NASA Contractor Report 177564

USAAVSCOM Technical Report 90-G-1

Comparison of Speech Intelligibility in Cockpit Noise Using SPH-4 Flight Helmet with and without Active Noise Reduction

Jeffrey W. Chan and Carol A. Simpson

(NASA-CR-177564) COMPARISON OF SPEECH INTELLIGIBILITY IN COCKPIT NOISE USING SPH-4 FLIGHT HELMET WITH AND WITHOUT ACTIVE NOISE REDUCTION (Army Aviation Systems Command) 38 p CSCL 17B G3/04

N90-28510

Unclas

0303924

CONTRACT NAS2-13188
July 1990

National Aeronautics and
Space Administration

US ARMY
AVIATION
SYSTEMS COMMAND

AVIATION RESEARCH AND
TECHNOLOGY ACTIVITY

NASA Contractor Report 177564

USAAVSCOM Technical Report 90-G-1

Comparison of Speech Intelligibility in Cockpit Noise Using SPH-4 Flight Helmet with and without Active Noise Reduction

Jeffrey W. Chan

DEV AIR Technical Associates
Menlo Park, California

Carol A. Simpson

Psycho-Linguistic Research Associates
Woodside, California

Prepared for
Ames Research Center
CONTRACT NAS2-13188
July 1990

National Aeronautics and
Space Administration

Ames Research Center
Moffett Field, California 94035-1000

US ARMY
AVIATION
SYSTEMS COMMAND

AVIATION RESEARCH AND
TECHNOLOGY ACTIVITY
MOFFETT FIELD, CA 94035-1099

CONTENTS

COMPARISON OF SPEECH INTELLIGIBILITY IN COCKPIT NOISE USING SPH-4 FLIGHT HELMET WITH AND WITHOUT ACTIVE NOISE REDUCTION

Jeffery W. Chan
Dev Air Technical Associates

Dr. Carol A. Simpson
Psycho-linguistic Research Associates

SUMMARY

Active Noise Reduction (ANR) is a new technology which can reduce the level of aircraft cockpit noise that reaches the pilot's ear while simultaneously improving the signal-to-noise ratio for voice communications and other information-bearing sound signals in the cockpit. A miniature, ear-cup mounted ANR system, developed by Royal Aerospace Establishment, Farnborough, United Kingdom, was tested by U.S. Army Aeroflightdynamics Directorate, Simulation and Aircraft Systems Division, Crew Station Research and Development Branch to determine whether speech intelligibility is better for helicopter pilots using ANR compared to a control condition of ANR turned off. The ANR system was installed in a stock Army SPH-4 flight helmet, and tested in a background of recorded AH-1S (Cobra) cockpit noise, using phonetically balanced word lists, per MIL-STD-1472C. Two signal-to-noise ratios (S/N),

representative of actual cockpit conditions, were used: 0 dB and +10 dB for the ratio of the speech to cockpit noise sound pressure levels. Speech intelligibility was significantly better with ANR compared to no ANR for both S/N conditions. Variability of speech intelligibility among pilots was also significantly less with ANR. When the stock helmet was used with ANR turned off, the average PB Word speech intelligibility score was below the "Normally Acceptable" level, per MIL-STD-1472C in the 0 dB S/N condition. In comparison, average PB Word intelligibility was above the "Normally Acceptable" level with ANR on in both S/N levels and exceeded the "Exceptionally High Intelligibility" level with S/N +10 dB.

INTRODUCTION

High ambient noise levels in aircraft present several potential problems to aircrew members. Such problems as reduced speech intelligibility and potential hearing loss could affect mission performance and individual health. Passive sound attenuation, already being used in Army flight helmets, either reduces cockpit sound levels reaching the ear in the case of equipment worn on the head or around the ear, or in the case of earplugs worn in the ear canal decreases both noise and desired acoustic signals such as speech and warning sounds transmitted via the earphones. Earplugs, often prescribed for enhanced passive attenuation, have the disadvantage of being either so uncomfortable or so inconvenient that pilots sometimes will not use them in actual operations. Active noise reduction, installed in flight helmet earcups, promises to improve the situation.

Passive attenuation generally works by absorbing or blocking sound transfer to the inner ear. In contrast, active noise reduction cancels out ambient noise by actively sampling the undesired signal, known as noise, at the outer ear and presenting a replica of the noise back at the plane of the outer ear with the phase of the signal inverted 180 degrees. If the system worked perfectly, instantaneously, with perfect transducers, matching of levels, absence of crosstalk, and so on, there would be a total cancellation of noise, that is, total silence. Total silence would not be desirable, however, since pilots use ambient auditory cues to monitor proper aircraft functioning.

In the real world, the effects of active noise reduction (ANR) and typical passive attenuation combine to reduce noise power by up to 20 dB at certain frequencies. 20 dB less noise is a reduction to one-hundredth of the power. Separately, each reduces noise in its respective band by approximately 10 dB, which is one-tenth the power. ANR most affects the noise band from about 30 Hz to 1 kHz; passive attenuation has its greatest effect from 1 kHz to 20 kHz. So the combination works to significantly but not totally reduce noise over the whole range of human hearing, except for the bottom two octaves.

