NASA PROPELLER NOISE RESEARCH

George C. Greene
National Aeronautics and Space Administration
Langley Research Center

General Aviation Aircraft represent a cost effective solution to many of the public's transportation problems. Due to their fuel efficiency, propeller driven commuter aircraft are appearing in ever increasing numbers, replacing jet CTOL's on short block time, low passenger density routes. Business aircraft have experienced a steady growth in recent years. Add these aircraft to the large number of privately owned general aviation aircraft which are already in operation and the resulting propeller noise represents a growing national problem.

The purpose of NASA's propeller noise research program is to provide a technology base for reducing propeller noise with a minimum of performance, weight, and economic penalties. The thrusts of this program are shown schematically in Figure 1. Noise prediction technology represents the most basic part of the program. The emphasis of this activity is on the understanding of and prediction of propeller noise using basic principles of physics. Deficiencies in the prediction process identify areas where further research is needed. New research results are incorporated in the noise prediction process until predicted results are satisfactory. Engineering noise prediction methods can then be developed.

Propeller noise/performance optimization studies emphasize the development of practical propeller design technology. The current program in this area utilizes single-engine aircraft. Future efforts will include larger twin engine aircraft. New design technology will be demonstrated with flight programs as required.

The third program area is interior noise reduction. Research topics include definition of the source input to the fuselage sidewall, evaluation of sidewall transmission characteristics for different types of structures, and development and evaluation of advanced noise control treatments. This research is especially important in view of the high predicted noise levels for advanced high speed propellers.

This paper will describe the current research program in propeller noise prediction, noise/performance optimization, and interior noise reduction. Selected results will be presented to illustrate the status of current technology and the direction of future research.

Propeller Noise Prediction Technology

Some characteristics of the propeller noise prediction effort are shown in Figure 2. The technology being developed is applicable to low and high speed propellers. It is based on the basic physics of the noise generation process, rather than empirical methods. The technology is relatively sophisticated to permit analysis of complex configurations such as that proposed for a high speed turboprop. Noise prediction requires a knowledge of the propeller geometry and a description of the aerodynamic characteristics of the propeller. Examples of noise calculations using this technology are shown in Figures 3 and 4. Figure 3 shows a comparison of measured and calculated noise for a Twin Otter aircraft. Sound pressure level is shown as a function of frequency expressed in multiples of the blade passage frequency. The acoustic data were taken in the plane of the propeller with a microphone mounted on a boom on the aircraft wing. The measured data include noise from sources other than the propeller, but in general the agreement is very good.

Typical results for an advanced high speed propeller configuration are shown in Figure 4. Again sound pressure level is presented as a function of blade passage harmonic number. The measured data were taken in an acoustic wind tunnel using a four-bladed model of the propeller configuration shown in the photo insert. This propeller configuration is known as the SR-3. The agreement between theory and data for the overall level is very good with some errors occuring at the high frequencies. The causes of this error are under investigation and will probably result in refinements to the prediction technique.

Propeller Noise/Performance Optimization

Characteristics of the propeller noise/performance optimization program are shown in Figure 5. This is a joint NASA/EPA program to demonstrate that propeller noise can be reduced in an economically reasonable manner. The goal of this effort is to reduce light aircraft propeller noise by 5 dBA while maintaining or improving propeller performance. The effort consists of 1) optimization studies to assess the potential noise and performance benefits of various propeller parameters, 2) wind tunnel tests to verify design concepts, and 3) flight tests to demonstrate the noise reduction technology. Parallel efforts are being conducted at Massachusetts Institute of Technology and Ohio State University. Some results from this program are shown in Figures 6-13.

Figure 6 shows the effect of varying the propeller diameter. This assumes a constant shaft rpm so that this is essentially the effect of varying propeller tip speed. Noise in terms of dB_A and efficiency are shown subject to the assumptions listed on the figure. For each calculated point, the propeller was optimized for that particular diameter. As can be seen both the noise and performance are quite sensitive to this parameter. A small percentage reduction in propeller diameter can result in a very substantial noise reduction. Efficiency is also compromised but not to the same extent that the noise is reduced. A reduction of propeller diameter must be accompanied by other parameter changes if the propeller efficiency is to remain constant.

The calculated effect of varying the number of propeller blades is shown in Figure 7. Subject to the listed assumption, this indicates that noise can be reduced by increasing the number of blades. Propeller efficiency is not changed significantly by changing the number of blades. It should be remembered that these are calculated results and do not contain the effects of blade interference at the larger blade numbers. Figure 8 shows the calculated effect of varying radial load distribution on the blade. Subject to the assumptions listed, it is shown that noise can be substantially reduced by moving the peak of this load distribution inboard. There is an optimum location which results in maximum propeller efficiency, however the efficiency is not very sensitive to small changes in the position of this peak loading.

Figure 9 shows the calculated effect of blade sweep on propeller noise. The calculated points are for sweep angles from zero degress, which represents a straight blade, to the extreme case of a propeller which is completely wrapped around itself. For practical sweep angles, which are relatively small, there is a slight noise reduction. The effect of sweep of this magnitude on performance has not been evaluated.

In order to test some of the concepts which were developed during the parametric studies, model propellers were constructed for testing in the MIT wind tunnel. Figure 10 shows two model propellers, a "quiet" propeller and a standard Cessna 172 propeller. Although not obvious due to the angle at which the photograph was taken, the modified propeller has the same diameter as the standard propeller. It has a wider cord which was designed to move the load distribution inboard on the propeller blade.

These propellers were tested over a wide range of conditions on a propeller spinning rig with and without an afterbody to simulate an aircraft fuselage. Figure 11 shows the test configuration in the MIT acoustic wind tunnel with a fuselage afterbody. Figure 12 shows a sample comparison of measured and predicted noise data. A schematic of the tunnel configuration is shown on the right part of the figure. The data are for the standard Cessna propeller model with no afterbody. Noise data were measured with a microphone mounted in the airstream 1 diameter from the center of propeller rotation. The data presented is a pressure time history for approximately 2 revolutions of the propeller. These data correspond to cruise conditions for an actual aircraft. As can be seen, the agreement between the predicted and measured noise is excellent. Similar results were obtained for other configurations.

