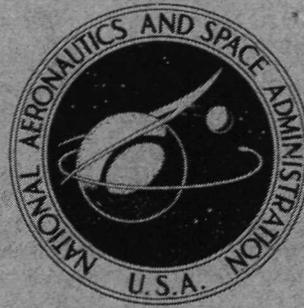


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PROPULSION TECHNOLOGY FOR
AN ADVANCED SUBSONIC TRANSPORT

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16. Abstract <p>NASA has initiated efforts to study the application of advanced technology to the improvement of future subsonic commercial transport aircraft. Engine design studies were conducted by General Electric and Pratt & Whitney in parallel to airframe studies conducted under contract by Boeing, General Dynamics, and Lockheed. These studies surveyed a broad distribution of design variables including aircraft configuration, payload, range, and speed with particular emphasis on reducing noise and exhaust emissions without severe economic and performance penalties. The results indicated that an engine for an advanced transport would be similar to the currently emerging turbofan engines. Application of current technology in the areas of noise suppression and combustors imposed severe performance and economic penalties; however, with advances in technology, an opportunity exists for making future advanced engines quieter and cleaner without exorbitant penalties.</p>			
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SUMMARY

Historically, the propulsion systems set the pace for advances in aircraft development. Therefore, in assessing the value of advanced technology to future transport development, the propulsion system technologies rank high on the list of factors to ensure that future aircraft are superior in international competition. In view of the widespread awareness of environmental problems, such as noise and pollution, future aircraft also must be readily accepted by the general public.

To identify those propulsion technologies of principal value, NASA contracted with General Electric and Pratt & Whitney to conduct engine studies in parallel to airframe studies conducted under contract by Boeing, General Dynamics, and Lockheed. These studies surveyed a broad distribution of design variables including aircraft configuration, payload, range, and speed.

The results of the studies indicated that an engine for an advanced transport will probably have a superficial appearance similar to that of the presently emerging generation of modern high-bypass and high-temperature turbofan engines. Application of current technology in the areas of noise suppression and combustors resulted in significant performance and economic penalties. With advances in technology, however, there is an opportunity for major strides in making advanced engines quieter and cleaner without an exorbitant economic penalty.

INTRODUCTION

It has often been observed that propulsion systems set the pace for advances in aircraft development. At this point in history it is as true as it ever was in the past. In spite of the enormous benefits of our present air transport system, its intrusions on the environment (due primarily to its propulsion system) appear to be a limiting factor in the growth of the industry. Since present airports are not exactly the best neighbors to have, there is widespread opposition to the development of new airports which are

needed to alleviate the ground and air congestion problems. In fact, even the use of some present air terminals could be curtailed because of impending curfews for noise abatement. The overall result would be less efficient utilization of present aircraft and potentially fewer sales of new aircraft. In addition, the traveling public would encounter poorer service and possibly higher costs.

Therefore, in assessing the value of advanced technology to future transport development, the propulsion technologies must be high on the list to ensure that the resulting aircraft is a superior product in international competition and is readily acceptable to the general public. To identify those propulsion technologies of principal value to achieve these goals, NASA contracted with General Electric and Pratt & Whitney to conduct engine studies in parallel to airframe studies conducted under contract by Boeing, General Dynamics, and Lockheed.

Obviously, the optimization of the engine cycle variables depends on the details of the many airframe variables and also depends upon forecasts of the rate of advancement that can be expected in each of the technical disciplines. Extremely complex economic factors and maintainability requirements for long service life in commercial applications further complicate engine design. Therefore, it was necessary to coordinate closely the engine design studies with the airframe system studies, so that the application of advanced technology was integrated into a total advanced transport system. The engine study contracts were managed by the NASA Lewis Research Center, while the airplane studies and the integration into a total transport system were managed by the NASA Langley Research Center.

The studies surveyed a wide distribution of variables including aircraft configuration, payload, range, and speed. The major emphases of the system studies were directed at achieving reduced noise and exhaust emissions with good economics and performance. Application of advanced technology provided an opportunity to achieve these goals. In the propulsion system area, it was found that higher cruise speeds offered the greatest technology challenge to meet these goals. Therefore, for purposes of this discussion, trends for a cruise speed of Mach 0.98 will be used to describe the results of the cycle optimization. Though there will be quantitative differences, the qualitative trends are equally applicable for Mach numbers from 0.85 to 0.90. Particular attention will be directed to the impact of cycle variables on the environmental factors of principal concern - noise and pollution.

ENVIRONMENTAL CONSTRAINTS

Noise is now the biggest problem facing the air transport industry since it is most objectionable to the general public and is very difficult to suppress without incurring

serious economic and operational problems. As indicated in figure 1, most of the internal noise sources are those resulting from high-speed rotating blades, and the noise is commonly called turbomachinery noise. The external noise sources indicated in figure 2 are the shear and eddy phenomena resulting from the mixing of the high-velocity jets with the ambient air. A typical frequency spectrum which results from the principal engine noise sources is shown in figure 3. The fan noise consists of high-frequency discrete tones and the jet noise of low-frequency broad-band noise. If these sources are suppressed, then the other sources indicated in figure 1 can become more dominant. If high fan tip speeds are required, then an unusual characteristic of fan noise (multiple pure tones) can be dominant at intermediate frequency ranges. As indicated in figure 3, multiple pure tones can be created at sharply discrete frequencies and cause a "buzz saw" type of noise phenomenon. These pure tones are a result of detached shock waves at the blade tips which reinforce each other at irregular intervals caused by small irregularities in the manufacturing tolerances of these fans.

