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ACOUSTIC ALTERATION OF SPEECH PROCESSED THROUGH AIR FORCE AIRCRAFT COMMUNICATION SYSTEMS

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USAF SCHOOL OF AEROSPACE MEDICINE
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Speech picked up at the speaker's lips and processed through standard Air Force electroacoustic-communication systems undergoes acoustic alteration that affects intelligibility. Features of such acoustic alteration and its importance to Air Force operations are presented.

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ACOUSTIC ALTERATION OF SPEECH PROCESSED THROUGH

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INTRODUCTION

The ability to hear and understand speech is vital to ground and airborne aerospace operations. Speech can convey vast information in a short time and, fortunately, has to undergo drastic deterioration before its transmission is seriously impaired (2, 5-7). One serious cause of speech deterioration is noise interference in the communication link. Various physical and psychologic factors may reduce the effectiveness of voiced communication, but the intrusion of ambient noise has long been recognized as paramount (1, 4-7). As a result, noise-cancelling lip-position microphones were developed to reduce noise mixing with the desired signal. Placing the microphone at a speaker's lips represents a compromise in flight operations since radio communications were introduced. The noise-cancelling characteristics of the lip microphone combined with existing electroacoustic systems were not always adequate, and throat-placed microphones were adopted. Both systems, lip and throat transducers, produce significant acoustic alterations in speech (5, 6).

Normal speech signals contain four basic components: vowels, diphthongs, and voiced and voiceless consonants (3). With throat microphones, the voiceless consonants are missing; and with lip microphones, the same consonants are significantly increased in relative amplitude. These acoustic alterations represent a compromise that needs further consideration. Research has quantified the degree of speech intelligibility that an electronic speech-communication system can provide (commonly referred to as the Articulation Index) (1, 4-7). Most tests of intelligibility (the meaning of the message) and articulation (understanding individual phonemes or sound components) use previously recorded speech signals without the acoustic alterations that a lip-placed microphone imposes.

Experienced flying personnel who fail existing pure-tone audiometric standards and also have a decrement in speech discrimination (or articulation) with accepted testing materials, frequently have little difficulty understanding oral communications in actual flight situations. The Audiology and Hearing Conservation Function at the USAF School of Aerospace Medicine has studied this problem for the past 3 years. This identifies acoustic features of voiced communications in aircraft that may enhance intelligibility of speech picked up with a lip-position noise-cancelling microphone.

CURRENT STUDY

Radio communications received within various aircraft during different phases of ground and airborne operation were recorded on electromagnetic tape for study in the laboratory. Words, phrases, and situational language (including jargon) were extracted so that the acoustic nature of the speech as heard by a listener could be studied. Voice prints (using a Kay Sonagraph Model 6061B) were made from samples of speech delivered to the headsets. These voice prints revealed that many speech sounds picked up by lip-position microphones had undergone significant acoustic alterations. For example, the voiceless consonant p (as in put) had been altered so that it represented a rather intense acoustic cue (considerably "louder" than normally heard in conversational speech). This type of acoustic alteration is the topic of this report, which represents the initial phase of an effort to quantify the auditory effect of such acoustic alterations. In the next phase, experienced flying personnel will be used to determine if acoustic alterations that occur actually enhance the intelligibility of speech signals.

Figure 1 shows a sample voice print[1] of "five, six, seven" spoken within a Cessna T-37B aircraft during ground runup with both engines operating at 40% rpm. This print shows the extent by which ambient noise invades the communication link. The signal was obtained by taking the electrical output of the intercommunication unit (AIC-10) installed in the

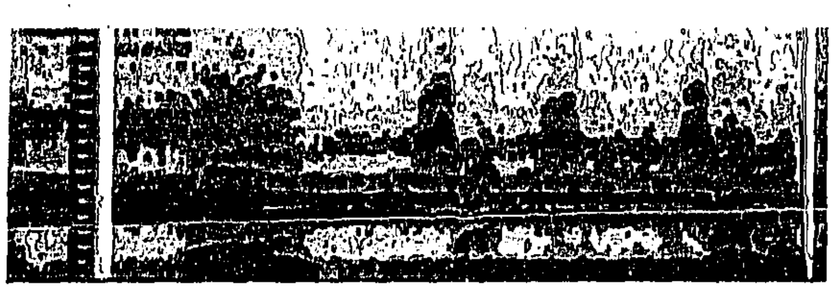

Figure 1. Voice print of author speaking "five, six, seven" in MBU-5/P oxygen mask within Cessna T-37B aircraft on the ground with both engines operating at 40% rpm.

