PERFORMANCE CHARACTERISTICS OF SEVERAL TAIL-PIPE BURNERS

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INTRODUCTION

Performance theoretically calculated for tail-pipe burning and experimental results indicating the effect of the various design considerations on burner characteristics at altitude are discussed in the two preceding papers of this series. Included in this paper are experimental results that show the performance and the operable range of several tail-pipe burners at altitude conditions.

A considerable amount of data was obtained for a large number of different tail-pipe-burner configurations with the J34 engine, the J35 engine, and an experimental version of the J47 engine. Some of the more recent tail-pipe burning results for four of these burners are presented. Thrust performance, burner-outlet temperatures, specific fuel consumptions, combustion efficiencies, the operable ranges of tail-pipe fuel-air ratio, and burner-inlet pressure, temperature, and velocity are shown for a range of flight conditions.

TAIL-PIPE-BURNER INSTALLATIONS

Four tail-pipe burners are considered. Burners A and B were installed on a J34 engine, burner C on a J35 engine, and burner D on an experimental version of the J47 engine.

Burner A. - Burner A (fig. 1), which was installed on a J34 engine, was attached to the standard engine tail cone and has an over-all length of about $8\frac{1}{2}$ feet. The gas leaving the turbine is diffused to a 23-inch-diameter section where the flame holder is installed. The combustion chamber is a 40-inch conical section that tapers from 23 inches in diameter at the flame holder to $18\frac{7}{16}$ inches at the outlet.

The flame holder consists of two semicircular-gutter-type rings joined with four radial struts of similar construction. This flame holder blocks approximately 25 percent of the cross-sectional area of the tail pipe. Both the rings and the radial struts of the flame holder are provided with small slots on the upstream face. Fuel is injected through five circular tubes located immediately upstream of the flame holder. Two of these tubes, which are alined with the two flame-holder rings, inject the fuel through several small orifices in a downstream direction through the slots of the flame holder. Fuel is injected from the other three tubes through small orifices in an upstream direction.

A two-position variable-area exhaust nozzle was used on the burner, which in the closed position has a projected elliptical area equivalent to a circular diameter of $15\frac{3}{8}$ inches. During tail-pipe burner operation, this nozzle was in the wide-open position and the throat area was provided by the outlet of the combustion chamber.

A shroud was installed around the burner through which air flowed to cool the burner shell during operation.

Burner B. - Burner B (fig. 2), which was also installed on a J34 engine, has an over-all length, including the diffuser section, of about 10 feet and a maximum diameter of $25\frac{3}{4}$ inches. The exhaust gas was diffused to the combustion chamber, which is $25\frac{3}{4}$ inches in diameter and 6 feet long. A flame holder was installed 18 inches downstream of the front flange of the combustion chamber, thus giving a burning length of $4\frac{1}{2}$ feet upstream of the fixed-area conical exhaust nozzle. The exhaust nozzle is $19\frac{1}{2}$ inches in diameter at the outlet.

Fuel is injected $4\frac{1}{2}$ inches downstream of the turbine through eight streamlined spray tubes; this arrangement gives a mixing length for the fuel of $35\frac{1}{2}$ inches between the fuel injector and the flame holder. Each spray tube has four pairs of impinging jets through which the fuel is sprayed into the diffuser. The downstream end of the inner cone was cut off where it was 5 inches in diameter with the blunt end covered by a disk, thereby profiding a turbulent region for the purpose of seating a stabilizing flame in the center of the tail pipe.

A two-ring V-gutter flame holder that blocks 32 percent of the burner cross-sectional area was installed. The mean diameters of the outer and inner gutters are 17 and 10 inches, respectively; the included angle of the gutters is 30°; and the distance across the open end of the gutters is $1\frac{3}{4}$ inches.

The burner shell was cooled only by the flow of low-velocity air over the outside of the burner.

Burner C. - Burner C (fig. 3), which was installed on a J35 engine , has an over-all length, including the diffuser section, of about 9 feet and a maximum diameter of 29 inches. The exhaust gas was diffused to the combustion chamber, which is 29 inches in diameter and 4 feet long. The flame holder was located at the upstream end of the combustion chamber, giving a 4-foot burning length between the flame holder and the fixed-area conical exhaust nozzle. The outlet diameter of the exhaust nozzle is $20\frac{1}{8}$ inches.

Fuel was injected in the diffuser through 12 streamlined spray tubes installed 14 inches upstream of the flame holder. Each tube had four pairs of small orifices that injected fuel from opposite sides of the tubes into the gas stream normal to the direction of flow. The downstream end of the inner cone was cut off where it was $8\frac{1}{2}$ inches in diameter and a concave dome was installed that provided a turbulent region for the purpose of seating a stablizing flame in the center of the pipe.

A two-ring V-gutter flame holder similar to the one used in burner B blocked 29 percent of the burner cross-sectional area. The mean diameters of the outer and inner flame-holder rings are $21\frac{1}{4}$ and $9\frac{7}{8}$ inches, respectively; the included angle of the gutters is 35°; and the distance across the open ends of the gutters is $1\frac{1}{2}$ inches.

A cooling liner extended the full length of the combustion chamber, and a $\frac{1}{2}$-inch radial gap was provided between the liner and the outer shell through which flowed part of the exhaust gas at approximately turbine-outlet temperature.

Burner D. - Burner D (fig. 4), which was installed on the experimental version of the J47 engine, has an over-all length, including the diffuser section, of about 9 feet and a maximum diameter of 32 inches. The exhaust gas was diffused to the 32-inch-diameter combustion chamber, which is 4 feet in length. The flame holder was installed at the forward end of the combustion chamber, thereby giving a 4-foot burning length upstream of the fixed-area conical exhaust nozzle. The diameter at the outlet of the exhaust nozzle is $25\frac{1}{4}$ inches.

Fuel was injected in the diffuser 14 inches upstream of the flame holder through 12 stream lined spray tubes similar to those used in burner C. Each tube had four pairs of orifices that injected fuel from opposite sides of the tubes into the gas stream normal to the direction of flow. The downstream end of the inner cone was cut off where it was 14 inches in diameter and a concave dome was installed that provided a large turbulent region for the purpose of seating a stabilizing flame in the center of the pipe.

The flame holder was a two-ring V-gutter flame holder, similar to those used in burners B and C, and blocked 32 percent of the burner cross-sectional area. The mean diameters of the outer and inner flame-holder rings are 23 and 14 inches, respectively; the included angle of the gutters is 35°; and the distance across the open end of the gutters is $1\frac{13}{16}$ inches.

A cooling liner, similar to that used in burner C, extended the full length of the combustion chamber and 12 inches into the exhaust nozzle. A $\frac{1}{2}$-inch radial air gap was provided between the liner and the outer shell through which part of the exhaust gas flowed.

TAIL-PIPE-BURNER PERFORMANCE

Burner A. - Performance data obtained with burner A over a range of flight Mach numbers at an altitude of 20,000 feet are presented in figures 5 and 6. These data were obtained at maximum engine speed with a turbine-outlet temperature of approximately 1600° R. The burner-inlet velocity varied from 440 to 480 feet per second for these conditions. The augmented thrust was obtained with the tail-pipe burner installed and the normal thrust was obtained with the standard engine tail pipe.

With tail-pipe burning (fig. 5), the ratio of augmented thrust to normal thrust increased from a value of 1.27 at a flight Mach number of 0.25 to 1.84 at a flight Mach number of 0.85. When the tail-pipe burner was inoperative, the thrust obtainable at limiting turbine-outlet temperatures was 4 percent less than that available with the standard engine tail pipe at the same operating conditions.

The specific fuel consumption with and without tail-pipe burning is shown in figure 6. With tail-pipe burning the specific fuel consumption decreased rapidly as the flight Mach number was raised, varying from a value of about 3.25 at a flight Mach number of 0.25 to a value of 2.10 at a flight Mach number of 0.85. The specific fuel consumption with the standard engine tail pipe and exhaust nozzle was 1.40 at a flight Mach number of 0.85.

The operable range of tail-pipe fuel-air ratios at an altitude of 20,000 feet is shown in figure 7. Tail-pipe fuel-air ratio is defined as the ratio of tail-pipe fuel flow to the unburned air flow entering the tail pipe. The maximum operable tail-pipe fuel-air ratio was limited by turbine-outlet temperature and the minimum fuel-air ratio by lean combustion blow-out. At a flight Mach number of 0.85 at an altitude of 20,000 feet, it was possible to operate burner A between tail-pipe fuel-air ratios of 0.0395 and 0.0486. The maximum operable fuel-air ratio is significant only for the exhaust nozzle used with burner A. With a larger outlet area, the burner could have been operated at higher tail-pipe fuel-air ratios.

The altitude limits of operation at maximum engine speed and turbine-outlet temperature of about 1625° R are shown in figure 8. At each flight Mach number, a band of uncertain operation amounting to about 8000 feet in altitude was encountered within which combustion blow-out occurred. Altitudes at which the engine could be operated without encountering combustion blow-out varied from 24,600 feet at a Mach number of 0.25 to 34,200 feet at a Mach number of 1.0. Over the entire range of flight conditions, this limit of combustion blow-out occurred at an approximately constant burner-inlet pressure.

Burner B. - Performance data obtained with burner B are presented in figures 9 and 10 for a range of flight Mach numbers at an altitude of 25,000 feet (reference 1). These data were obtained at maximum engine speed and the turbine-outlet temperature with tail-pipe burning was 1650° R, whereas the turbine-outlet temperature with the standard engine tail pipe varied from 1650° R at a flight Mach number of 0.25 to 1620° R at a flight Mach number of 0.72. The burner-inlet velocity was approximately 455 feet per second for these conditions.

