8. INTRODUCTORY REMARKS ON NACELLE ACOUSTIC TREATMENT APPLICATION

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These introductory remarks are related to the objective and history of the National Aeronautics and Space Administration Treated-Nacelle Program and the procedure that was used in predicting flyover noise from ground run-up data.

The objective of the program is to identify turbofan-nacelle modifications capable of reducing landing noise with the following constraints: no adverse effect on take-off or climbout noise, no compromise with flight safety, no additional flight-crew workload, and retention of an economically viable airplane.

Figure 1 indicates the sources of the noise radiated from a turbofan engine. Fan noise is emitted from the inlet and the fan discharge ducts, and jet noise is emitted from the fan discharge ducts and the primary nozzle. The effort of this program is limited to reducing the fan noise radiated from the discharge ducts and inlet.

Figure 2 shows the relative strength of the noise from each of the sources as a function of thrust and indicates one reason the program was directed toward reducing the fan noise. The perceived noise level (PNL) under the flight path of a four-engine transport is presented as a function of the thrust of one engine. It can be seen that at the higher thrusts, associated with take-off operations, the fan noise from the fan discharge duct is the controlling factor and would have to be reduced if any reduction in take-off noise is to be obtained. At the thrusts associated with landing approach, the fan noise is considerably above the jet noise. Reduction of the fan noise from the discharge ducts by about 15 PNdB and reduction of the noise from the inlet by about 12 PNdB will be required to reduce the total noise to the jet-noise floor. Because most complaints occur in this landing phase of operation, the greatest benefits can be obtained by attenuating the fan noise in the approach region.

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The type of noise spectrum under consideration is illustrated in figure 3, which is a plot of sound pressure level (SPL) in dB as a function of frequency in hertz (cycles per second). This is a typical spectrum of a turbofan engine during landing approach. The spectrum is divided into two regions: (1) the lower frequencies associated with the jet noise and (2) the higher frequencies attributed to the fan noise. The characteristic high-pitched whine associated with the turbofan engine at landing power settings is indicated by the spikes. The fundamental occurs at the fan-blade passage frequency of about 2500 Hz, and the other spikes are harmonics of the blade passage frequency. Suppression of these high-frequency spikes could reduce the overall noise level as well as alleviate the undesirable fan whine. On the basis of this possibility of noise reduction during landing, the NASA Treated-Nacelle Program was initiated.

In May 1967, contracts to accomplish the objective of the NASA Treated-Nacelle Program were made with McDonnell Douglas Corporation and The Boeing Company. In signing the contracts to accomplish the objective of the program, both companies agreed to make available to the NASA the results of all previous work pertaining to aircraft noise alleviation. Reports of these results have since been transmitted to the NASA.

The approach and goals of the two companies are different. The McDonnell Douglas Corporation approach is to investigate acoustically treated short discharge ducts and acoustically treated inlets, with the goal of a 7- to 10-PNdB reduction. The initial approach of The Boeing Company was to investigate acoustically treated long discharge ducts and sonic or near-sonic inlets, with a 15-PNdB-reduction goal. The reason for the different goals is that at the outset of the program, it was believed that a 7- to 10-PNdB reduction was the maximum that could be obtained by treating the inlet; however, the NASA wanted to evaluate the effects of obtaining a reduction of 15 PNdB. Therefore, McDonnell Douglas was directed to investigate treated inlets, and Boeing was directed to investigate sonic or near-sonic inlets.

Both companies followed certain procedures. They conducted initial studies of materials, duct-lining concepts, and inlet and duct design concepts. The contractor work on materials and duct-lining concepts has been discussed in references 1 and 2. Both companies used model tests to evaluate inlet and fan-discharge-duct design concepts. On the basis of results from the initial studies, configurations for full-scale ground run-up tests were selected. The full-scale boilerplate nacelles were tested with a Pratt & Whitney JT3D turbofan engine. From the results of these ground run-up tests, configurations for flight testing were to be selected. The economic impact of the nacelle modification was to be considered throughout the program.