In an earcups ANR system, the desired speech and sound signals are passed through from the headset input to the output transducers (earphones), and are mixed in with the anti-phase noise canceling signal. The result is continued presence of desired speech and sound with simultaneous reduction of unwanted noise.

Under the auspices of The Technical Cooperation Program (TTCP), a joint program for technical information exchange among the United States, Canada, United Kingdom, Australia, & New Zealand, a project was established within the Helicopter Technical Panel - 6 (HTP-6) for a collaborative effort between Royal Aerospace Establishment (RAE, formerly Royal Aircraft Establishment) Farnborough and US Army Aeroflightdynamics Directorate to assess the performance of ANR in military helicopters. The ANR system was developed by RAE Farnborough, and prototypes were given to AFDD for operational intelligibility testing. All data are shared within the TTCP. RAE agreed to provide AFDD with data on ANR acoustic performance. AFDD in turn would provide intelligibility data to RAE. The results presented here were obtained using the RAE miniaturized, earcup mounted ANR system.

Active noise reduction promises decreased ambient noise levels reaching wearers' ears and no reduction of desirable signals. In practical terms, active noise reduction would add little to the weight, cost or complexity of flight equipment. To the user, an active noise reduction earcup is practically identical in form to a standard earcup. The difference is functional; when the pilot turns on ANR, background noise levels are reduced and communication should be enhanced.

Given the potential advantages of ANR, its effect, if any, on cockpit communications needed to be measured. In October and November 1988, the authors conducted an experiment under controlled laboratory conditions to ascertain the effect of active noise reduction on speech intelligibility. Working in the lab permits greater repeatability of the acoustic environment and subject tasking than in a simulator or in actual aircraft flight. This laboratory experiment provided baselines for subsequent performance assessment in actual aircraft.

EXPERIMENTAL DESIGN

Hypothesis

In this study our hypothesis was that switching on ANR and thereby increasing the ratio of speech signal to cockpit noise would improve speech intelligibility in comparison to the ANR off condition.

Independent Variables

Two independent variables were used; ANR ON or OFF, and signal-to-noise ratio (S/N). From a large body of previous research, S/N was expected to influence speech perception. In general, S/N is the ratio of wanted to unwanted signals, for example, of speech to aircraft noise. It is usually expressed in decibels (dB), which is a logarithmic scale. In operational rotorcraft flight, we observed that pilots independently set preferred intercom listening levels to an S/N of between 0 dB and 10 dB, depending on the pilot. 0 dB means signal and noise are at the same level; +10 dB represents ten times more signal than noise energy. So S/N was one of the variables manipulated, with two conditions; 0 dB and +10 dB.

There are a number of methods for determining S/N. The resulting measurements vary with the different methods. Our measurement of S/N was defined as the ratio of a value 5 dB less than the highest peak speech level to the bottom of the noise range, measured using a type 1 sound level meter, as per ANSI Standard S1.4-1971, type 1, and the International Electro Technical Commission, IEC 651-1979 type 1. Figure 1 illustrates this. Pre-experiment testing had revealed scores lower than the most sensitive range (40 to 60% correct) of the PB word test. So the additional 5 dB was meant to bring the speech level up relative to the noise level in order to improve the sensitivity of the test. Noise and speech were each measured in the absence of the other. Both sound levels were measured electrically by connecting the output of the tape recorder directly to the electrical input of the sound level meter. The goal in the 0 dB S/N test condition was for the highest speech peaks to never rise more than 5 dB above the least noise. This is important because speech perception is greatly facilitated above 0 dB S/N, and that would decrease the sensitivity of our measurements at this level. +10 dB S/N was selected as representative of the speech being definitely above the noise.

The main experimental variable was the presence or absence of ANR. The ANR earcups were mounted in a standard Army SPH-4 flight helmet. A point to mention here is that the ANR earcups (which are standard British Ministry of Defense Mark 4A shells) do not precisely match the acoustical or electrical characteristics of the stock SPH-4 earcups, so simply switching ANR on or off on our single SPH-4 modified with ANR earcups is not equivalent to comparing a stock SPH-4 with stock earcups to an ANR helmet. In other words, switching off ANR does not turn the ANR earcups into stock SPH-4 earcups. We have indeed determined that the ANR earcup with ANR turned off does not have the same measured frequency response as the stock SPH-4 earcup. Later studies to be reported elsewhere, took this difference into account.

