NASA Contractor Report 159237

NASA-CR-159237
1980 0012616

DEVELOPMENT AND EVALUATION OF A GENERAL AVIATION REAL WORLD NOISE SIMULATOR

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NASA Grant NSG-1541
March 1980

National Aeronautics and
Space Administration

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N80-21100 #

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Development and Evaluation of a General Aviation Real World Noise Simulator

Abstract

The design, development and operation of a "real world" acoustic playback system is described that provides realistic quality and levels of acoustic simulation of engine and airframe noise to the cockpit of the General Aviation Simulator at the NASA-Langley Research Center. The system simulates the sounds experienced by the pilot of a general aviation aircraft during engine idle, take-off, climb, cruise, descent, and landing. The acoustic parameters of the system are modulated by analog control voltages from the aircraft simulator.

The physical parameters of the signal as they appear in the simulator environment are compared to analogous parameters derived from signals recorded during actual flight operations. The acoustic parameters of the simulated and real signals during cruise conditions are within plus or minus two dB in third-octave bands from 0.04 to 4 kHz. The overall A-weighted levels of the signals are within one dB of signals generated in the actual aircraft during equivalent maneuvers. Psychoacoustic evaluations of the simulator signal are compared with similar measurements based on transcriptions of actual aircraft signals. The subjective judgments made by human observers support the conclusion that the simulated sound closely approximates transcribed sounds of real aircraft. Subjective comments by simulator pilots are reported and discussed.

Single Engine Aircraft Sounds

The pilot and passengers of a single engine general aviation aircraft are exposed to sound levels high enough to make the investigation of their consequences important. These aircraft are almost universally powered by gasoline fueled reciprocating engines driving a single two- (and occasionally three-) bladed propeller. It should be noted at the outset that the sounds of an aircraft in flight are not merely "noise," that is non-information carrying acoustic signals; rather, aircraft sounds and their modulation during flight convey a variety of information to the experienced pilot. On the other hand these sounds are presently transmitted into the cockpit environment at high levels of acoustic power, and consequently may lead to performance changes as a consequence of at least two effects:

1) The sounds may mask important speech communications over the aircraft radio.

2) The sounds may impair information processing by distracting, fatiguing or overloading mental processes normally required by the pilot.

No consideration is given here to any possible noise induced physiological trauma to the auditory system, although it should be noted that the cockpit interior SPL's (sound pressure levels), which often reach 110 dB (EPA, 1975), may result in temporary or permanent noise induced auditory threshold shifts (Kryter, 1970, Kryter et. al. 1966; OSHA, 1970).

To simulate the acoustic environment of a general aviation aircraft the sources of sound in the real aircraft must first be considered. There are three major sound sources in a general aviation airplane.

1) Engine noise - generated predominantly by the propeller acting as an acoustic fan, and by the engine exhaust impulses. This noise is delivered to the aircraft cabin through the air and through the structures coupling the cabin to the noise sources.

2) Aerodynamic noise - generated by the passage of the atmosphere over the aircraft skin and modulated by surface variations and aircraft motion.

3) The cabin loudspeaker - generating both noise and voice outputs of radio transmissions, code identifier signals, and occasionally feedback from pilot's speech.

In addition, auxiliary power, venting and cooling/heating systems constitute further noise sources, although in a general aviation aircraft these sources contribute only in a relatively minor way to the total noise environment. Inadequate or defective air seals and/or ventilation ducting inlets may also create additional wind noise inside the cockpit area. No attempt is made here to simulate these idiosyncratic features of any given general aviation aircraft. Rather, the primary sources of sound--1 and 2--are simulated. Because radio transmission simulation has always been available in the simulator, this source of aircraft sound is not considered further. Aircraft radio simulation may be used as part of a test capability to evaluate, for example, the effects of the primary aircraft sounds on intelligibility of radio transmission.

It is necessary to consider in further deail the two major sources of sound in an airplane, the airstream noise, and the engine, propeller, and mechanical noise attributable to the operation of the power plant. The airstream noise amplitude is a function of the airspeed, (v. Gierke, 1957a) whereas the engine-propeller noise amplitude is contingent upon the phase of flight operation, the power drawn from the power plant, and the nature of the propeller and its rpm (v. Gierke, 1957b). In a simple single engine aircraft propeller rpm is identical to engine rpm because the propeller drive is direct. Engine exhaust impulse frequency in a four stroke engine is dependent on the number of engine cylinders. In the usual four cylinder engine the impulse rate is twice the rpm. Therefore, if the propeller has two blades, blade passage frequency and impulse exhaust frequency will coincide.

Insofar as the airplane noise sources radiate (during flight) into a free-field, it is difficult to simulate in the reflective environment of a room the acoustic events that take place in and around an aircraft. However because the cockpit of the aircraft is in close proximity to the sources of acoustic energy, one may place the acoustic transducers in close proximity to the pilot inside the simulator so as to minimize the relative contribution of reflected sound. Consequently, knowing the spectral and amplitude characteristics of the sound sources and how those characteristics vary under different operational conditions it should be possible to simulate faithfully the auditory experiences of a pilot in the cockpit by electro-acoustic means.

Simulation Techniques

Engine Noise Simulation - The reciprocating engine of a general aviation airplane generates a noise spectrum that peaks at blade passage and exhaust impulse frequencies of the engine, and therefore is correlated with engine rpm. In a two bladed, four cylinder, four stroke general aviation aircraft with a direct drive engine-propeller combination, the blade passage frequency and the exhaust impulse frequency coincide, although phase may be slightly shifted depending upon the propeller bolt-on position on the crankshaft. Acoustic spectra of these kinds of aircraft will therefore have a single peak in the frequency region corresponding to engine-propeller rpm. Increases in rpm will shift the frequency region of this peak. Furthermore, increases in rpm result in increases in sound pressure level (v. Gierke, 1957a). This increase tends to be uniform across the frequency spectrum except at very high propeller tip speeds (900-1000 ft. sec.)(Rudmose & Beranek, 1947). For an engine-propeller combination of this particular type it would be relatively straight forward simply to synthesize the sounds produced by the engine-propeller combination. However if the engine contains more than four cylinders or the propeller contains more than two blades or the propeller drive is indirect, then although the shift of the frequency peaks is still proportional to changes in properller rpm, the structure of the spectrum will be more complex. Therefore, in order to provide an engine-propeller noise source that could be tailored to any general aviation aircraft it was decided to adopt magnetic tape technology rather than synthesizer technology as the basis for the engine-propeller noise source.

