ICAS PAPER
No. 72 – 48

NASA AIRCRAFT ENGINE NOISE RESEARCH

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The Eighth Congress of the International Council of the Aeronautical Sciences

INTERNATIONAAL CONGRESCENTRUM RAI–AMSTERDAM, THE NETHERLANDS
AUGUST 28 TO SEPTEMBER 2, 1972

Price: 3. Dfl.

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Abstract

NASA research and development work on the noise of aircraft engines suitable for use on conventional take-off and landing subsonic cruise airplanes is reviewed. The work discussed was part of the NASA Quiet Engine program. Salient results in the areas of fan, jet and complete propulsion system noise are presented and briefly discussed.

I. Introduction

NACA began research on the noise of jet engines in the early 1950's. Early work was directed at jet noise reduction and received considerable emphasis before the introduction of long-range jet-powered civil transport aircraft in the late 1950's. With the formation of NASA in 1958, work on civil jet engine noise was greatly reduced. At about the same time introduction of the bypass engine eased the problem of the noise of aircraft operations.

However, rapid growth of civil air transport and the resultant increased frequency of aircraft noise events resulted in the decision in 1965 to establish a large-scale aircraft noise research and development program in NASA. The immediate problem was the noise of conventional take-off and landing (CTOL) aircraft for long-range subsonic cruise. As the program on CTOL aircraft noise became well established, attention was directed toward the noise of other types of aircraft -- SST, STOL and VTOL. This paper will concern itself, however, only with the CTOL engine noise research.

CTOL engine noise research is conducted at five of the NASA Research Centers. Ground and over-flight noise measurements are made at the Flight Research Center. Basic work on jet noise is carried out at the Jet Propulsion Laboratory. The Ames Research Center's 40x80 wind tunnel is used for assessing forward flight speed effects on noise. However, the principal NASA investment in facilities, manpower, and research and development funding is at the Langley and Lewis Research Centers. Since 1965 there has been steady growth in R&D funding and manpower committed to noise research. In 1973 over 200 NASA personnel will be engaged in noise research and the total research and development funding will be approximately $28.5 million.

In addition to work on the reduction of the source of noise, NASA carried out extensive work on two-segment approaches to landing in order to reduce the noise impact on the community during landing. Work on this subject continues with a series of demonstration flights by airline pilots during the coming year.

The NASA program on engine noise consists of a research program and focused technology demonstration programs. The two large programs of the latter category are the Quiet Engine and 707/DC-8 Acoustic Nacelle programs. In the latter, the use of nacelle acoustic treatment to reduce the fan noise of the JT3-D engine on the 707 and DC-8 airplanes was demonstrated in flight tests in 1969.

In the Quiet Engine program, all available noise reduction technology was incorporated into a high-bypass-ratio engine. A nacelle with acoustic treatment specifically tailored to the quiet engine for noise was built. The combination formed a low noise propulsion system. Specific aspects of the Quiet Engine program will be discussed in subsequent sections.

II. Fan Noise

The primary source of fan noise data in NASA is from experiments conducted in the full-scale fan test facility at the Lewis Research Center (Figure 1). A series of fans were tested as part of the Quiet Engine program. These fans span the pressure ratio range from 1.4 to 1.6 and the design tip speed range from 1100 to 1550 feet per second (Table 1).

