PROTECTION AGAINST HEARING LOSS IN GENERAL AVIATION OPERATIONS

Phase II

September 1972

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Prepared under Contract NASW-2265

by

BioTechnology, Inc.
Falls Church, Virginia

for

Aeronautical Life Services Division
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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Foreword

This is the second part of a two-part final report prepared by BioTechnology, Inc. under Contract NASW-2265 with the National Aeronautics and Space Administration. The work was performed under the direction of the Aeronautical Life Sciences Division with Mr. Raymond P. Whitten as Project Monitor. His help during the conduct of this study and his review and comments on the final manuscript are gratefully acknowledged.

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Introduction

One of the more noticeable characteristics of an industrial and technologically-oriented society is that it is noisy. New construction activities make noise; manufacturing processes by and large are noisy; and, in particular, all forms of transportation contribute to the noise. In commercial aviation, the noise problem has become quite severe and intensive programs of correction are underway. Consideration also is being given to techniques for combatting the noise of surface transportation. Even general aviation operations, as evidenced by several recent magazine articles, are being evaluated for their noise-producing character.

The general aviation noise problem differs from that of other transportation forms in that it has little if any impact on the public at large. The only significant effect of the noise is on the pilot and passengers, and their reaction has been to accept this noise simply as an unavoidable consequence of flying in light aircraft. As long as flights were only an hour or two and were relatively infrequent, the noise was of little consequence. Now, however, the picture is changing for at least three reasons. First, general aviation piston engine aircraft are being used more and more in everyday business operations as well as for personal transportation. In 1971, there were over 130,000 single- and multi-engine piston type aircraft registered with the Federal Aviation Administration. The total airmen licensed in 1971 was 729,900, in addition to over 127,000 new students registered in 1970. During calendar year 1970, the total number of hours flown by general avaiation aircraft in all categories of operations was 26,660,256.

The second reason for the changing picture rests with the capabilities of the aircraft now being manufactured. Many of today's single- and multi-engine aircraft can fly for five to six hours with ranges well in excess of 1000 miles nonstop. A flight, with a single refueling stop, from New England to Texas in a single day is not uncommon.

Finally, there is an increasing national awareness as to possible long term effects of frequent or sustained exposure to high intensity noise on the hearing of individuals. Noise control programs are being initiated in many fields. This new awareness also is reflected in the standards promulgated under the Williams-Steiger Occupational Safety and Health Act of 1970 (Federal Register, 29 May 1971). These standards, presented in Table 1, show the maximum period of time an individual can spend by law in an industrial noise situation without the use of some form of hearing protection.

Table 1

Permissible Occupational Noise Exposures

Duration per day, hours	Sound level dBA
8	90
6	92
4	95
3	97
2	100
1-1/2	102
1	105
1/2	110
1/4 or less	115

Occupational Safety and Health Administration,
Department of Labor

The OSHA standards, shown in Table 1, are exceeded by general aviation aircraft for flights of any reasonable duration. In a companion report to this (Phase I Report), noise levels for the various phases of flight in a twin-engine Piper Apache aircraft were measured. It was found that during the cruise phase, the cockpit intensity level was 102 decibels. This means that the maximum permissible flight duration, under the new standards, would be one and one-half hours.

In a study by Abell (1972), cockpit noise levels were measured inside three different general aviation aircraft under cruise conditions. It was found that with the radios off, intensity levels ranged from 99 to 102 dB. With the radios on, the range was from 102 to 104 dB. The author notes that every two hour flight in the aircraft which were tested would exceed the permissible limits of the Williams-Steiger Act.

It is obvious that if the new regulations are to be enforced, either the cabin noise of general aviation aircraft must be lowered or individual hearing protection devices must be used during flight. Certainly there will be continuing efforts on the part of aircraft manufacturers to reduce cabin noise in new aircraft. However, weight considerations preclude the use of heavy sound-proofing materials in the cabin or extensive baffling of engine exhaust systems. Therefore, attention must be given to the use of hearing protection devices for long duration flights, both in current aircraft and in those for the foreseeable future.

This report (Phase II) describes an inflight evaluation of four candidate aural protectors followed by the use of one system on a number of flights, with objective measures made of the protective benefit obtained by use of the device.

Aural Protectors

The basic hearing protection devices which might reasonably be used in general aviation operations are inserts, such as ear plugs; muffs (ear cups);

and helmets. There are a large number of ear plugs and ear muffs available, many of which have been tested under various conditions of military aviation. As a first step in this project, four candidate systems were selected for in-flight evaluation. These were:

1. Ear muffs
2. Plastic ear plugs
3. Rubber ear plugs
4. Wax ear plugs.

The following sections describe the specific characteristics, including measured sound attenuation, of these various candidate systems.

Ear Muffs

The ear muff device selected for test consists of two ear cups designed to fit entirely over the ears, lined with an acoustic absorbing material on the interior of the cup. An adjustable headband allows universal sizing. These ear muffs are the most expensive ($12.00) of the various protective devices considered in this study. The sound attenuation characteristics of the ear muff are shown in Figure 1, based on frequency attenuation levels provided by the manufacturer. In general, the protection seems to be excellent, ranging above 40 dB of sound attenuation for virtually all of the frequencies under consideration.