The experimental design matrix is shown below:

	ANR off	ANR on
0 db S/N		
10 db S/N		

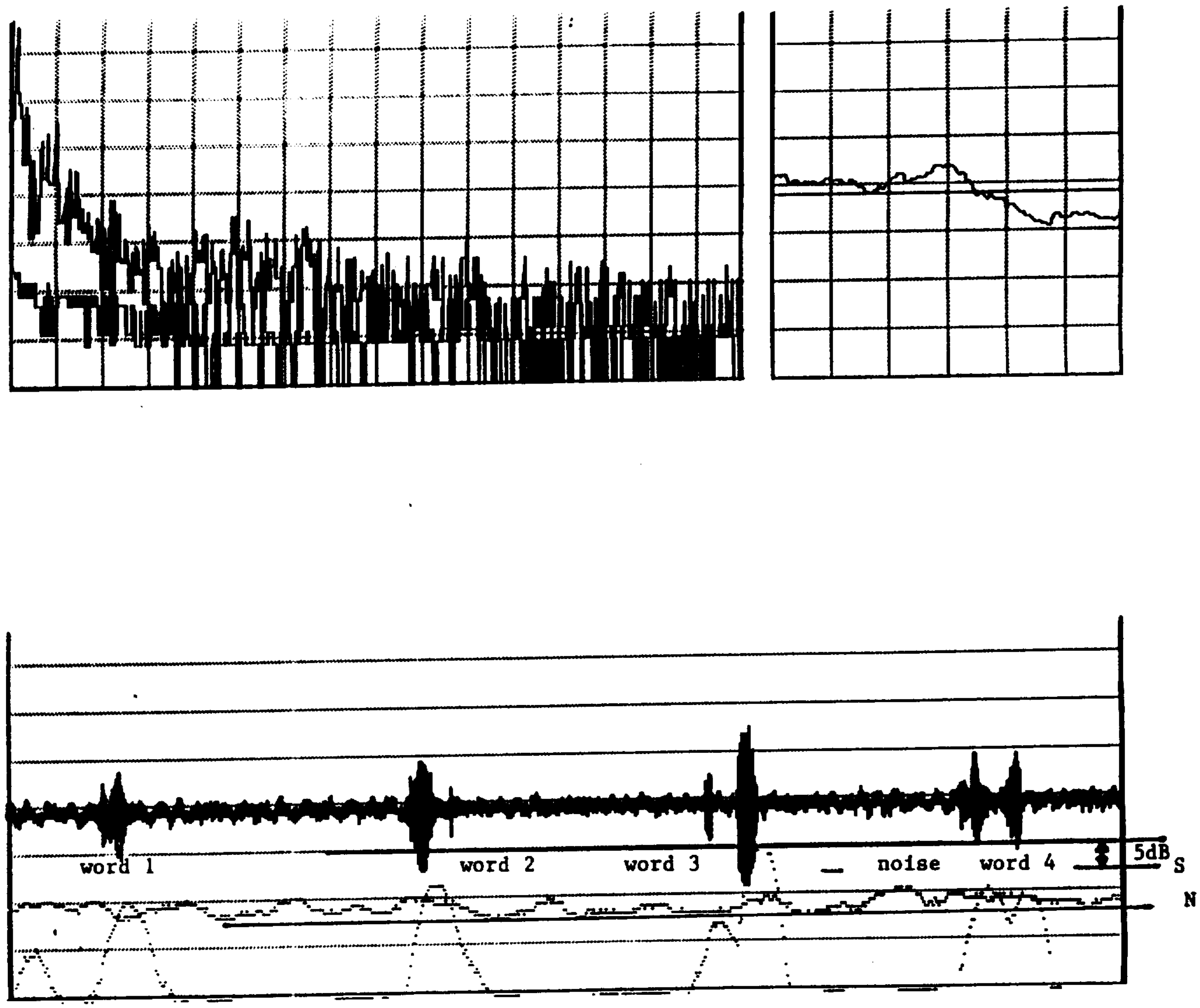

Figure 1

Illustration of Signal to Noise Measurement

Dependent Variable

The dependent variable was speech intelligibility measured as the percentage of words within each test list correctly recognized in the various noise and ANR conditions.

Subjects

There were a total of twelve pilots and eight runs per pilot. Our study had 2 fixed-wing and 10 rotorcraft rated pilots. Those who were currently rated for rotorcraft were given noise from a Cobra (AH-1S) helicopter. Fixed wing pilots were given Harrier noise. One pilot was then in the Army; the rest were either Army pilots detailed to NASA, or were NASA code FS (Flight Systems and Simulation Research Division) or OA (Aircraft Operations Division) pilots. The pilots reported varying degrees of hearing loss.

Test Materials - Background Noise

The Cobra and Harrier aircraft noise was originally recorded in straight and level flight using a Knowles microphone taped to the outside of the flight helmet at the earcup "bump" and a Nagra portable tape recorder worn in the pilot's flight suit. The microphone signal was preamplified with a kneebox provided for that purpose by RAE Farnborough, who also provided the microphone.

The Nagra tape was then transferred to a 1/4 inch tape, and sections of level flight at a nominal cruising speed were selected and repeatedly transferred to another 1/4 inch tape. The results were two relatively continuous tapes containing repeated sections of aircraft noise. The length of each repeated section was on the order of two to five seconds. Glitches between repeated sections were sometimes audible as very brief silent periods, but the overall effect was subjectively continuous.