FAN NOISE FACILITY

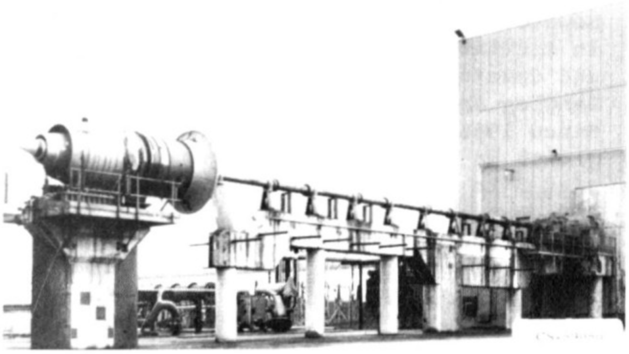

Figure 1. Full-Scale Fan Noise Test Facility at Lewis Research Center

FAN DESIGN CHARACTERISTICS

FAN	TIP SPEED, FT/SEC	PRESSURE RATIO	NUMBER OF STAGES
A	1160	1.5	1
B	1160	1.5	1
C	1550	1.6	1
D	1107	1.4	1
E	1107	1.5	1
F	1090	1.6	1
G	1000	1.45	2

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Table 1. Design Characteristics of Fans Tested in Quiet Engine Program

In Figure 2, fan noise data for several of these fans are shown as maximum perceived noise level as calculated for a 1000-foot flyover. These data are for low-speed fans and their acoustic performance is generally similar. In Figure 3, the data for the high-speed fan C are added to the figure. The noise level of the high-speed fan C is distinctly higher. High-speed fans are of considerable interest, however, because of the weight saving associated with the fewer stages required for the drive turbine. The noise disadvantage of the fan may be offset by the lower engine weight. Nacelle acoustic treatment could be used to reduce fan noise. Detailed design studies for specific aircraft systems are required to identify an optimum low noise system.

Fan noise data from various sources are shown in Figure 4, where the solid symbols represent experimental data and the open symbols, estimates for planned experiments. The data shown here cover a wide range of pressure ratios, spanning the range of interest from low pressure ratios for externally-blown-flap STOL systems to the relatively high pressure ratios required for augmentor wing STOL or transonic cruise.