Plastic Ear Plugs

The second candidate protection system consisted of flexible plastic ear plugs, similar in shape to the V-51R ear plugs developed by Paul Veneklasen at the Harvard Psycho-Acoustic Laboratory during World War II. The V-51R ear plugs have been evaluated and referenced so often in various investigations,

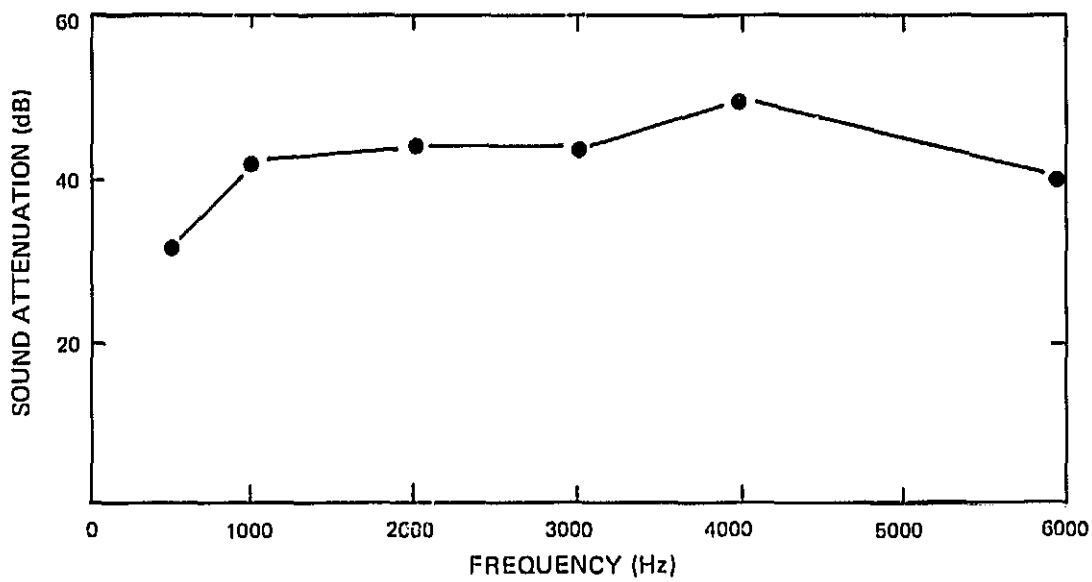

Figure 1. Sound attenuation characteristics of ear muffs.

generally in a military context, that a tendency has grown to use them as a point of reference in assessing the relative value or effectiveness of any newer device (Gasaway, 1971). The ear plug consists of a small cup approximately 1/8-inch in depth mounted on a longer fat stem extending for a total of about 3/8-inch. This is followed by a slender segment attached to one side to aid in inserting and withdrawing the plug.

Figure 2 shows the sound attenuation characteristics of the plastic ear plugs. The attenuation measures are based on tests conducted with the Ambco Model 601-B portable audiometer, averaged for two subjects. The curve in Figure 2 shows substantially less attenuation capability than was seen for the

ear muff. Part of this, however, may be attributed to the fact that the measures were obtained in a quiet but not a sound free environment under what were somewhat less than optimal conditions.

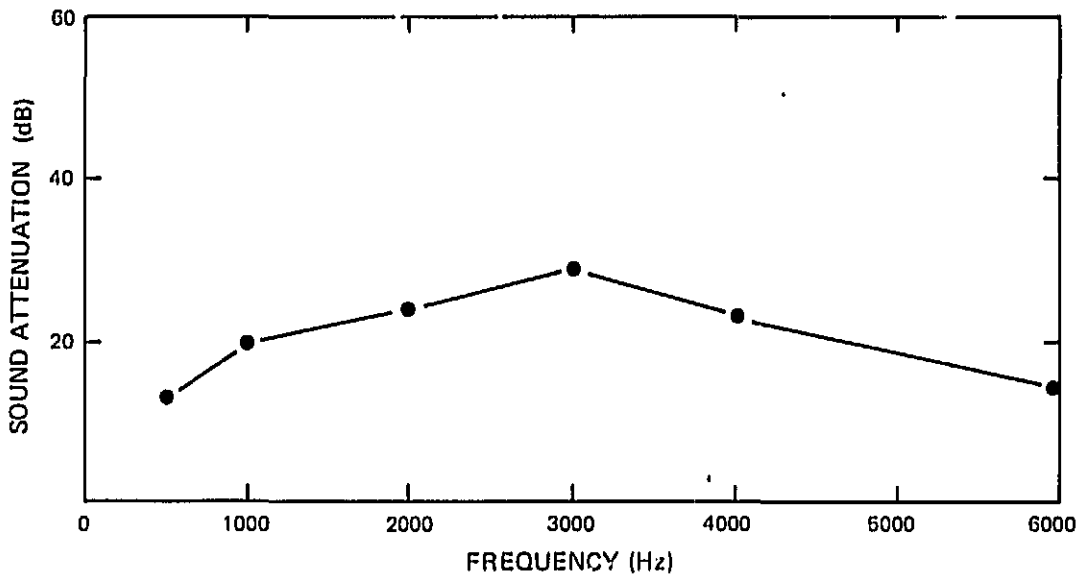

Figure 2. Sound attenuation characteristics of plastic ear plugs of V-51R type.

Rubber Ear Plugs

Rubber ear plugs were used as the third protective device. These are made of soft silicone rubber and consist of a long stem, approximately 1-1/4 inches, on the end of which are three soft rings about 1/8-inch apart. These ear plugs are inexpensive ($1.25 for two plugs with plastic carrying case) and are marketed through general aviation products retail outlets.

Figure 3 shows the sound attenuation characteristics for the rubber ear plugs. This curve was obtained through the same procedures as were

used with the plastic plugs (portable audiometer) and is seen to be quite similar in form, with maximum protection afforded in the 2000 to 3000 Hertz range.