The ratio of augmented thrust to normal thrust (fig. 9) increased from a value of 1.31 at a flight Mach number of 0.25 to 1.73 at a flight Mach number of 0.72. The burner-outlet temperature increased slightly with flight Mach number, reaching a value of 3470° R at a flight Mach number of 0.72. This temperature corresponds to a burner temperature rise of 1820° R and to an over-all fuel-air ratio of 0.052, where the over-all fuel-air ratio is defined as the engine fuel plus tail-pipe fuel divided by the total air flow.

The specific fuel consumption with and without tail-pipe burning (fig. 10) varied only slightly over the flight conditions investigated. At a flight Mach number of 0.72, the specific fuel consumption was 2.55 with tail-pipe burning compared with 1.19 with the standard engine tail pipe.

The tail-pipe combustion efficiency is presented in figure 11 as a function of tail-pipe fuel-air ratio. As mentioned previously, tail-pipe fuel-air ratio is defined as the ratio of tail-pipe fuel flow to unburned air flow entering the tail pipe. Because the tail-pipe fuel-air ratio was varied by changing the tail-pipe fuel flow with a fixed-area exhaust nozzle, the conditions at the burner inlet also changed.

Variations in burner-inlet total temperature, total pressure, and velocity with tail-pipe fuel-air ratio are also shown in figure 11. For the range of fuel-air ratios investigated, the total temperature, the total pressure, and the burner-inlet velocity increased with fuel-air ratio. As the tail-pipe fuel-air ratio was raised, the combustion efficiency dropped from a peak value of 0.96 at a tail-pipe fuel-air ratio of 0.025 to a value of 0.86 at limiting turbine-outlet temperature of 1650° R and tail-pipe fuel-air ratio of 0.050, the condition for which thrust and specific fuel consumption data are presented in figures 9 and 10. The increase in burner-inlet pressure accompanying the change in flight Mach number from 0.26 to 0.84 had no apparent effect on the tail-pipe combustion efficiency. The primary factor affecting combustion efficiency is believed to be the fuel distribution in the tail-pipe burner, because at a given fuel-air ratio changes in burner-inlet pressure had no apparent effect on combustion efficiency.

The operable range of tail-pipe fuel-air ratios at an altitude of 25,000 feet is shown in figure 12 as a function of flight Mach number. The maximum fuel-air ratio was limited by turbine-outlet temperature and the minimum fuel-air ratio by lean combustion blow-out. At a flight Mach number of 0.72, stable burner operation was possible at tail-pipe fuel-air ratios between 0.024 and 0.053. The minimum operable fuel-air ratio for burner B was somewhat lower than that for burner A, which was 0.041 at a Mach number of 0.72. The maximum fuel-air ratio is significant only for the size exhaust nozzle used.

<u>Burner C.</u> - Performance data for burner C at an altitude of 25,000 feet over a range of flight Mach numbers are presented in figures 13 and 14. These data were obtained at maximum engine speed

and at turbine-outlet temperature (both with and without tail-pipe burning) of 1600° R. The burner-inlet velocity was about 415 feet per second for these flight conditions.

The ratio of augmented thrust to normal thrust with tail-pipe burning (fig. 13) increased from 1.41 at a flight Mach number of 0.27 to 1.74 at a flight Mach number of 0.92. The burner-outlet temperature increased slightly with flight Mach number, reaching a value of 3150° R at a flight Mach number of 0.92. This temperature corresponds to a burner temperature rise of 1750° R with an over-all fuel-air ratio of 0.475. The net thrust obtained at limiting turbine-outlet temperature with the tail-pipe burner inoperative is shown to be about 1 percent less than the thrust obtainable with the standard engine tail pipe. This small loss in thrust results from the fact that the ratio of total-pressure loss between the turbine outlet and exhaust-nozzle outlet to the turbine-outlet total pressure is only slightly higher for the tail-pipe burner (0.025) than with the standard tail pipe (0.010) at the same turbine-outlet conditions. Neither value includes the pressure loss across the exhaust-nozzle outlet.

The specific fuel consumptions with and without tail-pipe burning increased only slightly with flight Mach number (fig. 14). At a flight Mach number of 0.92, the specific fuel consumption was 2.21 with tail-pipe burning compared with 1.26 with the standard engine. The specific fuel consumption with tail-pipe burning was slightly lower for burner C than for burner B. However, burner B, as shown subsequently, was operated at a higher tail-pipe fuel-air ratio and thus a greater percentage of the total fuel flow was being burned in the low-efficiency part of the engine plus tail-pipe-burner cycle.

Tail-pipe combustion efficiency is presented as a function of tail-pipe fuel-air ratio for a range of flight Mach numbers at an altitude of 25,000 feet (fig. 15) and for a range of altitudes at a flight Mach number of 0.27 (fig. 16). These data were also obtained with a fixed-area exhaust nozzle, and therefore, the variations in burner-inlet total temperature, total pressure, and velocity are shown in the figures. The burner-inlet temperature and pressure increased with tail-pipe fuel-air ratio, whereas the burner-inlet velocity remained substantially constant between 410 and 420 feet per second. At a given fuel-air ratio, the burner-inlet temperature remained approximately constant with changes in altitude and flight Mach number. Combustion efficiency increased rapidly with tail-pipe fuel-air ratio, reaching a peak at a fuel-air ratio of about 0.030. The combustion efficiency dropped off slightly at higher fuel-air ratios.

Over the range of flight Mach numbers investigated, changes in tail-pipe pressure due to variations in flight Mach number (fig. 15) or in altitude up to 35,000 feet (fig. 16) had no effect on the combustion efficiency. Increasing the altitude from 35,000 to 45,000 feet at a flight Mach number of 0.27 did result in a decrease in combustion efficiency amounting to about 0.10 at a turbine-outlet temperature of 1600° R. The trend of these combustion efficiency data with fuel-air ratio up to an altitude of 35,000 feet is again attributed to the fuel distribution in the tail-pipe burner because changing the pressure at a given fuel-air ratio within the range of pressure investigated had no effect on the combustion efficiency. With this particular burner-inlet velocity and fuel distribution, the critical burner-inlet pressure is reached between altitudes of 35,000 and 45,000 feet at a flight Mach number of 0.27, where the pressure then becomes a principle variable affecting the combustion efficiency.

The operable range of tail-pipe fuel-air ratios is shown in figure 17 as a function of altitude at a flight Mach number of 0.27. The maximum operable fuel-air ratio was limited by turbine-outlet temperature, whereas the minimum fuel-air ratio was limited by lean combustion blow-out. At each altitude, combustion blow-out was encountered within the range of fuel-air ratios shown in figure 17 as the region of uncertain operation. The region of uncertain operation occurred at higher tail-pipe fuel-air ratios as the altitude was increased. At an altitude of 45,000 feet and a flight Mach number of 0.27, operation was possible at tail-pipe fuel-air ratios between 0.029 and 0.040; however, the maximum fuel-air ratio is significant only for the size exhaust nozzle used.

Burner D. - Performance data obtained with burner D are presented in figures 18 and 19 for an altitude of 25,000 feet and a range of flight Mach numbers. These data were obtained at maximum engine speed and the turbine-outlet temperature was 1675° R both with and without tail-pipe burning.

The ratio of augmented to normal thrust increased from 1.34 at a flight Mach number of 0.22 to 1.78 at a flight Mach number of 0.82 (fig. 18). Burner-outlet temperatures increased from 2975° to 3525° R with this increase in flight Mach number. The large increase in temperature is mainly attributed to an increase in engine component efficiency as the flight Mach number was raised. The burner-outlet temperature of 3525° R corresponds to a burner temperature rise of 1850° R with an over-all fuel-air ratio of 0.053. The total-pressure-loss ratio measured across the tail-pipe burner when it was inoperative (0.050 to 0.055) was slightly more than that measured across the standard engine tail pipe (0.045) at the same turbine-outlet conditions. As a result, the net thrust obtainable at limiting turbine-outlet temperatures with the burner inoperative was 0.5 to 1 percent less than that obtainable with the standard engine tail pipe.

The specific fuel consumption with tail-pipe burning (fig. 19) increased slightly up to a flight Mach number of about 0.45 and then decreased slightly at higher Mach numbers. The increase in specific fuel consumption at low flight Mach numbers is attributed to the corresponding increase in tail-pipe fuel-air ratio with no change in tail-pipe combustion efficiency. The decrease in specific fuel consumption at flight Mach numbers above 0.50 is attributed to the fact that the combustion efficiency is increased. This increase in combustion efficiency had a greater effect than the further increase in tail-pipe fuel-air ratio. At a flight Mach number of 0.81, the specific fuel consumption was 2.49 with tail-pipe burning compared with 1.38 with the standard engine tail pipe.

Tail-pipe combustion efficiency is presented as a function of tail-pipe fuel-air ratio for a range of flight Mach numbers at an altitude of 25,000 feet (fig. 20) and for a range of altitudes at a flight Mach number of 0.22 (fig. 21). The variations in burner-inlet total pressure, total temperature, and velocity as a function of tail-pipe fuel-air ratio are also shown in these figures. At a given fuel-air ratio, changes in flight Mach number had no effect on burner-inlet velocities, although increases in altitude raised the burner-inlet velocity. The combustion efficiency increased rapidly with fuel-air ratio and reached a maximum value at a fuel-air ratio of about 0.035 with the exception of the data obtained at 45,000 feet altitude where operation was erratic. For the range of fuel-air ratios investigated, the combustion efficiency remained essentially constant above a fuel-air ratio of 0.035.