The psychological effect that a noise source has in annoying people depends not only on the sound pressure level, in decibels (dB), but also on the frequency. A perceived noise level (PNdB) is a summation of sound pressure levels that have been weighted to account for human response. The largest weighting occurs in the frequency range from 2000 to 4000 hertz. Higher and lower frequencies are weighted less because people find them less annoying. An effective perceived noise level (EPNdB) is a further modification to account for discrete tone content, which is more annoying than broad-band sound, and for the length of exposure. The EPNdB thus includes the effects of airplane speed and flight path, as well as a correction for discrete tones.

It has been necessary in recent years for the Federal Aviation Agency to establish regulations (FAR-36) concerning noise (see ref. 1). They are based on the EPNdB created by an aircraft at the three reference locations shown in figure 4. On approach, the measuring point is 1.85 kilometers (1 n mi) prior to touchdown. For a 3° glide slope, the aircraft altitude at this point is 113 meters (370 ft). Steeper glide slopes can influence the noise measured at this point. On takeoff, the measuring point is 6.48 kilometers (3.5 n mi) from the point of brake release. Altitude at this point depends upon the particular aircraft and flight procedures used. The third measuring location is the sideline after liftoff at a distance of 0.65 kilometer (0.35 n mi) for four engine aircraft and 0.46 kilometer (0.25 n mi) for three engine aircraft. FAR-36 specifies the permissible noise levels at each of these points as a function of aircraft gross weight.

It is possible that in the future more stringent noise restrictions will be required. For example, the CARD study (refs. 2 and 3) indicates that research goals should attempt a noise reduction of 10 dB per decade. Consequently, the propulsion studies examined the influence of three different levels of noise restrictions on the optimization of the engine design: (1) FAR-36, (2) FAR-36 minus 10 EPNdB, and (3) FAR-36 minus 20 EPNdB. The majority of effort was directed to the FAR-36-10-EPNdB goal.

Air pollution is the other principal environmental concern. Table I lists the major pollutants in jet aircraft emission levels and the major causes. The idle pollutants are obviously those associated with inefficient combustion occurring during off-design operation of a combustor that is relatively simple and cannot adapt to large changes in overall fuel-air ratios. The high-power pollutants (particularly the nitrogen oxides) appear to be an increasing problem as a result of the current trends in modern engine design to higher values of combustor-inlet pressure and temperature.

Although pollution regulations do not presently exist for aircraft, it is reasonable to assume that they will be required in the future. Therefore, goals were established for the propulsion studies as indicated in table I. The values selected for these goals are not necessarily representative of those appropriate for future national regulation but rather represent a significant improvement over present day emission levels and (pending further study) were thought to be achievable with advanced combustor concepts.

CYCLE OPTIMIZATION

In a crude sense, the philosophy of cycle optimization is that advanced engine technology can be applied to achieve high levels of combustor exit pressure and temperature. High values are desired to minimize engine size and specific fuel consumption. This hot, high-pressure gas has a potential energy that must be used to propel the aircraft while subject to many constraints including noise restrictions. A portion of this energy can be converted to thrust by expelling the gas through the core nozzle. However, jet noise limitations restrict this jet velocity, and in the range of practical interest for an advanced transport, artificial means of reducing jet noise (as with mixer nozzles) have not been very successful to date. The alternative, then, is to transfer a larger portion of this energy into the fan stream. Fan turbomachinery noise will be generated, but there are expectations that acoustical treatment can be added to the nacelle for effective noise suppression. This energy can be transferred into the fan stream with an infinite number of combinations of fan flow-rate (bypass ratio) and fan pressure ratio. A complex matrix of additional requirements must also be met in optimizing this specific combination of bypass ratio and fan pressure ratio. These requirements include (among other things) takeoff thrust, cruise thrust, nacelle drag, fan jet noise restrictions, turbomachinery noise suppression restrictions, propulsion system weight, and airframe installation requirements.

Even without environmental restrictions, the bypass ratio (and attendant fan pressure ratio) must be optimized to create an economically attractive aircraft. The optimization of these economic factors is also very complex, but a simple approximation that is useful in establishing trends is that the aircraft gross weight should be minimized

for a given mission capability. Figure 5 shows such an optimization of bypass ratios for transports with ranges of 5556 kilometers (3000 n mi). Noise constraints are ignored in this figure. In either case, the "bucket" is flat enough that a bypass ratio near 4.5 is near optimum and is about the same as that used in present modern engines. The corresponding fan pressure ratio is somewhat higher than in present engines and is greater than 2.0 rather than around 1.5 to 1.6. It should be noted that, in a study such as this, the interference drag resulting from airframe installation effects has been neglected simply because at the present time there is inadequate data to evaluate its magnitude in the speed range above about Mach 0.85. These effects would normally tend to decrease the optimum bypass ratio.

NOISE

Typical noise levels of the components of such an engine are shown in figure 6. Fan noise is dominant over jet noise. The level of noise ahead of the fan is comparable to that behind the fan, and either one could exceed the other depending upon details of the fan design and the influence of inlet flow distortion. The fan and core jet noise levels are also comparable to each other. These noise levels shift around depending upon flight conditions, as shown in figure 7. In all cases, fan noise dominates and is most severe during approach. If this fan noise could be suppressed by over 10 EPNdB, then the sideline jet noise would become the dominant problem.