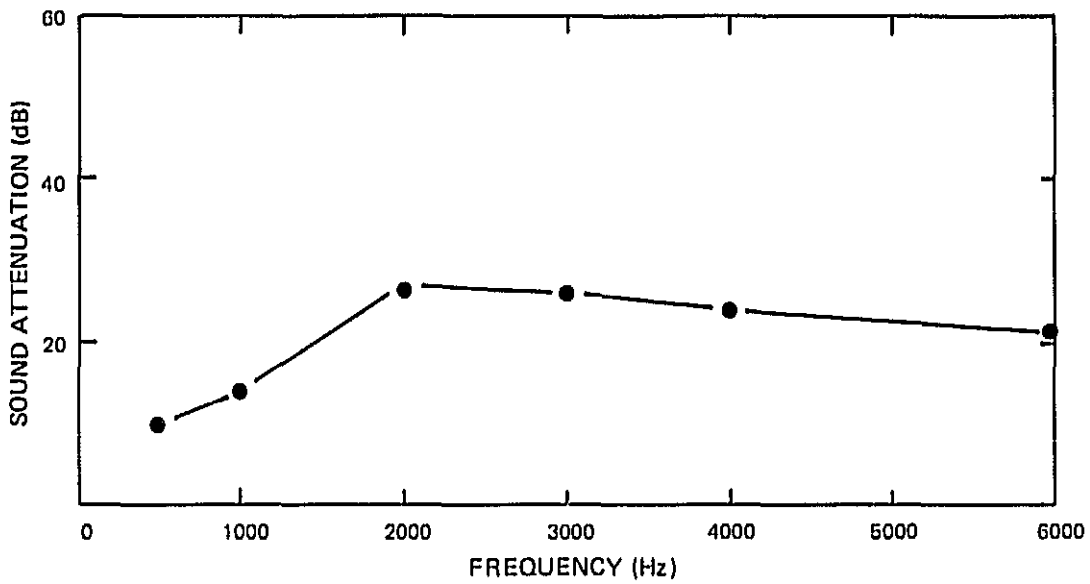

Figure 3. Sound attenuation characteristics of rubber ear plugs.

Moldable Wax Plugs

The fourth candidate protection system consisted of moldable heavy wax ear plugs. In use, the wax plug is first rolled between the fingers until it becomes soft and pliable. Then the resulting ball is placed in the ear and flattened out firmly with the thumb. In this manner, the opening of the ear generally can be completely sealed. Since a good bit of the wax protrudes from the ear opening, removal is accomplished rather easily simply by grasping the excess wax.

Figure 4 shows the sound attenuation characteristics for the wax ear plugs. Again, the curve was derived through the same procedures as followed with the two ear plugs. The form of the curve also is similar to that found for the ear plugs.

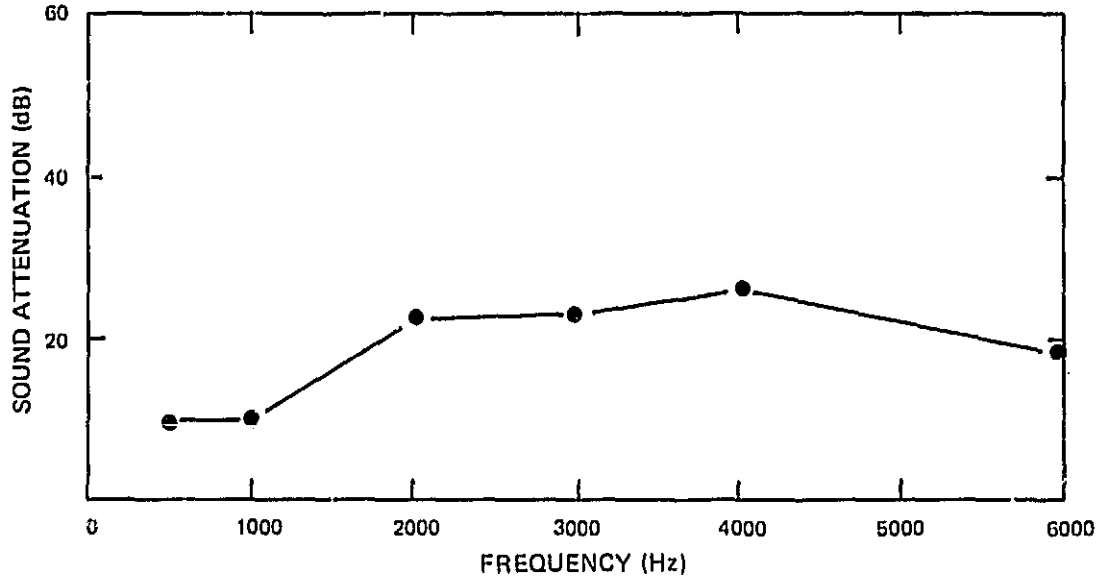

Figure 4. Sound attenuation characteristics of moldable wax ear plugs.

Selection of Protective System

Four flights, averaging about 1-1/2 hours in duration, were flown in the project aircraft with one of the candidate protective systems being evaluated in each flight. An evaluation form was developed so that both the pilot and co-pilot could record their assessment of each system at the end of the flight on which it was used. Systems were rated for general acceptability, comfort, and compatibility with required communications activities, both within the cabin and over the aircraft radio. The purpose of this evaluation

was to select one system for more extensive inflight evaluation in terms of the actual protective benefit provided by it.