Test Materials - Speech Tokens

Two types of word lists were used for test tokens. One was the CID-W-22 organized into 4 phonetically balanced (PB) lists of 50 words each[1]. A major advantage of phonetically balanced lists is that they are of equal difficulty even though individual lists do not have the same words. The other was a proprietary PLRA-developed list of words called PD-100 for Phonetic Discrimination testing[2]. The PD-100 lists were used as distractors between the PB word lists. The PD-100 words were broken into three lists with one list (a different one) repeated per subject. The three PD-100 lists had 34, 40 and 26 words each. PD-100 lists had four speakers for a total of 12 lists. The PB word lists had just one speaker

---

[1] Lehiste, I. & Peterson , G., Linguistic considerations in the study of speech intelligibility, JASA 1959, 31, 280-86

[2] Simpson, C. & Ruth, J., The Phonetic Discrimination Test for Speech Recognizers: Parts I and II, Speech Technology 1987, March/April, 48-53, and Oct./Nov., 58-61

for a total of four lists. Each subject was given the four PB word lists and the four PD-100 lists (three plus one repeated) for one of the four speakers. Both list orders were shuffled overall with respect to presentation order of PB lists, and PD-100 lists were shuffled for speaker order. Shuffling was done to minimize order effects. Each pilot heard a different shuffled order of lists with the constraint that PB lists and PD-100 lists were alternated.

Each word list's sound level was measured, and the range of levels was recorded. The maximum level obtained (that is, the word with the highest peak) was used for computing and setting levels later in order to standardize the speech token levels across lists. Measurements were taken via a Quest type 1 sound level meter with a Knowles probe microphone placed at the entrance to the ear canal. Mr. Chan wore the ANR helmet and probe microphone, by which words were presented and levels measured. The goal was to find levels for a helmet actually being worn; actual levels for different wearers probably varied somewhat. Each list was on a separate tape, each of which had a 1 kHz sine tone at the beginning, and the relative levels between the tone and highest speech for a particular list were called "tone deltas". Thus known speech levels, relative to the measured ambient noise reaching the pilot's ears, could be set by adjusting levels until the tone, also measured at the ear, matched the calculated level. Here is an explanation of the steps needed to calculate the desire level of the tone, as measured at the subject's ear:

1. Measure the level of background noise reaching the pilot's ear.
2. Subtract the tone delta.
3. Add the desired signal to noise ratio.
4. Add 5 dB to bring the test into a more sensitive range.
5. The result is the level to set at the ear for the tape's tone.

Here's an example with the first PB word list, and a +10 dB S/N:

1. If background noise was measured as 75 dB
2. Subtracting the tone delta from the table of 11 gives 64 dB
3. Adding the +10 dB S/N gives 74 dB
4. Adding 5 dB brings the tone level to:
5. 79 dB, which the tone should be set to at the ear.

As a check, speech levels were measured during the presentation of the words, and they generally agreed with predicted levels. Actual values used are listed in Table 1 below. In Table 1, speech level was measured with a probe microphone at the entrance to the ear canal using a type one sound level meter, SPH-4 helmet with ANR earcups installed, worn by Mr. Chan. Levels are in dB, unweighted. Tape counter positions are for Technics 686D cassette deck.

Table 1: ANR Word List Speech Levels

Type List	List number	speech level	tone	tone delta	tape counter
PB word,	List 1	63.5-76	65	11	
	List 2	62-74	65	9	
	List 3	64-78	65	13	
	List 4	60.5-76.5	65	11.5	
PD-100, Speaker 1,	List 1	72-79	65	14	9-27
(M)	List 2	73-80	65	15	29-42
	List 3	70.5-79.5	65	14.5	44-61
PD-100, Speaker 2,	List 1	71-81	65	16	9-24
(F)	List 2	73-81.5	65	16.5	25-36
	List 3	69-80	65	15	37-51
PD-100, Speaker 3,	List 1	73-85	65	20	10-31
(M)	List 2	72-81	65	16	33-47
	List 3	70-79.5	65	14.5	49-62
PD-100, Speaker 4,	List 1	72.5-80	65	15	9-29
(F)	List 2	73-82	65	17	31-45
	List 3	68-79.5	65	14.5	47-67

Equipment

Noise playback equipment consisted of a Sony TC-730 1/4 inch reel-to-reel tape recorder feeding a Crown D-75 amplifier and Leak loudspeakers. The speakers were the source of recorded aircraft noise and were positioned about a meter behind and to the left and right sides of a fixed chair location. Noise output levels were adjusted at the amplifier input gain controls. Speech playback came from a Technics stereo cassette deck model 686D, which was fed to two Shure M267 mixers and a custom intercom simulator built by Mr. Chan. The two mixers provided experimenter and pilot-subject, respectively, with test token monitoring, microphone preamplification and side-tone. The intercom simulator switched speech output from either person to the other for communication via flight helmet or headsets using a remote push-to-talk button.

