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# INFLUENCE OF HIGH TURBINE-INLET TEMPERATURE AND TAKEOFF JET NOISE ON A METHANE-FUELED SUPERSONIC TRANSPORT WITH VARIABLE-SWEEP WINGS

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16. Abstract

The benefits of high-turbine-inlet-temperature engines and the reduction of community noise levels by the use of a variable-sweep-wing SST were analyzed. Three optimized engine types, the afterburning and nonafterburning turbojet, and the duct-burning turbofan, were compared using methane fuel. Without noise constraints, the afterburning turbojet and the duct-burning turbofan yielded the best payload. With noise constraints, only the duct-burning turbofan maintained reasonable payload. Oversized engines and the excellent low-speed aerodynamics of the variable-sweep-wing design resulted in less community noise than a fixed-wing design used in another study.

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# INFLUENCE OF HIGH TURBINE-INLET TEMPERATURE AND TAKEOFF JET NOISE ON A METHANE-FUELED SUPERSONIC TRANSPORT WITH VARIABLE-SWEEP WINGS

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## SUMMARY

The benefits that can be obtained from designing high-turbine-inlet-temperature engines and the reduction of community noise levels by the use of a variable-sweep-wing airplane were analyzed. This was done by analytically flying three types of engines on a methane-fueled Mach 3.0 variable-sweep-wing supersonic transport (SST). The engine types considered were afterburning turbojets, nonafterburning turbojets, and duct-burning turbofans. A range of design turbine-inlet temperatures from 2200° to 3100° F (1204° to 1704° C) was examined. The high turbine-inlet temperatures were assumed to be consistent with the use of the heat-sink capacity of the methane fuel to cool the turbine blades. The engines were evaluated in terms of the number of passengers that could be carried on the SST when flying a 3500-nautical-mile (6482-km) mission. The takeoff gross weight of the airplane was held constant throughout the study.

It was found that payload improved with increasing turbine-inlet temperature for all the engine cycles when noise restrictions were not considered. The nonafterburning turbojet provided less payload than the other two cycles because of transonic and supersonic thrust limitations.

When jet noise limitations were considered, they were achieved by means of oversizing the engines and using less than full power for takeoff and flight over the community. This technique for limiting noise caused a large penalty in payload for the afterburning and nonafterburning turbojets at 2200° F (1204° C). Furthermore, as turbine-inlet temperature was increased, the payload for these two cycles actually decreased. In contrast, the payload with the duct-burning turbofan at 2200° F (1204° C) was unchanged when noise limits were imposed, and a small increase in payload was gained as turbine-inlet temperature was raised.

The assumed superior low-speed aerodynamics of the variable-sweep-wing design did not affect takeoff noise but considerably reduced the community noise level when compared to a fixed-wing design used in a previous study. Other characteristics of the two designs, such as structural weight, handling, and controls, and their effect on overall performance are not examined herein.

## INTRODUCTION

Methane (or liquefied natural gas) has been suggested as a desirable fuel for supersonic transports because of its improved heating value and cooling capacity relative to kerosene (e.g., refs. 1 and 2). The greater cooling capacity is beneficial in that it may permit the use of higher turbine-inlet temperature. This, in turn, yields lighter engines and/or lower specific fuel consumption. On the other hand, higher turbine-inlet temperature tends to increase exhaust-jet velocity and thus increase engine jet noise, which is currently a subject of increasing public concern.

Reference 3 reports a study of a typical fixed-wing supersonic transport (SST) that examined the effect on airplane performance of variations in engine type (afterburning turbojets, nonafterburning turbojets, and duct-burning turbofans) and design turbine-inlet temperature, both with and without engine noise limitations. Noise abatement was accomplished by oversizing the engines and operating at reduced power during takeoff and initial climb. This technique tends to reduce airplane payload because of the increased weight of the larger engines.

The present study parallels that of reference 3 except that a variable-sweep-wing design having improved low-speed lift-drag characteristics is assumed in place of the fixed-wing vehicle. No attempt is made to compare the two designs in terms of such important parameters as stability and control, cruise aerodynamics, or structural weight and the resulting range-payload performance. Rather, the purpose of this study is to determine how community noise levels and the selection of an engine type and design turbine-inlet temperature are affected by the use of an airframe that is considerably different from that of the earlier study.

The figure of merit in this study is airplane payload (number of passengers) for a fixed gross weight and range. The turbine-inlet temperature of the three engine types is varied from $2200^{\circ}$ to $3100^{\circ}$ F ($1204^{\circ}$ to $1704^{\circ}$ C). The compressor-pressure ratio, bypass ratio, and fan-pressure ratio are optimized for each turbine-inlet temperature, both with and without engine noise restrictions.