Table 2 shows the evaluation code which was used, in which systems could be rated from "quite acceptable" to "unacceptable," and the results which were obtained. It can be noted that in only one instance was any device given a 4 rating on any of the four dimensions of evaluation. The wax ear plugs were considered quite acceptable in terms of comfort by both pilot and co-pilot. In general, the overall acceptability of all four devices was rather low, ranging from 0.5 to 1.5 in terms of average rating. This means that the two most acceptable devices, the plastic ear plugs and the rubber ear plugs, were rated as intermediate between "all right--no obvious benefit" and "somewhat undesirable."

On the basis of the inflight evaluation results shown in Table 2, the plastic ear plugs and the rubber ear plugs were considered to be the leading contenders for further evaluation. The rubber ear plugs were selected since they seemed to be a bit better in terms of cockpit communications and, in particular, since they were readily available as a general aviation product. A supply of rubber ear plugs was acquired and potential subjects indoctrinated as to proper use.

In the process of selecting a system for further evaluation, little attention was given to the sound attenuation characteristics of the various systems. With a cockpit noise environment of 102 dB, only 10 dB of attenuation would be required to bring the effective noise level down to a point at which a six hour nonstop flight would be within permissible limits. Therefore, although the ear muffs obviously provide more sound attenuation than do the other three devices, they were given no special consideration in this regard. All systems were found to provide an overall sound attenuation in excess of 10 dB, making each one completely acceptable on the basis of protective qualities alone.

Table 2

Results of Inflight Evaluation of

Four Aural Protectors

Evaluation Code	
Quite acceptable	4
Acceptable	3
All right - no obvious benefit	2
Somewhat undesirable	1
Unacceptable	0

Dimensions of Evaluation	Device			
	Ear Muffs	Plastic Plugs	Wax Plugs	Rubber Plugs
Cockpit communications	0	1	0	1.5
Radio communications	1.5	2.5	3	2
Comfort	1.5	2	4	1
General acceptability	0.5	1.5	0.5	1.5

Flight Test Program

The protection characteristics of the selected system, the rubber ear plugs, were evaluated in more extended flights with, as in Phase I, an audio-

gram obtained immediately before and immediately following each flight for each subject. An attempt was made to use the same subjects for this part of the evaluation program as were used for the initial determination of threshold shifts following fixed periods of exposure (Phase I). On this basis, immediate comparisons could be made of the protection afforded by the device by referring to audiograms made during the earlier phase of this program. With one exception, however, this objective proved impractical since subjects from the earlier phase were unavailable by virtue of changes in employment or were ill at the time of the scheduled flight. For this reason, certain adjustments were made in the flight test program to allow the appropriate comparisons to be made.

In the first part of the flight evaluation, each subject wore the protection system continuously during a four hour flight exposure. In the second part, the flight was six hours in length. On this flight, no protection was used during the first two hours, with the rubber ear plugs worn only during the final four hours of the flight. This was done to see if a reasonable protection level could be achieved in longer flights without the requirement for continuous wear of the protection system. On six hour flights, a refueling stop is required at the three hour point. The subjects therefore used the ear plugs during the final hour of the first three hour leg and continuously during the final three hours.

Subsequent figures show the hearing loss suffered by subjects following various inflight exposures. These curves are developed simply by subtracting, at the six frequencies for which measures were made, the preflight hearing loss from the postflight hearing loss. In the rare instances in which hearing was found to be improved at a given frequency following a flight over that which had been measured prior to the flight, the hearing loss simply was scored as zero for that particular frequency. The observed improvement was judged to be an artifact of the measurement process.

Figure 5 shows the results for one subject for a four hour flight in which ear plugs were used as compared to a comparable flight using no aural protection. It was a rather dramatic finding to note that, for this subject, no hearing loss was observed at any of the measured frequencies following the flight in which ear plugs were used. On the earlier flight, with no plugs, this subject showed a substantial hearing loss, in excess of 20 dB, at the frequency range around 4000 Hz. It is obvious that in this instance the ear plugs were totally satisfactory as a protective device.

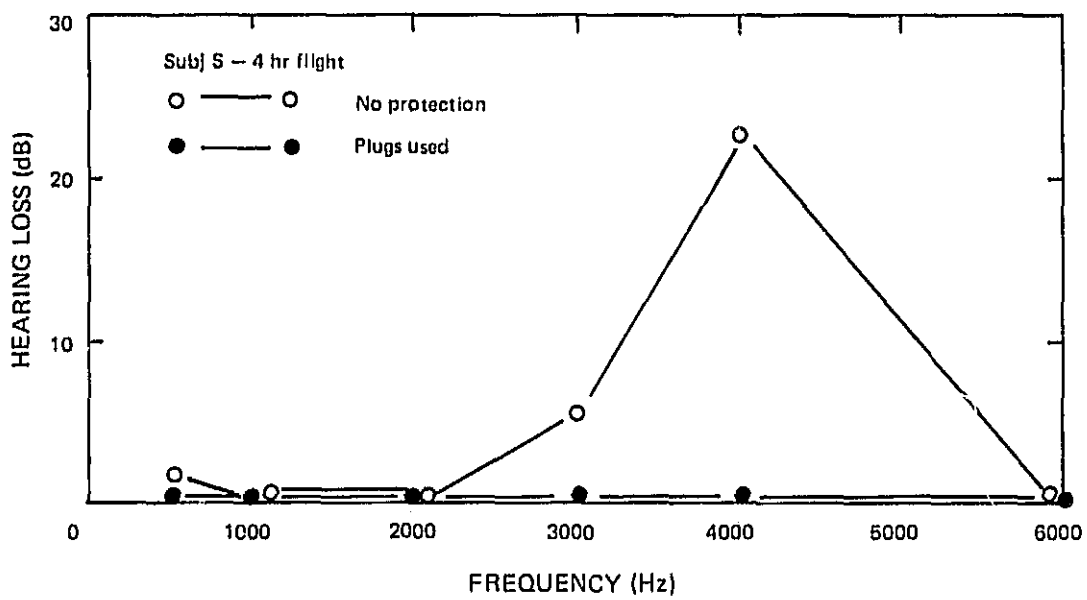

Figure 5. Protection afforded by use of rubber ear plugs for four hour flight (subject S).