Since the fan noise is the principal noise source for such an aircraft, any attempts to compromise the engine cycle to meet noise constraints will require fairly accurate predictions of the fan noise level. But that is one of the problems since fan acoustics is a relatively new area of research. One guess for the relation between fan approach noise and design fan pressure ratio is shown in figure 8. These curves for one- and two-stage fans fit most existing data rather well but tend to underestimate the multiple pure tone problems of the high-pressure-ratio one-stage fan. In addition, the data for two-stage fans may not be representative of that which could be achieved with wide spacing between rotors and stators so as to minimize noise generation. It is of interest that the fan pressure ratio range of interest for an advanced transport (around 2.0) is precisely in the range where one- and two-stage concepts are directly competitive. It is also a range which is not getting much attention these days for any other application, and hence an expanded effort directed to this area might be justified.

To achieve any significant reduction in noise below FAR-36, more needs to be done than making a judicious selection of fan design. The most promising tools available are those illustrated in figure 9 - acoustic treatment on all surfaces and on splitter rings ahead of and behind the fan and variable-area nozzles to control more precisely the jet

velocity and hence its noise. With current technology these techniques are expected to provide about 10 to 15 EPNdB of suppression.

Figure 10 summarizes the effect that various levels of noise constraints would have on the bypass ratio of a bare engine and also on one using current technology acoustic suppression such as that illustrated in figure 9. The bare engine requires a large increase in bypass ratio to about 7 in order to meet FAR-36 with an attendant increase in takeoff gross weight (from fig. 5) of about 3 percent. Chances of reducing noise even further seem to be unlikely with the bare engine, but the treated nacelle provides this opportunity. The corresponding changes in takeoff gross weight for the treated nacelle are shown in figure 11. The optimum bypass ratio of the treated nacelle has shifted to a value near 5.5, where the noise would be about FAR-36-5 EPNdB.

With this increase in bypass ratio the fan pressure ratio would drop back into the range 1.8 to 2.0, which makes the single-stage fan an even stronger contender. However, it would have to operate at the higher tip speeds, where multiple pure tones would arise, and additional technology is required to cope with this problem. Because of the "flatness" of the bucket in figure 11, lower noise goals could be achieved without excessive increases in takeoff weight, but the noise would be unlikely to get below the FAR-36-10-EPNdB goal with current technology.

Since actual operating costs are influenced by so many more factors than those affecting aircraft gross weight, it is harder to estimate costs. Nevertheless, one analysis of these costs of noise constraints in terms of return on investment is shown in figure 12. With current noise technology, the direct operating costs increase very rapidly for constraints below FAR-36-10 EPNdB and thereby decrease the return on investment. With advances in noise technology which hopefully can be achieved in the next decade, noise goals near FAR-36-15 EPNdB might be achieved without exorbitant cost increases. With current technology, turbomachinery noise suppression of about 10 to 15 PNdB seems feasible. The advanced noise technology presumes that an additional 10 PNdB can be achieved through expanded research and technology programs.

POLLUTION

As indicated in table I, two factors that have a strong effect on pollutant emissions are the combustor-inlet pressure and temperature. Both factors must also be optimized for the overall mission capability. The overall pressure ratio from the face of the fan to the compressor discharge determines the combustor-inlet pressure and temperature, and, its effects on takeoff gross weight are shown in figure 13. In a manner similar to that for bypass optimization in figure 5, the "bucket" is fairly flat and is nearly equal for 5556- and 10 200-kilometer (3000- and 5500-n-mi) range aircraft. The optimization

of cruise combustor-exit temperature is more complex since it is dependent on the level of technology that is available for turbine cooling. Results obtained with current technology are shown in figure 14. An optimum value near 1260°C (2300°F) applies to both the short- and long-range aircraft. Based on predicted advances in turbine cooling using full coverage film techniques, it is anticipated that increasing combustor exit temperature to values in excess of 1427°C (2600°F) will eventually be desired for such aircraft.

The expected levels of pollutants for engines with conventional combustors are shown in figures 15 to 18. Shown in figure 15 are the anticipated hydrocarbon emissions during idle operation for various values of the design overall engine pressure ratio. These results fortunately show that the study goal can be achieved with the values of engine design pressure ratio (25 to 30) needed to minimize aircraft weight. Similar results for carbon monoxide emissions during idle operation appear in figure 16. In fact, it would appear that lower emission goals could possibly be established without significantly compromising the aircraft design. This is particularly true if advanced combustor concepts can be developed which have variable features in order to keep combustion efficiency at high levels during idle operation.

The air transport industry already has made significant advances in reducing the smoke emissions during takeoff to values near and below the visibility threshold. Predicted results for advanced engines are shown in figure 17. Again, it can be seen that, for pressure ratios around 25 to 30, the study goals could be achieved. As indicated in figure 13, these values are very near the optimum values anyway.

Takeoff nitrogen oxide emission is a different story though. As shown in figure 18, emissions of oxides of nitrogen for current combustors are strongly dependent upon the overall pressure ratio. This is true because the air temperature entering the combustor increases rapidly with increases in pressure ratio. As a result, the study goal could not be achieved for pressure ratios within the range of interest. Attempts to achieve the study goal could not be made by lowering the pressure ratio without exorbitant compromises in the aircraft design. Also shown in the figure are the emissions of oxides of nitrogen obtained and predicted for advanced design combustors. However, even these do not meet the study goal. One solution to this question of oxides of nitrogen is to revise the goal upward to values near those that can be achieved with advanced design combustors. Many suggestions are available for such improved designs. One concept that is not proprietary is the swirl can element illustrated in figure 19. It is a carbureting concept for mixing the fuel and air. An array of such elements would be used in a complete combustor design as shown in figure 20. By having such a large number of small combustion zones, the hot gas residence time would be shorter than it would be in a single large combustion zone, and hence the formation of nitrogen oxides would be retarded.