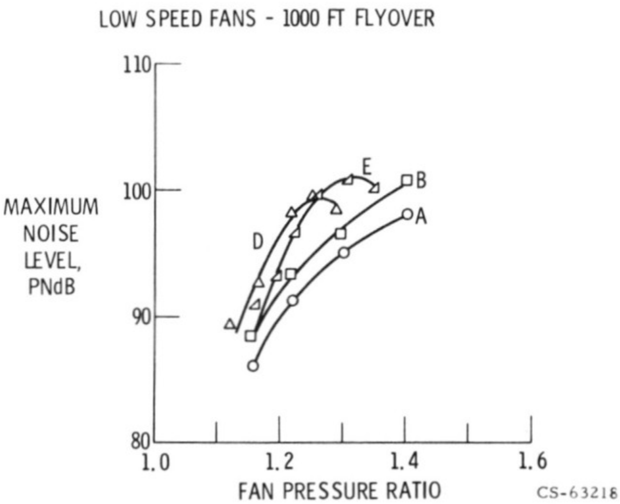


Figure 2. Low-Speed Fan Flyover Noise Levels

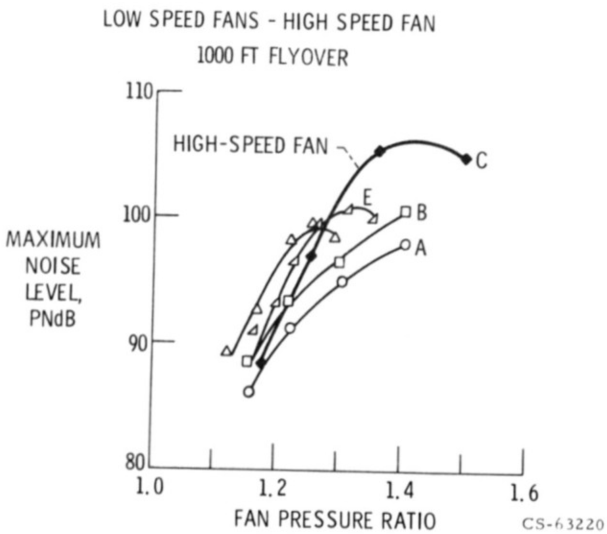


Figure 3. Comparison of High- and Low-Speed Fan Flyover Noise Levels

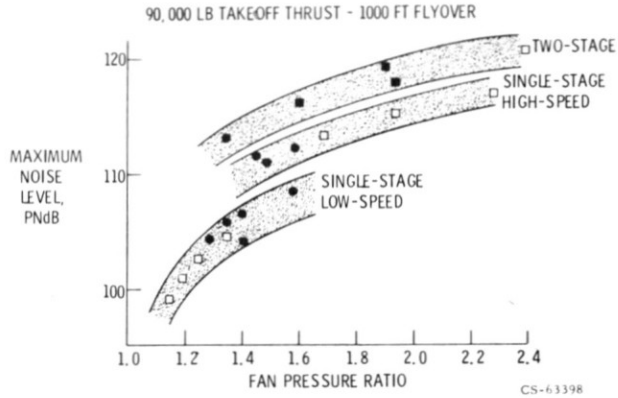


Figure 4. Correlation of Fan Noise Level with Pressure Ratios

The noise levels are of the order of 100 PNdB or more for 100,000 pounds of installed thrust. In order to achieve lower fan noise levels, we must learn more about the influence of fan design parameters on fan noise output. The other avenue for fan noise control is the use of nacelle acoustic treatment. Acoustic treatment consists of porous facing sheets over cavities (Figure 5) which line the internal flow surfaces of the nacelle. The effect of nacelle acoustic treatment is to reduce the sound pressure levels in the duets. Thus, a weaker acoustic signal radiates to a far-field observer. In general, the amount of noise reduction achieved is a direct function of the amount of acoustic treatment used in the nacelle. Similarly, weight and pressure loss associated with the presence of the acoustic lining are directly linked with the amount of treatment. The result is that large amounts of suppression are possible at the cost of weight and pressure loss.

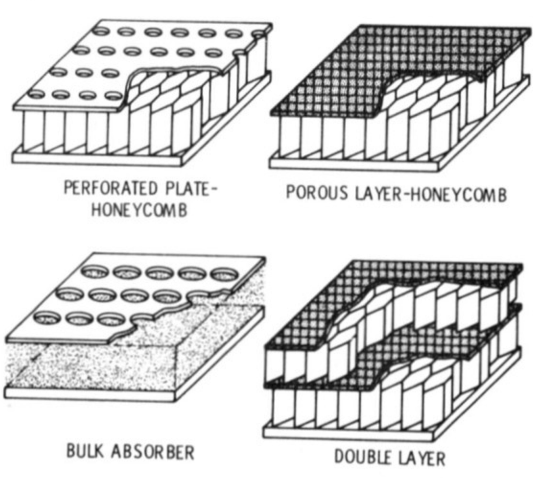


Figure 5. Nacelle Acoustic Lining Materials

A considerable amount of attention has been directed at determining optimum design characteristics of linings. The NASA-sponsored development of acoustic nacelles by Boeing and McDonnell Douglas for the 707 and DC-8 aircraft was the most significant NASA contribution in this field. This program demonstrated in flight tests the capability of suppressing fan noise 15 EPNdB or more with tolerable weight and performance penalties.

Development of acoustic treatment continues, and such linings are in use on the new wide-body civil transports. There has been considerable activity on such acoustic treatment for the fans of high-bypass-ratio engines in the full-scale fan research at Lewis Research Center. Data from tests on two of the quiet engine fans are illustrated in Figures 6 through 9. In Figure 6, the effects of acoustic treatment on the noise output of fan A is shown. One-third octave band data are shown for the 50° microphone position (maximum sound pressure level in the front quadrant). In the lower part of the figure the difference between the unsuppressed and suppressed spectra is shown as the attenuation spectrum. The attenuation at the blade passing frequency is sufficiently high that only a vestige of that peak remains in the suppressed spectrum. The inlet section of the suppressor is shown in Figure 7. It can be seen to contain three inlet rings. The aft-duct section contained one splitter ring.