Figure 6 shows the results for a second subject with and without protection on a four hour flight. The curve showing the results when ear plugs were used is an average of two four-hour flight exposures. Again it can be seen that, while hearing loss was not zero using the protective system, a significant measure of protection was afforded by the ear plugs. In all, the use of

the plugs brings the hearing loss down to acceptable temporary threshold shift levels.

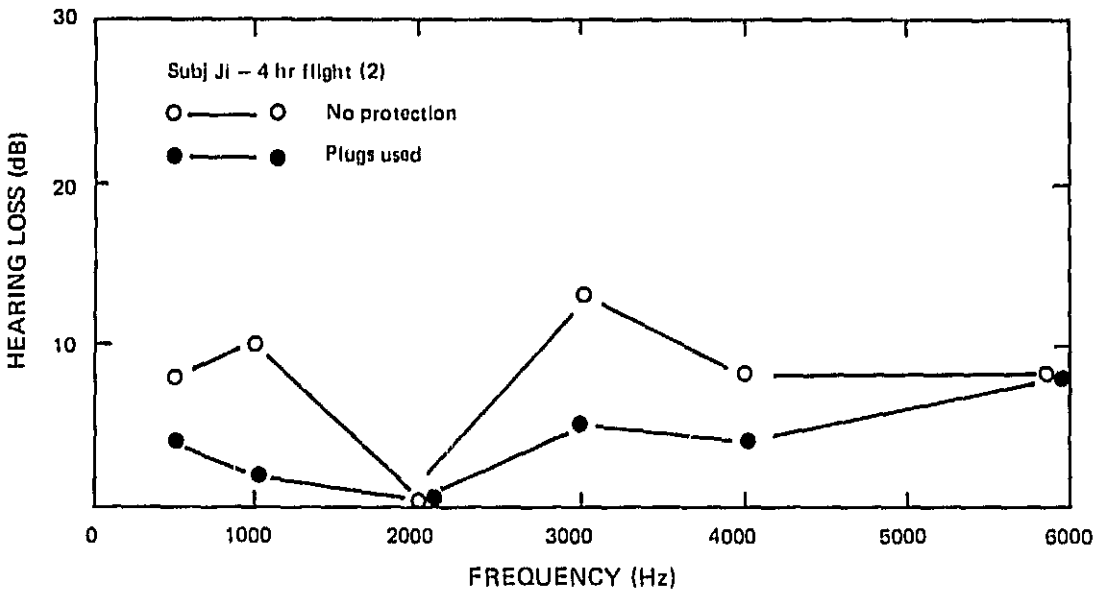

Figure 6. Protection afforded by rubber ear plugs for a four hour flight (subject JI).

Figure 7 presents the results for three subjects in which hearing loss was measured following a six hour flight exposure with the rubber ear plugs used during the final four hours of flight. Although some loss is noted for all subjects at certain frequencies, in no case does the measured hearing loss exceed 10 dB. For the most part, the loss ranges from 5 dB to 0, very reasonable following a six hour exposure to a 102 dB noise environment.

For one subject it was possible to make a comparison of the six hour flight using the ear plugs during the final four hours with an earlier flight in which no protection was used for the entire six hour exposure. These results are shown in Figure 8. Again it can be seen that use of the ear plugs does

result in a lessened hearing loss. It is interesting, however, that at the 2000 and 3000 Hz frequencies no loss is seen for a flight of this duration even when no protection is used. This may be an artifact of some kind since this subject (noted as subject 4 in the Phase I report) did show a hearing loss of 5 dB or greater at both of these frequencies for two hour and four hour flights using no protection. This obviously is not in keeping with the general finding among all subjects that hearing loss increases as the duration of noise exposure increases.

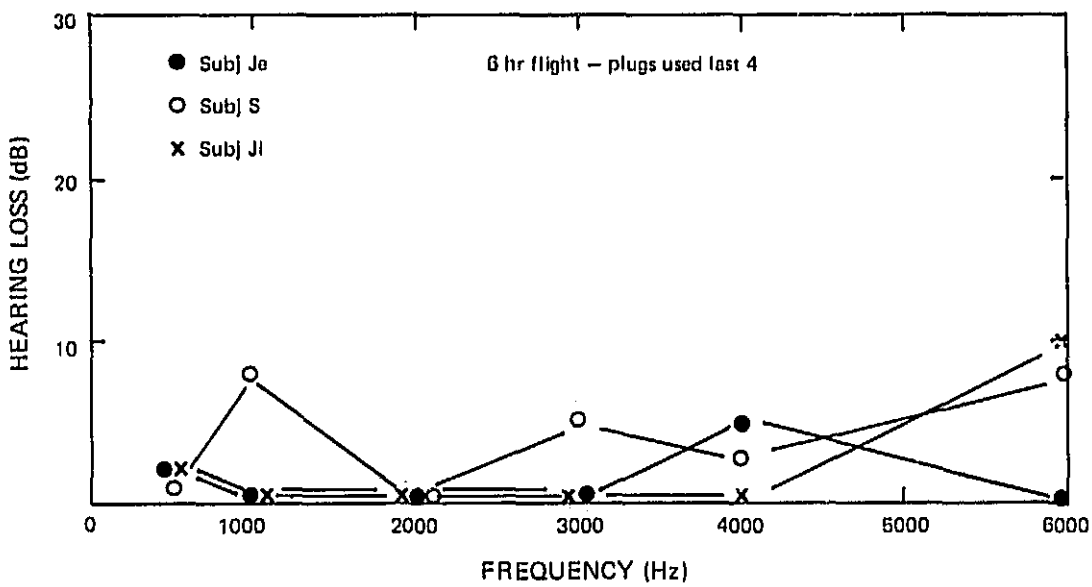

Figure 7. Measured hearing loss for three subjects following a six hour flight with ear plugs used during the final four hours.