The data base that generates the simulator noise for the engine-propeller combination is an instrumentation recording (Nagra IV SJ) made inside any arbitrary (a Cessna 172 and Piper PA-28 were used) general aviation aircraft during cruise flight. Recordings made during flight and in a stationary aircraft on the ground over grass produced similar acoustic spectra at cruise rpm. However, such similarity must be interpreted with caution because aerodynamic noise in flight and ground reflections are uncontrolled variables (Catherines & Mayes, 1975). Inflight recordings were chosen to obviate the problem of estimating and then compensating for the effect of ground reflection. Thus the engine propeller simulation source contains some aerodynamic noise. The effect on the engine noise spectrum was minimized by passing the inflight recordings through a low pass filter (cutoff, 2000 Hz). Thus in the frequency region where aerodynamic noise is the dominant source, the signal was effectively removed without much effect on engine-propeller signal. Below 2000 Hz, aerodynamic noise is at least 10 dB below the engine-propeller signal (except at frequencies below 50 Hz), therefre contributing minimally to the spectral levels.

These tapes, when reproduced on a tape deck capable of continuous variations in play-back speed, generate continuous variations in their acoustic spectrum. As the tape speed is slowed, the acoustic spectrum shifts in a way identical to the way in which dominant components of the real spectrum of the engine noise change when the rpm is reduced. The design of the noise simulator takes advantage of this fact by mimicking in this manner the frequency envelop of the engine-propeller combination. Although changes in tape speed also induce changes in output amplitude, the amplitude changes are small compared to changes required for faithful simulation. Sound pressure level changes for doubling tape speed are approximately 3 dB, whereas informal measurements on the ground showed that for two particular aircraft sound pressure levels increased ca. 10 dB for doubling of rpm in the inflight operating range (>1000 rpm). Consequently, the signal from the tape deck is passed through a signal multiplier that outputs a signal change of ca. 10 dB when the input changes 3 dB. In this way changes in the engine and propeller rpm are mimicked by the output of the variable speed tape signal.

The tape deck speed is slaved to the same voltage that drives the simulator tachometer, and therefore engine tachometer rpm and engine noise tape speed are interlocked. The slewing rate of the tape recorder is such that it will follow faithfully changes of a factor of 10 in rpm within 300 msec. This is well within operator control speed and tachometer drive-throttle interlock lag. The result is that if the pilot of the simulator pushes the throttle forward, the aircraft engine noise simulator increases in output at ca. 10 dB per doubling of rpm, and yields a frequency peak in its wide band noise spectrum located at the point predicted by propeller rpm and engine exhaust impulse rate. At cruise (2400 rpm) this peak is ca. 80 Hz.

Tape recorder playback characteristics at different tape speeds vary slightly. To minimize this effect the nominal playback speed was equalized for the most likely maneuver--cruise flight. Comparisons of recorded peak noise output at various speeds showed little change from 3 to 18 ips.

Airframe Noise Simulation - The need to control the level of airstream noise apart from the engine propeller noise is crucial during phases of flight in which the engine is run at or near idle (low propeller rpm). This is a common configuration during final approach or descent. For this reason, the simulation provides a separate source for aerodynamic noise. The airframe noise produced by general aviation aircraft was recorded in the planes used as models for this simulation. With the engine shut down and propeller stopped the plane was flown at 60, 80, 100, and 120 knots. Instrumentation recordings of airframe noise were obtained (Figure 1). The noise spectrum as measured near the right ear of the pilot of the aircraft is a broad band noise that can be simulated by rolling off "pink noise" (noise that contains equal energy per octave) at approximately 3 dB per octave above 200 Hz. This spectrum slope agrees with that obtained in other types of aircraft (Hubbard & Houbolt, 1961). Notice that the spectrum shape tends to be invariant over changes in airspeed, although the octave band levels increase. The recordings were made starting at an altitude of 8000 ft., but changes in altitude are believed to make only small changes on spectrum and SPL (v. Gierke, 1957b).

In the simulation a pink noise generator plays its signal through a spectrum tilting network so that the output approximates the overall spectrum shape of the airframe noise measurements. The airframe noise level is proportional to aircraft airspeed, and grows at slightly more than the square of the airspeed (v. Gierke, 1957b). To produce these changes in the airframe noise as a function of airspeed, the airframe noise signal is fed through a voltage controlled amplifier whose control voltage is derived from the signal that operates the simulator's airspeed indicator. As the computer changes the simulator airspeed indicator, the voltage controlled amplifier passes an ever greater airframe signal level to the airframe speaker systems. Thus, if the simulator was at 10,000 feet, the throttle retarded and the mixture control placed in idle cut-off, then as the airspeed increased during a noise-down maneuver, the airframe noise level would increase to follow the airspeed indicator.