Figure 4 presents the scheduled occurrence of events. The dashed line indicates the present date. The companies would be about halfway through the original program, which contemplated flight tests in the latter part of 1969. However, as the results of the McDonnell Douglas ground run-up tests of treated inlets became available in the early part of 1968, it was apparent that McDonnell Douglas could meet its goal of a 7- to 10-PNdB reduction with what is called a single-ring treated inlet in combination with its treated short fan discharge ducts. That is, as a result of the initial studies by both companies, more efficient duct-lining concepts were developed which provided larger attenuation than was thought possible at the start of the program. The results of the McDonnell Douglas tests also indicated that inlet noise suppression on the order of 12 PNdB could be obtained with an acoustically treated inlet.

These results and the results of The Boeing Company ground run-up tests of its treated long fan discharge ducts indicated that Boeing could potentially accomplish the goal of a 15-PNdB reduction with a treated inlet, in combination with its treated long fan discharge ducts, and thereby avoid the complications of the sonic or near-sonic inlet. On the basis of these results and with the concurrence of the contractor in May 1968, Boeing was redirected to flight test a treated inlet and fan discharge duct instead of the sonic inlet. Boeing was also to continue work on the sonic inlet through ground run-up tests. At the same time The Boeing Company effort was redirected, the NASA asked the contractors to accelerate their program so that the flight data could be available on a more timely basis. As a result, the flight tests are scheduled for completion 4 months earlier than originally planned, as indicated by the arrows on the flight-test bars in figure 4.

Figure 5 is a schematic drawing of the flight-test nacelles to be tested by Boeing and McDonnell Douglas. The McDonnell Douglas configuration (top sketch) consists of a single-ring treated inlet and short fan discharge ducts, and the Boeing configuration (bottom sketch) consists of a treated two-ring inlet and treated long fan discharge ducts. The major effort of both companies at this time is manufacturing the nacelles for flight tests. The McDonnell Douglas flight tests are scheduled for completion in March 1969, and the Boeing flight tests, in June 1969.

Figure 6 defines the points at which both contractors will present their predicted flyover noise. An approach reference point 1 nautical mile from the 50-foot obstacle under a 3° glide slope has been selected. For take-off, the reference point under the flight path has been selected as 3.5 nautical miles from brake release.

The overall procedure followed by each contractor to predict flyover noise with the use of ground run-up data is outlined in figure 7. The ground run-up data were taken at predetermined engine power settings with microphones located around the engine at a constant radial distance. A run consists of obtaining data at each of the power settings, and a minimum of three runs were made with each configuration. The data, taken at corresponding power settings, were averaged and corrected to standard-day conditions. These averaged data were then projected along each radius to intersect lines parallel to the engine center line, simulating various altitudes or distances from the engine. This projection takes into account attenuation due to spherical spreading and atmospheric corrections. The next step is to obtain the sound pressure level as a function of time, with corrections applied to the lower frequencies for relative jet velocity and to the higher frequencies for fan-tip Mach number. Finally, the variation of perceived noise level with time is calculated by using the accepted procedures outlined in reference 3.

In conclusion, it should be pointed out that references 4 to 11 are, in essence, status reports of a research and development effort and are presented to show what has been done to date. It should be stressed that the results of the program, presented in terms of predicted flyover noise and direct operating costs, are based on ground run-up data and that the determination of any final conclusions will have to be reserved until after the flight tests. In addition, the economic viability of the configurations will have to be determined by each airline for its system.