Another approach that would help the nitrogen oxide problem is the use of water injection ahead of the combustor to minimize flame temperature. Water injection has frequently been used on current aircraft for thrust augmentation, and therefore the operational techniques have already been established for airline usage. By combining the advanced combustor concepts with the water injection procedures, the theoretical results of figure 21 are attainable. Nitrogen oxide emission is shown as a function of the percent water injected into the core airflow. Even without any water, the nitrogen oxide level is significantly less than that of the conventional combustor of figure 18 for values of overall pressure ratio needed for this type of aircraft. Furthermore, even the very low study goal apparently can be achieved with about 2 percent (in terms of compressor airflow) water injection. Experimental verification of these trends is needed for future progress in this area.

COMPONENT TECHNOLOGY

There are many other aspects of engine component technology that would contribute to the development of improved transport engines. They would make an engine lighter, more compact, more easily controlled, and more easily maintained and would reduce fuel consumption. The pace of these improvements depends to a large extent on the results being obtained in the general national effort to advance aeronautical propulsion as applied to all types of aircraft. For example, trends in turbine gas temperature are summarized in figure 22. High-temperature technology is first developed in rigs and demonstrator engines, later appears in advanced military aircraft, and eventually can be applied in commercial engines, where the requirements for long service life are most severe. As indicated in the section POLLUTION, temperatures in excess of 1427°C (2600°F) appear desirable for an advanced type of engine. Another area where significant improvements seem achievable is that of engine materials. Some projected improvements are summarized in table II. Composites are attractive for the lower range of temperatures and superalloys for the high range. More efficient compressors reduce the number of stages, but an adequate stall margin is essential for airline usage. High work turbines are needed to minimize the number of stages, particularly for low tip speed fan concepts. Electronic controls could increase engine response, simplify power management problems, and provide closer engine condition monitoring. Better accessories and secondary power systems could improve maintainability and minimize weight and complexity.

CONCLUDING REMARKS

An engine for an advanced transport will probably superficially resemble the presently emerging generation of modern high-bypass and high-temperature turbofan engines. Incorporated, however, would be advances in component and system technology as identified by the propulsion system studies. These advances could be used to achieve significant gains in aircraft economics with no increase in noise, or to achieve significant reductions in noise and pollution with little or no economic penalty. And perhaps, the latter is what the air transport industry of the future needs most of all.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, June 22, 1972,
737-54.

REFERENCES

1. Anon.: Noise Standards: Aircraft Type Certification. FAA Regulations, vol. III, pt. 36, Federal Aviation Administration, Dec. 1969.
2. Anon.: Joint DOT-NASA Civil Aviation Research and Development Policy Study Report. NASA SP-265, 1971.
3. Anon.: Joint DOT-NASA Civil Aviation Research and Development Policy Study. Supporting Papers. NASA SP-266, 1971.

TABLE I. - JET AIRCRAFT EMISSIONS

Pollutant	Critical operating condition	Typical emission levels, g/kg fuel	Major causes	Study goals, g/kg fuel
Hydrocarbons	Idle	7 to 75	Poor fuel atomization, lean fuel-air ratios, low combustor pressure and temperature	8
Carbon monoxide	Idle	30 to 77		40
Oxides of nitrogen ^a	Takeoff	13 to 40	High flame temperature	3
Smoke	Takeoff	(b)	High pressure, rich fuel-air ratios	(c)

^aReported as nitric oxide.

^bSAE smoke number, 20 to 65.

^cSAE smoke number, 15.

TABLE II. - PROJECTED IMPROVEMENTS IN ENGINE MATERIALS

Component	Improved material	Application
Fan and compressor blades	Polymer matrix composites	Increase in use temperature to 316° C (600° F)
Latter stage compressor blades	Titanium alloys	Increase in use temperature to 649° C (1200° F)
Turbine and compressor disks	Nickel base alloys by pre-alloyed powder processing	Doubling of strength in 649° to 704° C (1200° to 1300° F) range; over-cast alloys permit reduced disk section thickness and engine weight
Stator vanes	Dispersion strengthened superalloys	Increase in use temperature to 1316° C (2400° F)
Turbine blades	Superalloy matrix composites	Increase in use temperature to 1204° C (2200° F)
Corrosion resistance	Superalloys	Advanced coatings and claddings
Thermal fatigue resistance	Superalloys	Directional solidification and coatings

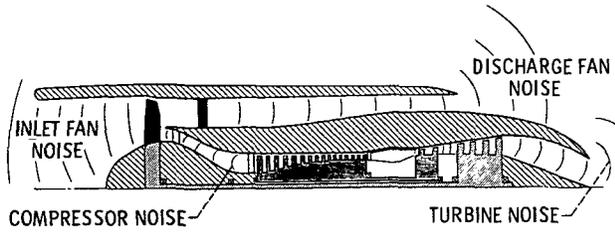
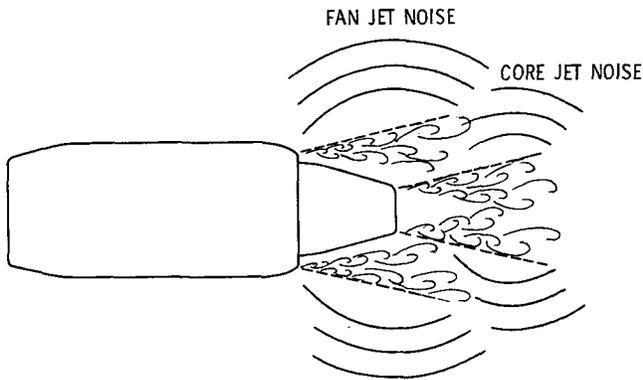