Procedure - Set-up and Calibration

Our study had 2 fixed-wing and 10 rotorcraft rated pilots. Those who were currently rated for rotorcraft were given noise from a Cobra (AH-1S) helicopter. Fixed wing pilots were given Harrier noise. In both cases, the noise level was set at 85 dBA peak maximum, measured near the earcup "bump" on the outside of the helmet. (Actual sound pressure levels in aircraft are higher than this, but this is the upper limit allowed for experiments with human subjects at NASA Ames Research Center.) Noise level measurements were always made with the helmet worn by Mr. Chan, who was sitting at the location designated for experimental testing. The noise level was set before data runs for a given type of noise, Harrier or Cobra, and was left fixed for all runs with the same type of noise. So the reference for setting absolute noise levels was consistent across all subjects.

When they entered the lab pilots were seated at the fixed chair location with a typing table in front of them as a desk and a clipboard as writing surface and standard retractable ball point pen as writing implement. They were given a brief set of instructions:

> Recorded aircraft noise will be presented in the background.
> Sometimes the ANR will be turned on, sometimes off.
> Pilot will hear words and write them on response sheet.
> One of two types of word lists contains some non-real words.
> Experimenter will tell pilot in advance what type of word list to expect. Noise will be presented at 85 dBA.

They were also given a complete alphabetical list of all 200 PB words and instructed to scan but not memorize them. The list was removed from pilot's view after 3 minutes. The pilots, however, were not given any opportunity to look at the PD-100 word lists.

The pilots were fitted with the same placement of probe microphone and sound level meter at the entrance to the ear canal as was used to make the word level measurements. The microphone was cleaned with alcohol prior to each use. It was taped in place using surgical tape, with the microphone facing outward. The microphone did not obstruct the ear canal. Instead, it was taped just below the entrance to the ear canal.

At the start of runs 1 and 5, ambient room noise in the closed lab (mostly due to air conditioning) was measured with the helmet off and then with the helmet on and with ANR off and then on. The pilot was instructed in the use of the ANR toggle switch, and with the switch in the off position the ANR cable was plugged into the battery box. A communications check between pilot and experimenter was performed. Then, recorded aircraft noise was started and the level of noise reaching the pilot's ear was recorded, and noise was switched off. This pilot-specific noise level was used for calculating the signal to noise ratio and setting speech levels as described above and also below.

Particular attention was paid to the fitting of the ANR headset, since a proper fit is essential for proper function. With ANR systems a proper seal must be maintained with respect to the wearer's head in order for the ANR system to remain stable. When the seal is broken, the system goes into low frequency oscillation, which is audible to the wearer. The solution to this problem is to ensure that the headset is properly fitted before use. If this is done, seal integrity has been demonstrated to be adequate even in jet fighter supersonic live firing exercises[3].

Proper fit was checked by having the pilot don the helmet, and tighten the chin strap. If the position of the earcups on the ears did not feel correct to the pilot, then the position was adjusted by removing the helmet and moving the straps on the harness that held the earcups in place. The helmet was put back on and once the fit seemed right, the pilot was instructed to switch on ANR by flipping the toggle switch on the battery box/power supply. If no oscillation was heard with the pilot stationary, the pilot was asked to turn his head sharply from left to right, and then up and down in an attempt to break the seal. If the seal remained intact then the testing proceeded. When necessary, pieces of soft foam about the size of a small sponge were inserted between the helmet and earcups. If it seemed that the break was occurring near the top of the earcup, then more foam was placed there. If a custom helmet could have been used for each pilot, then fewer and/or less radical adjustments would probably have been necessary in general. For this experiment, one helmet was shared by all pilot-subjects.

After 4 runs, the helmet was removed, while leaving the probe

---

[3] Personal communication from Dr. Graham Rood of RAE Farnborough

microphone attached, for two reasons. One reason was comfort. The ANR helmet was an extra large and somewhat heavier than current SPH-4 helmets since it was a double visor model. This largeness sometimes necessitated use of foam inserted between the earcups and helmet and/or a unusually tight chin strap in order to achieve a reliable seal. The extra pressure needed to fit a helmet larger than appropriate for a given head size may have made the helmet unusually uncomfortable. The other reason for placing and removing the helmet more than once and re-measuring sound levels was to see how much variability this introduced into the measurements.

Speech levels for a given run (that is, a word list) were set in quiet by adjusting the tone on the tape to levels calculated on a run worksheet, duplicated below. When ANR was used, it was switched on after setting word levels via the tone and before the noise. This was done to protect the pilots from possibly uncomfortable sound levels of the calibration tone.

Even with ANR off, the tone was uncomfortably loud for some pilots on some runs. The levels were never actually above the maximum allowed level, but may have been subjectively loud since people are generally not accustomed to hearing steady state tones. If ANR was on during ANR playback, the tone was found to be boosted to yet higher levels so the tape was advanced beyond the tone before starting noise in order to avoid uncomfortable levels. Word lists were started only after starting recorded aircraft noise.