After demonstrating the noise prediction techniques in the wind tunnel, full-scale propellers were designed for flight tests at both Massachusetts Institute of Technology and Ohio State University. Figure 13 shows the flight test aircraft which will be used by the OSU. It is a Beech Sundowner aircraft and is equipped with a microphone boom which can be extended to measure noise in and behind the plane of the propeller. Ground noise measurements will be made for 500-feet and 1000-feet flyovers. Noise measurements will be made with and without an engine exhaust muffler to determine the relative levels of propeller and exhaust noise. A similar flight demonstration will be conducted by MIT using a Cessna 172 aircraft; however, the MIT aircraft will not be equipped for near-field inflight noise measurements and will not have an engine exhaust muffler.

A final purpose of this program is to establish a center for effective distribution of propeller optimization technology. Because of its current involvement in the NASA program and its ready access to aircraft manufacturers, the Ohio State University Airfoil Design and Analysis Center has been chosen to serve this function.

Interior Noise Reduction

Interior Noise Reduction involves altering the characteristics of the sound path from the source to the observer, as well as altering the characteristics of the noise source itself. The major elements of the interior noise reduction program are listed in Figure 14. The definition of the input or source for transmission studies is obviously important. The understanding of sidewall noise transmission mechanisms and the evaluation of potential noise control treatment are also key elements of the program. Structureborne noise is also of interest due to the problems encountered by small piston engine aircraft. One source of interior noise in light aircraft is vibration. This originates in the engine, is transmitted through the support structure, and is radiated into the cabin.

An example of structureborne noise research is shown in Figure 15. The research was directed toward determining the relative magnitudes of structureborne noise and noise from other sources such as the propeller which might be transmitted through the air and through the fuselage sidewall into the aircraft cabin. The principle feature of the setup shown is the use of stanchions located at the firewall on each side of the aircraft to support the engine weight and thrust loads so that the engine can be operated without any mechanical attachment to the fuselage. The fuselage is located in the correct geometry relative to the engine so that other noise sources are the same. The engine can also be attached to the fuselage in a normal configuration . The engine attached configuration provides the total interior noise from all sources and paths while the engine detached configuration provides all sources except the structureborne noise, so the difference provides the structureborne contribution.

The bar chart at the right of the figure indicates typical results. The total bar height indicates the total interior noise as measured in the engine attached condition. The shaded portion of the bar indicates the structureborne contribution. As indicated by the overall level bar at the right of the figure, detaching the engine reduced the level by 3 dB, indicating that the structureborne contribution is about equal to the contribution from all other source/path combinations. Examination of the spectrum indicates that the structureborne contribution is significant over a relatively wide frequency range, up to about 2000 Hertz. Current research efforts are directed toward prediction of the structurally transmitted noise and development of noise control methods involving control of both noise radiated from panels to the aircraft interior as well as noise transmitted through the engine mounting vibration isolators.

Fuselage sidewall transmission is very important for those aircraft which have wing-mounted propellers operating close to the fuselage sidewall.

Research is currently underway to evaluate possible structural treatments to improve the fuselage sidewall noise attenuation. An aircraft used in one such study is shown in the upper left photograph on Figure 16. This aircraft is an Aero Commander 680, modified for evaluating interior noise control treatments. To provide a baseline for structural modifications being investigated, the interior trim and insulation were removed in the area of interest and the windows were replaced with stiffened aluminum panels similar to the fuselage construction. These modifications are shown in the lower right photograph of the aircraft interior. The area investigated is shown as the shaded area in the sketch in the lower left of the figure.

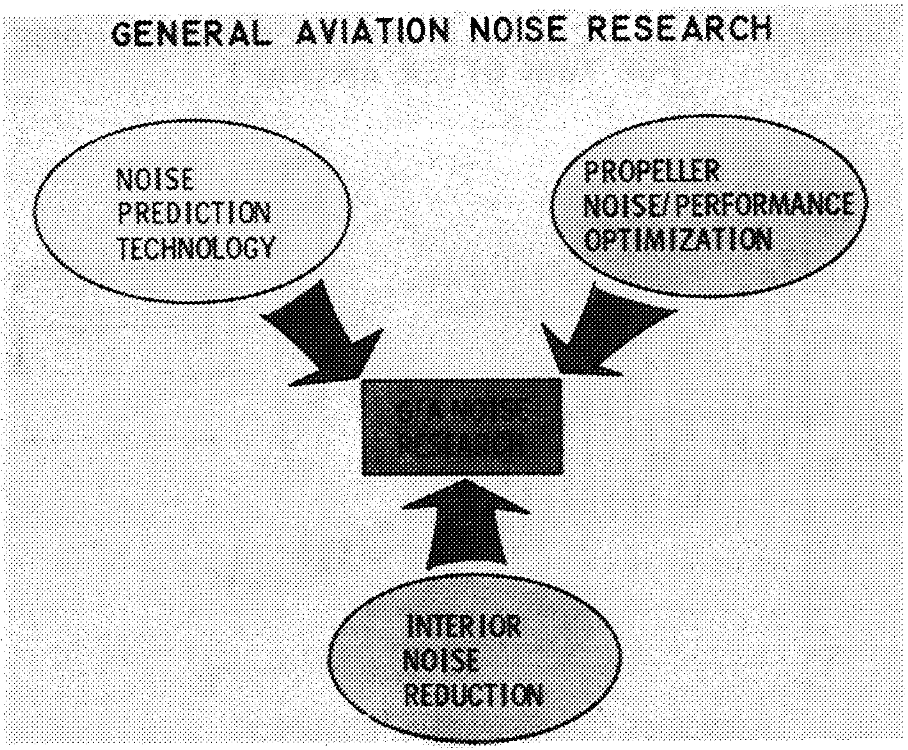
Sidewall noise attenuation characteristics were measured for propeller noise inputs and for artificial noise inputs from the large horn shown in the photograph. Attenuation provided by the sidewall for the horn input is shown as noise reduction in the upper right of the figure. Noise reduction is the difference between the inside and outside sound levels as a function of the frequency. The two curves shown are for the bare sidewall and for the sidewall with 15 pounds of asphalt type, glue on mass added to the aircraft. These results indicate that even a modest amount of appropriately added mass may reduce interior noise by 4-15 dB depending on the frequency of noise.