It should be noted that the simulator environment was not a closed chamber. Because of the need to introduce other instrumentation into the simulator, a large opening to the left of the pilot at the position of the pilot's window provided acoustic coupling between the interior cabin of the simulator and the interior volume of the simulator room. The original plan for the noise simulator envisioned a speaker system mounted outside the simulator cockpit and directing sound energy into the cockpit through the cockpit walls. Thus, the sounds impinging on the simulator hull would reproduce the sound impinging on the hull of an actual aircraft. However, the need to keep the sounds in the General Aviation Simulator laboratory environment within reasonable bounds made it necessary to abandon this original procedure and use an in-cabin speaker array to simulate the acoustic environment. Insofar as findings from this simulation suggest the importance of a thorough analysis of aircraft noise, the contruction of a new simulator facility isolated from the other facilities of the laboratory is recommended. This would make possible the use of the originally proposed simulation technique: an acoustically superior method.

The simulator room encloses approximately 85 cubic meters as compared to the General Aviation cabin whose interior volume is 5.8 cubic meters.

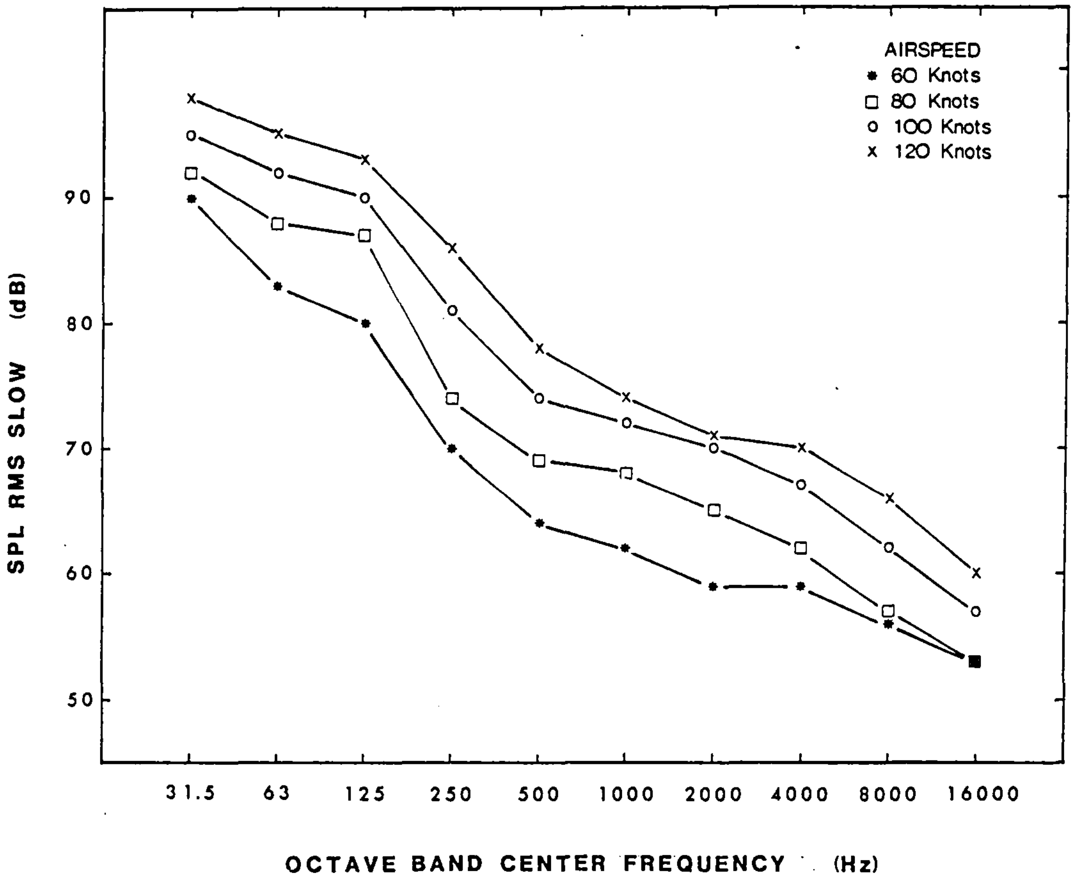

Figure 1

Aerodynamic noise spectra in a single engine aircraft measured in flight at four airspeeds (engine and propeller stopped).

Figure 2 is a schematic diagram of the location of the speakers inside the cabin of the General Aviation Simulator. Figure 3 is a photograph of the control panel of the simulator noise sources. Note that there are three classes of acoustic signal transmitted to the aircraft simulator cabin. There is a low frequency component from the engine noise simulation signal that drives a 38 cm diameter low frequency speaker mounted in a 1.3 cubic meter sealed enclosure behind the pilot's seat and angled slightly toward the right forward corner of the cabin. The remainder of the engine noise signal passes through a set of eight 4-inch speakers mounted in pairs radiating front and back from the spar box that supports the pilot and copilot seats. The third component of the signal, the aerodynamic noise simulation is delivered to two 4-inch speaker pairs. One pair is located forward of the aircraft windscreen and pointing up. The simulator windscreen itself is cut away to allow viewing of the visual screen simulation. A half-silvered mirror at 45° to the pilot's line of regard is directly above these speakers, and so reflects much of the signal toward the pilot through the windscreen aperture. The other pair of speakers is mounted in a concealed position under the aircraft control panel at the right forward section of the cockpit, angled toward the pilot.

Comparisons of the simulator sound with sounds recorded by others in a variety of general aviation aircraft have been performed: The variability in third-octave band interior noise levels, both between and within aircraft models within the general aviation category has been found to be large (Tobias, 1969). Figure 4 shows the average one-third octave band levels for inflight recordings in the planes used as models for the simulation. Also plotted are the average one-third octave band levels as recorded in identical fashion during simulated flight in the NASA simulator. As the figure shows, the maximum discrepancy in any one-third octave band is 4.5 dB. Usually the difference is less. In separate measurements, the A-weighted sound levels in the real airplane and in the simulator were found to be within ± 1 dB. Whether or not the simulation is an adequate approximation to the real situation must finally be determined in the context of the variation observed in actual flight situations. Included in the same figure is the range of measurements obtained on fifteen single engine aircraft (Tobias, 1969). The upper and lower boundaries cannot be associated with any <u>one</u> aircraft, but rather represent the total (within and between aircraft) variability. Given the range of observed values in flight, the simulator must be considered an accurate representation of real life. Nevertheless, the discrepancies deserve some comment. The consistent elevation in level, at the high frequencies of the simulator above the actual flight recording is most likely the result of insufficient high frequency roll-off in the pink noise signal. This can be corrected by including an additional filter network in the circuit. The source of the elevation at the lowest frequencies is probably due to the presence of low frequency aerodynamic noise in the engine noise recording. The introduction of a third octave equalization network on playback would resolve both this problem and the overshoot at the high frequencies. A caution in interpreting the faithfulness of the simulation must here by included.