## METHOD OF ANALYSIS

The effect on airplane performance of increasing design turbine-inlet temperature with and without noise restrictions was evaluated by analytically flying a typical variable-sweep-wing airplane over a standard mission profile. The engines used methane for fuel. Engine size and design parameters such as compressor-pressure ratio, fan-pressure ratio, and bypass ratio were varied in order to maximize the payload. A minimum thrust-to-weight ratio of 0.32 was maintained at the start of takeoff roll. This ensured adequate liftoff distance and initial climb rate.

## Mission

The mission requirements for this study and for reference 3 are shown in table I. The only differences are in the sonic boom limits and the ramp gross weight. The flight path in this study was fixed in all cases up to Mach 1.0 and was similar to that shown in reference 3. At higher Mach numbers, the maximum sonic boom overpressure limit for climb dictated the flight path.

No firm minimum climb-acceleration thrust-to-drag-ratio requirement exists today. But since many authorities believe it should be at least 1.4 on a standard day, this was the minimum used in this study. After climb and acceleration to the cruise Mach number, climb was continued until the Breguet cruise factor was maximized. This results in minimum fuel consumption during the cruise phase of the mission. A constant 20 minutes and 206 nautical miles (381 km) was allowed for descent with fuel consumption calculated at engine idle.

The fuel reserve for the mission allows for (1) an additional 7 percent of the total mission fuel, (2) an extension of 261 nautical miles (483 km) to an alternate airport at the cruise altitude and Mach number, and (3) a 30-minute hold at 15 000 feet (4572 m) altitude at Mach 0.5. An additional allowance was incorporated in the mission fuel for a 10-minute taxi-out and a 4-minute departure air maneuver.

TABLE I. - MISSION

| | This study | | Reference 3 | |
|---|---|---|---|---|
| Range, n mi; km | 3500 | 6482 | 3500 | 6482 |
| Cruise Mach number | 3.0 | --- | 3.0 | --- |
| Maximum sonic boom overpressure: | | | | |
| Climb, $lb/ft^2$; $N/m^2$ | 2.5 | 120.0 | 2.0 | 95.76 |
| Start of cruise, $lb/ft^2$; $N/m^2$ | 1.8 | 86.18 | 1.5 | 71.82 |
| Minimum thrust-to-drag ratio | 1.4 | --- | 1.4 | --- |
| Maximum lift-off distance, ft; m | 4450 | 1460 | 4450 | 1460 |
| Ramp gross weight, lb; kg | 675 000 | 306 500 | 460 000 | 208 652 |

## Airplane Weight

The airplane ramp gross weight was fixed at 675 000 pounds (306 500 kg). The fuselage was fixed in cross-sectional area, but the length, weight, and drag varied according to the number of passengers carried. A curve of fuselage weight against length is shown in figure 1. Each passenger and his baggage was considered to weight 200 pounds (91 kg). The equipment associated with each passenger, such as air-conditioning, food

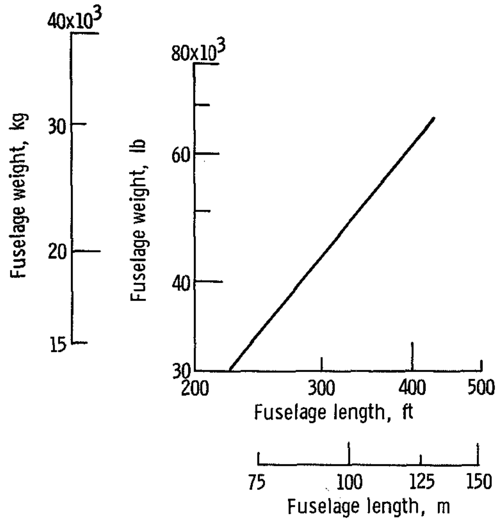


Figure 1. - Variation of fuselage weight with length.

service, passenger furnishings, emergency equipment, etc., weighed 110 pounds (50 kg) per passenger. In the parts of the fuselage that were lengthened or shortened, six-abreast seating was used. The seat pitch was 34 inches (86 cm). The fixed weight items, wing, horizontal and vertical tail, fuel system, surface controls, hydraulic and electrical systems, and landing gear, totaled 151 000 pounds (68 500 kg).