Conventional treatment will not be sufficient for the new generation of high-speed propeller-driven aircraft. Figure 17 shows the relationship between desired cabin noise levels and currently predicted propeller noise levels for current designs of high-speed propellers. The bar on the left indicates the range of noise levels experienced in testing of current propellers and the projected improvement due to advanced propeller design. These levels are on the order of 140 dB with possible improvements below that. Predicted interior noise levels and the interior noise goal are shown by the bars on the right. As can be seen, there is a gap of approximately 25 dB in the cabin attenuation which must be obtained from new technology. This problem is being addressed in two ways. First there are continuing efforts to reduce the noise of high-speed propellers through careful design of advanced configurations. In addition, improved estimates of propeller noise will be obtained in the summer of 1980 when a propfan model is flown on a Jet Star aircraft.

Analytical studies are also being pursued to define low weight, low-noise-transmitting sidewalls. Preliminary results from two studies are shown in Figure 18. The primary conclusion of this study is that acceptable cabin interior noise levels can be achieved using conventional technology. Both studies employed a double-wall design using an optimum combination of added mass, structural damping, and tuning of the structure. These studies estimated the acoustic weight penalties which would accrue for the types of aircraft listed in Figure 18. The weights listed are penalties in addition to the acoustic treatment weights currently carried. Although these weights are high, the potential of the propfan as a fuel efficient propulsion system is still viable.

Future Research

Trends of future NASA research are shown in Figure 19. There will be a continued effort in the development and refinement of noise prediction methods. As these methods mature, simplified design techniques will be developed to permit their practical application. The emphasis of prediction and design technology will shift to twin and commuter size aircraft to reflect their growing importance. Interior noise research will continue for all classes of aircraft with a special emphasis on developing the technology necessary for the timely development of high-speed propeller-driven aircraft.



GENERAL AVIATION NOISE RESEARCH

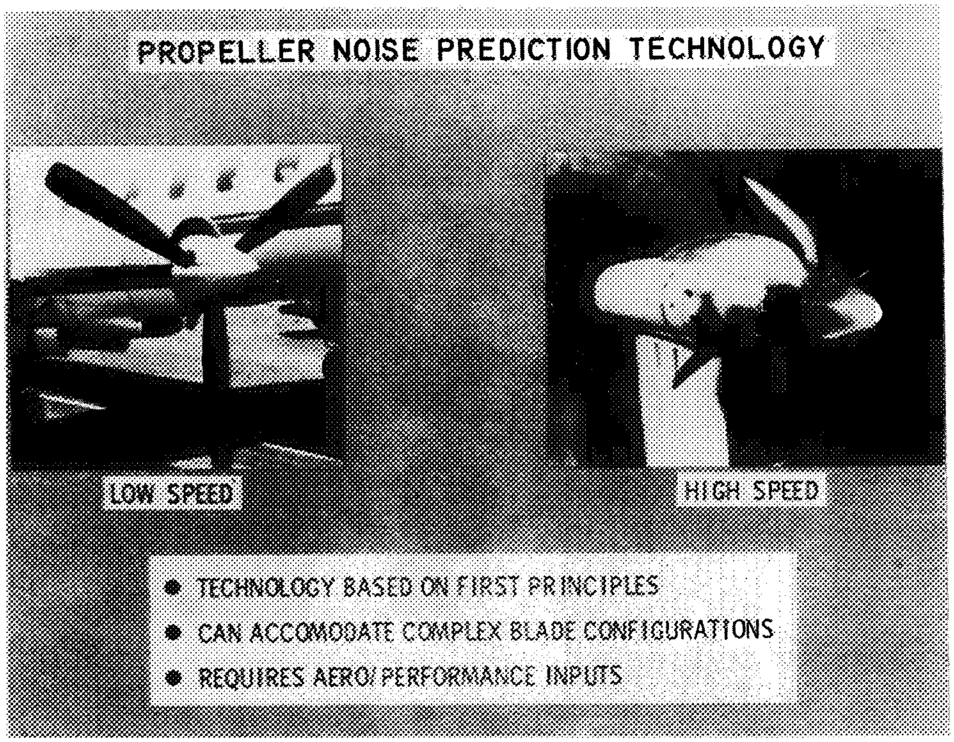
NOISE PREDICTION TECHNOLOGY

PROPELLER NOISE/PERFORMANCE OPTIMIZATION

[illegible]