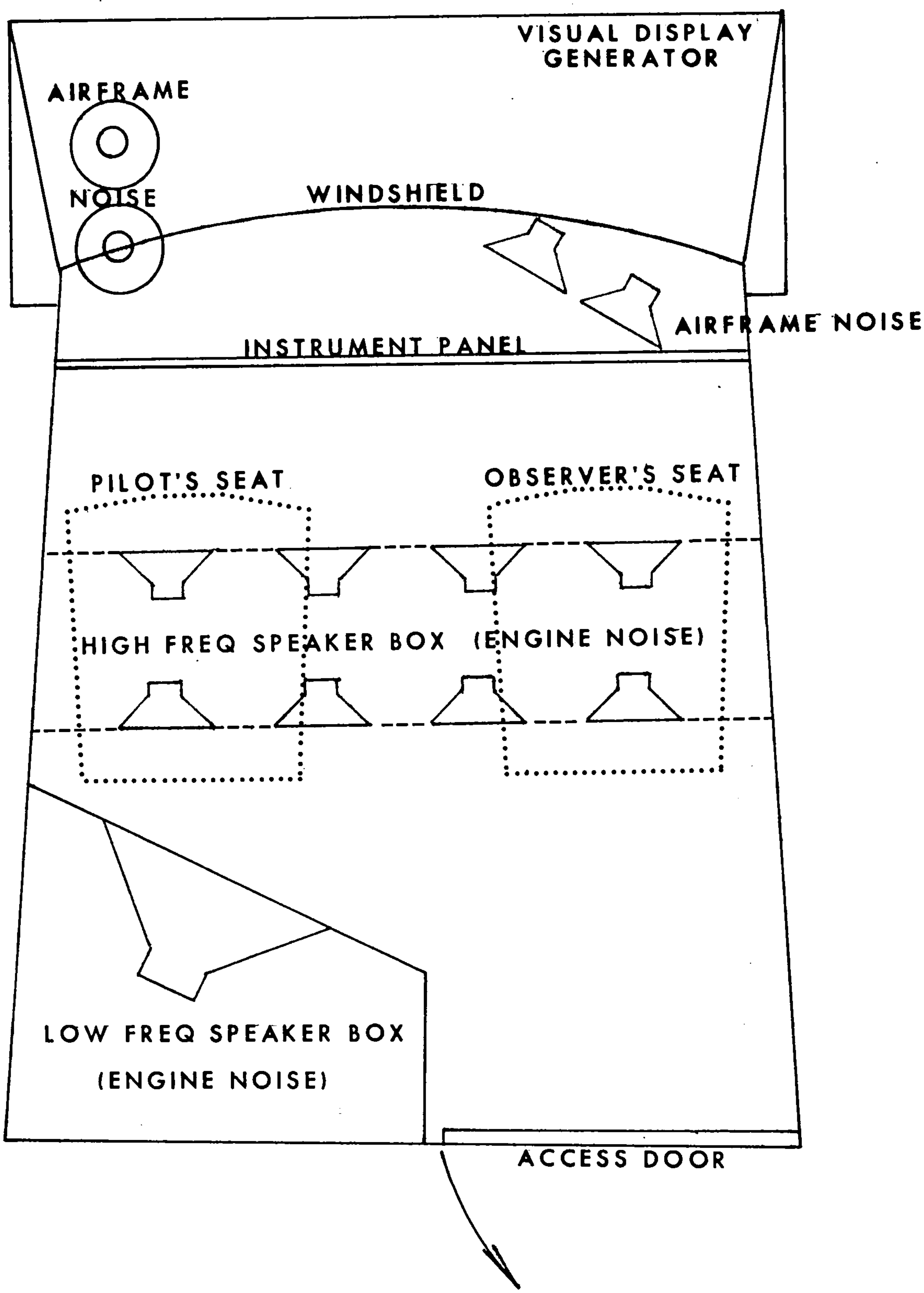

Figure 2

Cockpit location of loudspeakers for noise simulation in the NASA-Langley General Aviation Simulator.