The data in figure 20 show that the variations in burner-inlet pressure, accompanying changes in flight Mach number for the range of burner-inlet velocities from 460 to 515 feet per second, had a definite effect on the tail-pipe combustion efficiency. Raising the flight Mach number from 0.27 to 0.52, which represents a change in tail-pipe pressure of 15 percent, had no apparent effect on the combustion efficiency. A further increase in flight Mach number, however, from 0.52 to 0.81, which corresponds to a rise in tail-pipe pressure of about 30 percent, raised the peak combustion efficiency from 0.80 to 0.90.

Increasing the altitude from 15,000 to 35,000 feet resulted in uniform reductions in peak combustion efficiency from 0.85 to 0.76 (fig. 21), which accompanied a decrease in pressure and a slight increase in velocity. Between 35,000 and 45,000 feet, a critical region was encountered with the result that operation was somewhat erratic at 45,000 feet with considerably lower combustion efficiency. At a given tail-pipe fuel-air ratio (fig. 21), operation was possible in two regions of tail-pipe combustion efficiency at 45,000 feet altitude. In the higher region of combustion efficiency, it was observed through a periscope that the flame was seated on the entire flame holder. When the lower combustion efficiencies were encountered, however, observation through a periscope revealed that the flame on the outer ring of the flame holder had blown out.

The fuel distribution with burner D was quite similar to that of burner C and, although the diffuser inner cone was shorter and was larger in diameter at the downstream end, the primary difference between the two burners was an increase in burner-inlet velocity from about 415 feet per second with burner C to a range of 460 to 515 feet per second with burner D.

The operable range of tail-pipe fuel-air ratios is presented as a function of altitude at a flight Mach number of 0.20 in figure 22. The maximum operable tail-pipe fuel-air ratio was limited by turbine-outlet temperature and the minimum operable fuel-air ratio was limited by lean combustion blow-out. As with burner C, combustion blow-out occurred over a range of fuel-air ratios at each altitude. This range of combustion blow-out is indicated as the region of uncertain operation. The region of uncertain operation occurred at higher tail-pipe fuel-air ratios as the altitude was increased to 35,000 feet. The data obtained were insufficient to completely determine the region of uncertain operation at 45,000 feet. The rapid reduction in maximum tail-pipe fuel-air ratio at altitudes up to 35,000 feet is attributed to lowered engine component efficiency at the high altitudes. Operation at a somewhat higher fuel-air ratio at 45,000 feet than was possible at 35,000 feet is attributed to the large drop in combustion efficiency between these two altitudes, which, as a result, required a considerably higher tail-pipe fuel-air ratio at 45,000 feet in order to obtain limiting turbine-outlet temperature. At 35,000 feet, operation was possible between tail-pipe fuel-air ratios of 0.031 and 0.038. The minimum fuel-air ratio was slightly higher than that with burner C, 0.026 at 35,000 feet. The maximum fuel-air ratio is significant only for the size exhaust nozzle used.

SUMMARY OF RESULTS

The data presented herein showed that at an altitude of 25,000 feet and a flight Mach number of 0.85 it was possible to obtain thrust gains with tail-pipe burning amounting to about 0.80 of the normal thrust. The data also showed that up to 35,000 feet altitude it was possible to maintain the tail-pipe combustion efficiencies in the region of 0.85 with burner-outlet temperatures of about 3500° R. Burner-inlet velocity was shown to be a principle factor in maintaining the combustion efficiency approximately constant over a wide range of flight conditions.

With a burner having an inlet velocity of 415 feet per second, the combustion efficiency was unaffected by changes in flight Mach number up to 0.92 at 25,000 feet altitude and changes in altitude up to 35,000 feet at a flight Mach number 0.27. With a burner having an inlet velocity of about 460 to 515 feet per second, however, increasing the burner-inlet pressure by raising the flight Mach number from 0.52 to 0.81 at 25,000 feet altitude increased the peak combustion efficiency from 0.80 to 0.90. Increases in burner-inlet velocity were also shown to raise the tail-pipe fuel-air ratio at which lean blow-out of the burner occurred at all altitudes.

REFERENCE

1. Fleming, William A., and Wallner, Lewis A.: Altitude-Wind-Tunnel Investigation of Tail-Pipe Burning with a Westinghouse X24C-4B Axial-Flow Turbojet Engine. NACA RM No. E8J25e, 1948.

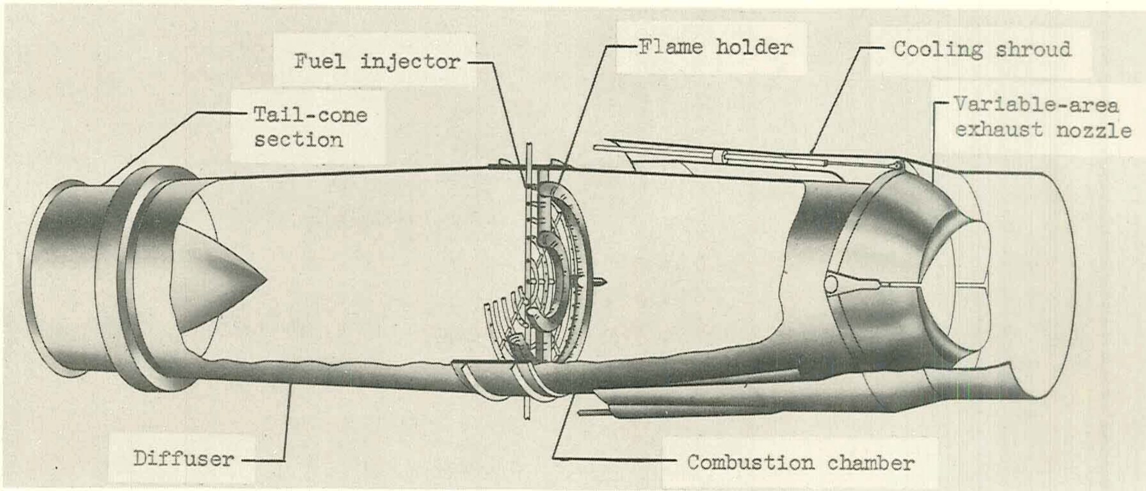

Figure 1. - Burner A.

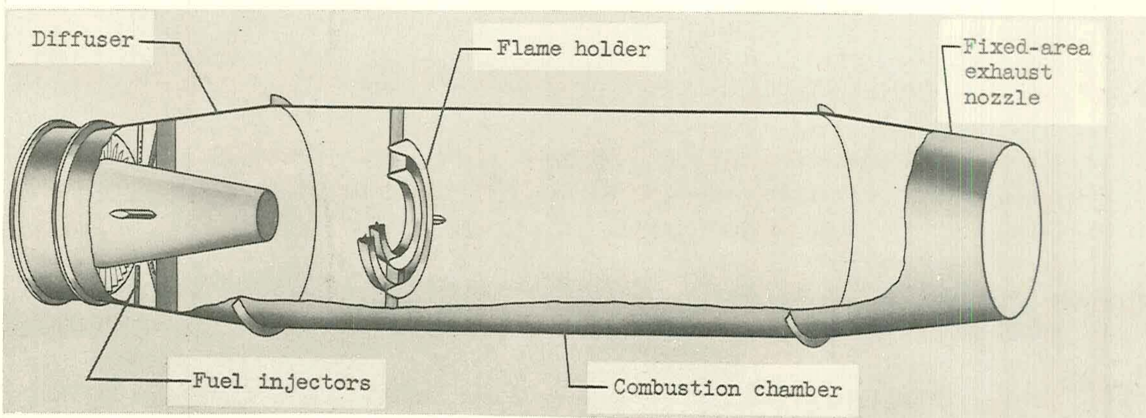

Figure 2. - Burner B.

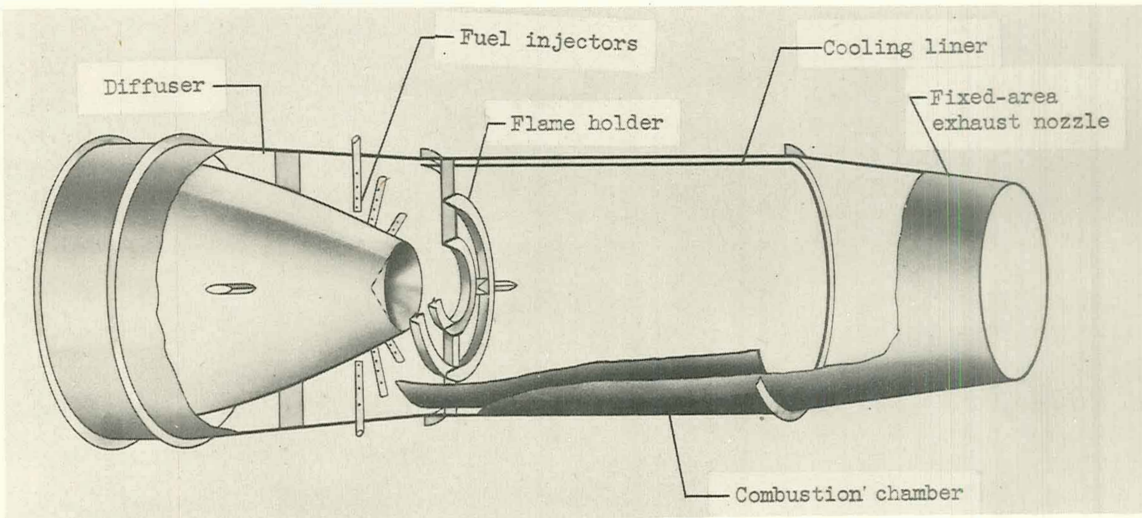

Figure 3. - Burner C.