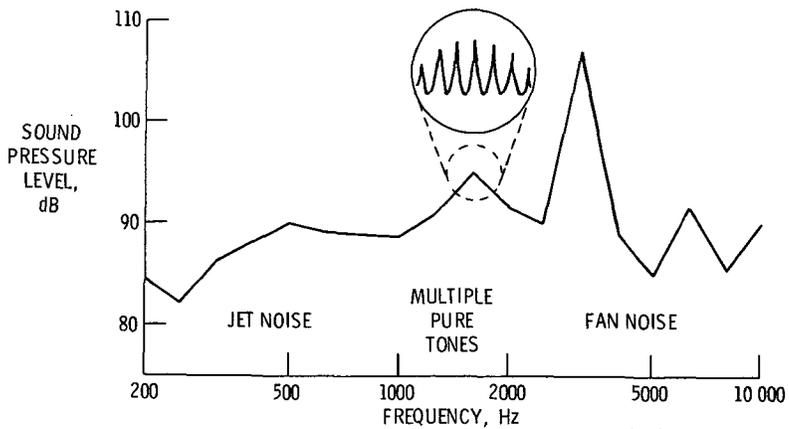
Figure 1. - Internal noise sources.

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Figure 2. - External noise sources.



CS-60786

Figure 3. - Engine noise spectrum.

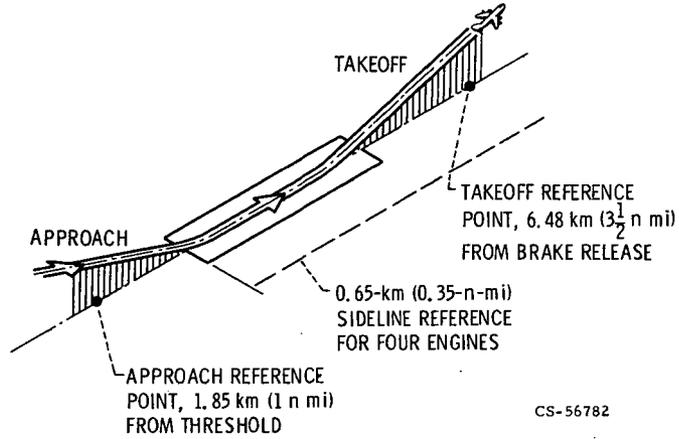


Figure 4. - Noise reference locations.

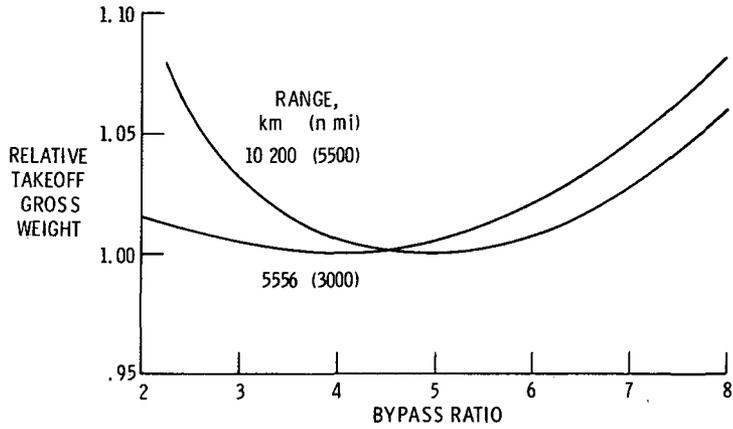


Figure 5. - Untreated bypass optimization. No noise constraint.

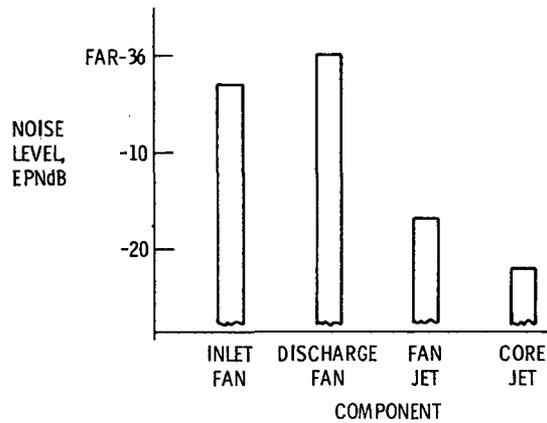


Figure 6. - Noise of components.

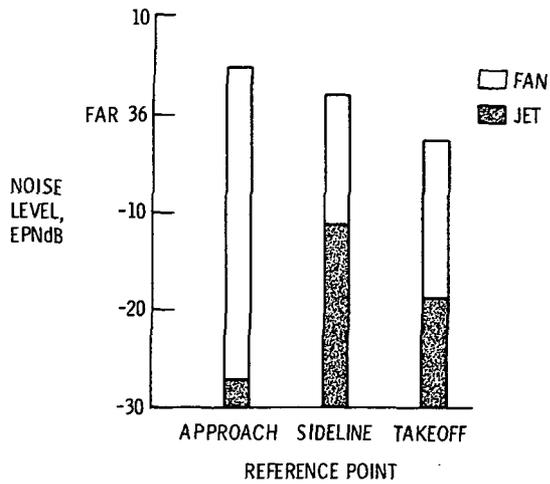


Figure 7. - Reference point noise.