Figure 9 presents data which can be presumed to have more stability than those determined from measures of a single subject. These curves show the results of six hour flights taking the average response of six subjects who used no protective device (Phase I). These results are compared with a comparable six hour flight, based on an average from three subjects, in which

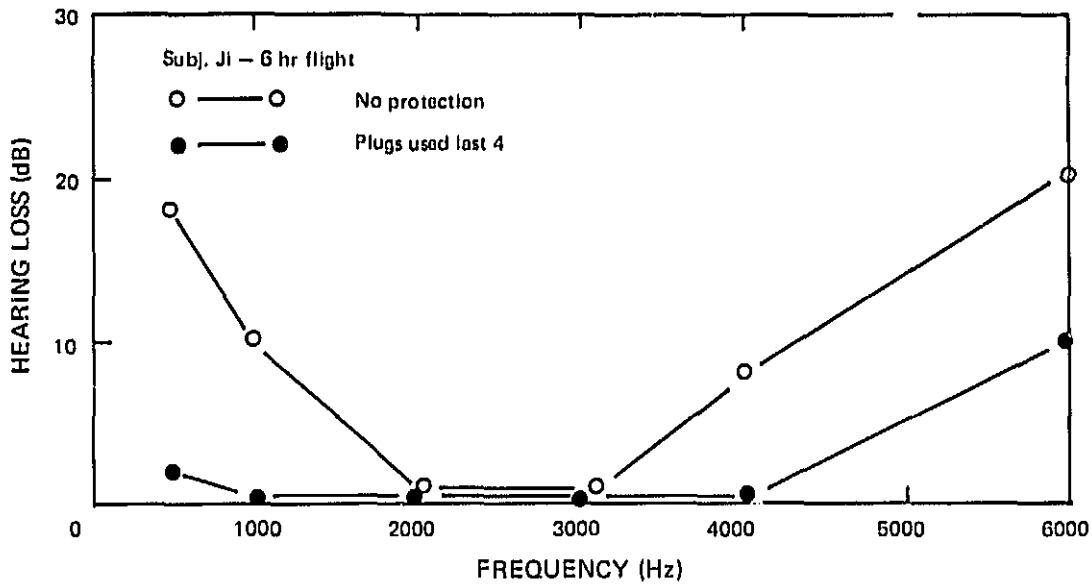

Figure 8. Protection afforded by use of ear plugs during the final four hours of a six hour flight for one subject.

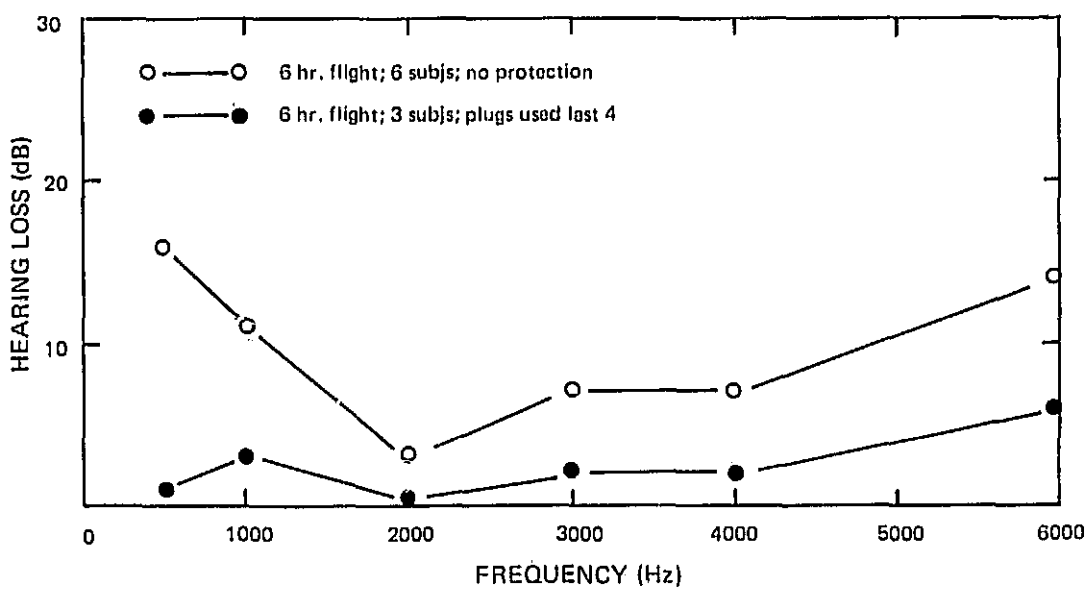

Figure 9. Average protection afforded through use of ear plugs in the final four hours of a six hour flight.

ear plugs were used during the last four hours of flight. Here the curves are quite clear in showing the protective benefit to be derived through use of the ear plugs. With no protection, hearing loss exceeds 10 dB at three of the data points. When ear plugs are used during the final portion of the flight, the temporary hearing loss is reduced to much smaller levels, for the most part ranging again between 0 and 5 dB of threshold shift.