INTERIOR NOISE REDUCTION

Figure 1



PROPELLER NOISE PREDICTION TECHNOLOGY

LOW SPEED

HIGH SPEED

- TECHNOLOGY BASED ON FIRST PRINCIPLES
- CAN ACCOMODATE COMPLEX BLADE CONFIGURATIONS
- REQUIRES AERO/PERFORMANCE INPUTS

Figure 2

COMPARISON OF MEASURED AND CALCULATED NOISE FOR TWIN OTTER AIRCRAFT

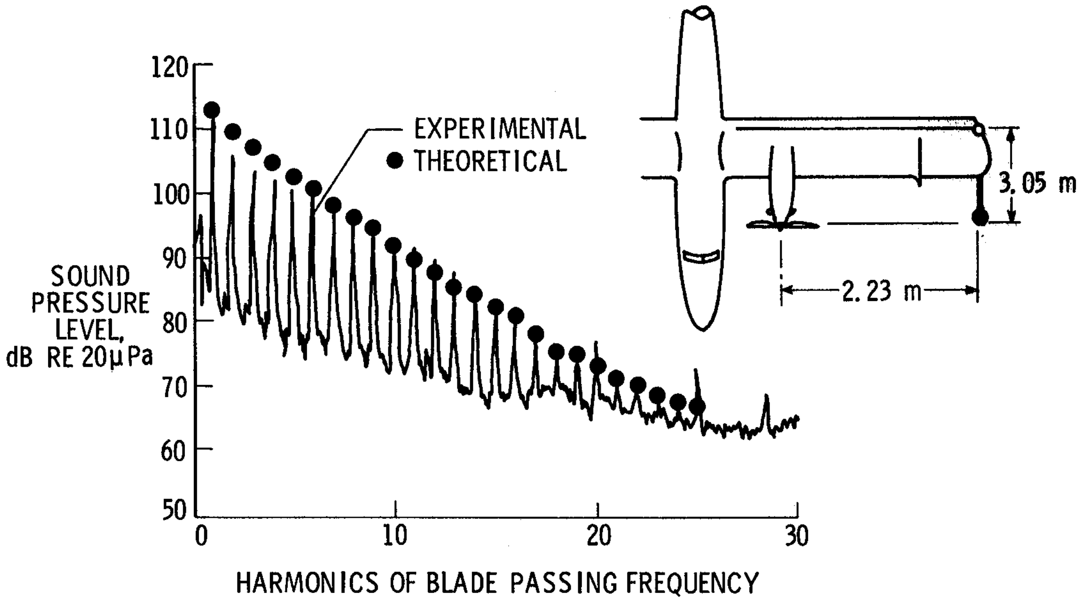


Figure 3

COMPARISON OF MEASURED AND CALCULATED RESULTS FOR SR-3 PROPELLER

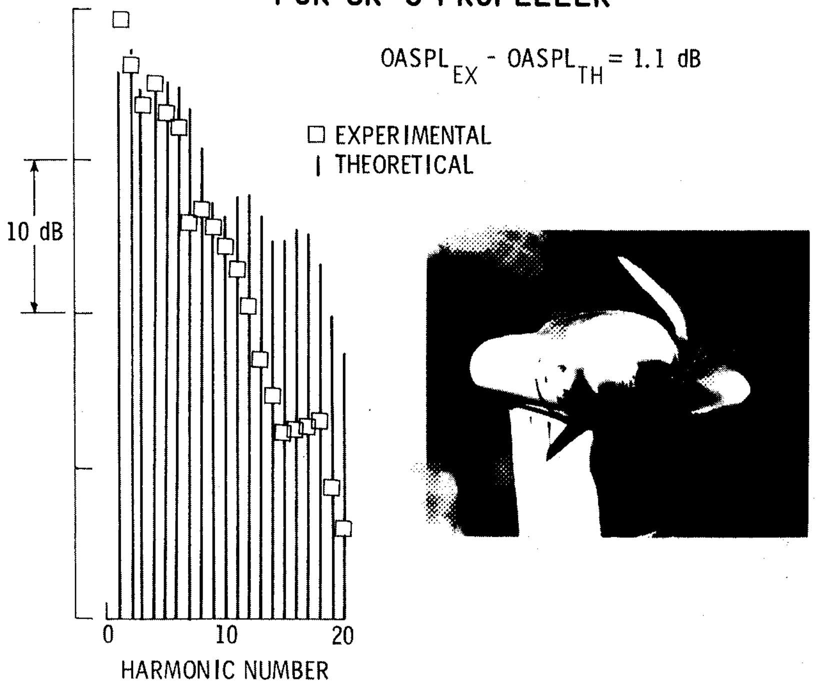
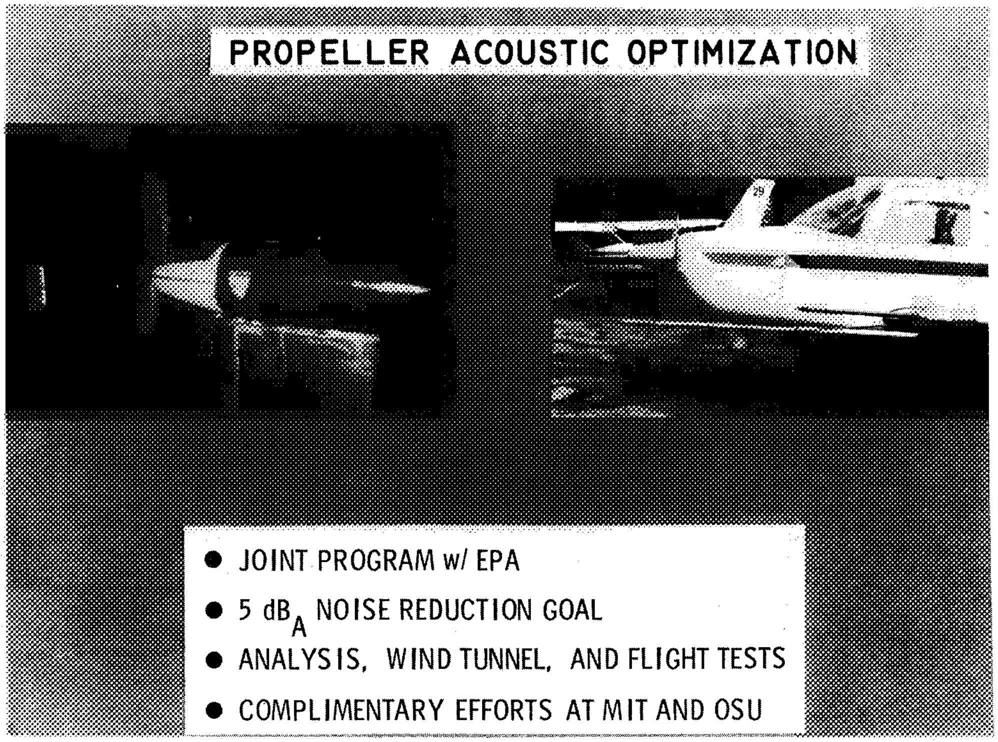