It should also be noted that different pilots obtained different amounts of passive attenuation and active noise reduction when wearing the helmet, as measured with the probe microphone at the ear and with aircraft noise in the background. This may be due to size and fit differences between pilots, the amount of foam used for an adequate seal, shape of the head, and so on. Further study is needed, in particular comparing custom helmets with ANR installed and the single extra large size helmet used in this experiment, in order to examine the contribution, if any, of helmet size and fit on noise attenuation and reduction.

The difference in attenuation, passive and active, between pilots means that the baselines for S/N computation and therefore the absolute tone levels were different between pilots. In addition there is some variation, inherent to lists of words, on the tone deltas. These two sources of variation sometimes combined to produce high tone levels.

During the experiment runs, the tone level for a given word list was calculated by subtracting each list's "tone delta" from the noise level reaching the ears as measured above, adding the signal-to-noise ratio, and then adding 5 dB. The "tone delta" was the difference between the tone and maximum peak speech level for each list as described under "test materials." Tone deltas were measured for each word list before any data runs and were used consistently across runs.

Procedure - Data Collection

The eight runs consisted of four PB word lists alternated with four PD-100 lists. The S/N and ANR on or off conditions of each run were shuffled independently of the lists, again to minimize order effects. Pilots were provided with a two page answer sheet, each page with a single column of 25 blank spaces down the center. The test token tapes were manually paused between words to allow time for completion of written responses. In all cases, both pages were used, requiring change of pages part way through. Extra time was given between words to change pages. Before each run, the pilot-subject was instructed to write down the word heard. In the case of PD-100 lists, the words were not necessarily real words and this distinction was announced before each PD-100 list run.

The same procedure was repeated for each run, starting with the setting of levels for word lists. After the fourth run, the helmet was removed, as described above. After the eight run, the helmet was removed, microphone was removed and answer sheets were collected.

ANR TEST RUN DATA

SUBJECT________________ DATE________________

RUN # ______________ SESSION____________

SET PROBE MIKE [ ]

AMBIENT ROOM NOISE, EAR UNCOVERED_______________dB SPL

AMBIENT ROOM NOISE, EAR COVERED, ANR OFF________________dB SPL

AMBIENT ROOM NOISE, EAR COVERED, ANR ON_________________dB SPL

SET ANR OFF [ ]

TYPE OF INTRODUCED NOISE________________________

dB OUTSIDE HEADSET________________________dB A

SPL INSIDE EARCUP, ANR OFF _______________dB SPL (X)

STIMULUS LIST_______________________

TONE______________ PEAK WORD LEVELS___________________

TONE DELTA______________

SIGNAL - TO - NOISE RATIO___________________dB (Y)

(0 dB = HIGHEST SPEECH PEAKS 5 dB ABOVE NOISE AT EAR)

Y (ANR OFF)

SET TONE TO (X) - TONE DELTA ( ) + 5 + ( ) =_________ [ ]

dB SPL

PREDICTED PEAK SPEECH LEVEL____________dB S/N (Y+5)

PREDICTED PEAK WORD LEVEL RANGE____________dB SPL

MEASURED PEAK WORD LEVEL RANGE_____________dB SPL

SET ANR_________________[ ]

START NOISE. [ ]

MEASURED NOISE LEVELS INSIDE EARCUP_____________dB SPL

(ANR IN RUN SETTING ABOVE)

DATA ANALYSIS

Scoring

Scoring of the answer sheets was relatively straightforward. Responses were compared to a master list, and any misses, false alarms or incorrect recognitions by the pilot of one phoneme or greater were marked as errors. Spelling (orthographic) and other homophonic variants were not counted as errors. As an example, the following, though not necessarily representative, would be considered valid responses for a stimulus of "their":

their

there

they're

thair

thaire

and so on, as long as the phonemic content was the same.

One recording error was detected on PB word list 3. Word 24, which was recorded as "through" on the stimulus tape, should actually have been pronounced "though," as was printed on the list. The word "through" actually occurred again as word 27 of PB word list 4. In this case it was in agreement with the printed list and therefore was correct. Responses for PB word list 3 were scored to take this into account. If the written response was "through", it was counted as correct. Though this means that the phonetic balance between the lists was off by one phoneme, overall balance was not affected for purposes of this test.

The table below shows the response scores for each pilot in each condition with the PB word lists. Conditions and lists were presented in independently shuffled orders.

ANR Laboratory Speech Intelligibility Study

Percent Correct Responses, by Pilot and Condition

Pilot #	0 dB -ANR	0 dB +ANR	+10 dB -ANR	+10 dB +ANR
1	90	94	94	100
2	80	88	94	94
3	58	82	82	100
4	12	22	76	76
5	42	72	80	92
6	56	66	90	92
7	48	90	74	94
8	90	90	96	98
9	84	90	94	100
10	74	92	92	94
11	88	88	94	98
12	90	98	96	100
mean	68	81	89	95
s.d.	24.8	20.7	8.1	6.7

(-ANR means ANR off, +ANR means ANR on)

Statistical Analysis

Analysis of Variance for a within subjects design was used to test for statistically significant differences associated with the two independent variables: ANR OFF or ON, and S/N. Because of the small sample size and particularly because of the large individual differences in reported hearing loss, a significance level of 0.05 was chosen.

