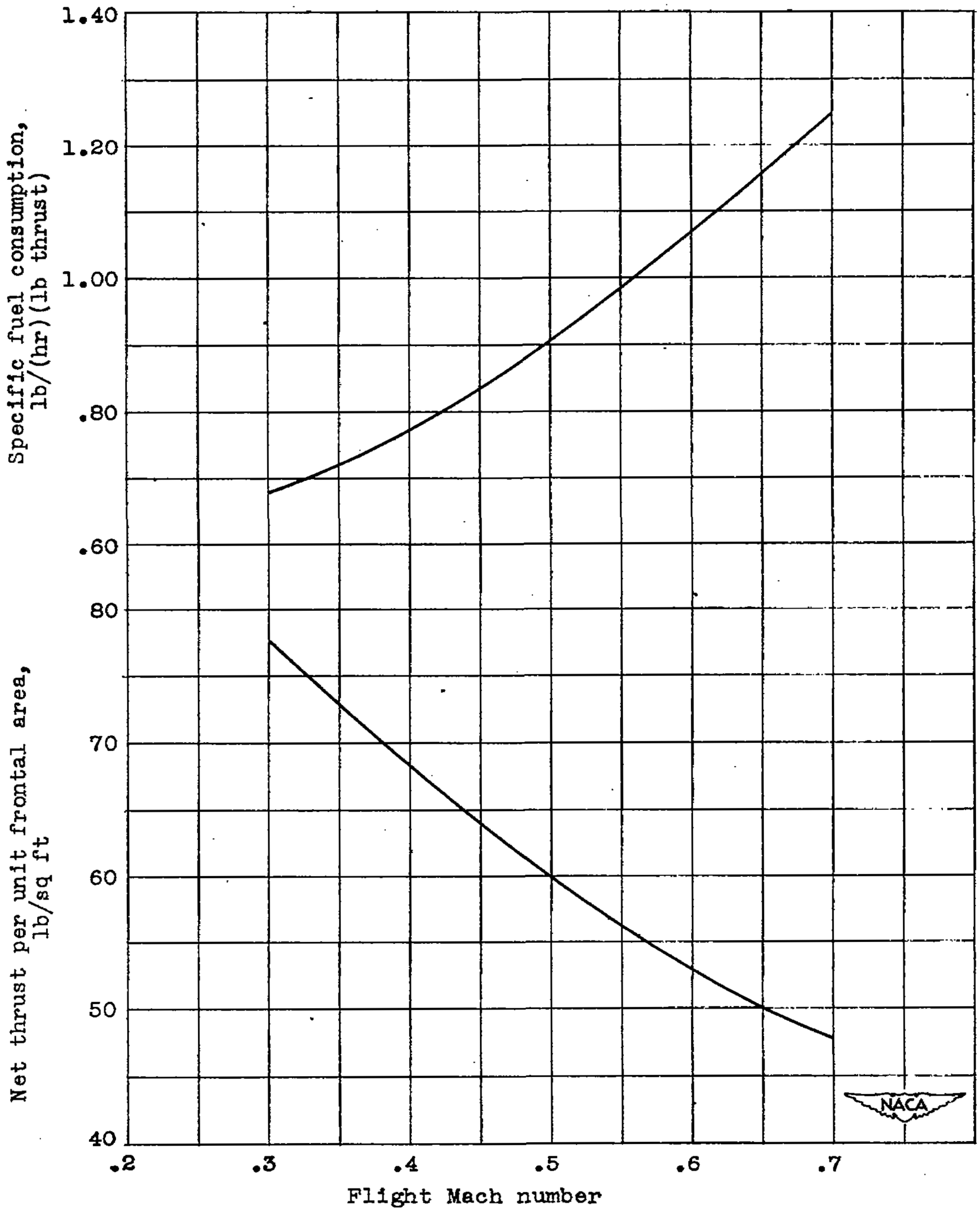


Figure 9. - Effect of flight Mach number on cruise performance at altitude of 35,000 feet. Engine speed, rated; engine frontal area, 10 square feet.