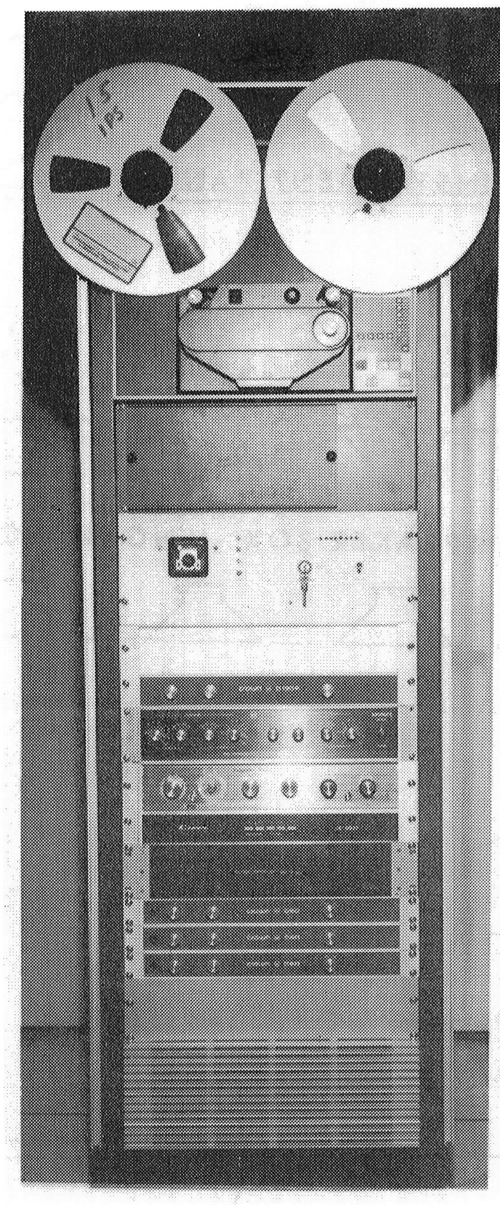

Figure 3

Control panel arrangement of noise generating, processing, and amplifying instrumentation for cockpit noise simulation.

The above comparisons are valid for cruise condition only. However most phases of flight present operational demands on the aircraft that are similar to those encountered in cruise. Even during landing and take-off only slight changes in spectrum and almost no changes in overall level have been observed (Tobias, 1969), although some level increases during take-off have been reported (Gasaway, 1971). Nevertheless, further evaluation of simulator quality is called for during a wide range of flight phases.

Before reviewing the psychoacoustic data and analysis the safety systems are described which were incorporated in the simulator to prevent the possibility of noise levels in excess of those permitted by current OSHA regulations as well as the Man-Rating Committee requirements of the NASA-Langley Research Center. In order to defend against inadvertant changes (increases) in SPL, the master gain control of the pre-amplifier through which all of the signals are passed is adjusted by a lock-nut and consequently cannot be moved without conscious effort. In addition, the output signal from this pre-amplifier passes through a key switch attenuator which permits maximum signal levels of 75 dB(A) to enter the speaker system. The key switch must be operator-actuated to set the system into "real-life" levels which are permitted to go to 94.5 dB(A). (See Figure 5).

The speaker outputs of the power amplifiers are fitted with crowbar circuit systems of matched Zener diodes that will clip voltages that would drive the speaker output above 95 dB(A). Within the simulator cockpit there is a microphone actuated relay that will short the outputs of all of the amplifiers to ground if the microphone reads a signal level in excess of 94.5 dB(A). The sensitivity setting of this unit is nut-locked and its calibration is checked daily as well as before any simulated flight. This microphone monitoring system is itself fail-safe in the sense that interruption of the AC power to the unit will result in engine noise shutdown.

Psychoacoustic Comparisons

The data in the preceding sections show that the physical parameters of the sounds in the General Aviation Simulator are essentially identical to those recorded in an actual aircraft during equivalent operational maneuvers. But the primary justification that the acoustic signals in the simulator represent the same effect as the sounds in the actual airplane can only come from human judgments that demonstrate a strong conformity in comparisons of transcriptions of actual aircraft sounds and transcriptions of sounds recorded in the simulator. To this end a series of psychoacoustic experiments were conducted, as described below.

Judgmental Functions of Psychological Dimensions - Nine subjects were run in the Psychophysics Laboratory in Atlantic City, five general aviation pilots (four male and one female) and four other adults, two male and two female. Signals recorded from the simulator, and from other aircraft were transferred to a single tape so that sequences of