When ear plugs are used only during the final four hours of a six hour flight, it can be presumed that there is a measurable loss of hearing during the first two hours, as verified by the results of Phase I, and that this loss either will be sustained at that level during the remaining four hours of flight or will show some measure of recovery as the use of ear plugs reduces the effective noise level to a more acceptable value. Figure 10 presents curves which compare the results of a two hour flight, averaged through six subjects, in which no protection was used with that of a six hour flight, averaged through three subjects, in which plugs were used for the last four hours. Here the curve for the six hour flight reflects a lower hearing loss at all data points than does that for the two hour flight. These curves indicate that a significant hearing loss occurs following a two hour exposure, reaching a 10 dB level at 500 Hz, but that a significant recovery of hearing function occurs if hearing plugs are used during remaining portions of a flight. These results clearly indicate that some measure of protection can be achieved in longer flights without a requirement for continuous wear of a protective system. It might well be that for certain reasons, such as ear discomfort or interference with communications during a critical phase of flight, continuous wear of a device such as ear plugs would be undesirable. In this event, hearing loss can still be controlled to acceptable limits by the use of aural protectors during only a portion of the flight.

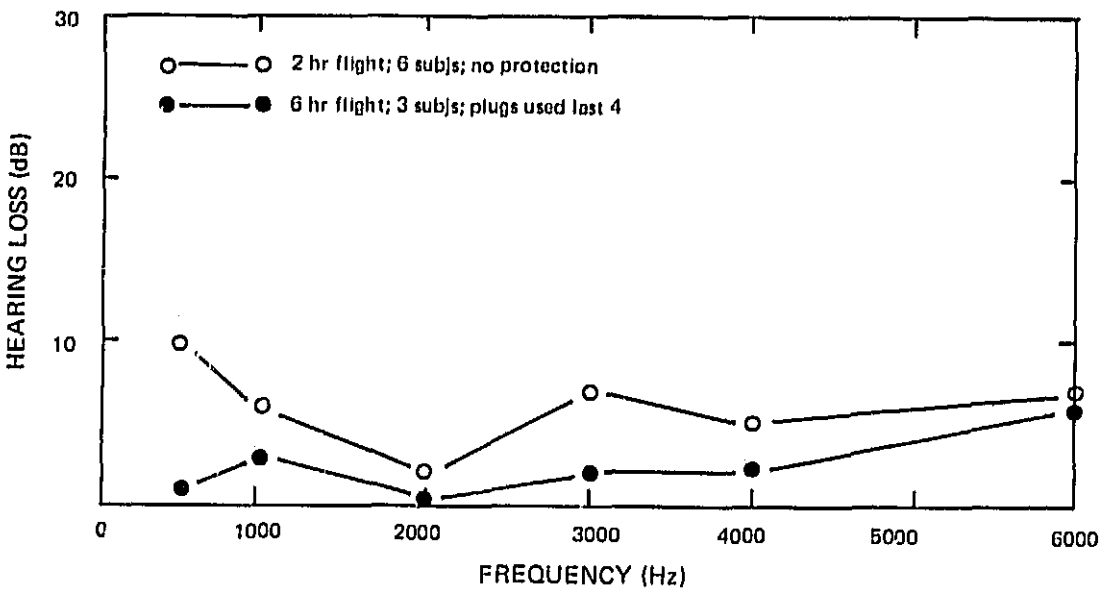

Figure 10. Comparison of six hour flight results, with ear plugs used during final four hours, with a two hour flight with no protection.

Discussion and Conclusions

The purpose of this study was to investigate short term hearing loss due to flight in general aviation aircraft and to determine empirically the protection which might be obtained through use of aural protectors. The results of this study bear on a number of issues relating to measurement of hearing loss and to the use of protective devices. The principal issues are:

Protective Benefit

All project data are consistent in showing that a significant reduction in hearing loss can be achieved through the use of some aural protective system such as rubber ear plugs. In general, measured hearing loss following an extended period of flight does not exceed 5 dB when ear plugs are worn. Even

greater protection could be obtained through the use of an ear muff type of protective system. The ear muff type of device consistently shows a 5 to 15 dB superiority over ear plugs in terms of sound attenuation (Gasaway, 1971). However, as noted earlier, the general aviation noise environment, which seems to be fairly consistent at 100 to 104 dB of cabin noise, does not require more than about 10 dB of noise attenuation even for maximum duration flights. This level of attenuation generally can be achieved through the more simple system of ear plugs and does not require the use of the heavier and more expensive ear muffs. In all, it is concluded that ear plugs are entirely satisfactory when evaluated solely in terms their capability to provide the necessary sound attenuation in a general aviation aircraft.

Variability

In all phases of this project, substantial variability in subjects' responses was noted. Part of this variability may be inherent in the organism. However, it is obvious that part of it must be attributed simply to the difficulties of obtaining a precise measure of auditory acuity, particularly when the measurement is attempted under field conditions. An example of the variability which was noted can be seen in Figure 11, which shows the measured sound attenuation achieved with two subjects while each was using the rubber ear plugs. At a frequency of 3000 Hz, one subject shows that the sound attenuation (protective benefit) of this device is almost twice that found for the other subject. To the extent possible, this variability was controlled by presenting information representing an average response of a number of subjects. However, even then it should be recognized that a certain measure of variability remains in the data and that response curves by no means represent the definitive statement as to attenuation or hearing loss. A curve showing a 20 dB attenuation at 2000 Hz reasonably should be interpreted to mean that one can expect an attenuation at this frequency ranging probably between 15 and 25 dB if further measures were to be taken.