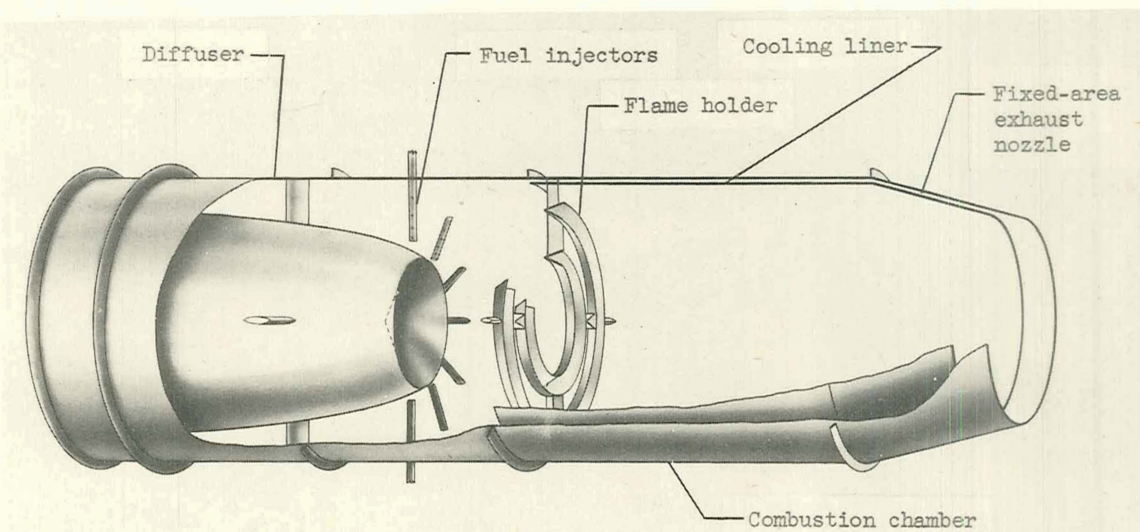

Figure 4. - Burner D.

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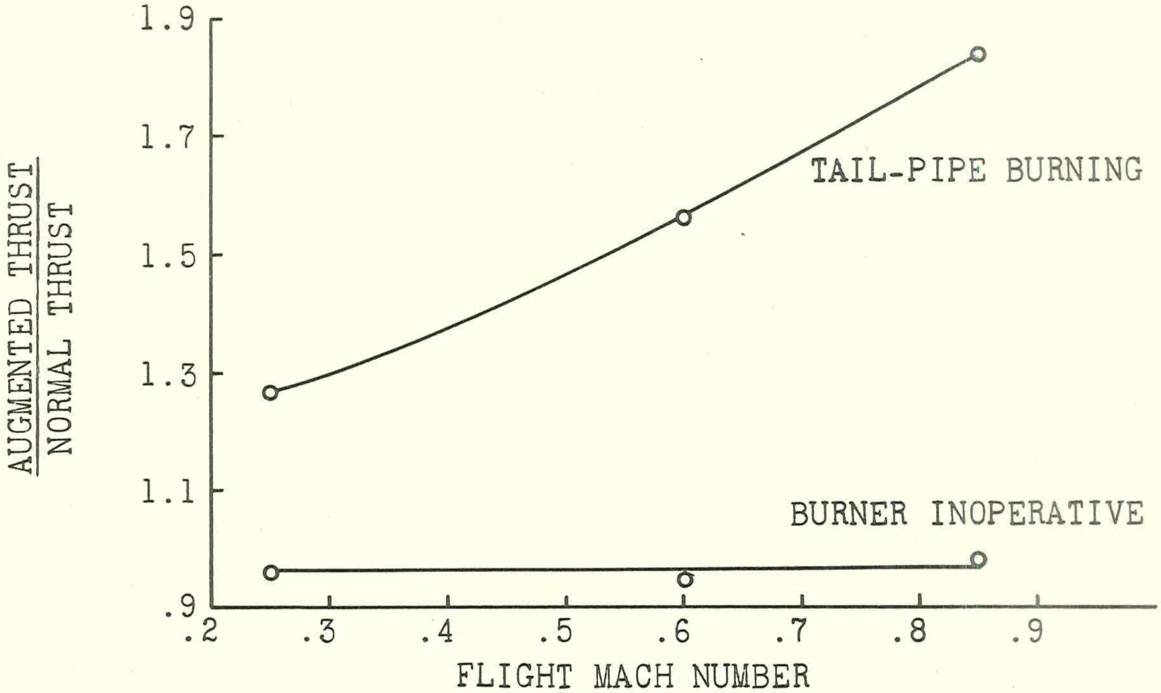

Figure 5. - Thrust performance for burner A. J34 engine; altitude, 20,000 feet; burner-inlet velocity, 440 to 480 feet per second; turbine-outlet temperature, 1600° R.

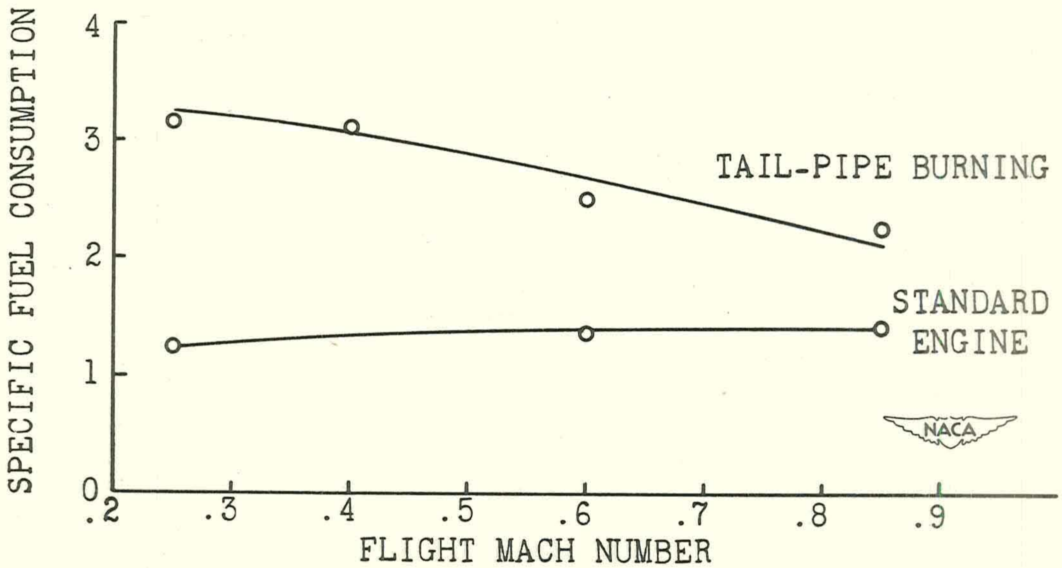

Figure 6. - Comparison of specific fuel consumption for J34 engine with standard tail pipe and with burner A. Altitude, 20,000 feet; burner-inlet velocity, 440 to 480 feet per second; turbine-outlet temperature, 1600° R.

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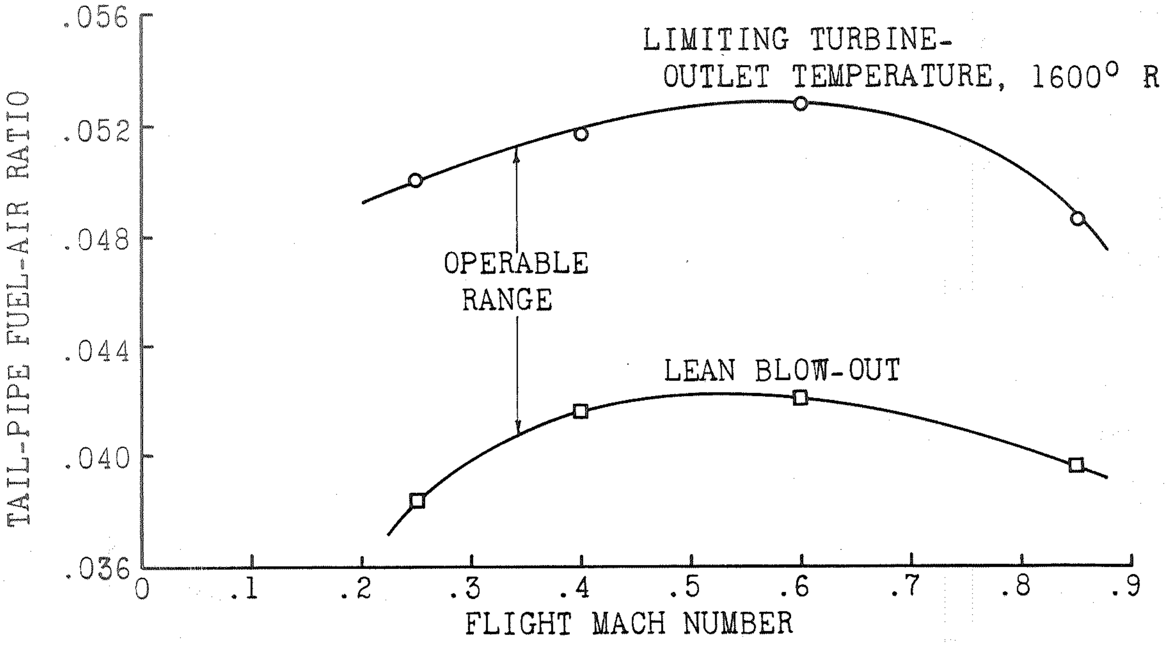

Figure 7. - Operable range of tail-pipe fuel-air ratios for burner A. J34 engine; altitude, 20,000 feet; burner-inlet velocity, 440 to 480 feet per second.