## Airplane Aerodynamics

The aerodynamic data used for this study are typical for a variable-sweep SST with a wing loading of 75 pounds per square foot (3495 $N/m^2$). Typical lift over drag values (L/D) were 8.45 for supersonic cruise and 14.6 for subsonic cruise. During noise abatement takeoffs, it was assumed that special flap and slat settings were used to improve the L/D. Typical values of L/D were 11.0 to 11.5 during power cutback over the commu-

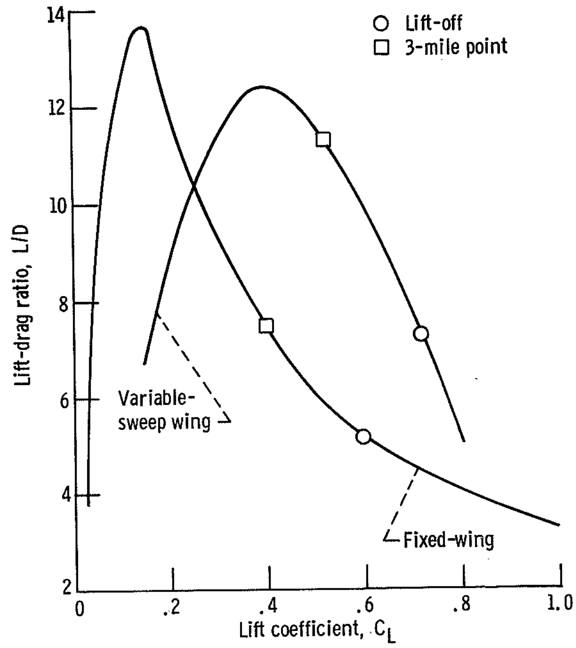


Figure 2. - Comparison of subsonic lift over drag values for two types of airplanes. Flaps and slats are deployed for takeoff.

nity. This compares with L/D values from about 7 to 8 for the fixed-wing airplane used in reference 3. This can be seen in figure 2 where the subsonic L/D curves for the variable-sweep-wing airplane and the fixed-wing airplane are compared.

## Engines

Three engine types were examined: afterburning turbojets, nonafterburning turbojets, and duct-burning turbofans. A comparison was made between the three engine

TABLE II. - RANGE OF ENGINE DESIGN VARIABLES

| Design variable | Range |
|---|---|
| Turbine-inlet temperature, °F; °C | 2200 to 3100; 1204 to 1704 |
| Compressor-pressure ratio | 7 to 19 |
| Fan-pressure ratio | 1.5 to 3.5 |
| Bypass ratio | 1.0 to 3.0 |

TABLE III. - ENGINE DESIGN CHARACTERISTICS

| Characteristic | After-burning turbojets | Nonafter-burning turbojets | Duct-burning turbofans |
|---|---|---|---|
| Fan efficiency | ----- | ----- | 0.85 |
| Compressor efficiency | 0.87 | 0.87 | .87 |
| Primary combustor efficiency | .98 | .98 | .98 |
| Primary combustor pressure loss | .06 | .06 | .06 |
| Turbine efficiency | .88 | .88 | .88 |
| Afterburner efficiency | .93 | ----- | ----- |
| Duct-burner efficiency | ----- | ----- | .93 |
| Inlet total-pressure recovery, Mach 3.0 | .851 | .851 | .851 |
| Exhaust nozzle thrust coefficient, Mach 3.0 | | | |
| Maximum augmentation | .966 | ----- | .966 |
| Minimum augmentation and maximum nonaugmented | .977 | .977 | .977 |

types when they were flown on a variable-sweep-wing SST. The performance and weight of each engine was calculated over the range of design variables shown in table II in order to find the optimum cycle combination. Engine design characteristics are shown in table III.

All the engines had a maximum augmentation gas temperature of $3100^{\circ}$ F ($1704^{\circ}$ C). Engine design point refers to sea-level-static operation of the engine at maximum thrust. Design and off-design engine performance was calculated by matching each component to satisfy the relations involving continuity of flow, engine rotational speed, and power balance between the compressor (or fan) and its driving turbine. The procedures used are similar to those discussed in reference 4.

Engine weight. - The engine weight was calculated from empirical equations which relate installed engine weight to the design airflow, compressor-pressure ratio fan pressure ratio, bypass ratio, and turbine-inlet temperature. While the form of each equation was the same, some constants and exponents did vary with engine type. The equations and relative weight factors that go into the equations are based on a composite of industry data. The equations and relative weight data are presented in reference 3.

Engine operation and sizing. - The method of engine operation depended on whether noise restrictions were observed.

When noise restrictions were not observed, takeoff was made with the maximum power available. When a flight Mach number of 0.4 was reached, the power was set at maximum nonaugmented until a Mach number of about 0.95. At that point, maximum power was applied to shorten the transonic-acceleration period. This power setting was maintained until the optimum Breguet cruise altitude was reached. Cruise was accomplished at the maximum Breguet factor. Letdown and reserves were described in the Mission section of this report. Engine size was determined by the 0.32 thrust-to-weight ratio at takeoff, the 1.4 thrust-to-drag ratio during supersonic acceleration, or the maximum payload point, whichever required the largest engine.