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[1] The Sonagrams illustrated in Figures 1, 2, and 4-6 represent three parameters: time, frequency spectrum, and amplitude. Each sample covers 2.8 seconds and is displayed on the abscissa. The ordinate shows frequency spectrum ranging from 80 Hz (bottom) through 8000 Hz (top); the spectrum can be displayed either in linear or logarithmic form. The vertical bars at the far left side of each Sonagram identify 500-Hz spectrum intervals. Amplitude is seen by the "shading" -- the darker the "burn," or contour, the greater the amplitude.

T-37B; it does not reflect the amount of ambient noise invading the ear via the earphone cushion and receiver. The presence of pure tone components is evident; these enter the intercommunication system both acoustically (through the microphone) and electrically (electrical inductance). Figure 2 shows the same signal ("five, six, seven") recorded with the same system, but in quiet; the absence of ambient noise is obvious. Both transmissions were spoken into an MBU-5 oxygen mask fitted with an M-101 microphone assembly (standard Air Force issue).

Figure 2. Voice print of author speaking "five, six, seven" in MBU-5/P oxygen mask in quiet.

Nonflyers who first encounter speech as it is received in aircraft are usually impressed that flying personnel can understand such "unintelligible" signals. This phenomenon is universal enough to suggest that normal hearing acuity does not insure understanding signals received within aircraft. In fact, experienced pilots report that it takes a few transition flights within a new aircraft before they can hear easily. Pilots apparently "learn" to understand voiced communications that have been a ustically altered.

To demonstrate that normal conversational speech undergoes significant acoustic alterations, the phrase "Put boards out on steep approach" was recorded using three transducers. An Electrovoice Model 636 microphone was placed 6 inches (15.24 cm) directly in front of the speaker (diaphragm of microphone perpendicular to lips). This position represented a near-field recording of the acoustic character of the phrase. Two microphones commonly used in the Air Force picked up the signals at the lips (an M-87/AIC boom-mounted microphone fitted on the H-157 headset, and an M-101/AIC microphone fitted in a standard Air Force MBU-5/P oxygen mask used with an HGU-2A/P crash helmet). The Electrovoice microphone was used with a General Electric preamplifier, and the signal was recorded on one channel of an Ampex Model 350 tape recorder (1/2 track at 7.5 ips). Signals picked up by the two lip-position microphones were delivered to a standard Air Force AIC-10 intercommunication unit, and the output from the AIC-10 went to the tape recorder. From the recordings, the Kay Sonagraph (Model 6061B) made voice prints. Each sample was adjusted to -3 on the VU meter of the Sonagraph so that the overall amplitude of the phrases could be considered as essentially equivalent in studying the voice prints. Figure 3 shows how the phrase was recorded and processed.

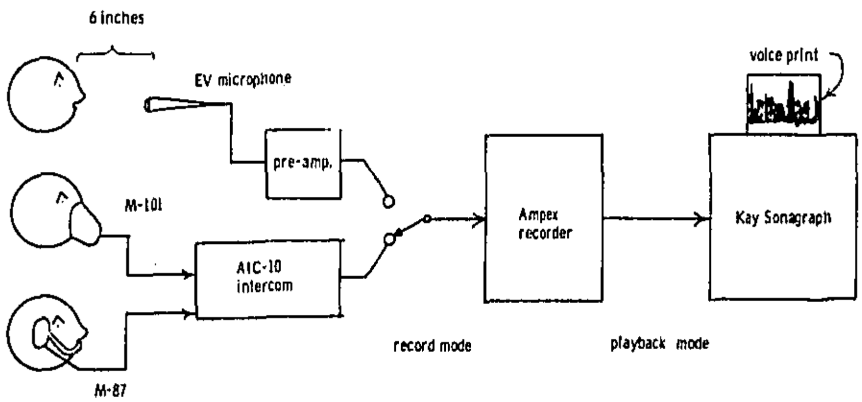

Figure 3. Diagram of test setup used in this study.