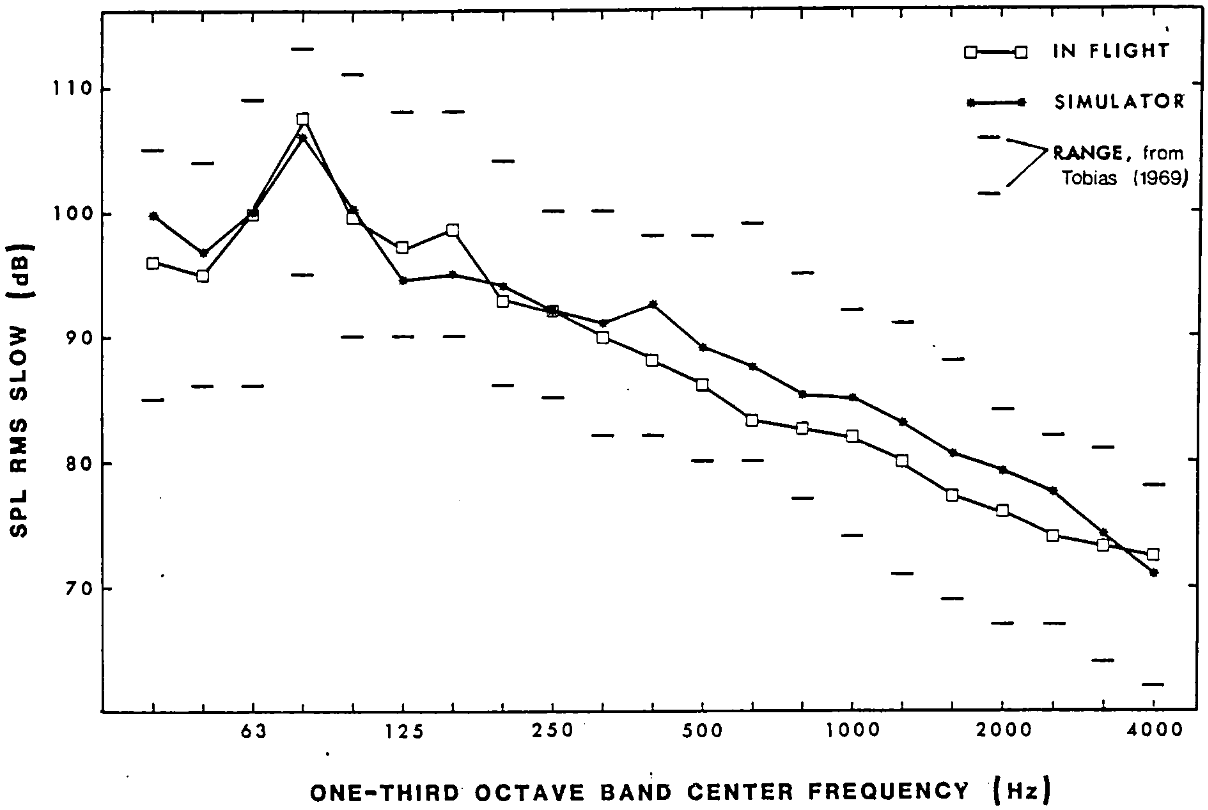

Figure 4

Comparison of noise spectrum obtained in actual cruise flight with spectrum from cruise simulation in the General Aviation simulator. The dashes indicate the range of levels obtained by Tobias (1969) inside 15 single engine aircraft during cruise.

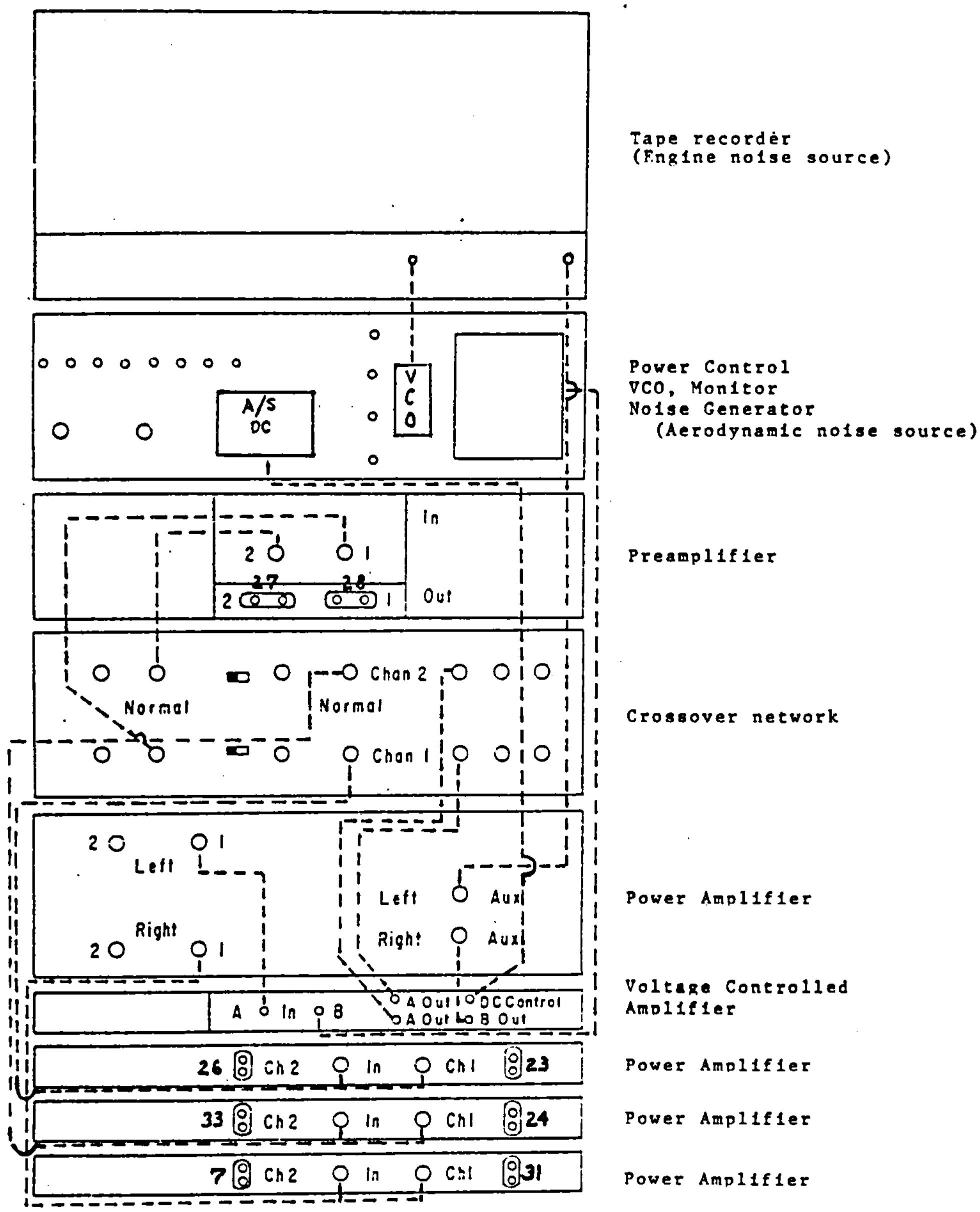

Figure 5

Component connections of simulator electronics.

5 sec. sounds from the General Aviation Simulator operation as a PA-28; a real PA-28 at cruise; or a C-172 at cruise were played in an irregular order. Each trial consisted of 5 seconds of one of the three signals at one of seven different amplitudes from 65 to 95 dB(A). The signal amplitudes were equated for each of the different signal sources in terms of their A-weighted sound levels. Thus a simulation signal at 85 dB(A) and an actual C-172 at 85 dB(A) were construed as equivalent in intensity. Observers were administered standard magnitude estimation judgment instructions for judgments of loudness. Figure 6 represents the geometric means of the judgments of the nine observers for each of the twenty-one signals (three aircraft times seven levels.) Each observer was run through the sequence twice using either an 80 dB signal as a standard modulus given the value "100" or a signal of 85 dB(A) was used as the modulus and called "10." The order of standards was randomized between observers. The analysis of these data adjusted the second run by a multiplicative factor (0.1 or 10) and an additional multiplier to adjust modulus level, so to make all judgments numerically comparable to the first run. All data were then appropriately converted to a convenient scale. The subject's data sheet shows 25 trials/session. This display minimizes "anticipatory cognitive shutdown," a kind of serial position effect observed at the end of any series of experimental trials.