When noise restrictions were observed, the engine power was always reduced to a level where the start-of-takeoff noise goal was met. For the turbojets, this power setting always meant turbine-inlet temperatures below design levels. The nozzle on the turbojets was opened in such a manner as to keep the engine airflow constant. This method of part-power operation, which was used in references 3 and 5, gives the most thrust for any given noise level. For the duct-burning turbofan, the best part-power setting to meet the takeoff noise goal was always some combination of turbine-inlet and duct-burner temperature that gave the most thrust for a given noise level. Of course, when the throttle setting of the engines was reduced at the start of takeoff, the engine size (design airflow) was increased if necessary to maintain the 0.32 thrust-to-weight requirement.

At the 3-mile (4.8-km) community noise checkpoint, the thrust of the engines was further reduced so a 500-foot-per-minute (152-m/min) climb could be maintained. If the noise on the ground was above the goal after this power reduction, the entire process was started over again at takeoff using larger engines. When the 3-mile community noise goal was finally met, the engine power was gradually increased as the airplane continued its climb. Thus a constant noise was maintained on the ground as the aircraft climbed, until normal climb power was reached. From then on, the engine operation for the rest of the mission was the same as mentioned for the engines where noise was not a consideration.

## Noise Calculations

The procedures followed for calculating jet noise are those outlined by the Society of Automotive Engineers (SAE) in references 6 and 7. This method is in common use today throughout the industry. It includes such effects as atmospheric absorption, ground attenuation, and multiple engines.

A two-point takeoff noise criterion was used in this report. These two points are (1) at the airport, 1500 feet (457 m) from the centerline of the aircraft at the start of takeoff role (assumed goal, PNdB) and (2) over the community at a point directly under the flight path of the airplane when the airplane is 3 statute miles (4.8 km) from brake release (assumed goal, 105 PNdB). This noise is measured after the power is reduced for a 500-foot-per-minute (152-m/min) climb. The assumed noise goals of 116 and 105 PNdB are the same as those used in the fixed-wing study of reference 3.

When calculating community noise, many flight paths are examined. Each one results in a different Mach number and altitude at the community noise checkpoint. Each Mach number and altitude combination requires a different thrust level to maintain the

500-foot-per-minute (152-m/min) climb after power cutback. The combination that yields minimum noise on the ground is sought for each engine studied.

## RESULTS AND DISCUSSIONS

### Comparison of Engine Types

Three engine types, afterburning turbojets, nonafterburning turbojets, and duct-burning turbofans, are compared over a range of turbine-inlet temperatures, first without noise restrictions and then with noise restrictions.

Without noise restrictions. - The afterburning turbojet carried 354 passengers over the nominal mission when the engines were sized for 1.4 thrust-to-drag ratio (T/D) at 2200° F (1204° C). This is shown in figure 3. Three more passengers could have been carried if the engines had not been sized by the 1.4 T/D requirement. The payload, shown in figure 3, increases to 375 passengers at 2900° F (1592° C) and then drops off to 374 passengers at 3100° F (1704° C). This is because the engine is sized for the 1.4 T/D ratio instead of maximum payload as in reference 3. The payload penalty due to

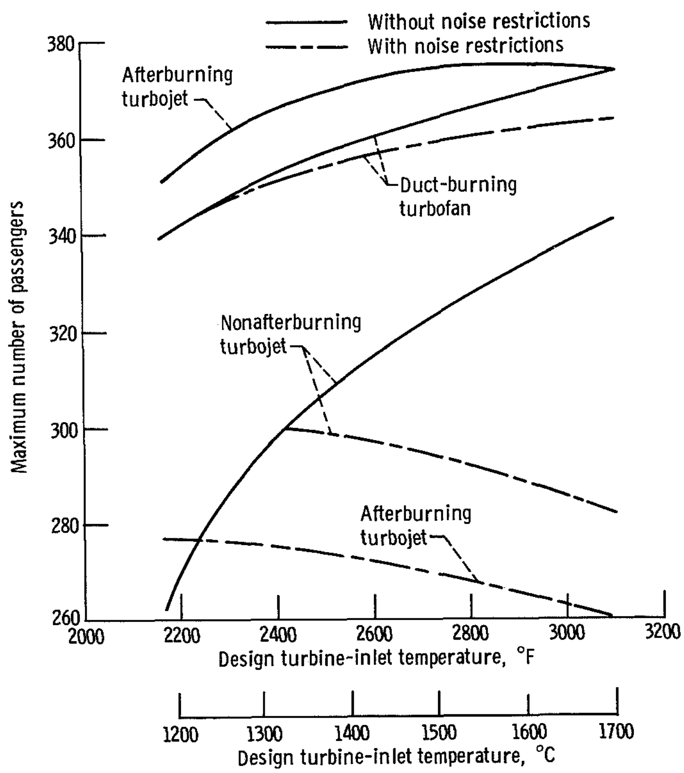


Figure 3. - Effect of design turbine-inlet temperature on payload-carrying ability.

this 1.4 margin increases from three passengers at $2200^{\circ}$ F ($1204^{\circ}$ C) to 14 passengers at $3100^{\circ}$ F ($1704^{\circ}$ C).