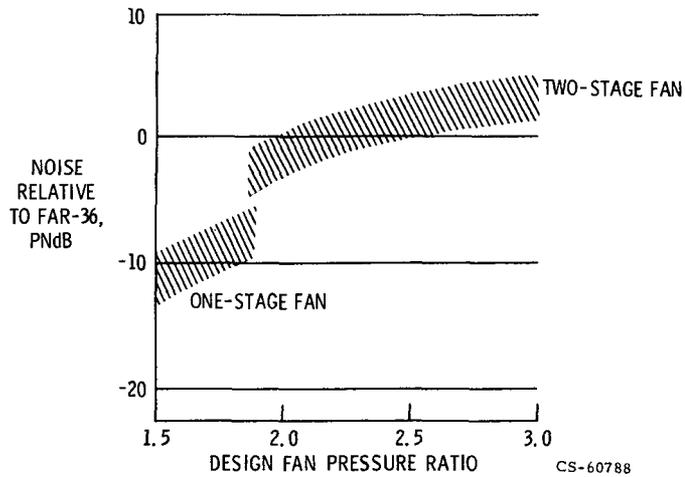


Figure 8. - Fan approach noise. Near sonic airplane; 15 PNdB suppression.

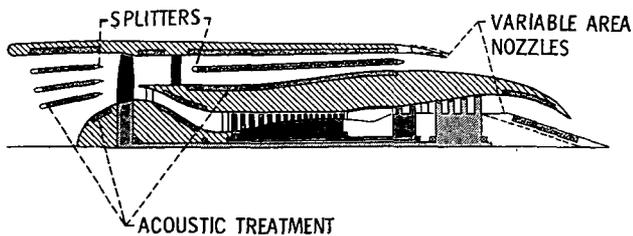


Figure 9. - Noise suppression techniques.

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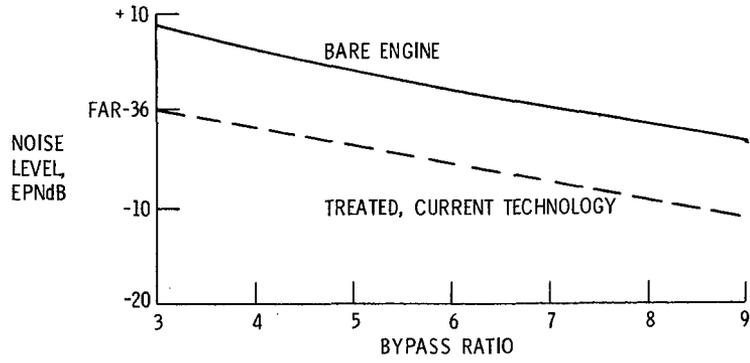


Figure 10. - Noise constraint effects.

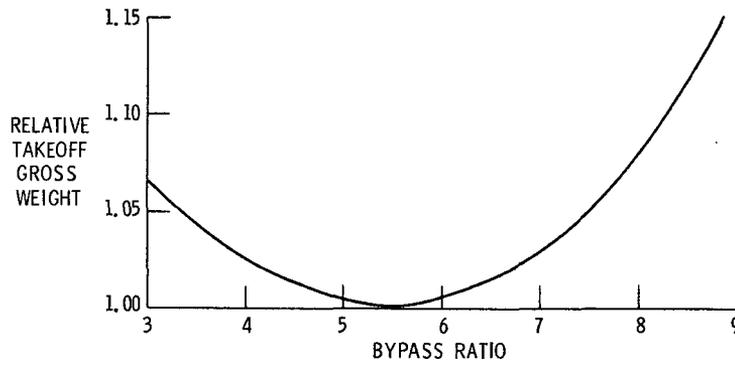


Figure 11. - Optimization of treated engine for 10 200-kilometer- (5500-n-mi) range. Current technology.

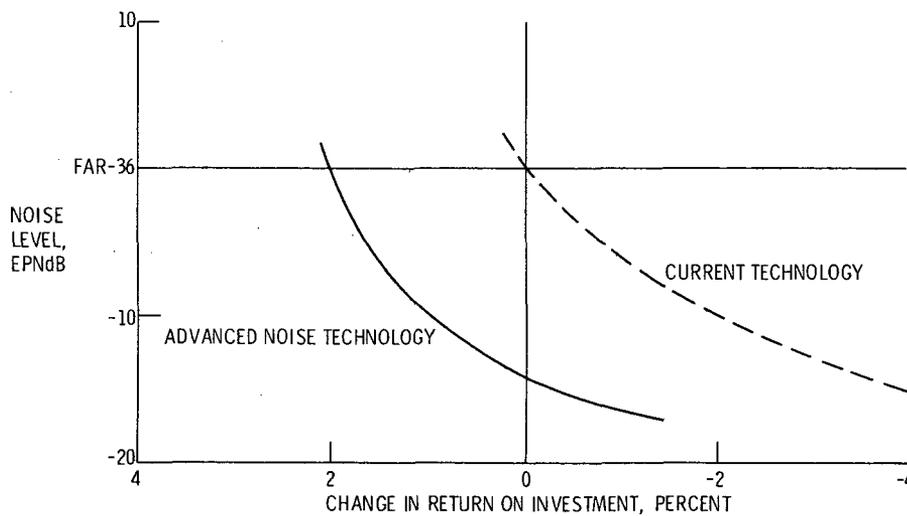


Figure 12. - Cost of noise constraint.