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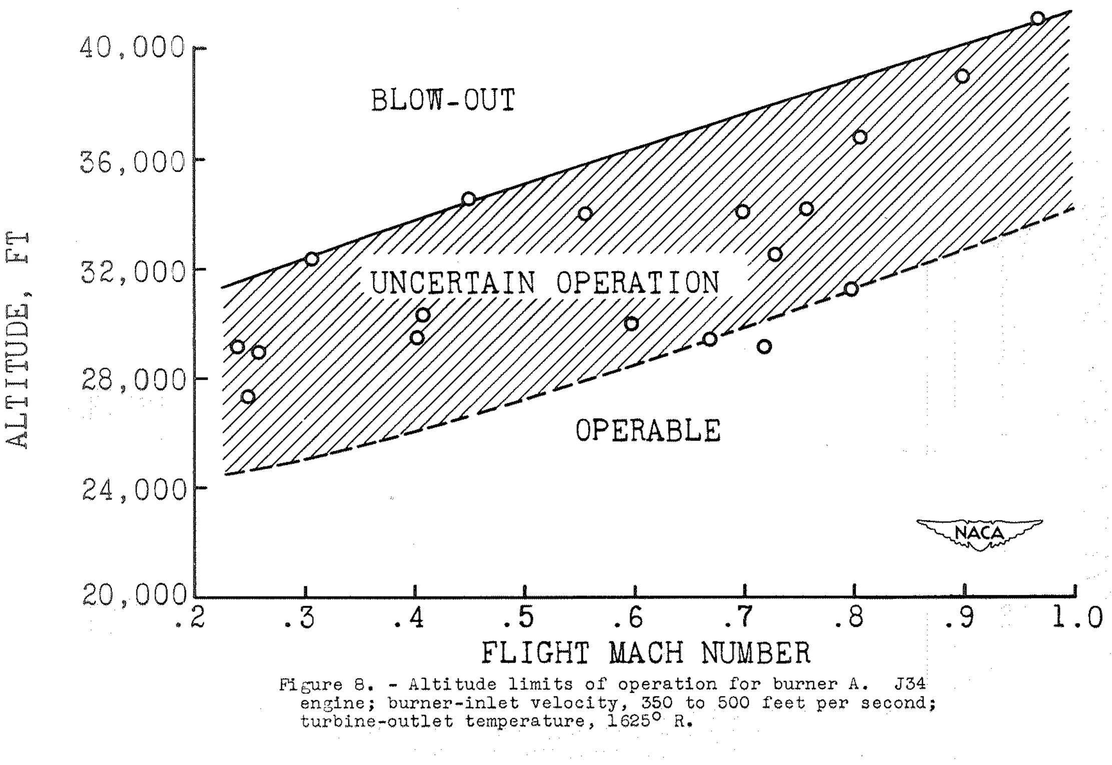

Figure 8. - Altitude limits of operation for burner A. J34 engine; burner-inlet velocity, 350 to 500 feet per second; turbine-outlet temperature, 1625° R.

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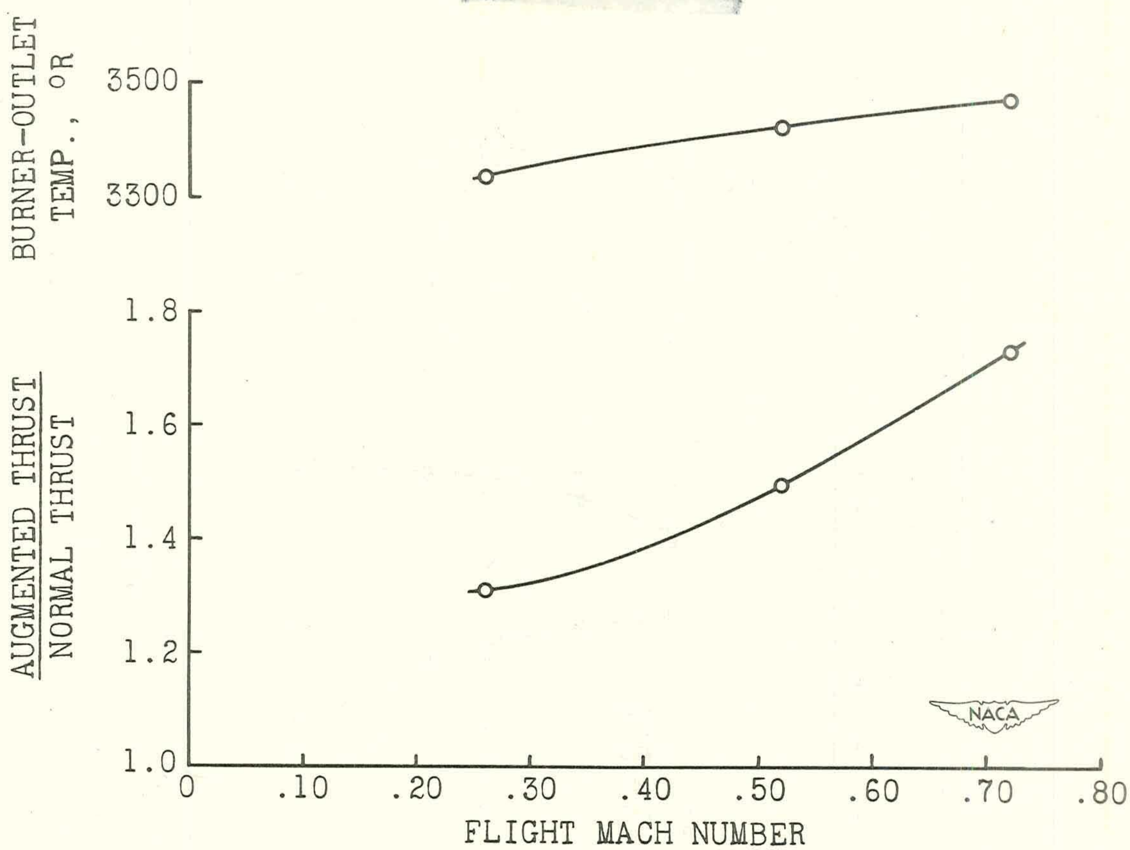

Figure 9. - Thrust performance and burner-outlet temperature for burner B. J34 engine; altitude, 25,000 feet; burner-inlet velocity, 455 feet per second; turbine-outlet temperature, 1650° R.

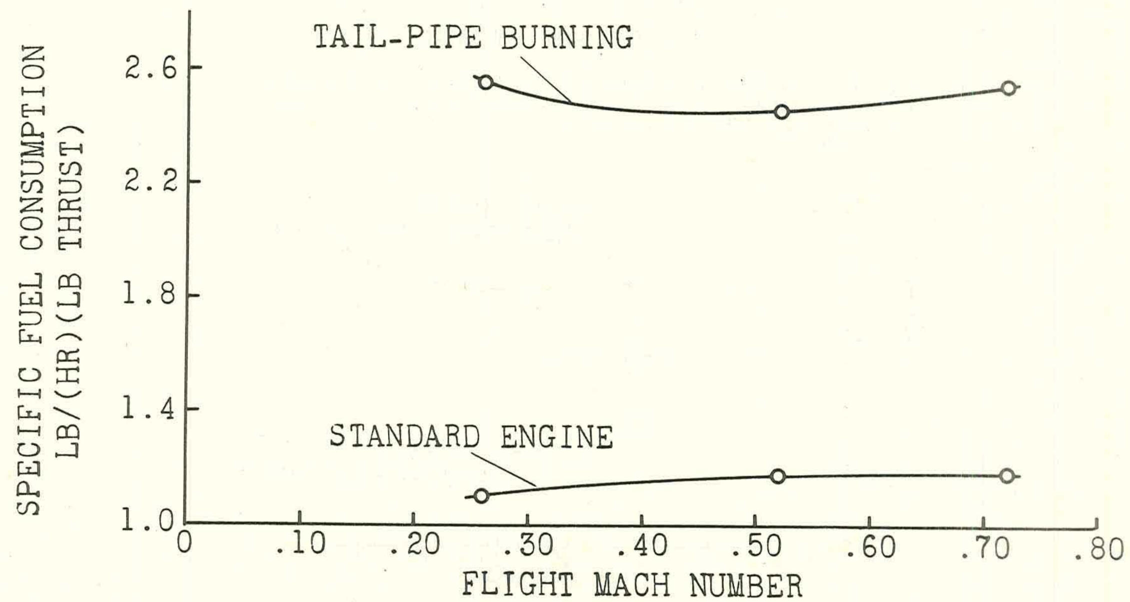

Figure 10. - Comparison of specific fuel consumption for J34 engine with standard tail pipe and with burner B. Altitude, 25,000 feet; burner-inlet velocity, 455 feet per second; turbine-outlet temperature, approximately 1650° R.