The duct-burning turbofan engines suffered some penalties due to the 1.4 T/D margin also. The penalties ranged from eight passengers at $2200^{\circ}$ F ($1204^{\circ}$ C) to 14 passengers at $3100^{\circ}$ F ($1704^{\circ}$ C). The resulting curve for the duct-burning turbofan is shown in figure 3 where payload increases from 342 to 374 passengers as the design turbine-inlet temperature is increased from $2200^{\circ}$ to $3100^{\circ}$ F ($1204^{\circ}$ to $1704^{\circ}$ C).

Because the nonafterburning turbojet does not have an augmenter, its design airflow had to be much greater than that of the afterburning turbojet in order to meet the 1.4 T/D ratio. This airplane had less area-ruling than the SCAT-15F of reference 3 and thus had more difficulty in meeting the 1.4 T/D margin. Because of this a proportionately larger nonafterburning turbojet was needed. Thus the weight saving due to removing the afterburner was more than offset by the additional weight of the larger engines.

The results when using nonafterburning turbojets can be seen in figure 3. The payload of the nonafterburning turbojet increases from 270 to 343 passengers as the design turbine-inlet temperature increases from $2200^{\circ}$ to $3100^{\circ}$ F ($1204^{\circ}$ to $1704^{\circ}$ C). The penalty due to the 1.4 T/D ratio ranged from 50 passengers at $2200^{\circ}$ F ($1204^{\circ}$ C) to 30 passengers at $3100^{\circ}$ F ($1704^{\circ}$ C). If the sonic boom limit during climb had been ignored in this study, the nonafterburning turbojet would avoid a good part of the penalties just mentioned. It then would have been more competitive in this study.

With noise restrictions. - There were some large payload penalties in this study due to sizing the engines to meet the 116-PNdB noise at the start of takeoff roll. However, good subsonic aerodynamics (due to the variable-sweep wing) allowed this aircraft to reach an altitude and Mach number at the 3-mile point that met the 105-PNdB noise. This was accomplished without ever having to enlarge the engines above the size required for 116 PNdB at the start of takeoff roll. This was not the case in reference 3 when 3-mile (4.8-km) noise sometimes sized the engines.

The duct-burning turbofan engine suffered the smallest penalties when the engines were sized and optimized for takeoff noise. In figure 3 it can be seen that the payload for the duct-burning turbofan increases from 342 to 364 passengers as the turbine-inlet temperature increases from $2200^{\circ}$ to $3100^{\circ}$ F ($1204^{\circ}$ to $1704^{\circ}$ C). Thus the penalty for meeting the takeoff noise goals ranges from none at $2200^{\circ}$ F ($1204^{\circ}$ C) to 10 passengers at $3100^{\circ}$ F ($1704^{\circ}$ C).

When the nonafterburning turbojet was sized for noise, there was no payload penalty at $2200^{\circ}$ F ($1204^{\circ}$ C). This was the result of the very large engine required at this temperature to meet the 1.4 T/D ratio. Merely throttling back the engine to some part-power setting reduced the noise to 116 PNdB at takeoff and still provided the necessary thrust. This same situation existed up to a design turbine-inlet temperature of about

2400° F (1318° C). From then on, as design turbine-inlet temperature increased, the payload decreased.

The reason this occurred can be traced to the greater weight of the high-turbine-inlet-temperature engines. This greater weight per unit of airflow is required to provide for the cooling capability required in the high-temperature engines. Yet all the engines had essentially the same design airflow because the power reduction method of meeting the noise goals forced all the engines to operate at about the same reduced turbine-inlet temperature (and therefore about the same jet velocity) while the takeoff thrust-to-weight minimum forced all the engines to about the same design airflow. The higher optimum compressor-pressure ratios needed at the higher design turbine-inlet temperature also played a part in increasing the weight per pound of design airflow since higher pressure ratios mean heavier compressors.

The reason that the high-turbine-inlet-temperature engines could not overcome this weight disadvantage is that the hoped-for improvements in climb and cruise specific fuel consumption (SFC) were not fully realized. While some improvement in climb SFC for the high-temperature engines did result, the engines were so oversized that when the power was reduced for cruise, the SFC of the high-temperature engines was actually worse than the SFC of the low-temperature engines.