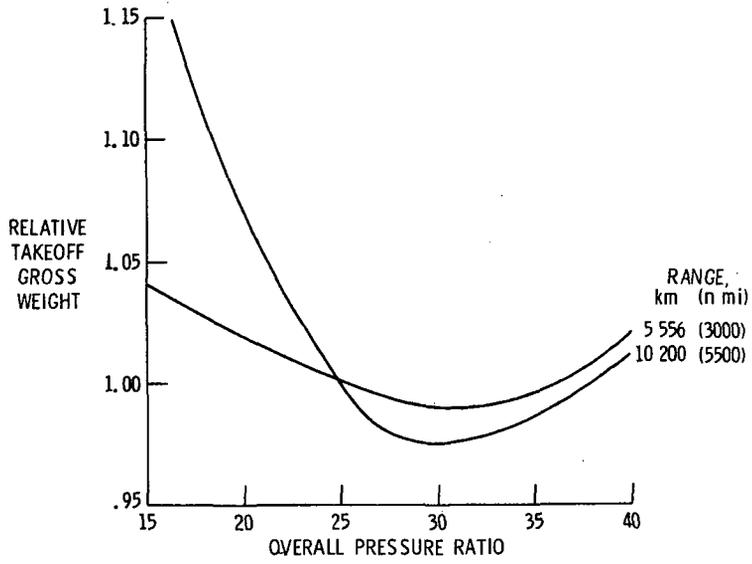


Figure 13. - Pressure ratio optimization.

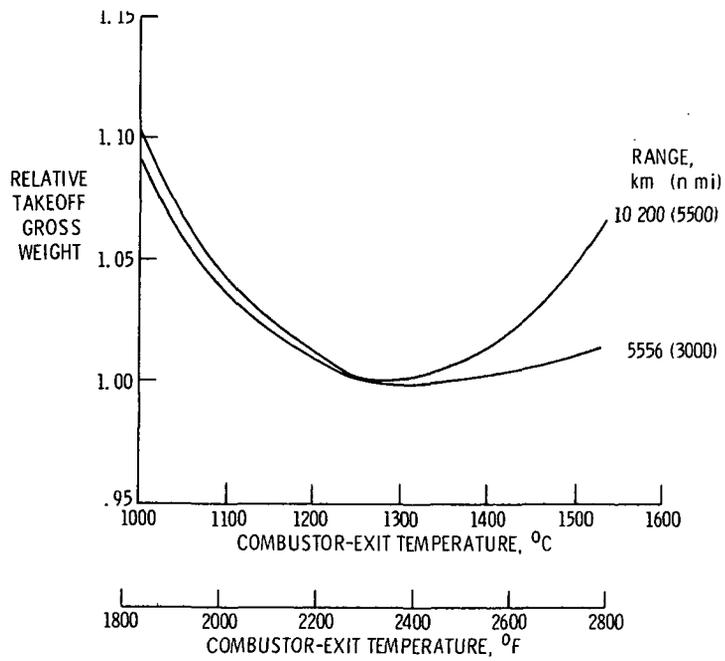


Figure 14. - Combustor-exit temperature optimization.

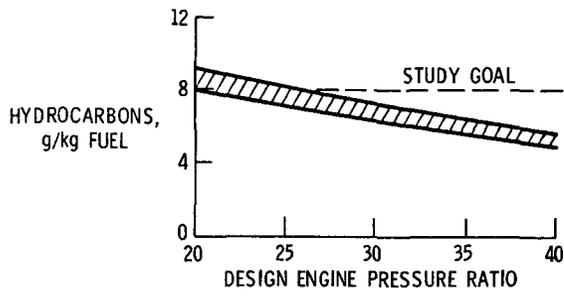


Figure 15. - Idle hydrocarbon emission.

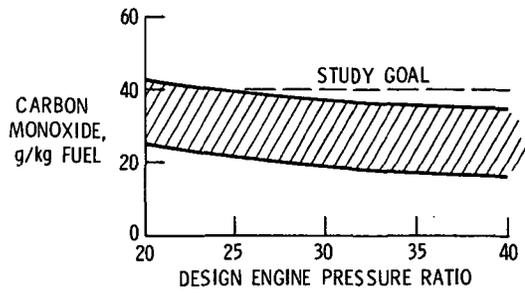


Figure 16. - Idle-operation carbon monoxide emission.

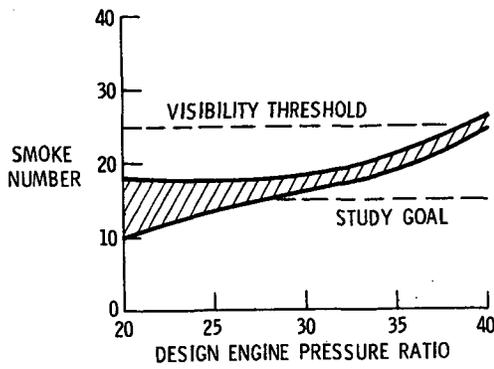


Figure 17. - Takeoff smoke emission.