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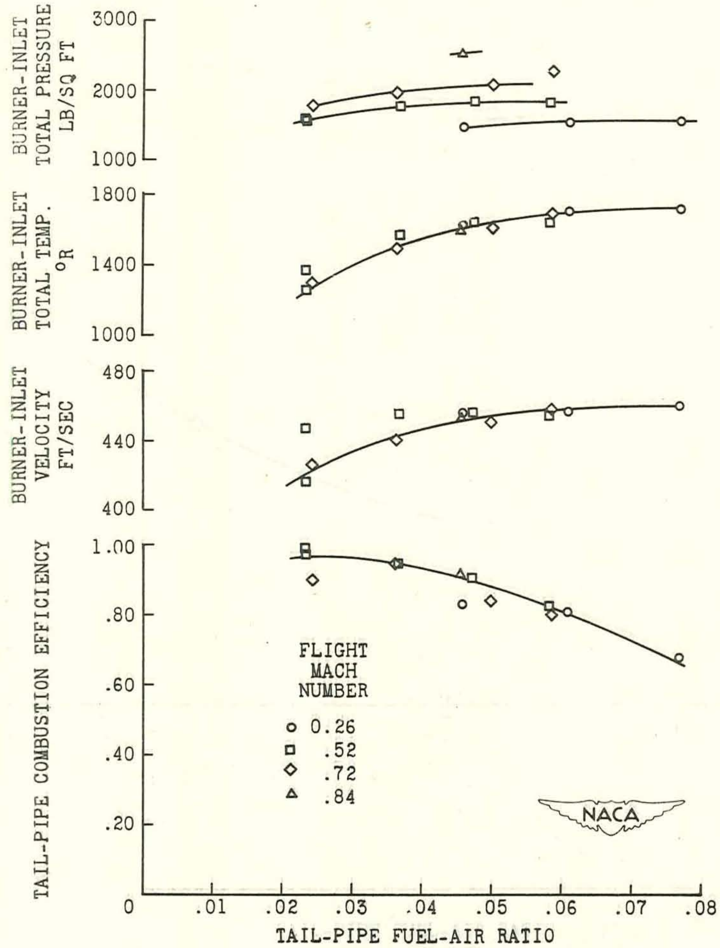

Figure 11. - Variation of combustion efficiency, burner-inlet total temperature, total pressure, and velocity with tail-pipe fuel-air ratio for burner B. J34 engine; altitude, 25,000 feet.

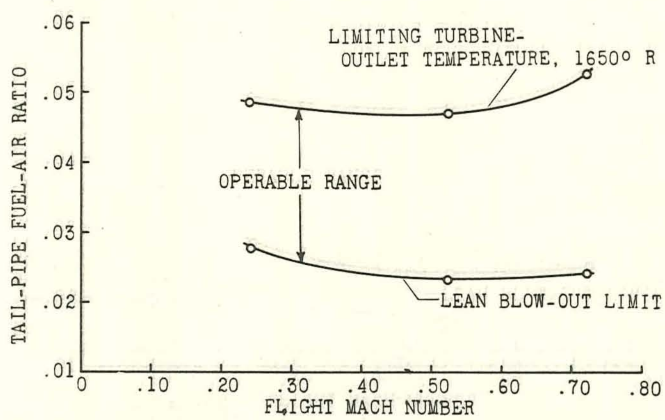

Figure 12. - Operable range of tail-pipe fuel-air ratios for burner B. J34 engine; altitude, 25,000 feet; burner-inlet velocity, 420 to 460 feet per second.

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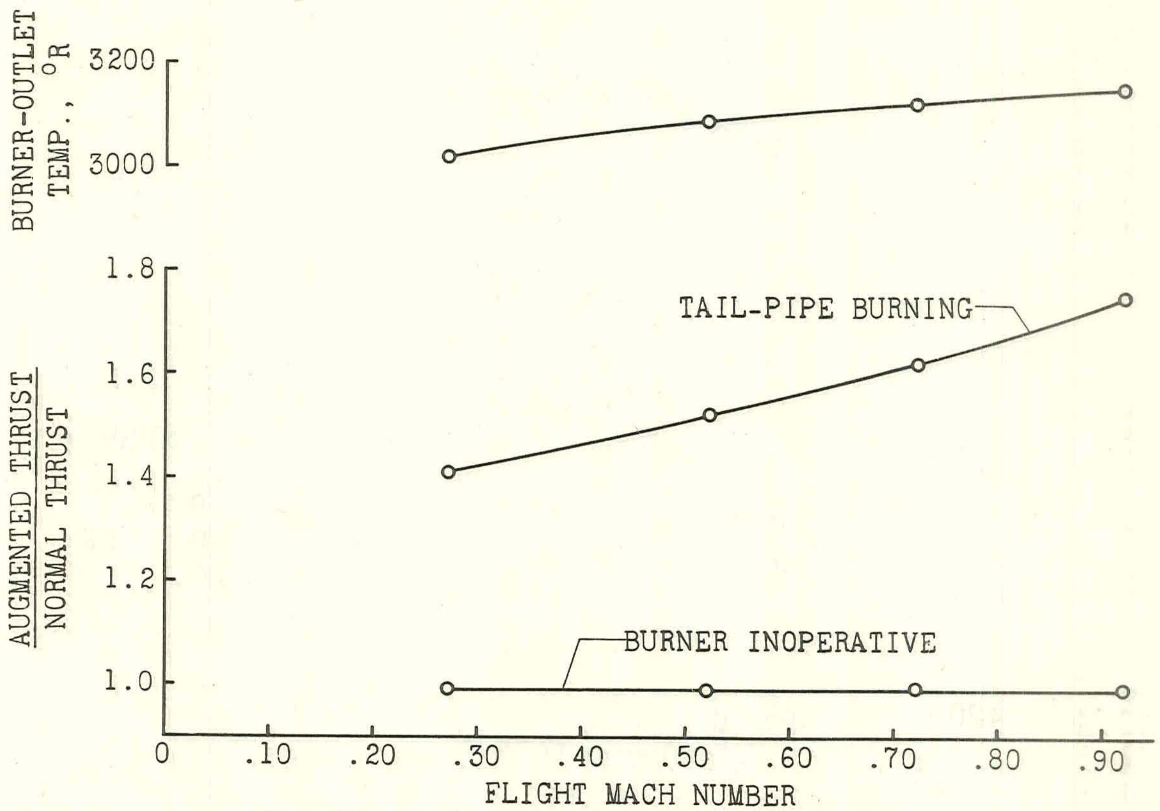

Figure 13. - Thrust performance and burner-outlet temperature for burner C. J35 engine; altitude, 25,000 feet; burner-inlet velocity, 415 feet per second; turbine-outlet temperature, 1600° R.

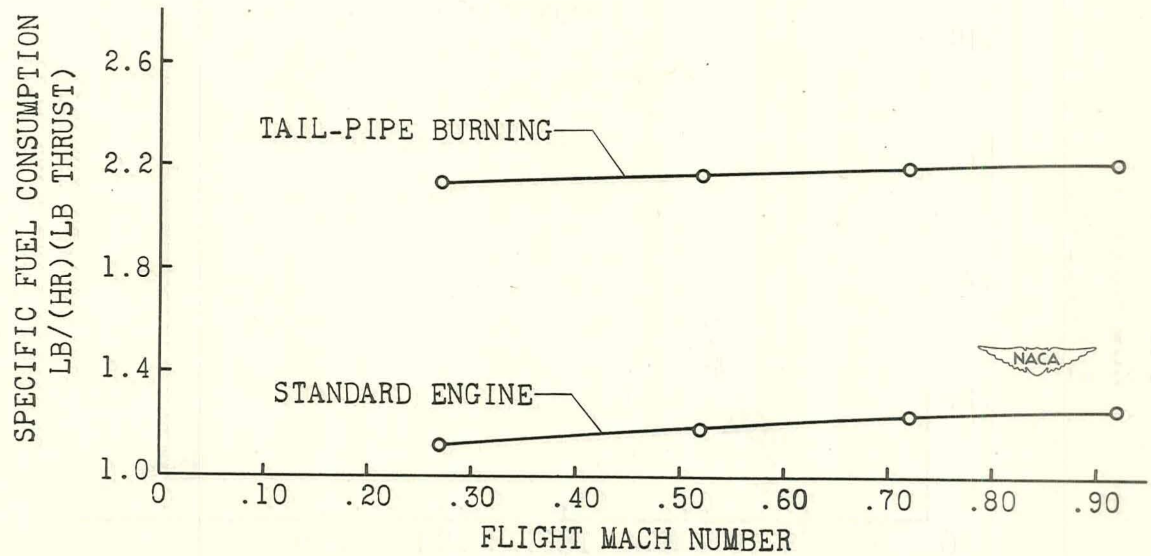

Figure 14. - Comparison of specific fuel consumption for J35 engine with standard tail pipe and with burner C. Altitude, 25,000 feet; burner-inlet velocity, 415 feet per second; turbine-outlet temperature, 1600° R.