For any given set of design parameters, the afterburning turbojet always weighs more than the nonafterburning turbojet due to the additional weight of the afterburner. However, when noise is considered, the two engine types require almost the same part-power turbine-inlet temperature and design airflow to meet the 116 PNdB at takeoff and the 0.32 thrust-to-weight ratio. Therefore, it is not surprising that the afterburning turbojet carries less payload than the nonafterburning turbojet when they are both sized for noise.

Figure 3 shows that the afterburning turbojet payload decreases from 277 to 260 passengers as the design turbine-inlet temperature increases from 2200° to 3100° F (1204° to 1704° C). Compared to the no-noise-restriction case with the same engine type, this is a penalty of from 77 passengers at 2200° F (1204° C) to 114 passengers at 3100° F (1704° C).

Optimum engine design parameters. - Figure 4 shows the optimum design compressor-pressure ratios for the two turbojet types.

When noise is not a consideration, the afterburning turbojet's optimum design compressor-pressure ratio increases from 11.5 to 19 as design turbine-inlet temperature increases from 2200° to 3100° F (1204° to 1704° C). The nonafterburning turbojet tends toward lower design compressor-pressure ratios to increase the thrust per pound of air. The design compressor-pressure ratio of the nonafterburning turbojet increases from 8.7 to 15.2 as the design turbine-inlet temperature increases from 2200° to 3100° F (1204° to 1704° C). This is also shown in figure 4.

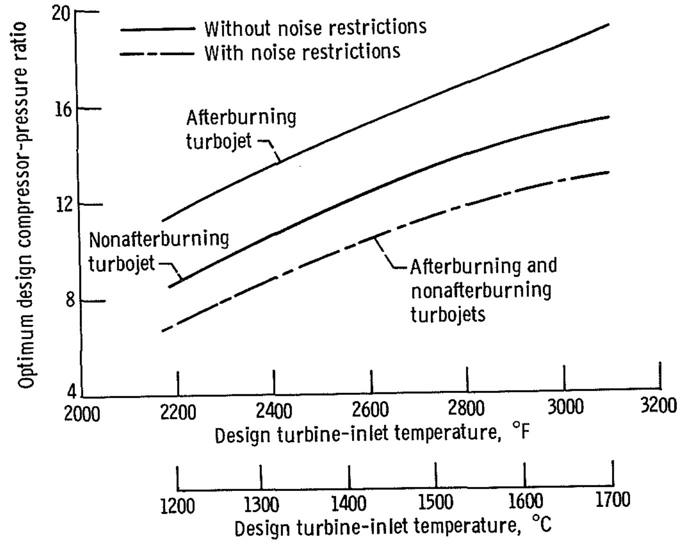


Figure 4. - Effect of design turbine-inlet temperature on afterburning and nonafterburning turbojet optimum compressor-pressure ratio.

When noise is considered, the afterburning and nonafterburning turbojets optimize at the same design compressor-pressure ratio. Figure 4 shows the optimum design compressor-pressure ratio for both engine types. The optimum design compressor-pressure ratio increases from 7 to 13 as design turbine-inlet temperature increases from $2200^{\circ}$ to $3100^{\circ}$ F ($1204^{\circ}$ to $1704^{\circ}$ C). The reason it tends to be the same for both engine types is because both engine types are operating as nonafterburning turbojets at part power to meet the noise requirements at takeoff.

Figure 5 shows the optimum design fan-pressure ratio, overall compressor-pressure ratio, and bypass ratio of the duct-burning turbofan. It is plotted against design turbine-inlet temperature both with and without noise restrictions.

The optimum design fan-pressure ratio (fig. 5(a)) increases from 2.6 to 3.4 as design turbine-inlet temperature varies from $2200^{\circ}$ to $3100^{\circ}$ F ($1204^{\circ}$ to $1704^{\circ}$ C); this is without noise restrictions. When noise restrictions are imposed, the optimum fan-pressure ratio increases from 2.5 to 2.7 over the same range of temperature. The lower fan-pressure ratio tend to reduce the jet velocity of the duct stream and, thus, the jet noise.

Figure 5(b) shows the optimum overall compressor-pressure ratio for the duct-burning turbofan. Without noise restrictions the optimum overall compressor-pressure ratio increases from 10 to 13.5 as design turbine-inlet temperature increases from $2200^{\circ}$ to $3100^{\circ}$ F ($1204^{\circ}$ to $1704^{\circ}$ C). When noise restrictions are imposed, optimum overall compressor-pressure ratios are lower.