Figure 4

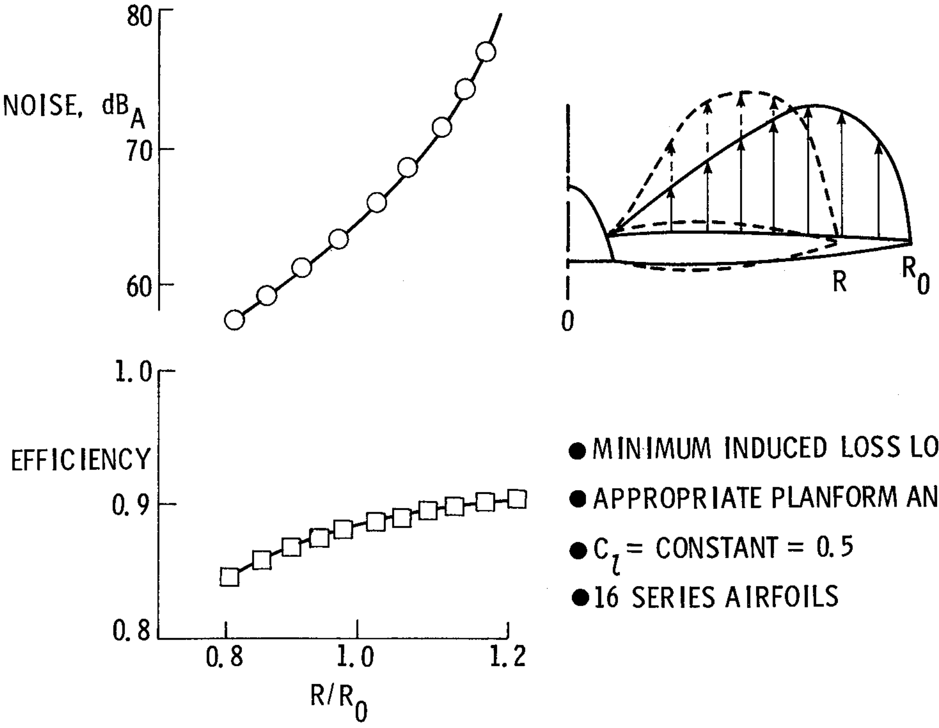


PROPELLER ACOUSTIC OPTIMIZATION

- JOINT PROGRAM w/ EPA
- 5 dB_A NOISE REDUCTION GOAL
- ANALYSIS, WIND TUNNEL, AND FLIGHT TESTS
- COMPLIMENTARY EFFORTS AT MIT AND OSU

Figure 5

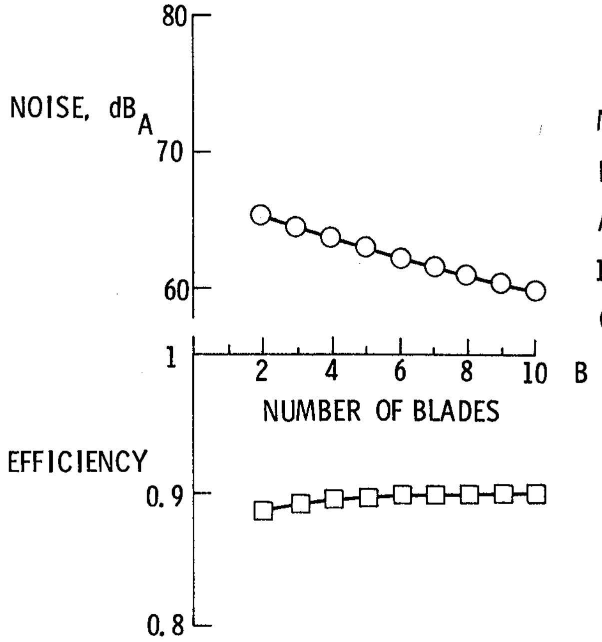
CALCULATED EFFECT OF VARYING PROPELLER DIAMETER



- MINIMUM INDUCED LOSS LOADING
- APPROPRIATE PLANFORM AND TWIST
- C_l = CONSTANT = 0.5
- 16 SERIES AIRFOILS

Figure 6

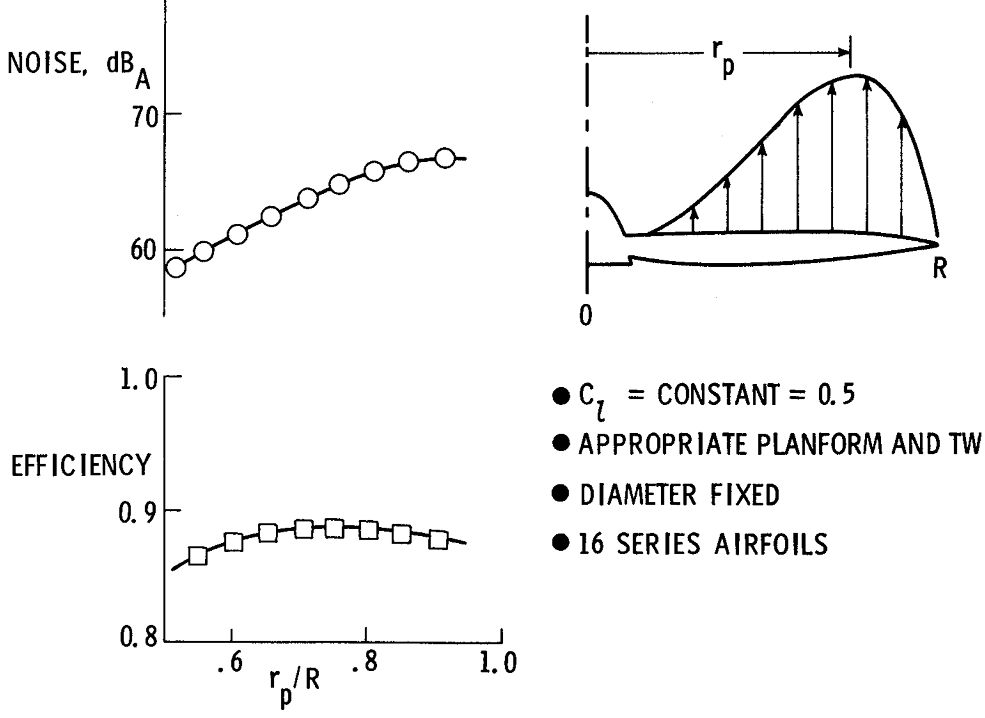
CALCULATED EFFECT OF NUMBER OF BLADES



MINIMUM INDUCED LOSS LOADING
PLANFORM FOR CONSTANT $C_l = 0.5$
APPROPRIATE TWIST
16 SERIES AIRFOILS RN $\cong 3 \times 10^6$
CONSTANT C_D