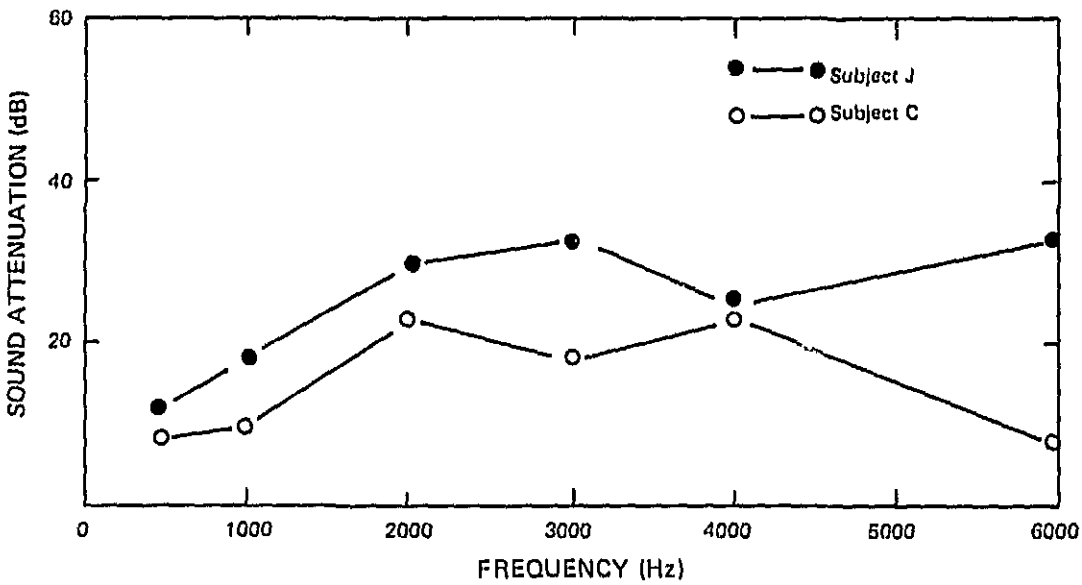

Figure 11. Illustration of variability encountered in determining sound attenuation characteristics of rubber ear plugs.

Device Use

If a protective device such as ear plugs is to be considered for use in light aircraft, there are certain problems which must be handled. All persons who use ear protection devices, even if for just a single exposure, should receive adequate explanation as to their use. Gasaway (1971) suggests that an indoctrination program concerning the use of protection devices should include four principal points: (1) Unless an ear protection device obtains and retains an airtight seal, the device is not effective; some devices may work loose and thus will require reseating in order to re-establish an airtight fit; (2) an adequate airtight seal cannot be obtained during initial fittings without a slight

degree of discomfort; (3) ear protection devices should be kept clean, and if the device becomes hard or causes undue irritation, it should be replaced immediately; and (4) warning signals and loud communications can still be understood when wearing ear protection in a noise environment.

The above guides by Gasaway are concerned principally with using a protection device properly. Another, and possibly even more severe problem, concerns getting people who are not particularly sensitive to this issue to use protection devices at all. As Gasaway notes, getting persons to wear ear protection devices in intense noise poses no great problem. The real problem is getting people who work in less intense but still potentially hazardous noise environments to wear ear protection. This is certainly true for general aviation personnel. It may be especially true in this case since all of the aural protectors considered in this project imposed some measure of discomfort. The discomfort associated with use of the rubber ear plugs for a continuous four hour period was noted by all subjects. Each person expressed considerable relief when the test period was over and the ear plugs could be removed. In one instance, a subject noted a minor earache which persisted for about two hours following the test period. Obviously, it will be difficult to sell general aviation personnel on the use of protective systems such as ear plugs until the problems of discomfort and degrading of intracockpit communications have been addressed and improvement is noted.

Summary and Recommendations

The objective of Phase II of this project was to determine empirically the protective benefit of using hearing protection in general aviation operations and to document particular problems associated with the use of protective devices. Four candidate protection systems were evaluated inflight as to acceptability, comfort, and interference with voice and radio communications.

Rubber ear plugs were selected for additional inflight testing to determine the extent to which hearing loss could be reduced through their use. The following are the principal findings and recommendations of this study:

1. Protective Benefit. The rubber ear plugs provided entirely adequate protection against the noise environment (102 dB) found in the cabin of a general aviation aircraft. Use of these plugs would allow a six hour flight to be flown without danger to hearing in terms of the permissible limits established by the Occupational Safety and Health Act of 1970. An examination of sound attenuation curves for the other devices which were considered indicates that each of them also would provide adequate protection.

2. Comfort and Internal Communications. The two principal problems found with the use of a protective device such as ear plugs related to comfort and interference with cabin communications. Gasaway (1971) notes that comfort is an important factor that may, by itself, negate the overall value represented by a particular device. The discomfort found with the use of ear plugs in this study was of such a magnitude that it seems unlikely they will be used voluntarily in general aviation without an extensive enforcement program. It also was found that communications between the pilot and co-pilot were degraded to such an extent that normal conversations were restricted altogether and the required coordination of activities was accomplished more by gestures and terse phrases. Obviously, protection devices cannot be considered as acceptable until the problem of intra-cabin communications shows significant improvement.

3. Indoctrination. Hearing conservation in general aviation will require a sizeable indoctrination effort. The devices now available, while providing more than adequate protection, suffer other severe limitations as noted above. Even should an excellent protection system become available, it will fail to achieve the avowed purpose unless aviation personnel are made aware of the need and become self-motivated toward its use. This can only be accomplished through an extensive indoctrination and education program.

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