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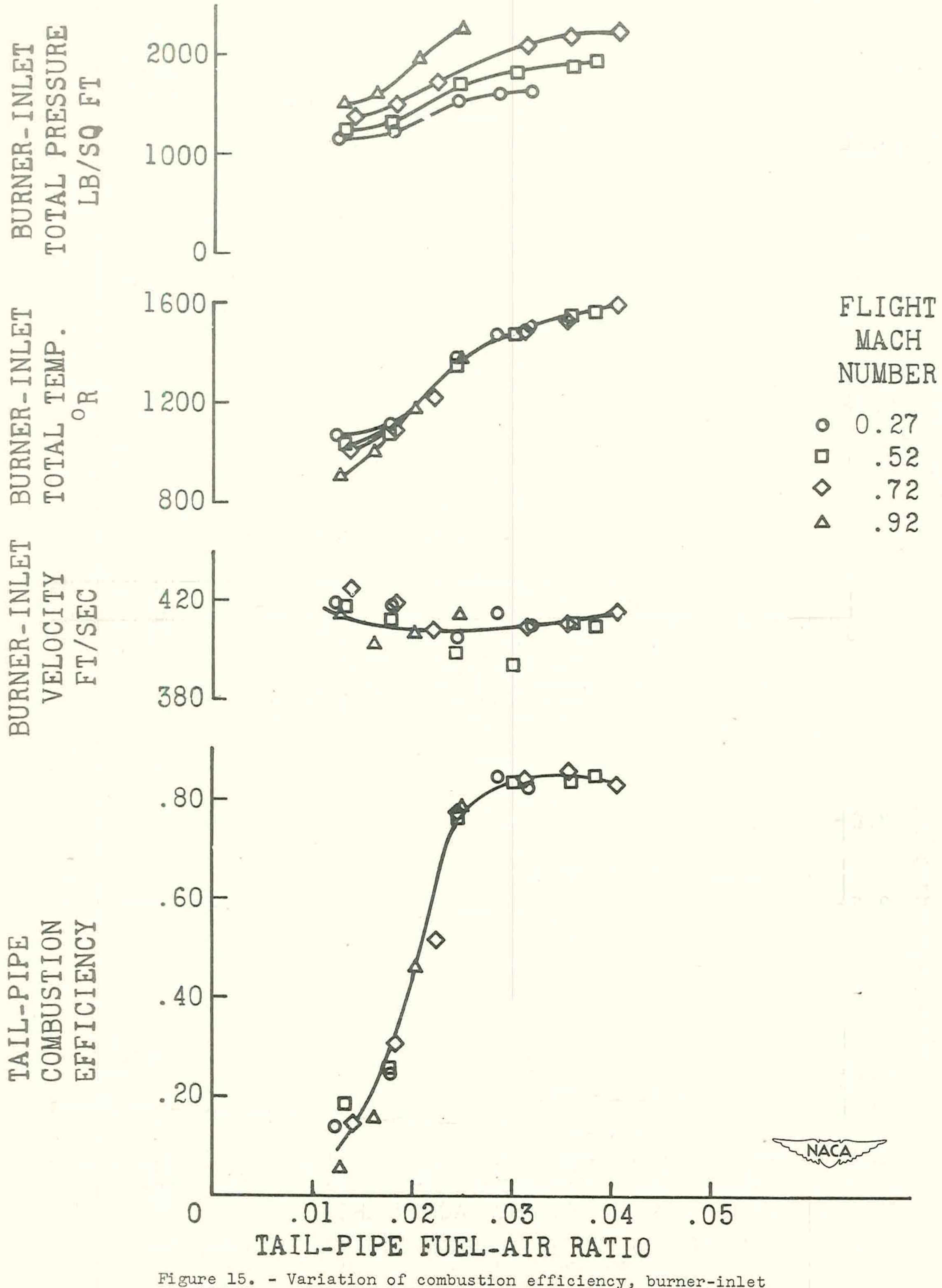

Figure 15. - Variation of combustion efficiency, burner-inlet total temperature, total pressure, and velocity with tail-pipe fuel-air ratio for burner C at altitude of 25,000 feet. J35 engine.

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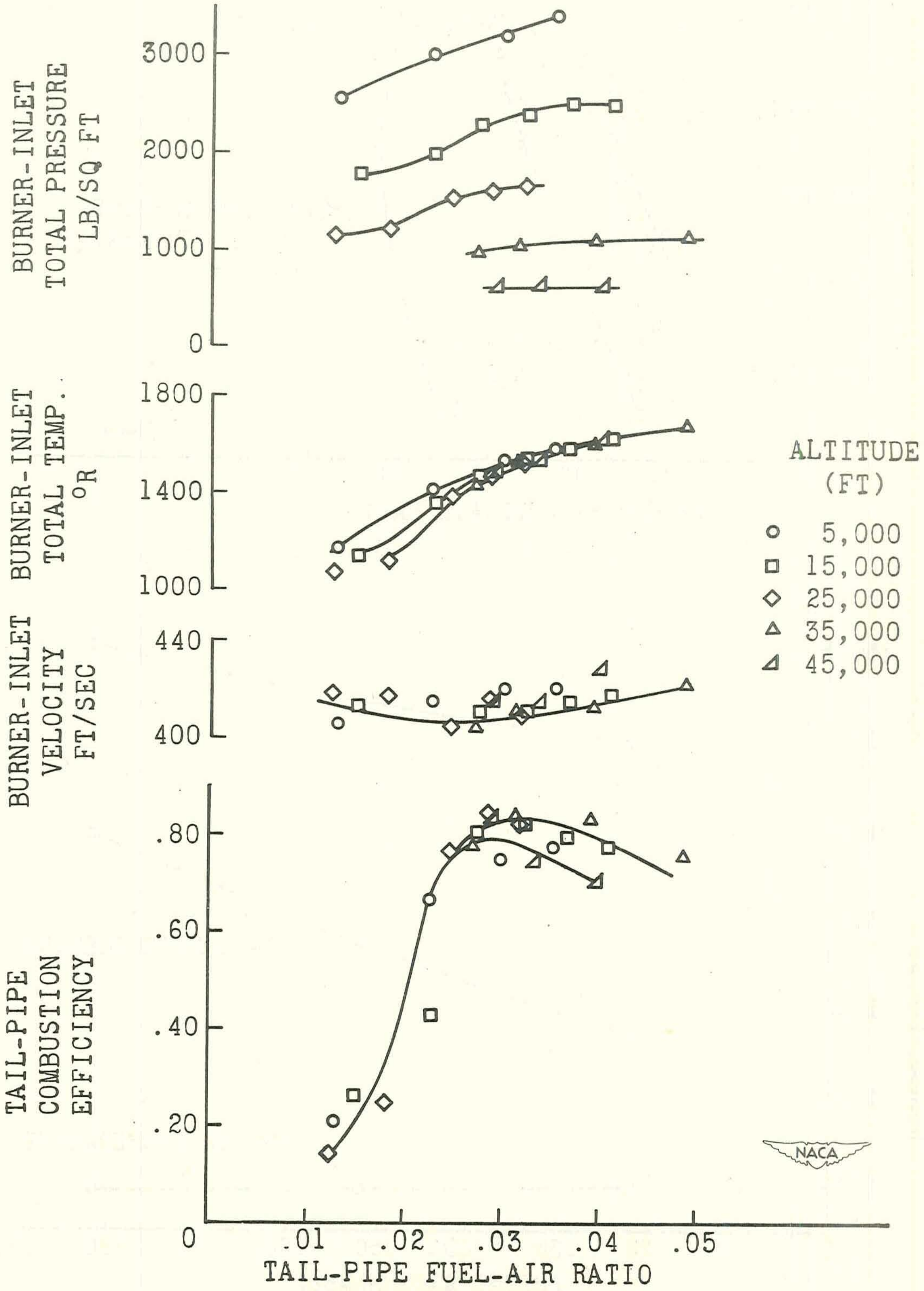

Figure 16. - Variation of combustion efficiency, burner-inlet total temperature, total pressure, and velocity with tail-pipe fuel-air ratio for burner C at Mach number of 0.27. J35 engine.

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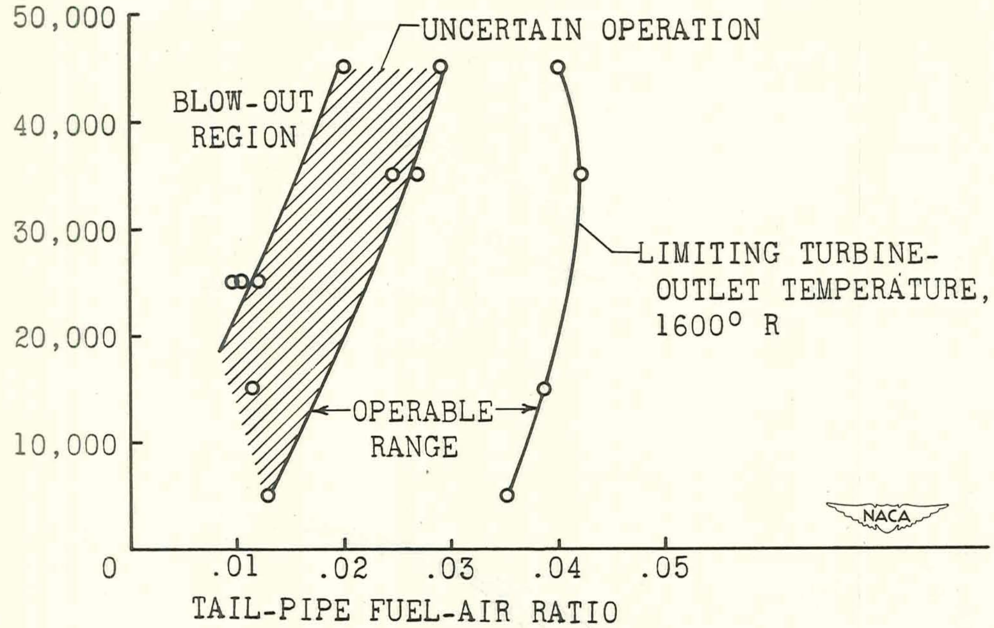

Figure 17. - Operable range of tail-pipe fuel-air ratios for burner C. J35 engine; Mach number, 0.27; burner-inlet velocity, 415 feet per second.