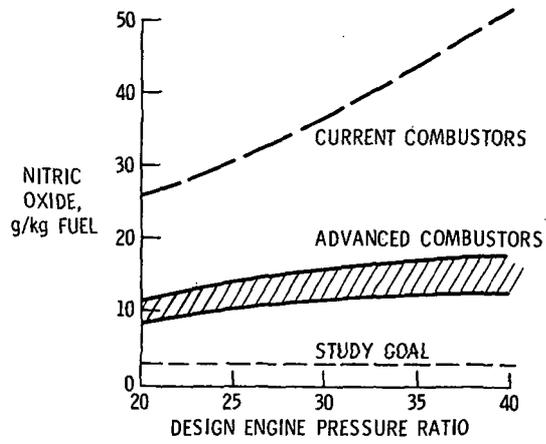


Figure 18. - Takeoff nitric oxide emission.

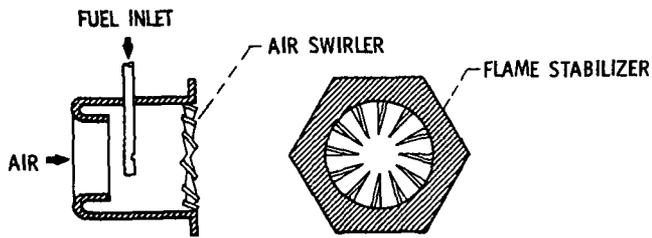


Figure 19. - Swirl-can element.

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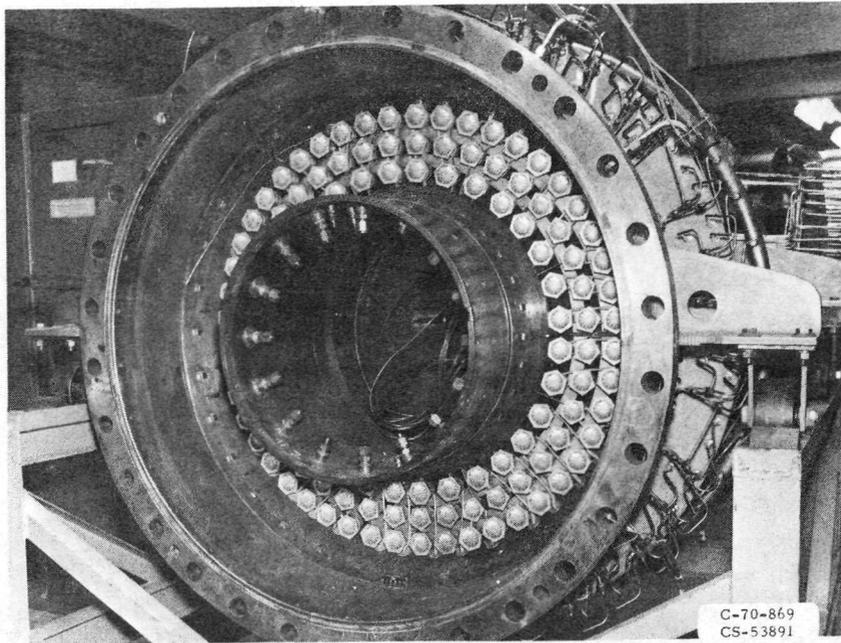


Figure 20. - Swirl-can combustor.

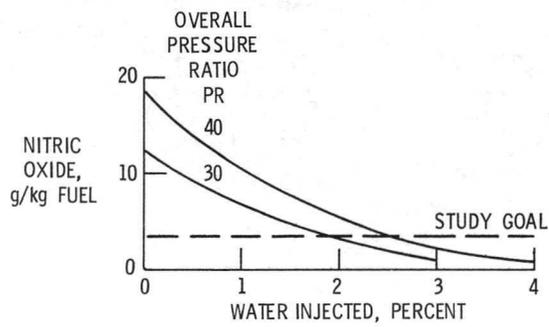


Figure 21. - Nitric oxide reduction by water injection.

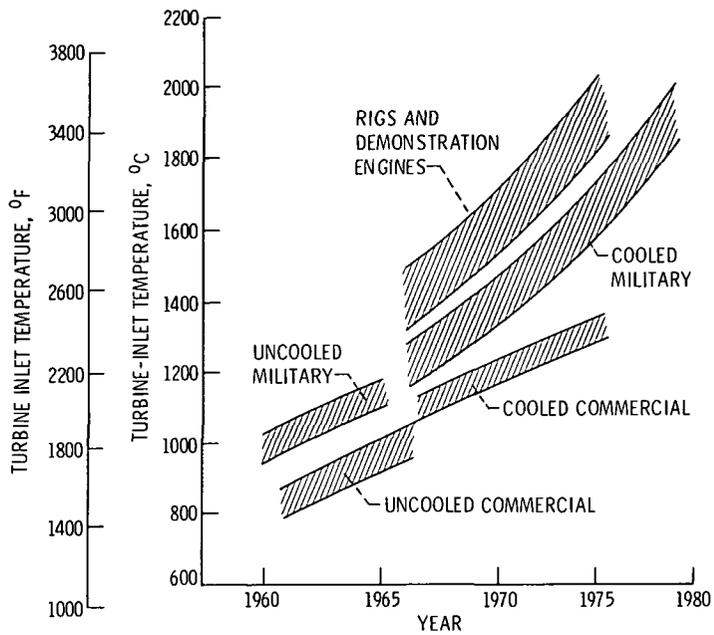


Figure 22. - Trends in turbine gas temperature.

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