A second experiment was run using four observers from the preceding experiment and adding two additional observers who had not participated in the first experiment. In this design subjects were presented with three five second bursts of sound per trial. The three bursts consisted of the recording of an actual 172 at cruise, the recording of an actual PA-28 at cruise, and the recording of the simulator at "cruise." The order in which the three events occured was randomized from trial to trial. The sound levels of the three events were equated on the A-scale. For each trial the levels were presented at either 75, 80, 85, or 90 dB(A). The subjects were given the following instructions:

> "Different kinds of aircraft are often considered to have different degrees of noisiness. In this experiment we are going to ask you to judge the noisiness of three different airplane sounds. Each trial will consist of three five-second sounds of three different airplanes all at the same intensity. At the end of each trial I will ask you to tell me which was the noisiest, the first, the second, or the third. All you have to say at the end of each three sounds is one, two, or three. The three sounds will occur at different intensities during different trials, but we would like your judgments to rep resent the noisiness within each group of three, not between one group and another. Do you have any questions?"

Any queries that did not bear on the trial sequencing or the identifiability of the aircraft were answered. The six possible orders of the presentation of the three aircraft were repeated at each amplitude level, for a total of twenty-four trials per subject.

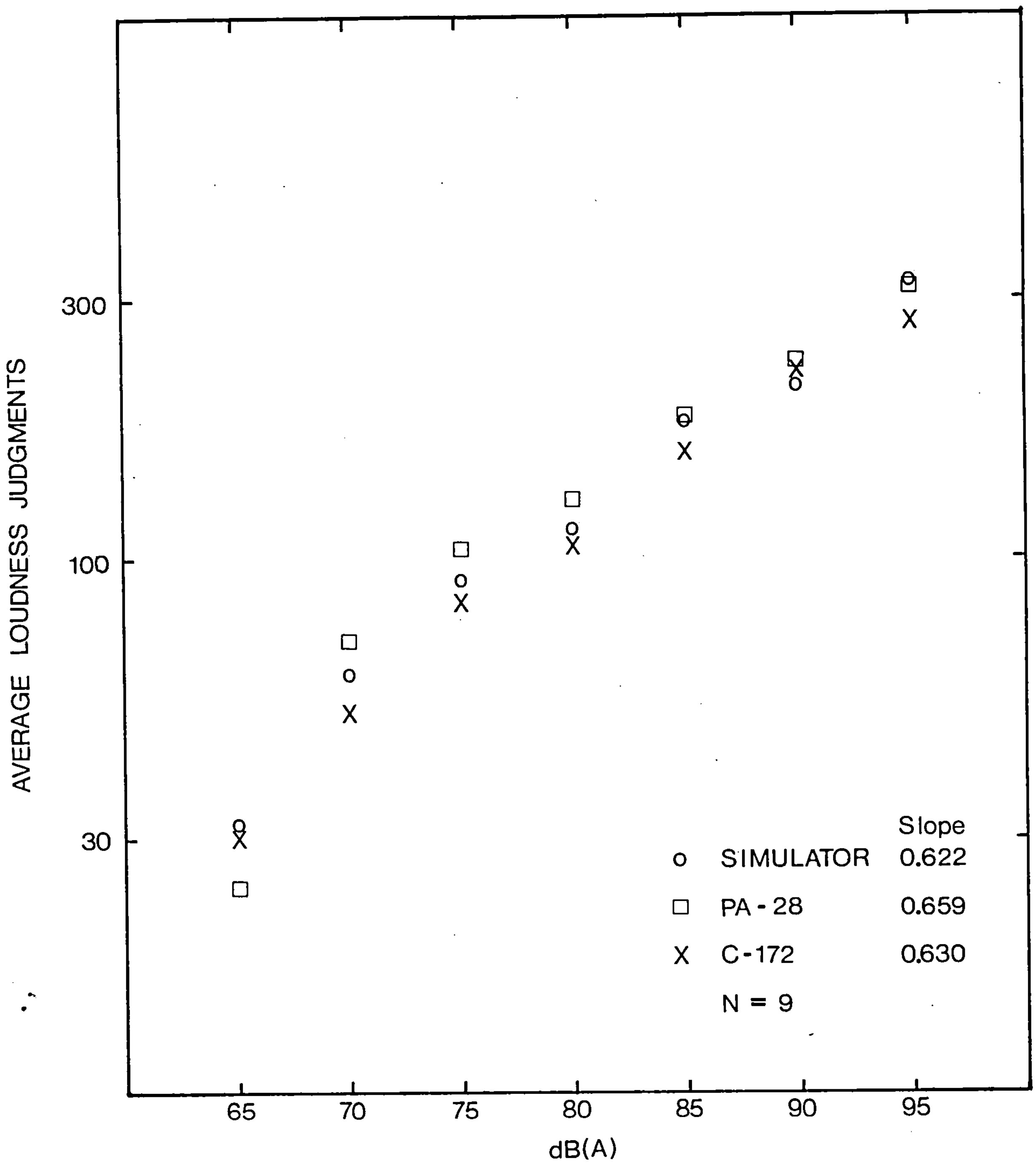

Figure 6

Loudness functions for in-flight and simulated noise spectra.

A plot of the average loudness judgments (Figure 6) demonstrates without question that the growth of loudness of the simulator aircraft is indistinguishable from the growth of loudness of a real airplane. This result is not surprising, and yet it does represent the fact that over the dynamic range of intensity levels that a pilot is likely to experience in the simulator, variations in intensity level will not give rise to unusual experiential effects or effects that are noticeably different from such experiences in an actual aircraft.