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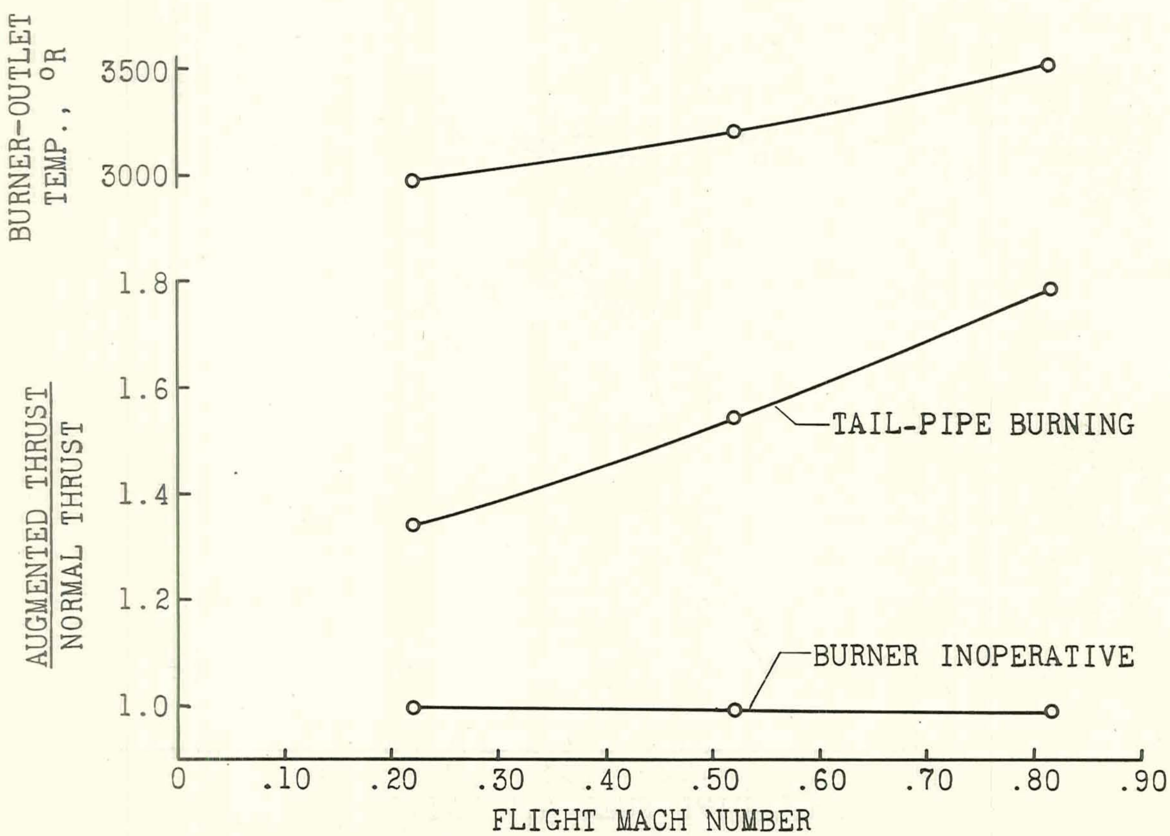

Figure 18. - Thrust performance and burner-outlet temperature for burner D. J47 engine; altitude, 25,000 feet; burner-inlet temperature, 465 feet per second; turbine-outlet temperature, 1675° R.

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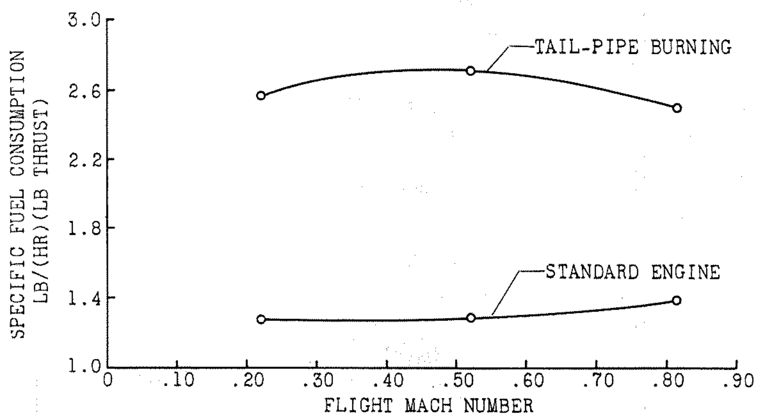

Figure 19. - Comparison of specific fuel consumption for J47 engine with standard tail pipe and with burner D. Altitude, 25,000 feet; burner-inlet velocity, 465 feet per second; turbine-outlet temperature, 1675° R.

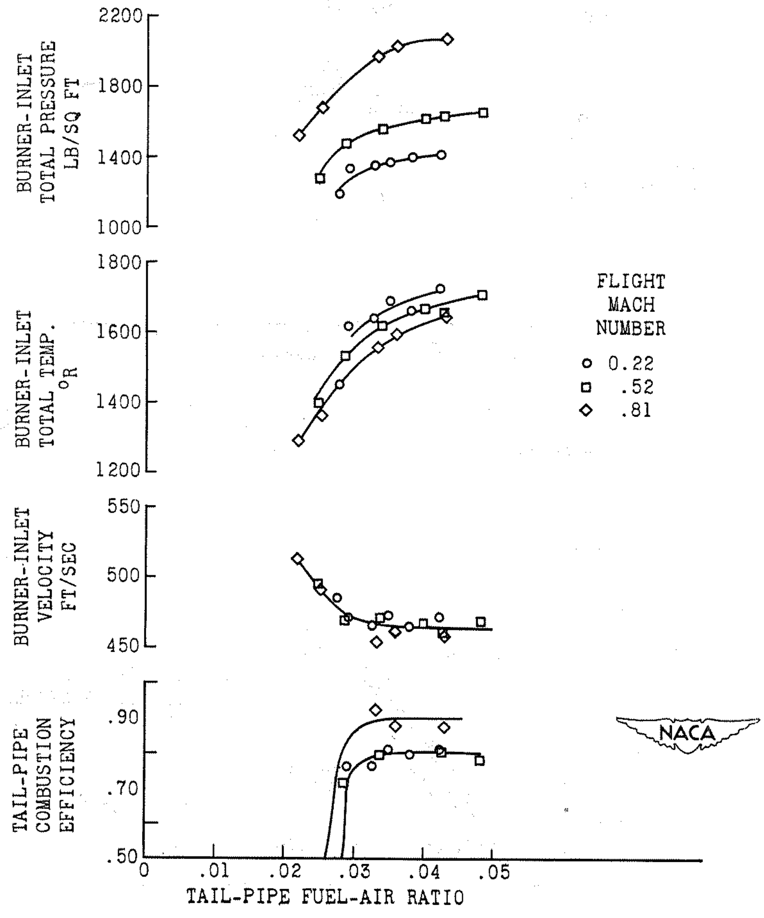

Figure 20. - Variation of combustion efficiency, burner-inlet total temperature, total pressure, and velocity with tail-pipe fuel-air ratio for burner D at altitude of 25,000 feet. J47 engine.

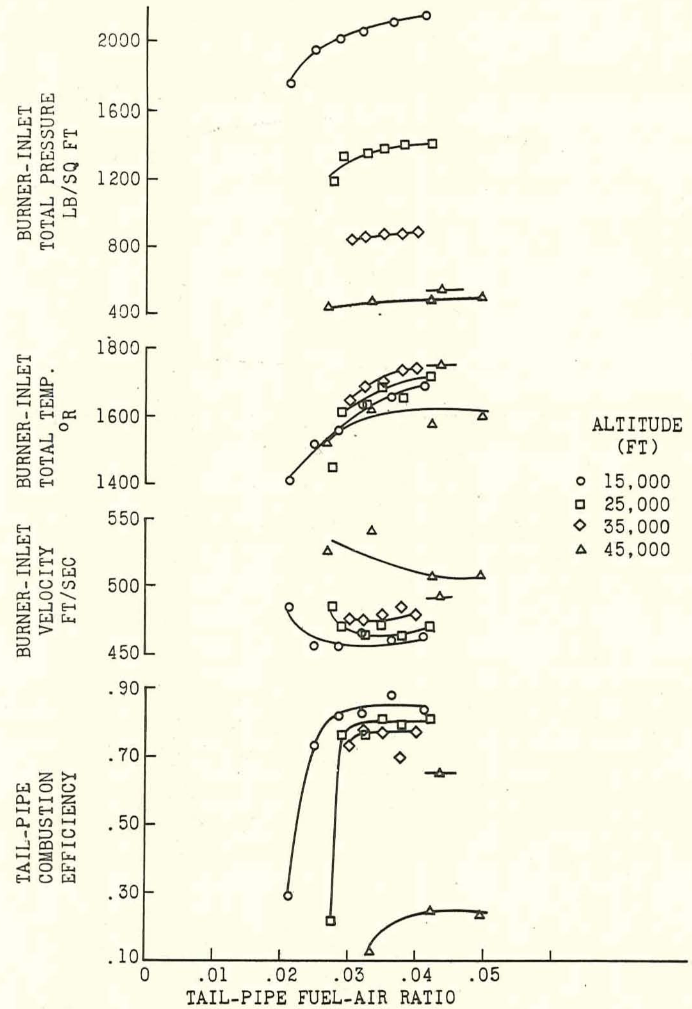

Figure 21. - Variation of combustion efficiency, burner-inlet total temperature, total pressure, and velocity with tail-pipe fuel-air ratio for burner D at Mach number of 0.22. J47 engine.

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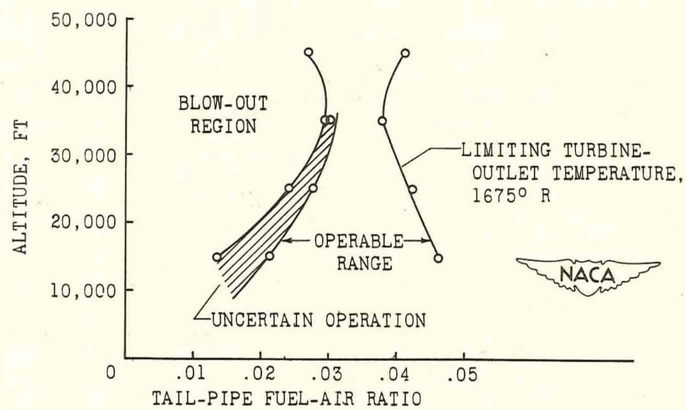

Figure 22. - Operable range of tail-pipe fuel-air ratios for burner D. J47 engine; Mach number, 0.20; burner-inlet velocity, 460 to 515 feet per second.