REFERENCES

1. Mangiarotty, R. A.; Marsh, Alan H.; and Feder, Ernest: Duct-Lining Materials and Concepts. Conference on Progress of NASA Research Relating to Noise Alleviation of Large Subsonic Jet Aircraft, NASA SP-189, 1968. (Paper No. 5 herein.)
2. Watson, H. A., Jr.; Thompson, J. D.; and Rucker, Carl E.: Structural and Environmental Studies of Acoustical Duct-Lining Materials. Conference on Progress of NASA Research Relating to Noise Alleviation of Large Subsonic Jet Aircraft, NASA SP-189, 1968. (Paper No. 7 herein.)
3. Anon.: Definitions and Procedures for Computing the Perceived Noise Level of Aircraft Noise. ARP 865, Soc. Automot. Eng., Oct. 15, 1964.
4. Pendley, Robert E.: Design Concepts. Conference on Progress of NASA Research Relating to Noise Alleviation of Large Subsonic Jet Aircraft, NASA SP-189, 1968. (Paper No. 9 herein.)
5. Marsh, Alan H.; Zwieback, E. L.; and Thompson, J. D.: Ground-Runup Tests of Acoustically Treated Inlets and Fan Ducts. Conference on Progress of NASA Research Relating to Noise Alleviation of Large Subsonic Jet Aircraft, NASA SP-189, 1968. (Paper No. 10 herein.)
6. Coxon, J. S.; and Henry, C. A.: Flight-Test Nacelles. Conference on Progress of NASA Research Relating to Noise Alleviation of Large Subsonic Jet Aircraft, NASA SP-189, 1968. (Paper No. 11 herein.)
7. Pendley, Robert E.; and Marsh, Alan H.: Noise Predictions and Economic Effects of Nacelle Modifications to McDonnell Douglas DC-8 Airplanes. Conference on Progress of NASA Research Relating to Noise Alleviation of Large Subsonic Jet Aircraft, NASA SP-189, 1968. (Paper No. 12 herein.)
8. Higgins, C. C.; Smith, J. N.; and Wise, W. H.: Sonic-Throat Inlets. Conference on Progress of NASA Research Relating to Noise Alleviation of Large Subsonic Jet Aircraft, NASA SP-189, 1968. (Paper No. 13 herein.)
9. Drakeley, George T.; and McCormick, Ralph B.: Treated Inlets. Conference on Progress of NASA Research Relating to Noise Alleviation of Large Subsonic Jet Aircraft, NASA SP-189, 1968. (Paper No. 14 herein.)
10. McCormick, Ralph B.: Fan-Duct Development. Conference on Progress of NASA Research Relating to Noise Alleviation of Large Subsonic Jet Aircraft, NASA SP-189, 1968. (Paper No. 15 herein.)

11. Nordstrom, D. C.; and Miller, D. S.: Noise Predictions and Economic Effects of Boeing Nacelle Modifications. Conference on Progress of NASA Research Relating to Noise Alleviation of Large Subsonic Jet Aircraft, NASA SP-189, 1968. (Paper No. 16 herein.)