The second experiment demonstrates the intrinsic confusability of the simulator with the other aircraft by requesting that the pilots identify the noisiness of the "worst" aircraft. Table 1 represents the subjects' judgments for each of the intensity levels at which the signals were presented. A goodness of fit test shows that none of the three spectra is chosen as worst significantly more often than any other. The point this experiment demonstrates is not that pilots or anyone else would be incapable of distinguishing one aircraft from another, but rather that qualities of the simulator or the aircraft sounds are not so unique as to render them identifiable on any given judgmental dimensions. If individuals were asked to absolutely identify which of three aircraft was being presented on each trial they might make those identifications with zero or few errors. This is because all the aircraft in fact have distinctive signatures. However, the signatures of the two real aircraft are in no way intrinsically different from the signature of the simulator.

dB(A)	Simulator	PA-28	C-172
75	11	11	14
80	14	11	11
85	11	11	14
90	12	9	15
	Σ 48	42	54

$\chi^2 = 1.5$ df = 2

Not Significant

Table 1

Frequency of Judging One of Three Spectra as "Worst" (Six Subjects)

Discussion

The physical comparisons and the psychophysical judgments both point to the realism of the sound generated by the acoustic simulator. But equally important is user acceptance in terms of subjective evaluation by the subject pilots who fly the machine. During initial studies of the effects of the simulated noise on pilot performance, it was possible to interrogate the pilots who fly the simulator under three noise conditions: no noise, low noise (ca. 75 dB(A)), and real life noise (ca. 95 dB(A)).

Of the four subject pilots who flew the simulator during the summer of 1979, three of them were able to provide subjective reports. In these reports a single comment emerges, that is that the simulator noise levels seem louder than the real airplane. Using magnitude estimation judgments as the basis for evaluating the apparent difference in loudness between the simulator and the real aircraft, the pilots were asked that if the loudness of a real aircraft is rated as "100", then proportionately what is the loudness of the simulator? The replies ranged from "120" to "175". These loudness ratio judgments, based as they are upon remembered loudnesses in a real aircraft, may be attributable to two psychological sources. On the one hand, expectations of the pilot in a simulator located in a laboratory environment in a small room may lead him to believe that such loud sounds are louder than they would be in an aircraft. This response bias, in the form of expectation changes, may be the source of these judgments. On the other hand, proximity to a sound source may result in a growth rate of loudness that is faster than the classical 10 dB for each doubling of loudness. That is to say, subjects may modulate their loudness judgments by identifying the sound source as being in close proximity to them. This question may be answered experimentally by examining loudness growth rate as a function of sound source distance.

The second point reported on by one of the pilots was that the "vibrations" induced by the noise seemed to be uncomfortable as compared to those in a real aircraft. The pilot pointed out that real aircraft vibrations are usually transmitted through the aircraft structure whereas the vibrations in the simulator appeared to affect the body directly. It is possible that the physical location of the low frequency speaker directly behind the pilot's seat produces a more efficient coupling to the pilot's body at low frequencies than is encountered in the real airplane. A comparison of vibration spectra obtained in real and simulated flight would help clarify this point. It should be kept in mind, however, that the region of maximum vibration annoyance (below 10 Hz, see Dempsey et. al., 1979) is below the cutoff frequency of the low frequency speaker (approximately 22 Hz) and that in the <u>audio</u> range (above 20 Hz) the simulator and the real airplane are in good agreement (see Figure 4).

In general the pilots found the audio simulation very realistic.

However, one pilot did note that the airstream noise seemed relatively more intense in the simulator than in a real aircraft. This may be a phenomenon attributable to the possible localization of the airstream noise as arising from a source independent of the engine noise. It may also be the case that further adjustment of the balance between the airstream noise and the engine noise components of the audio system may be necessary to represent psychologically the apparent balance between the two sources. Insofar as cabin ventilation noise may be identified as airstream noise, the variability of this source from one plane to another may also explain this comment.

Two of the three pilots found that although the noise was annoying they did not believe that it interferred with their piloting tasks. One of the three on the other hand thought that the noise might have some detrimental effect on his performance, although he was unsure exactly how the effect might be influencing him. Insofar as data on pilot performance were obtained in these initial runs, it will be possible to compare performance under various noise level conditions to ascertain objectively whether the noise levels did have such an effect.

Conclusions

The acoustic real life noise simulator introduced into the General Aviation Simulator at the NASA-Langley Research Center was shown to conform physically with the acoustic parameters of a real aircraft in flight. It was also shown that psychophysical judgments concerning the nature of the noise made by subjects who listened to recordings of the simulator and other aircraft did not distinguish between the simulator and other aircraft sounds. Finally, comments by the pilots in the simulator indicated that the simulator was quite realistic although the pilots believed that the sound levels, i.e. the loudness, was greater in the simulator than it was in a real aircraft. The effects of the noise on pilot performance are to be evaluated.

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1. Report No. NASA CR-159237	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Development and Evaluation of a General Aviation Real World Noise Simulator		5. Report Date March 1980
		6. Performing Organization Code
7. Author(s) Eugene Galanter and Richard Popper		8. Performing Organization Report No.
		10. Work Unit No.
9. Performing Organization Name and Address Columbia University Psychophysics Laboratory 324 Schermerhorn Hall New York, NY 10027		11. Contract or Grant No. NSG-1541
		13. Type of Report and Period Covered Contractor Report
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, DC 20546		14. Sponsoring Agency Code

15. Supplementary Notes

Langley Technical Monitor: Dr. Randall L. Harris
Final Report

16. Abstract

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17. Key Words (Suggested by Author(s)) Noise Simulation, General Aviation, Aircraft Noise	18. Distribution Statement Unclassified - Unlimited

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
Unclassified	Unclassified	19	$4.00

N-305

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