Figure 4 shows three voice prints of the test phrase " Put boards out on steep approach." The top print was recorded with the Electrovoice Model 636 microphone positioned 6 inches in front of the lips, the middle print with the M-87 fitted on a headset, and the lower print with the M-101 in an oxygen mask used with a crash helmet. Even with the microphone just 6 inches (15.24 cm) from the speaker's mouth, only the voiceless alveolar fricative was obvious. The p (voiceless bilabial stop) and the ch (voiceless alveolar palatal affricate) were considerably more intense when picked up at the lips. This acoustic alteration of the voiceless consonants may be the key to the fact that many flying personnel with high-tone hearing loss can still understand voiced communications in aircraft, even though they demonstrate decrements in speech discrimination in the clinic where the testing materials do not contain such acoustic alterations.

The voice prints in Figure 4 were obtained using the typical analysis technique (noncontour) with frequency-spectrum parameter set on linear response. Figure 5 shows a second set of voice prints for the same phrase samples but analyzed using the contour (amplitude) display where each contour describes 6-dB ranges (42 dB from darkest to lightest contour). These voice prints demonstrate the acoustic alterations even more dramatically than those in Figure 4. Finally, Figure 6 illustrates the same phrase by using amplitude contours and showing frequency spectrum logarithmically 80-8000 Hz, vertical display).