TURBOFAN-ENGINE NOISE EMISSION

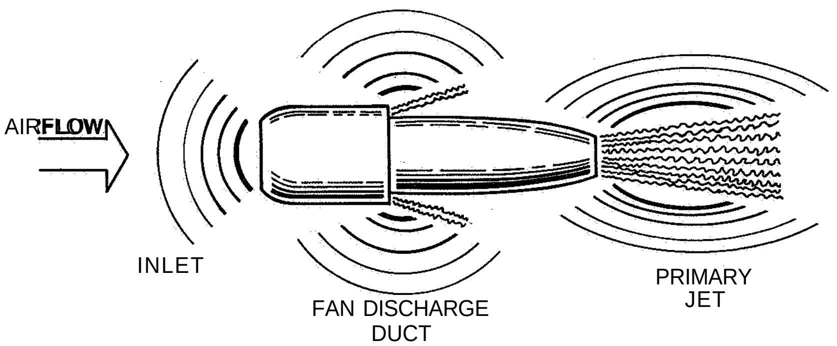

Figure 1

TURBOFAN-ENGINE NOISE

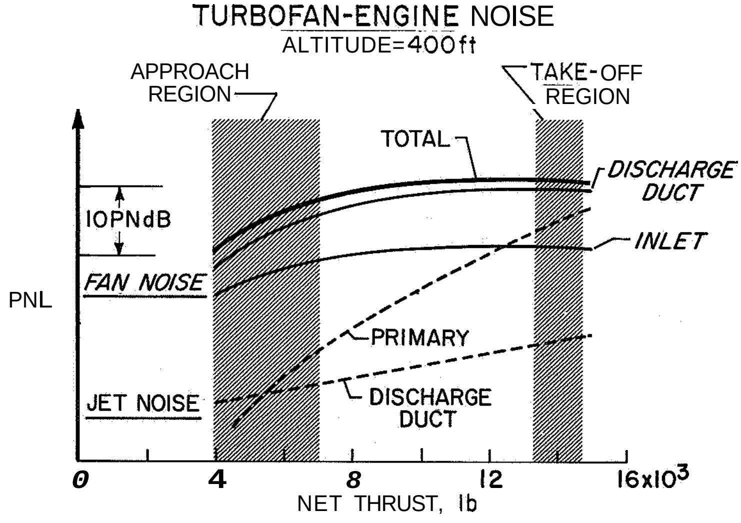

Figure 2

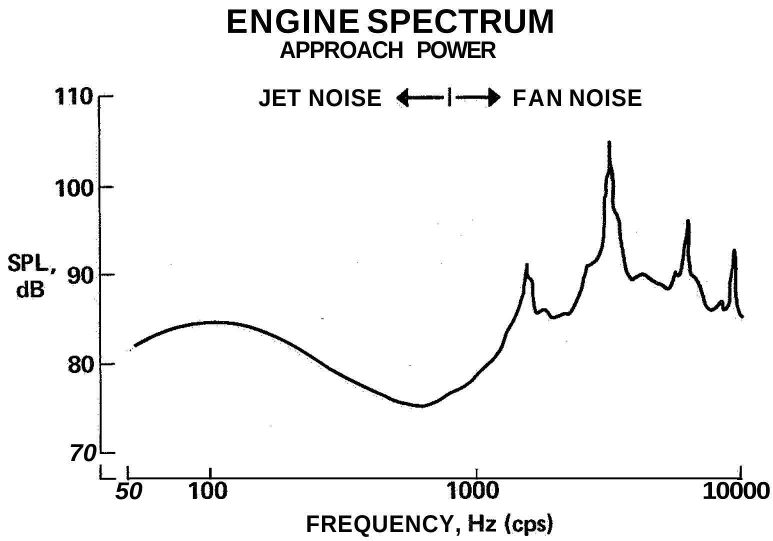

Figure 3

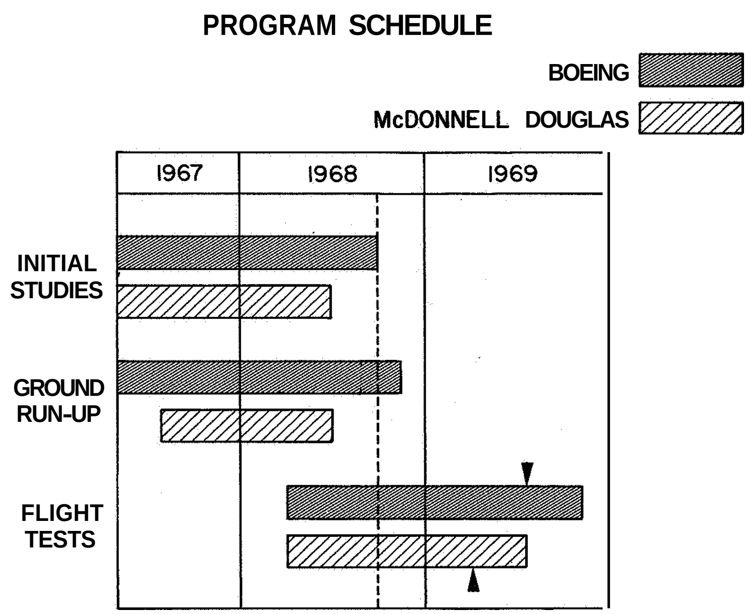

Figure 4

NACELLE TREATMENT CONFIGURATIONS

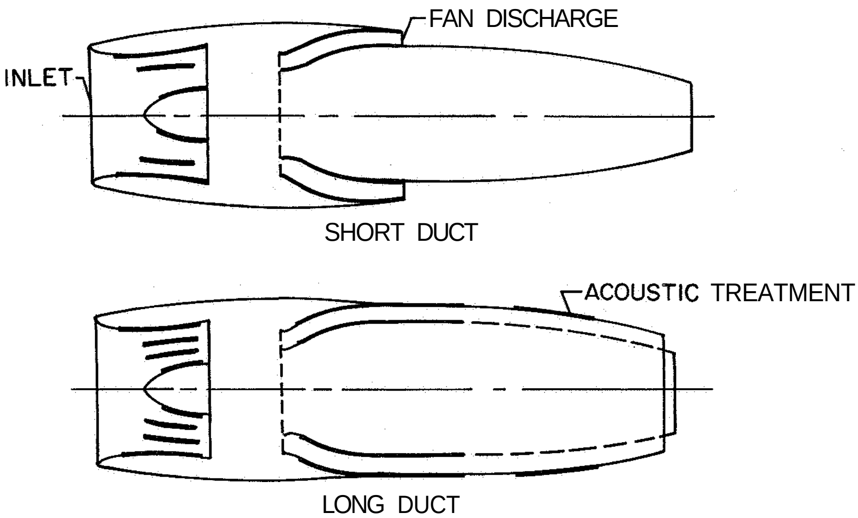