Similar data for fan C are shown in Figure 8. Again the attenuation spectrum is quite broad but not all the noise associated with bladed leading-edge shock waves (500 and 1400 Hz) is absorbed.

Perceived noise levels as a function of angular position for fans A and C, suppressed with acoustic treatment and unsuppressed, are shown in Figure 9. The noise levels shown are those calculated for the contribution to a 1000-foot flyover noise signature from the various microphone locations in a static test. The lower noise output of the low-speed fan is apparent for both the suppressed and unsuppressed configurations.

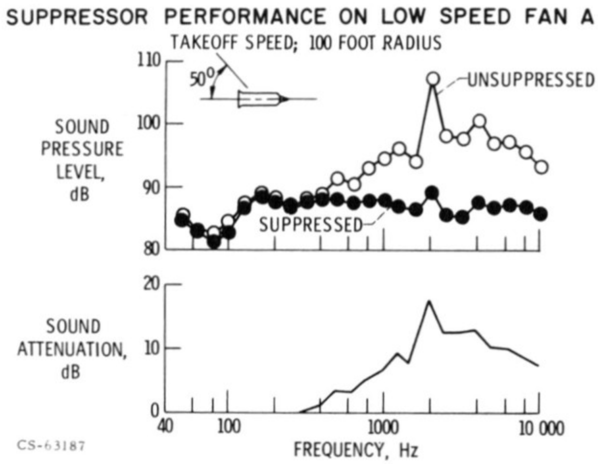


Figure 6. Effect of Acoustic Treatment on Fan A Noise

INLET DUCT WITH ACOUSTIC TREATMENT

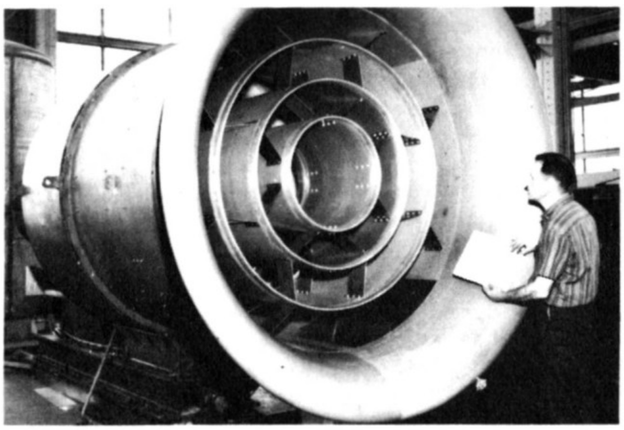


Figure 7. Acoustically Treated Inlet for Static Tests

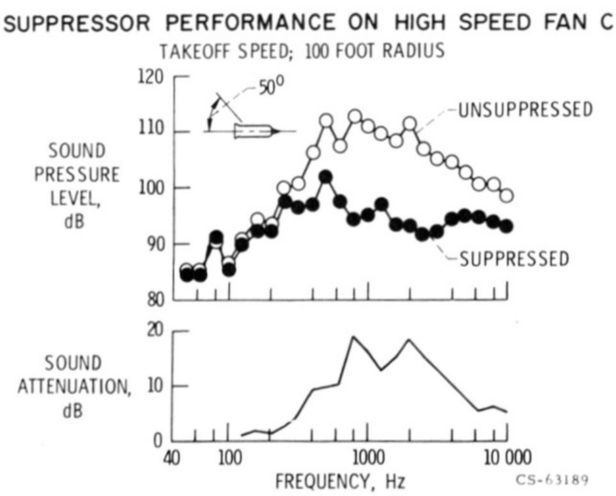


Figure 8. Effect of Acoustic Treatment on Fan C Noise

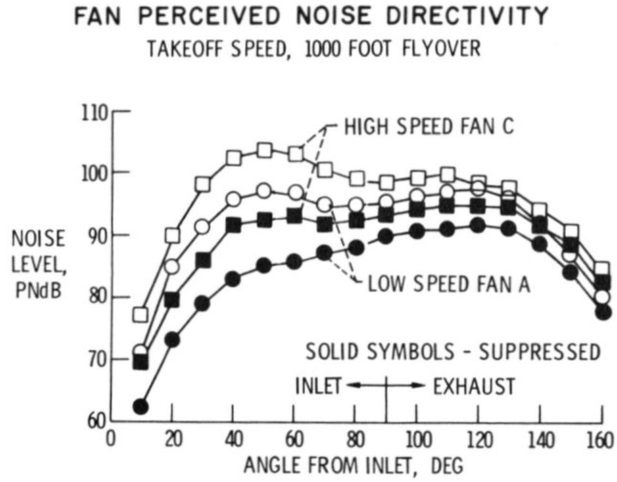


Figure 9. Treated and Untreated Noise of Fans A and C as a Function of Angular Position

III. Jet Noise

The jet noise of an aircraft engine represents the lowest practical level of noise that can be achieved during operation of an engine. In principle it is possible to reduce the fan noise arbitrarily large amounts by the extensive use of nacelle acoustic treatment. However, the lack of effective jet noise suppressors for jet velocities in the range of interest for subsonic cruise engines means that the only effective way available today to reduce jet noise is by reducing jet velocity.

The correlation of jet noise with jet exhaust velocity is shown in Figure 10. The SAE correlation is fairly well accepted for jet velocities