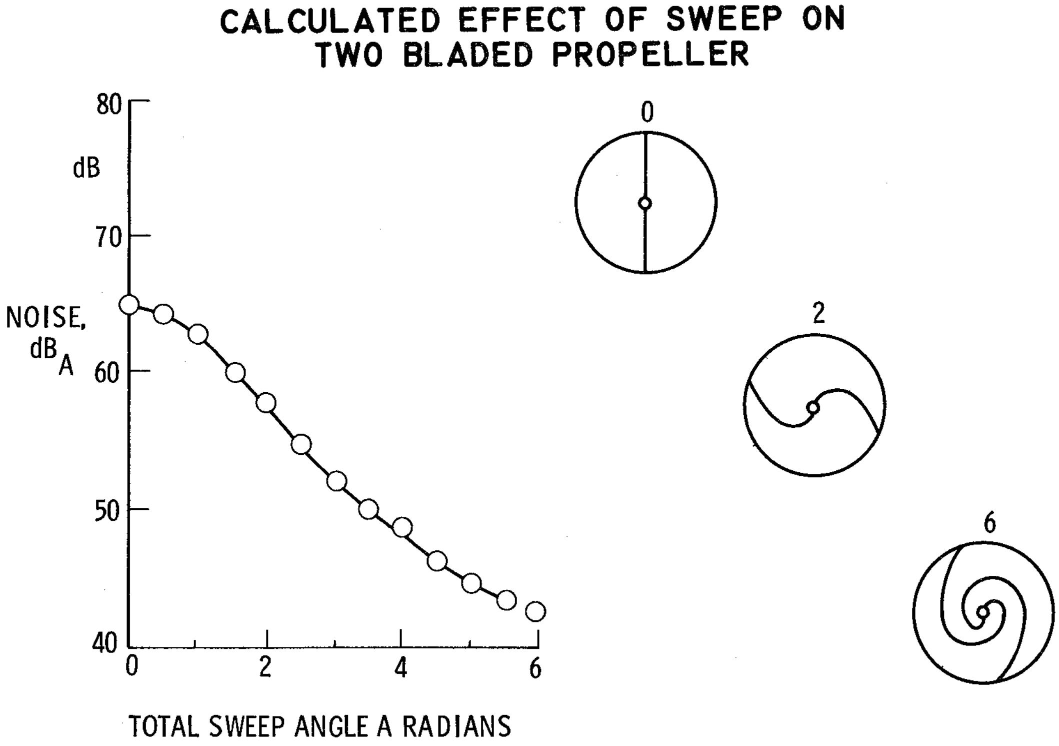
Figure 7

CALCULATED EFFECT OF VARYING RADIAL LOAD DISTRIBUTION



- C_l = CONSTANT = 0.5
- APPROPRIATE PLANFORM AND TWIST
- DIAMETER FIXED
- 16 SERIES AIRFOILS

Figure 8



CALCULATED EFFECT OF SWEEP ON TWO BLADED PROPELLER

Figure 9

STANDARD AND MODIFIED PROPELLERS

Figure 10

PROPELLER TEST IN MIT WIND TUNNEL

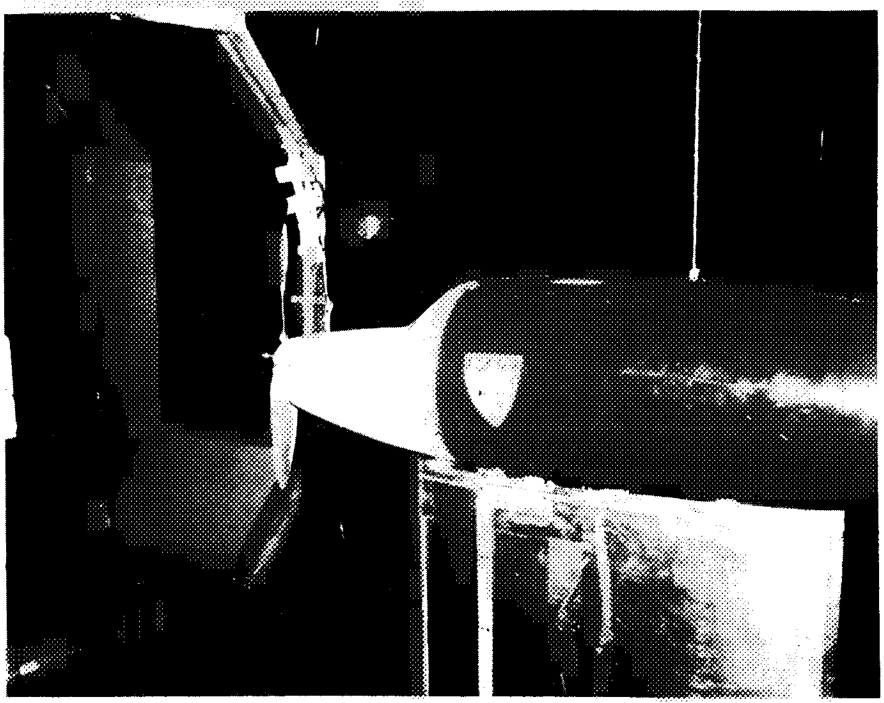


Figure 11

COMPARISON OF MEASURED AND PREDICTED PROPELLER NOISE

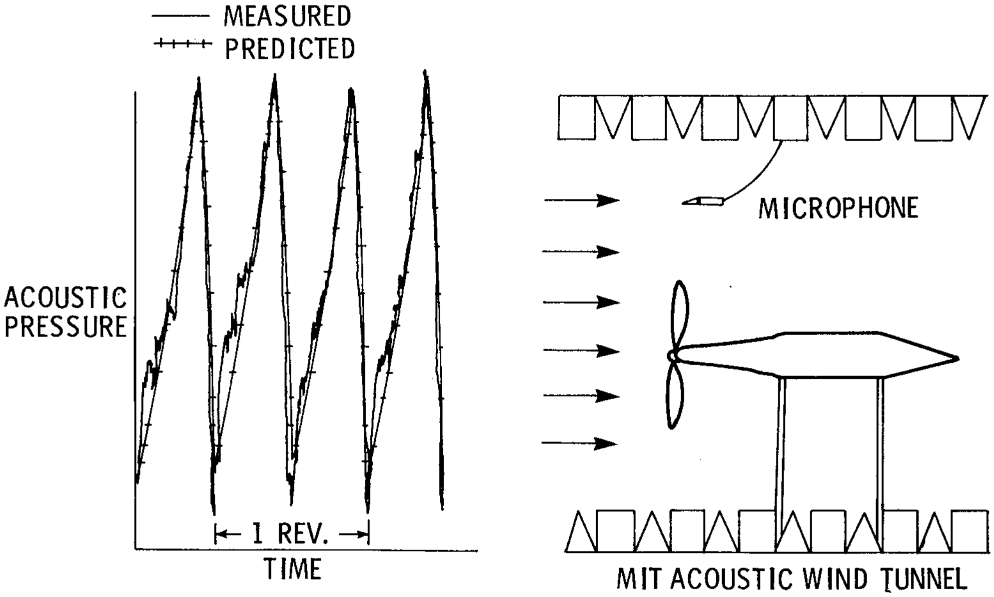


Figure 12

OSU FLIGHT TEST AIRCRAFT