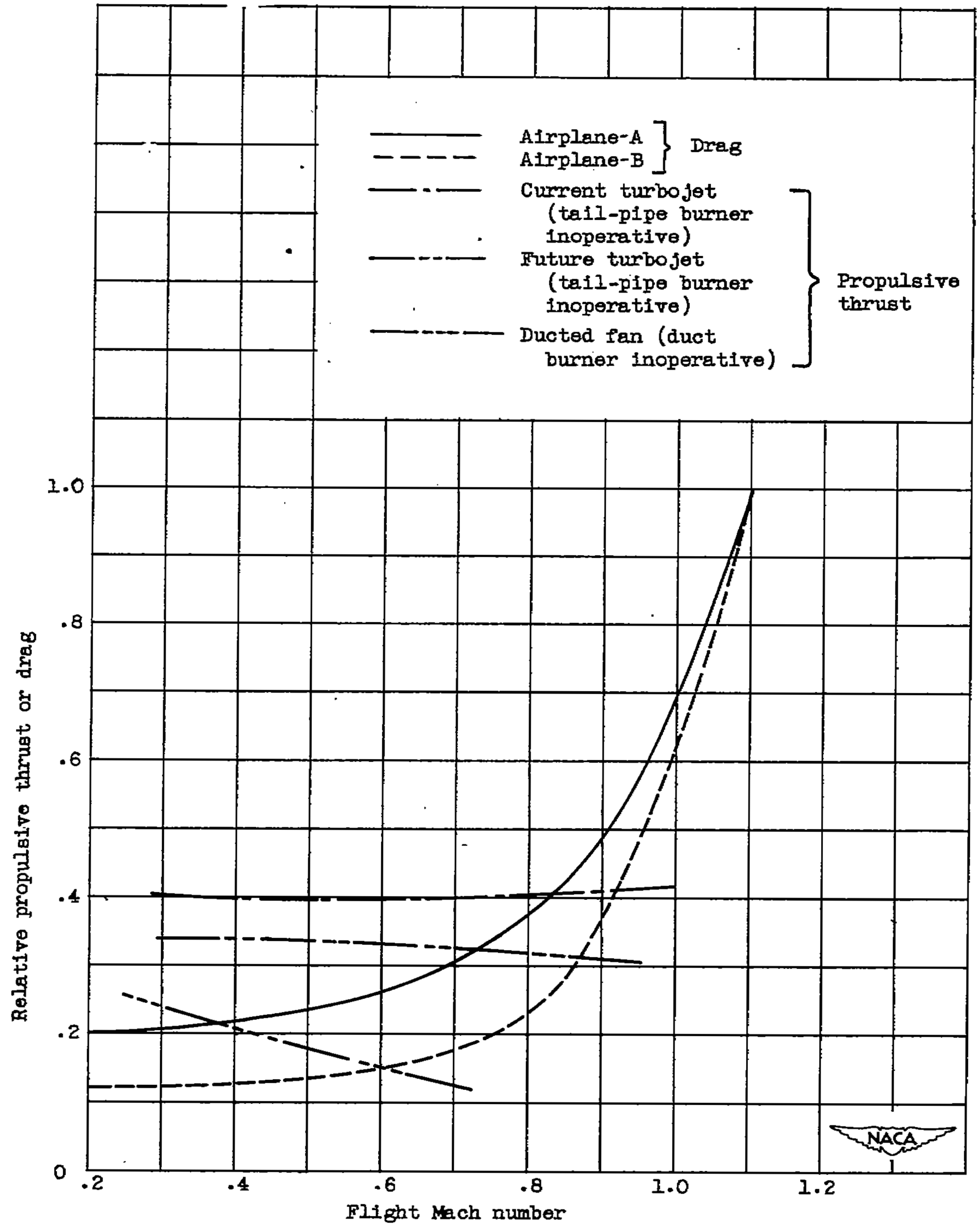


Figure 10. - Cruising speeds of ducted-fan and turbojet-engine configurations for level flight at altitude of 35,000 feet. Engines supply equal power at flight Mach number of 1.1.