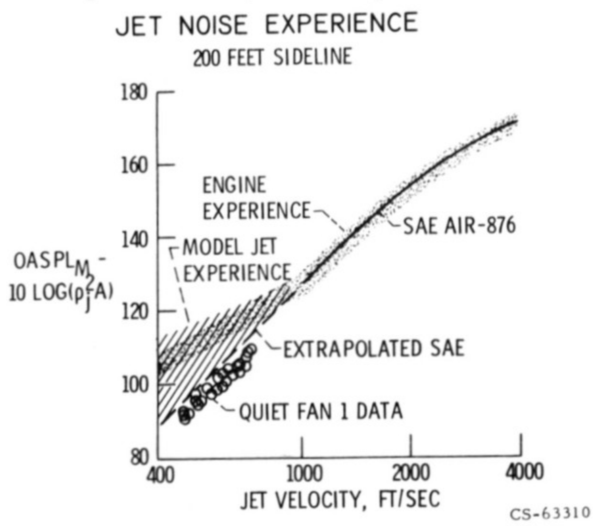


Figure 10. Jet Noise Correlation with Jet Velocity

above 1200 feet per second. If one extrapolates the SAE correlation below 1000 feet per second, the dashed line is obtained. Actual engine data and some model jet data fall in a scatter band above the SAE extrapolation.

The jet noise component of the noise from full-scale fan tests is plotted as the circles. The fan tested was fan D (of Table 1) with nacelle acoustic treatment. This treatment suppressed the internally generated noise leaving the jet noise rather well defined. These data points lie just below and parallel to the SAE extrapolation. It is possible that the data represented as engine and model jet data contain a significant amount of internally generated noise. The internal noise was well suppressed in the case of the fan data. In order to explore this phenomenon further, an experiment using a J-65 engine was devised. The engine was fitted with an inlet suppressor, tuned for high frequency compressor noise (Figure 11). The exhaust passage was lined with acoustic treatment tuned for relatively low frequency noise. The center body of the exhaust suppressor is shown in Figure 12. The exhaust suppressor absorbed a significant amount of the noise in the frequency range below 1000 Hz, the part of the spectrum generally thought to be dominated by external jet mixing noise.

If these data are plotted as maximum sideline overall sound pressure level for the cases with and without exhaust suppression, Figure 13 is obtained. In the lower velocity range, reduction of the internally generated noise by the acoustic lining results in the exhaust noise correlating more closely with the usual V^8 jet noise correlating parameter.