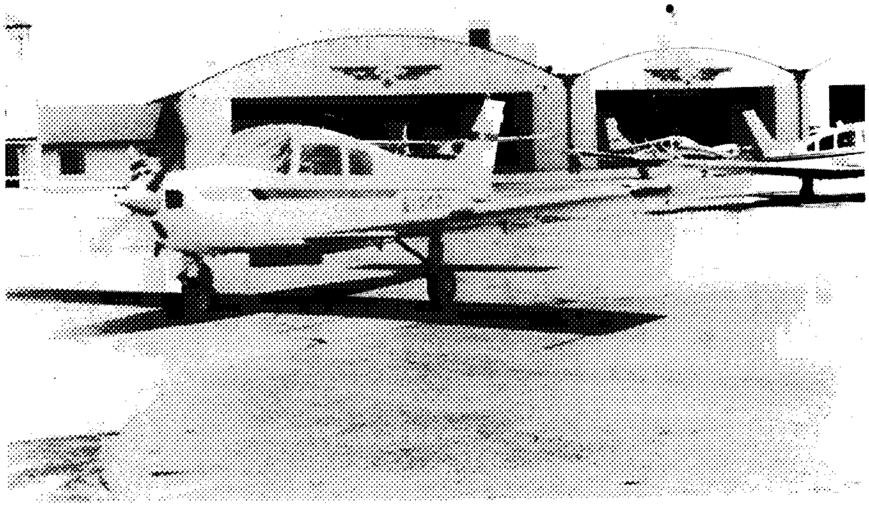


Figure 13

INTERIOR NOISE REDUCTION

- SOURCE DEFINITION
- SIDEWALL NOISE TRANSMISSION
- NOISE CONTROL TREATMENT
- STRUCTURE BORNE NOISE TRANSMISSION

Figure 14

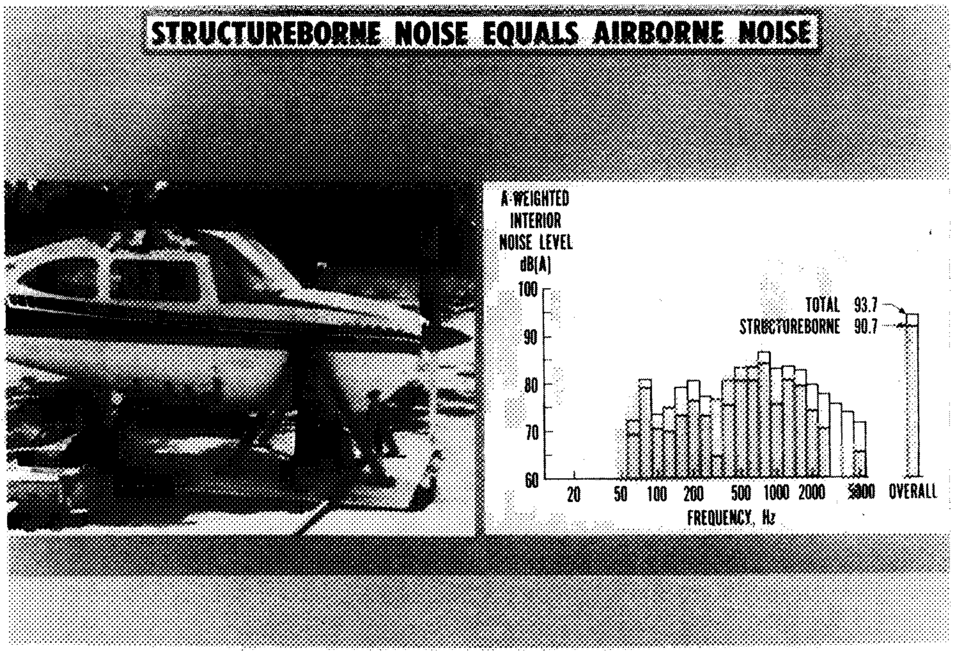


Figure 15

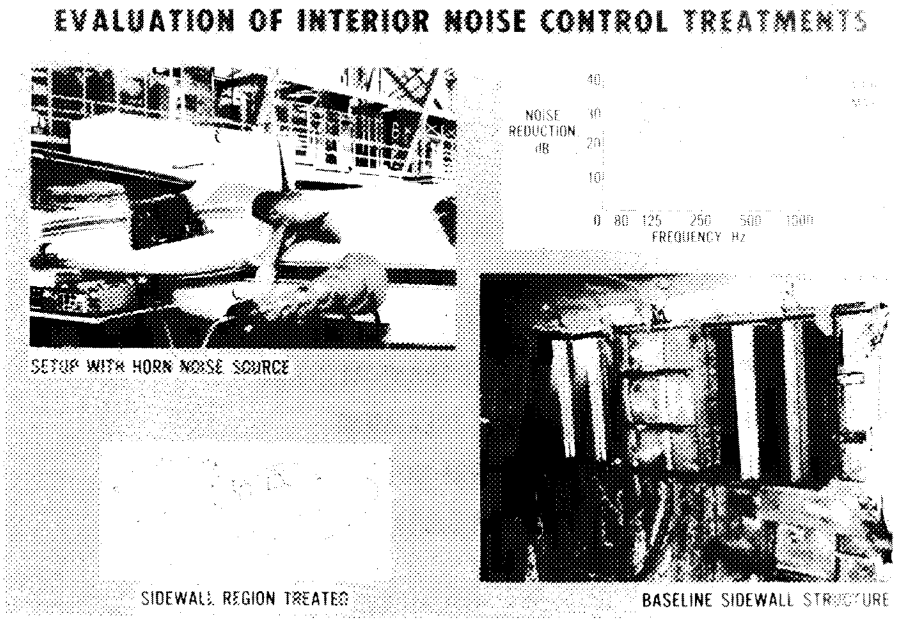
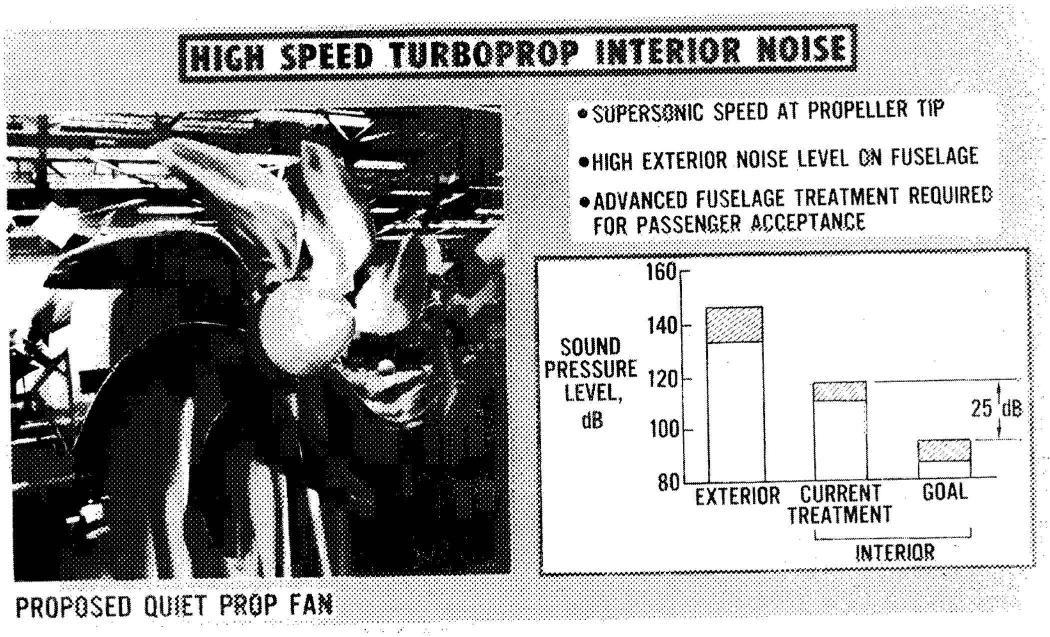


Figure 16



HIGH SPEED TURBOPROP INTERIOR NOISE

- SUPERSONIC SPEED AT PROPELLER TIP
- HIGH EXTERIOR NOISE LEVEL ON FUSELAGE
- ADVANCED FUSELAGE TREATMENT REQUIRED FOR PASSENGER ACCEPTANCE