Figure 5(c) shows the optimum design bypass ratios for the duct-burning turbofan. Without noise constraints, the optimum bypass ratio decreased from 1.8 at $2200^{\circ}$ F

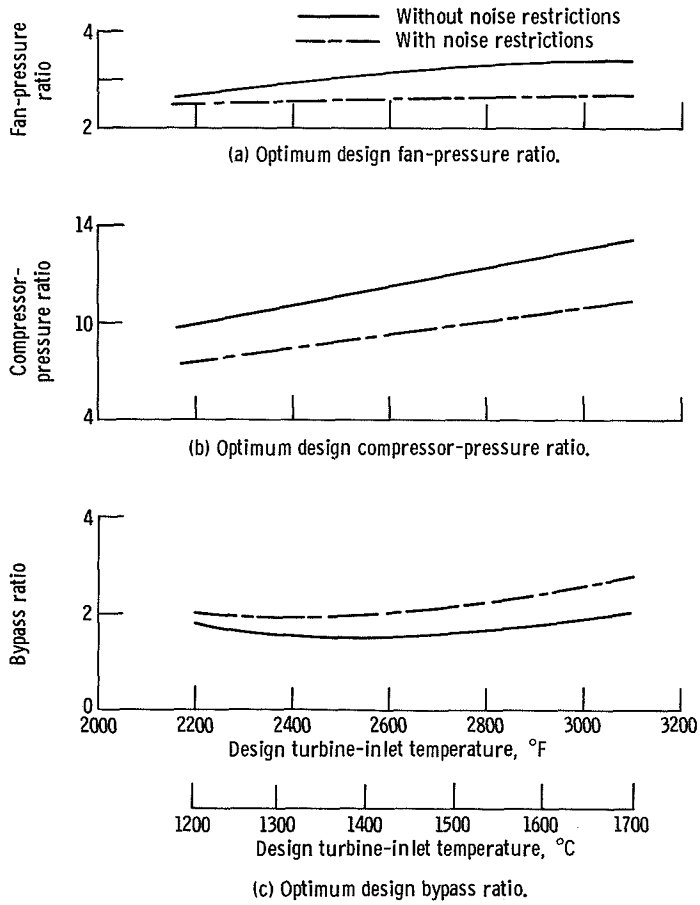


Figure 5. - Effect of design turbine-inlet temperature on optimum duct-burning turbofan engine parameters.

($1204^{\circ}$ C) to 1.5 at $2500^{\circ}$ F ($1370^{\circ}$ C). From that point on, the optimum bypass ratio increases again to 2.0 at $3100^{\circ}$ F ($1704^{\circ}$ C). When noise was considered, the optimum design bypass ratio tended to be a little higher at all design turbine-inlet temperatures than in the no-noise case.

## Comparison by Aircraft Types

In terms of the objectives of this report the main difference between the fixed-wing airplane of reference 3 and the variable-sweep airplane of this study is the L/D obtained between lift-off and the 3-mile (4.8-km) point. The fixed-wing airplane has a lift-off L/D of about 5. The variable-sweep airplane has a L/D at lift-off of about 7. As the flight proceeds toward the 3-mile (4.8-km) point, the L/D improves for both airplanes. However, the variable-sweep airplane has a decided advantage all of the way to the checkpoint.

This L/D advantage enables the variable-sweep airplane to reach a higher altitude at the 3-mile point for any given Mach number and takeoff thrust-to-weight ratio. Also, the drag for the variable-sweep airplane will be relatively less after power cutback at the 3-mile point than for the fixed-wing airplane.

As a result, the variable-sweep airplane will yield lower jet noise levels over the community than the fixed-wing airplane for any given takeoff thrust-to-weight ratio. This is shown in table IV where all engines except those showing 105 PNdB had a takeoff

TABLE IV. - THREE-MILE COMMUNITY JET NOISE

| Design turbine-inlet temperature | | Fixed-wing airplane[a] | | | Variable-sweep airplane | | |
|---|---|---|---|---|---|---|---|
| | | Afterburning turbojets | Nonafter-burning turbojets | Duct-burning turbofans | Afterburning turbojets | Nonafter-burning turbojets | Duct-burning turbofans |
| $^oF$ | $^oC$ | Three-mile community jet noise, PNdB | | | | | |
| 2200 | 1204 | 101 | 101 | 105 | 84 | 84 | 84 |
| 2500 | 1370 | 102 | 102 | 105 | 84 | 84 | 84 |
| 2800 | 1537 | 102 | 102 | 105 | 84 | 84 | 85 |
| 3100 | 1704 | 102 | 102 | 105 | 84 | 84 | 86 |

[a]Unpublished data from study in ref. 4.

thrust-to-weight of 0.32. The takeoff jet noise for all the cases shown is 116 PNdB. All the turbojets for both airplanes and the duct-burning turbofans for the variable-sweep airplane met the community jet noise goals with the engine size that satisfied the 116 PNdB at takeoff. But it can be seen from table IV that the duct-burning turbofan engine was sized by the community noise level when flown in the fixed-wing airplane. The reduction in community jet noise due to the variable-sweep airplane ranged from about 18 PNdB for the turbojets to about 20 PNdB for the duct-burning turbofans.