Figure 5

NOISE REFERENCE POINTS

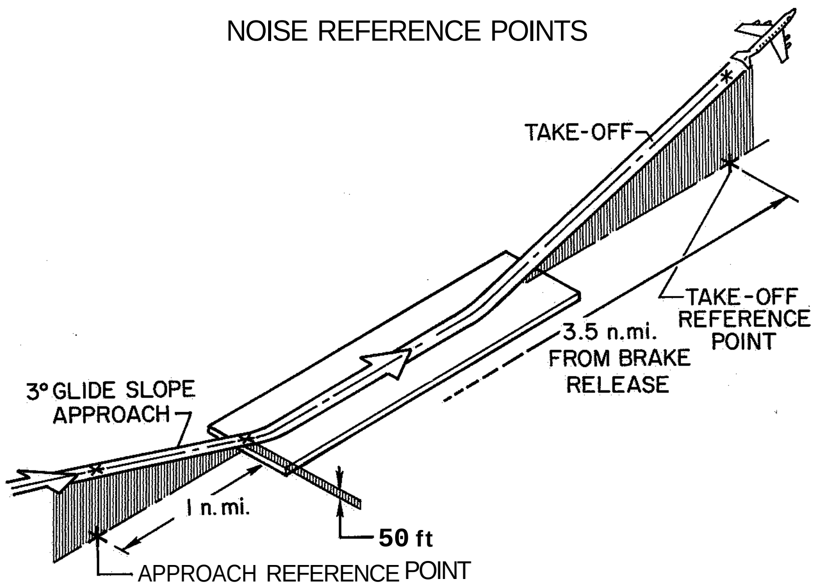

Figure 6

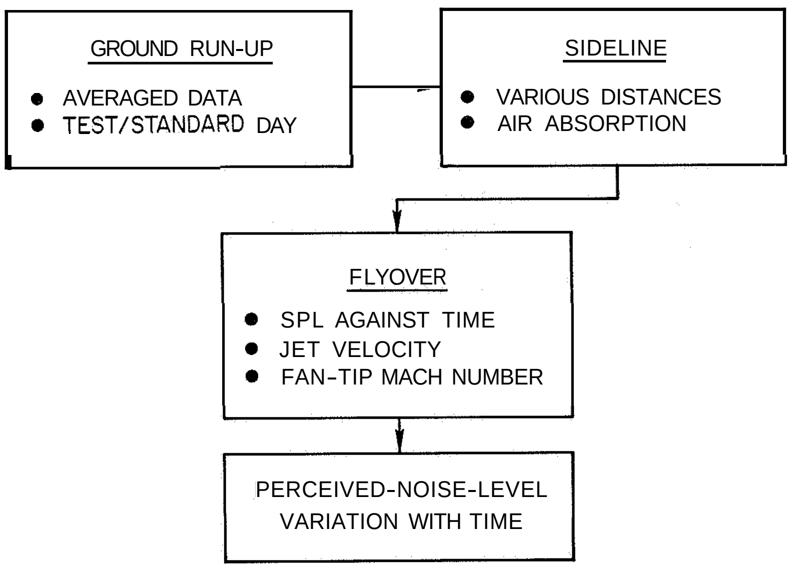
GROUND RUN-UP
● AVERAGED DATA
● TEST/STANDARD DAY
SIDELINE
● VARIOUS DISTANCES
● AIR ABSORPTION
FLYOVER
● SPL AGAINST TIME
● JET VELOCITY
● FAN-TIP MACH NUMBER
PERCEIVED-NOISE-LEVEL VARIATION WITH TIME

Figure 7