From the table above, an analysis of variance[4] yields:

---

[4] Bruning, J., & Kintz, B. L., Computational Handbook of Statistics, Scott, Foresman and Company, 1968, Section 2.6, Treatments-by-Treatments-by-Subjects Design, 47-54

Source	SS	dF	MS	F	p
Total	17,592	47			
Subjects	8,786	11			
S/N	3,605.3	1	3605.3	14.49	<.005
ANR	1,160.3	1	1160.3	13.28	<.005
S/N x ANR	147.1	1	147.1	8.31	<.025
error S/N	2,737	11	248.8		
error ANR	961.7	11	87.4		
error S/N x ANR	194.6	11	17.7		

(SS = sum of squares, MS = mean of SS)

This shows that the presence or absence of ANR had a significant effect on speech intelligibility as did signal-to-noise ratio. There was also a significant interaction between ANR and S/N.

RESULTS

Using the guidelines in MIL-STD-1472C[5], reproduced in the table below, intelligibility in the 0 dB condition was generally below the "normally acceptable" level with ANR off, but above "normally acceptable" level with ANR on:

[5] MIL-STD-1472C Human Engineering Design Criteria for Military Systems, Equipment and Facilities, 10 May 84, published by the U.S. Department of Defense.

Intelligibility Criteria for Voice Communications Systems

per U.S. MIL-STD-1472C

5.3.1.12 Speech Intelligibility

Communication Requirement	Score PB	Score MRT	Score AI
Exceptionally high intelligibility; separate syllables understood	90%	97%	0.7
Normally acceptable intelligibility; about 98% of sentences correctly heard; single digits understood	75%	91%	0.5
Minimally acceptable intelligibility; limited standardized phrases understood; about 90% sentences correctly heard (not acceptable for operational equipment)	43%	75%	0.3

PB = Phonetically Balanced Word Score

MRT = Modified Rhyme Test Score

AI = Articulation Index

In no case did switching on ANR decrease PB word intelligibility scores. In order to determine any significant difference between ANR off and on conditions, a Wilcoxon's Signed Ranks Test was performed on the data, collapsed across S/N.

Pilot #	(S/N)	-ANR	+ANR	Difference	Rank
1	0	90	94	4	5
	+10	94	100	6	8
2	0	80	88	8	10.5
	+10	94	94	0	n/a
3	0	58	82	24	18
	+10	82	100	18	15.5
4	0	12	22	10	12.5
	+10	76	76	0	n/a
5	0	42	72	30	19
	+10	80	92	12	14
6	0	56	66	10	12.5
	+10	90	92	2	2
7	0	48	90	42	20
	+10	74	94	20	17
8	0	90	90	0	n/a
	+10	96	98	2	2

9	0	84	90	6	8
	+10	94	100	6	8
10	0	74	92	18	15.5
	+10	92	94	2	2
11	0	88	88	0	n/a
	+10	94	98	4	5
12	0	90	98	8	10.5
	+10	96	100	4	5

---

sum:		1874	2110
mean:		78.08	87.91
variance:		438.08	276.34
s.d.:		20.930	16.623

sum of positive ranks = 210

sum of negative ranks = 0

$p \ll 0.01$

With 0 as the smaller sum of ranks, for 20 pairs and a two-tailed test, Wilcoxon's Matched-Pairs Signed-Ranks Test[6] gives a level of significance well beyond 0.01. The test is two tailed because either negative or positive differences were possible. So the effect of the ANR condition was highly significant.

---

[6] Bruning, J., & Kintz, B. L., Computational Handbook of Statistics, Scott, Foresman and Company, 1968, Section 5.4, A Signed-Test (Wilcoxon) for Differences Between Related Samples, 205-206

On average, scores did increase with S/N, and were higher with ANR on than ANR off. In addition, variability was significantly less for ANR on than ANR off. A test for differences of variances of two related samples[7] (that is, pairs of intelligibility scores for ANR off and ANR on) gave a t value of 2.91 with 22 degrees of freedom, which was significant to beyond .01 for a two-tailed test.

DISCUSSION

Active noise reduction generally made a noticeable improvement in speech intelligibility under laboratory conditions. Active noise reduction has the advantage of increasing intelligibility without increasing the overall speech level to possibly uncomfortable listening levels. ANR increases intelligibility in representative helicopter cockpit listening conditions. The degree of improvement should translate to more effective and efficient voice communications in military helicopters. These positive effects on speech intelligibility come in addition to the objective and subjective reductions of unwanted external noise measured in the laboratory.