Figure 11. J-65 Engine with Inlet and Exhaust Suppressors

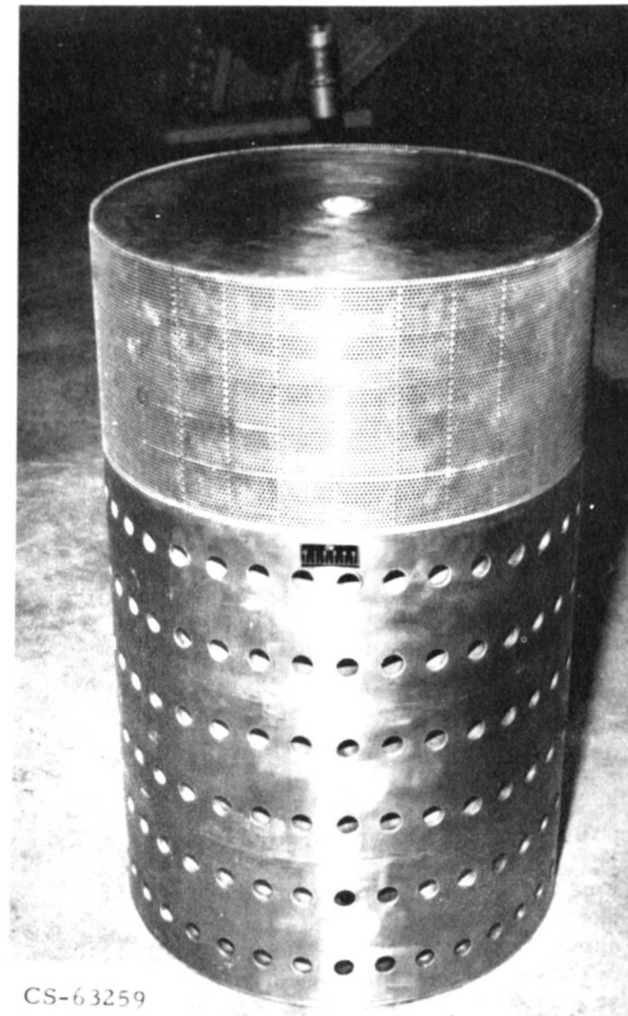


Figure 12. Treated Center Body of J-65 Exhaust Suppressors

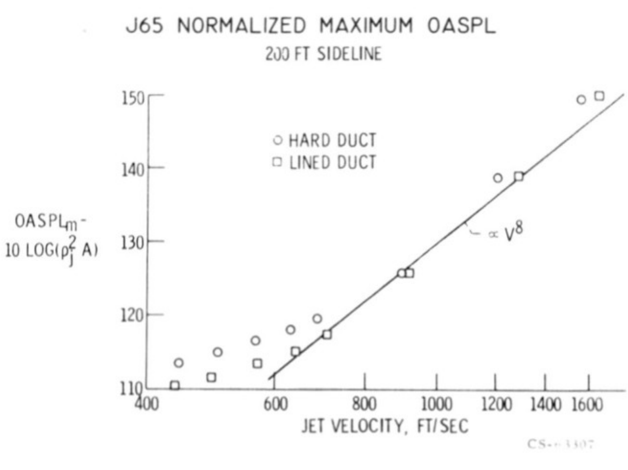


Figure 13. Exhaust Noise from Treated and Untreated J-65 Engines

There has also been considerable work on supersonic jet noise. These activities include model, static engine and flight tests. However, a discussion of these efforts is beyond the scope of this paper.