As was noted before, the nonafterburning turbojet showed very poor payload-carrying ability in this study. This was due to the high supersonic drag of the variable-sweep airplane considered. This airplane was not area-ruled nearly as much as the SCAT-15F of reference 3. As a result of this high supersonic drag problem, the nonafterburning turbojet is not suitable for this variable-sweep airplane unless a lower climb path (i.e., higher sonic boom) or a lower T/D ratio can be accepted. In reference 3, the nonafterburning turbojet was a close contender without noise restrictions because it did not have to be oversized so much to meet the 1.4 T/D ratio.

The high supersonic drag of the variable-sweep airplane also tended to limit the amount of improvement in payload that was obtained as turbine-inlet temperatures were increased. The afterburning turbojet, for instance, showed an increase of 6 percent in payload as turbine-inlet temperature was increased from 2200° F (1204° C) to 3100° F (1704° C) without noise restrictions. This gain would have been 8.5 percent if the T/D restraint had been removed.

## CONCLUDING REMARKS

An analytical study was made of a variable-sweep-wing, Mach 3.0 SST. Possible reductions in community jet noise resulting from improved low-speed aerodynamics of a variable-sweep-wing SST (as compared to a fixed-wing design) were analyzed. The study determined what payload benefits can be obtained from designing high-turbine-inlet-temperature engines both with and without noise restrictions. Methane fuel was used to provide the necessary heat sink for turbine cooling at the high turbine-inlet temperatures considered. The engine types considered were the afterburning turbojet, nonafterburning turbojet, and the duct-burning turbofan.

It was found that the community noise level can be substantially lowered by the use of a variable-sweep-wing SST if such an airplane provides higher L/D values during takeoff climb than a fixed-wing design. This is accomplished through higher altitude at the 3-mile (4.8-km) point for any 3-mile (4.8-km) velocity and takeoff thrust-to-weight ratio.

Jet exhaust noise during takeoff and climb was the only noise source considered. At low power settings, other engine noise may dominate. Thus, prior to selecting an engine type or design to meet the noise restriction limits, all noise sources should be accounted for.

It was found in this study that the payload for all the engines increased as design turbine-inlet temperature increased when noise restrictions were not imposed. Without the noise restrictions, the afterburning-turbojet-powered SST gave the best payload at all design turbine-inlet temperatures considered. When duct-burning turbofan engines were used, the airplane carried 12 less passengers at 2200° F (1204° C) design turbine-inlet temperature. This difference in payload became smaller as design turbine-inlet temperature increased. Finally, the payload of the duct-burning turbofan was equal to that of the afterburning turbojet at 3100° F (1704° C). The nonafterburning turbojet was a poor third choice. It had 24 percent less payload than the afterburning turbojet at 2200° F (1204° C) and 8 percent less at 3100° F (1704° C). This was mainly due to the weight of the very large engines used in order to meet the 1.4 T/D ratio imposed in this study.

In the present study, noise abatement was accomplished solely through engine oversizing. Imposing noise restrictions resulted in performance penalties that had a marked effect on the benefit of high turbine-inlet temperatures. Only the duct-burning-turbofan-powered airplane showed any payload improvement with increasing design turbine-inlet temperatures. This benefit was small compared to that realized when no noise restrictions were imposed, and the absolute payload level was generally lower.

The payloads for the duct-burning-turbofan-powered airplanes were equal at 2200° F (1204° C) both with and without noise restrictions. But when the design turbine-inlet temperature reached 3100° F (1704° C), 10 passengers less were carried when noise restrictions were imposed on this engine type.

With the noise restrictions, both turbojets showed poor payload-carrying ability. The payload generally decreased for both engine types as design turbine-inlet temperature increased. Payload losses, as compared to the afterburning turbojet without noise restrictions, ranged from 15 to 23 percent for the nonafterburning turbojet as design turbine-inlet temperature increased from 2200° to 3100° F (1204° to 1704° C). Payload for the afterburning turbojet was generally 8 percent less than that of the nonafterburning turbojet at all temperatures.

The optimum engine overall compressor-pressure ratio, fan-pressure ratio, and bypass ratio appear to be dependent not only on design turbine-inlet temperature but also on the level of noise restrictions. As noise restrictions become more strict, lower compressor-pressure ratios, lower fan-pressure ratios, and higher bypass ratios become desirable.

This study illustrates the importance of jet noise on payload-carrying ability. The penalties indicated by this study because of noise restrictions should be weighed against the penalties involved with developing and installing a noise suppressor.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, July 17, 1969,
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