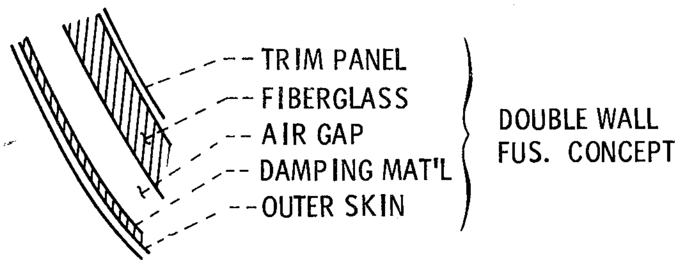
PROPOSED QUIET PROP FAN

Figure 17

FUSELAGE INTERIOR NOISE REDUCTION STUDY

$M = 0.8,\ \Delta dB \approx 45$

INTERIOR = 80dBA



AIRCRAFT	GROSS WT.	$D_{PROP}/D_{FUS.}$	ACOUSTIC WEIGHT PENALTY % G.W.
4 ENG. WIDE BODY	217 TO 252K	0.6 TO 1.0	0.8 TO 2.3
2 ENG. SMALL A/C	30 TO 32K	1.0 TO 1.4	1.5 TO 1.7

Figure 18

FUTURE RESEARCH

- CONTINUED DEVELOPMENT AND REFINEMENT OF PREDICTION METHODS
- EMPHASIS TO INCLUDE TWIN AND COMMUTER SIZE AIRCRAFT
- CONTINUING RESEARCH IN INTERIOR NOISE REDUCTION

Figure 19