IV. Propulsion System

Two versions of the quiet engine were built. Engine A uses fan A (Table 1) and a four-stage fan turbine, and engine C uses fan C (Table 1) and a two-stage fan turbine. Engine A has been tested at the General Electric Company's engine noise facility and at the Lewis Research Center (Figure 14). Engine A mounted in the test stand at Lewis with its acoustic nacelle as manufactured by The Boeing Company is shown in Figure 15. A cutaway drawing of the acoustic nacelle is shown in Figure 16. The sound pressure level is a maximum in the front quadrant at the 50° angle position. The effect of the nacelle acoustic treatment on the one-third octave spectrum at that microphone position is shown in Figure 17. The low frequency portion of the spectrum is not affected; however, the noise output in the frequency range of above 500 Hz is strongly affected. The effect of this acoustic treatment on thrust is shown in Figure 18. The thrust loss resulting from the presence of the acoustic treatment is about 5% at take-off conditions.

Substantial amounts of data on the engine acoustic and aerodynamic performance in various configurations are being generated in the Quiet Engine program. These results will be published in future NASA reports.

LEWIS ENGINE ACOUSTIC TEST FACILITY

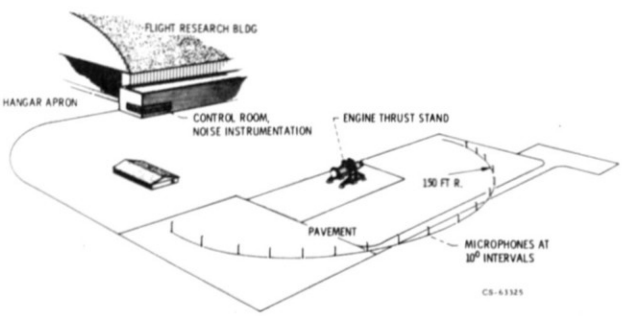


Figure 14. Engine Acoustic Test Facility at Lewis Research Center

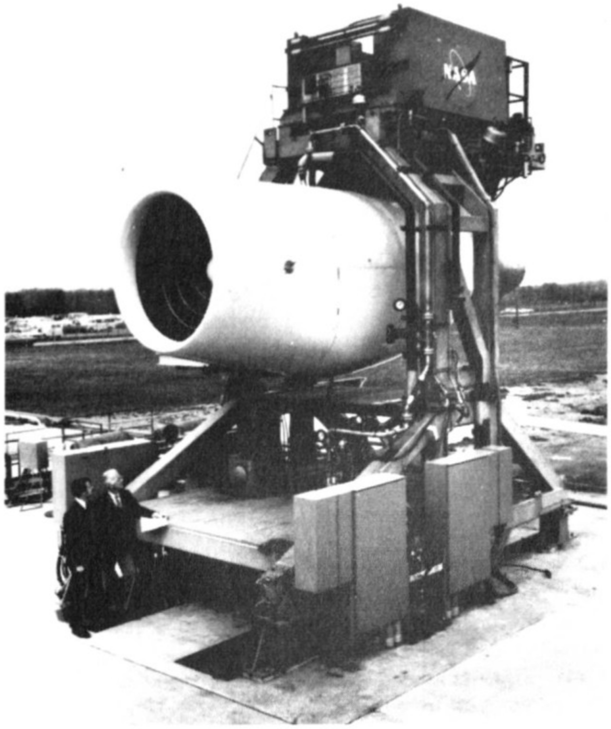
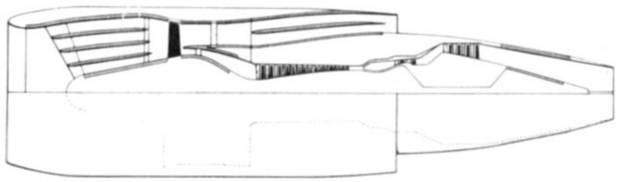


Figure 15. Quiet Engine A with Acoustically Treated Nacelle in Test Stand at Lewis Research Center