With lower background noise levels, intercom levels can be set lower with the same or improved speech intelligibility. An

[7] ibid. Section 3.2, 109-110

important side benefit of reduced overall noise and speech levels reaching the ear should be improved hearing conservation and less fatigue. This could result in reduced medical, disability and pension costs attributable to hearing damage. The capital investment in production-based ANR equipment would be very small compared to helmets in particular and aviation life support equipment in general, especially considering the possible long-term health benefits and pension implications.

Active noise reduction could be beneficial in any application requiring radio or intercom communications in high noise environments, such as on a flight line, near generators, in noisy surface or air vehicles, and perhaps in some industrial or heavy equipment situations. In military operations, however, the benefits of Active Noise Reduction to mission performance and successful mission completion would be paramount, because it could ensure that the military standard for communications intelligibility will be met.

FURTHER WORK

Based on the laboratory results reported here, testing of ANR in flight has begun in order to determine whether the improvements in intelligibility observed in the acoustic cockpit environment simulated in the laboratory will also occur in flight under operational conditions. Preliminary results from ongoing field testing in flight operations indicate similar benefits for speech intelligibility. Such benefits could lead to improved communications ability and hence to improved mission performance.

ACKNOWLEDGMENTS

The work presented here was performed under NASA Ames Contracts NAS2-12425 and NAS2-13188 For the U.S. Army Aeroflightdynamics Directorate (AFDD), Simulation and Aircraft Systems Division, Crew Station Research and Development Branch. Dr. Nancy M. Bucher served as Contract Technical Monitor. This research is part of a collaborative effort between AFDD and the Royal Aerospace Establishment (RAE) at Farnbourough, England, conducted under the auspices of an international technical exchange program. The Technical Cooperation Program, within the Helicopter Technical Panel 6 (HTP-6). Special thanks are due to Ms. Kathy Glaeser, Dev Air Technical Associates, who prepared this report for publication, and to Dr. Graham Rood and Ms. Susan James of RAE Farnbourough who provided the ANR system, acoustic data recording equipment, and their their technical expertise.

NASA National Aeronautics and Space Administration

Report Documentation Page

1. Report No. NASA CR-177564 USAAVSCOM TR-90-G-1	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Comparison of Speech Intelligibility in Cockpit Noise Using SPH-4 Flight Helmet with and without Active Noise Reduction		5. Report Date July 1990
		6. Performing Organization Code
7. Author(s) Jeffrey W. Chan* and Carol A. Simpson		8. Performing Organization Report No. A-90264
		10. Work Unit No. 505-61-51
9. Performing Organization Name and Address Ames Research Center, Moffett Field, CA 94035-1000, and Aeroflightdynamics Directorate, U.S. Army Aviation Research and Technology Activity, Ames Research Center, Moffett Field, CA 94035-1099		11. Contract or Grant No.
		13. Type of Report and Period Covered Contractor Report
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, DC 20546-0001, and U.S. Army Aviation Systems Command, St. Louis, MO 632120-1798		14. Sponsoring Agency Code

15. Supplementary Notes

Point of Contact: Nancy Bucher, Ames Research Center, MS 243-4, Moffett Field, CA 94035-1000
(415) 604-5161 or FTS 464-5161

*DEV AIR Technical Associates, Menlo Park, CA

16. Abstract

Active Noise Reduction (ANR) is a new technology which can reduce the level of aircraft cockpit noise that reaches the pilot's ear while simultaneously improving the signal-to-noise ratio for voice communications and other information-bearing sound signals in the cockpit. A miniature, ear-cup mounted ANR system, developed by Royal Aerospace Establishment, Farnborough, United Kingdom, was tested by U.S. Army Aeroflightdynamics Directorate, Simulation and Aircraft Systems Division, Crew Station Research and Development Branch to determine whether speech intelligibility is better for helicopter pilots using ANR compared to a control condition of ANR turned off. The ANR system was installed in a stock Army SPH-4 flight helmet, and tested in a background of recorded AH-1S (Cobra) cockpit noise, using phonetically balanced word lists, per MIL-STD-1472C. Two signal-to-noise ratios (S/N), representative of actual cockpit conditions, were used: 0 dB and +10 dB for the ratio of the speech to cockpit noise sound pressure levels. Speech intelligibility was significantly better with ANR compared to no ANR for both S/N conditions. Variability of speech intelligibility among pilots was also significantly less with ANR. When the stock helmet was used with ANR turned off, the average PB Word speech intelligibility score was below the "Normally Acceptable" level, per MIL-STD-1472C in the 0 dB S/N condition. In comparison, average PB Word intelligibility was above the "Normally Acceptable" level with ANR on in both S/N levels and exceeded the "Exceptionally High Intelligibility" level with S/N +10 dB.

17. Key Words (Suggested by Author(s)) Cockpit communications, Crew station R&D, Helicopter, Performance and evaluation, Speech intelligibility, Active noise reduction		18. Distribution Statement Unclassified-Unlimited Subject Category – 04	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 39	22. Price A03

NASA FORM 1626 OCT 86

For sale by the National Technical Information Service, Springfield, Virginia 22161