[redacted]

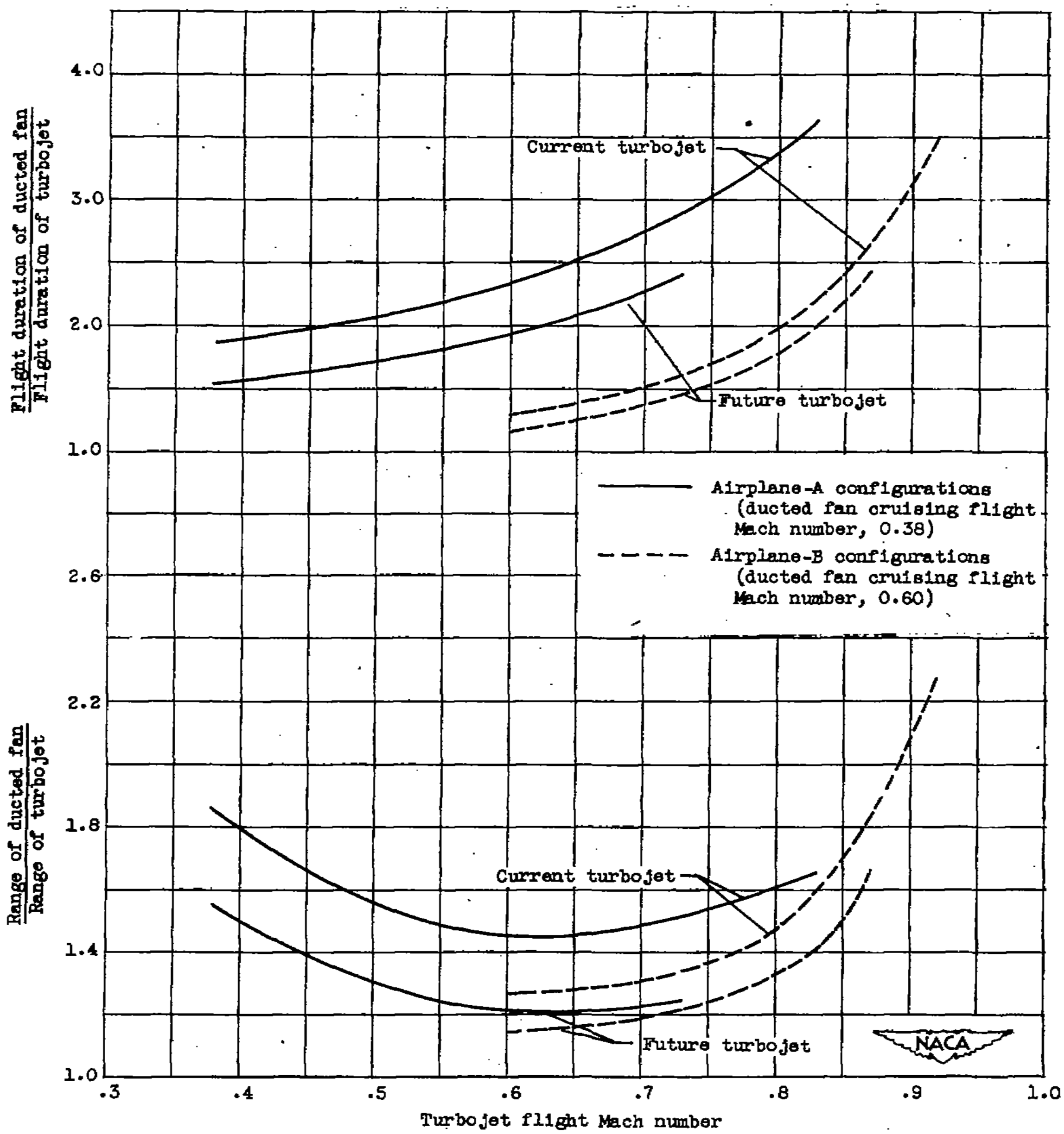


Figure 11. - Comparison of flight duration and range of ducted fan and turbojet engines cruising at altitude of 35,000 feet. Engines supply equal power at flight Mach number of 1.1.