NACELLE ACOUSTIC TREATMENT

	INLET DUCT	EXHAUST DUCT
AREA, SQ FT	353	362
WEIGHT, LB	846	666

Figure 16. Cross-Section of Quiet Engine Acoustically Treated Nacelle

1/3 OCTAVE BANDS; TAKEOFF SPEED, 1000 FT SIDELINE

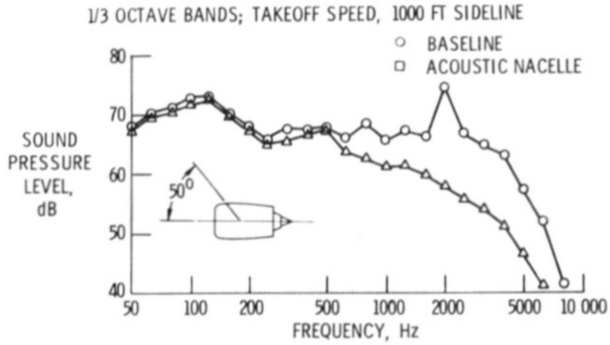


Figure 17. One-Third Octave Band Frequency Spectrum of Quiet Engine A with and without Nacelle Acoustic Treatment

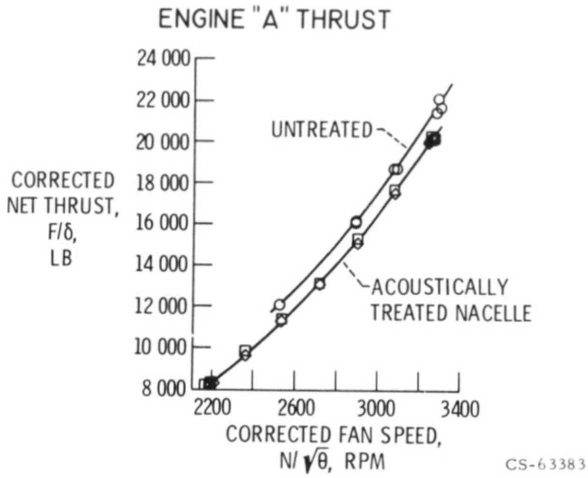


Figure 18. Effect of Nacelle Acoustic Treatment on Thrust

The engine noise data can best be summarized by considering the noise levels for four-engine aircraft at FAR-36 measuring stations. Those data are summarized in Table 2. The noise levels shown are at the FAR-36 measuring stations for take-off and approach. The DC-8 levels and the FAR-36 noise levels permitted for new four-engine aircraft of the 325,000-pound class are shown for reference. The noise levels achieved by the quiet engine A without nacelle acoustic treatment are shown as the baseline data. The addition of nacelle acoustic treatment results in the levels shown in the fourth line of the table. The data shown for the quiet engines are for four engines. For take-off conditions, the airplane was assumed to have achieved an altitude of 1000 feet; however, no cutback in power was assumed in arriving at these numbers. Power cutbacks would result in even lower noise levels. The quiet engine noise levels with nacelle

FLYOVER NOISE COMPARISON

FOUR ENGINE AIRCRAFT

	TAKEOFF	APPROACH
	EPNdB	
DC-8	116	118
FAR-36	104	106
BASELINE QUIET ENGINE A	97	98
QUIET ENGINE A WITH ACOUSTIC NACELLE	90	89

Table 2. Comparison of Flyover Noise Levels

acoustic treatment are 14 EPNdB below FAR-36 levels at take-off (without cutback) and 17 EPNdB below FAR-36 at approach. Compared with the DC-8/707 noise levels, the quiet engine with nacelle acoustic treatment is 25 to 30 EPNdB lower.

V. Concluding Remarks

The application of research and development attention over the last six years in NASA has resulted in the demonstration that civil jet transport aircraft operations can be made significantly quieter. The primary means for controlling the engine noise sources have been elucidated. For jet noise, control of the engine cycle parameters can effectively lower the jet noise "floor." For fan noise, fan aerodynamic design control and nacelle acoustic treatment can together bring fan noise down to levels approaching the reduced jet noise. The remaining task is to incorporate these technological concepts into practical flight systems at reasonable weights. Development of such systems will permit major improvements in the noise environment of near-airport communities. Such an environmental improvement will permit the continued vigorous growth of the world air transportation system.