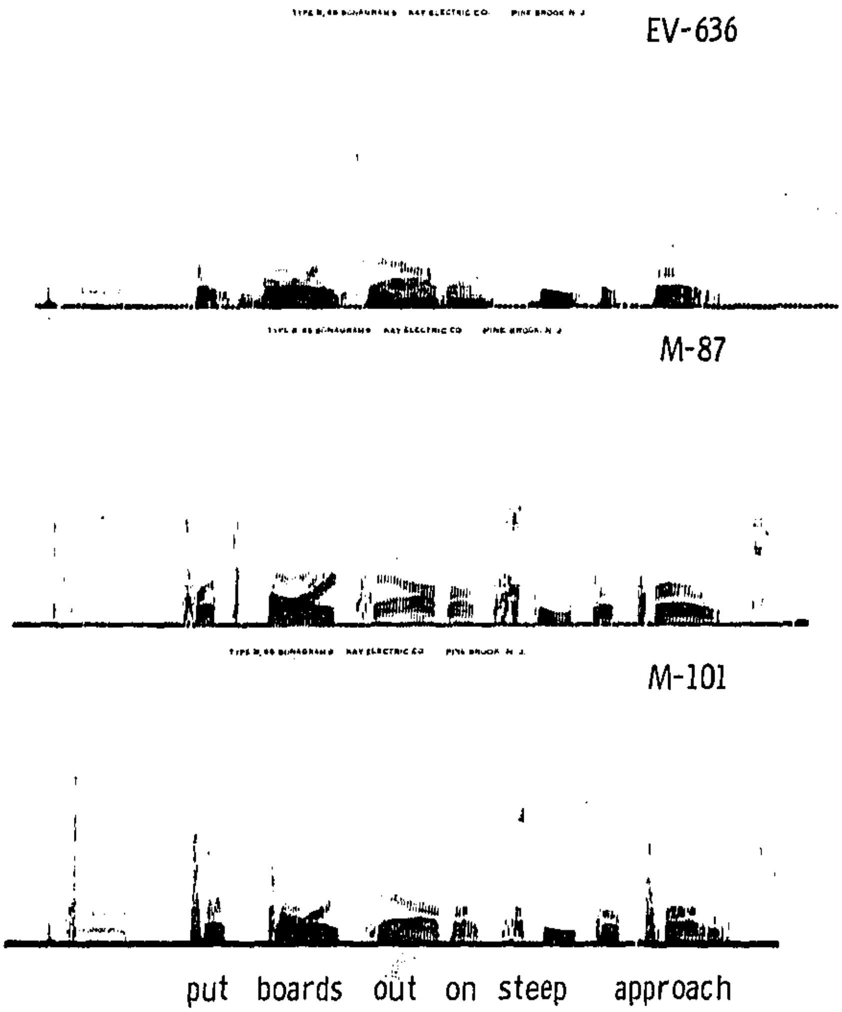

Figure 4. Comparison of voice prints obtained using three transducers and standard linear (frequency) Sonagraph analysis.

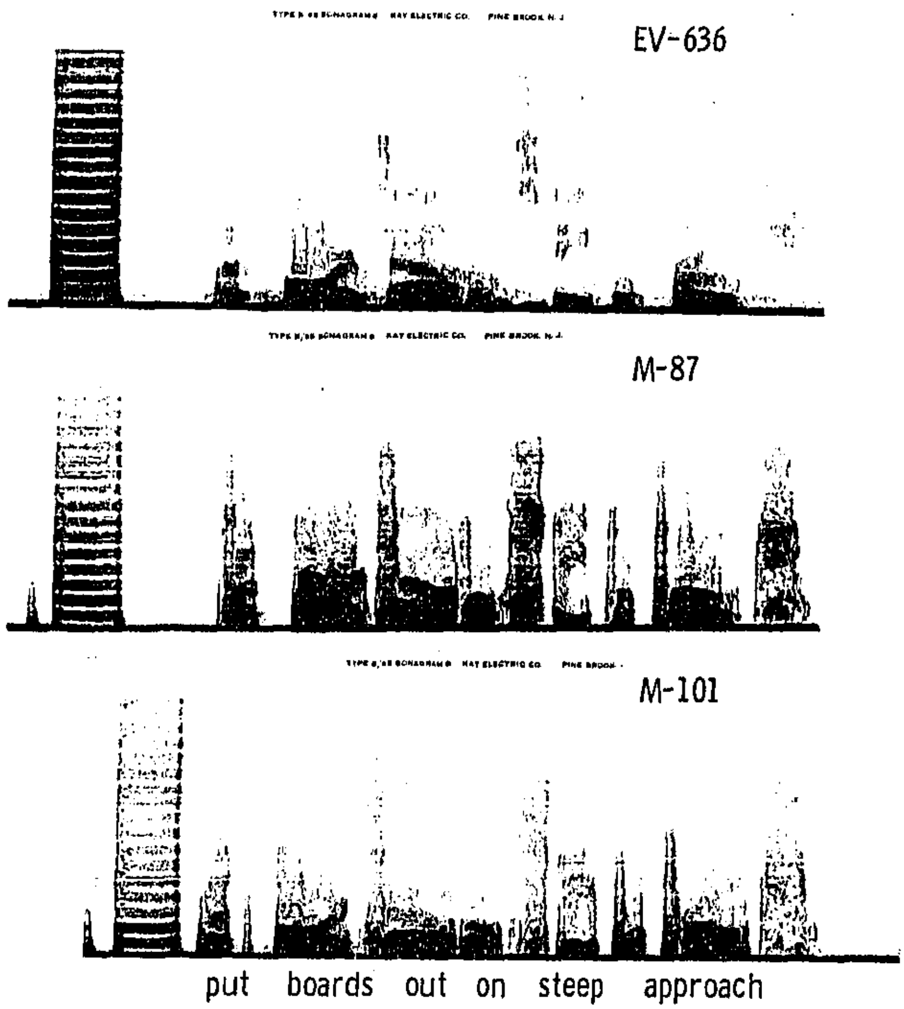

Figure 5. Comparison of voice prints obtained using three transducers and standard linear (frequency) Sonagraph analysis with amplitude contours (6-dB contour).

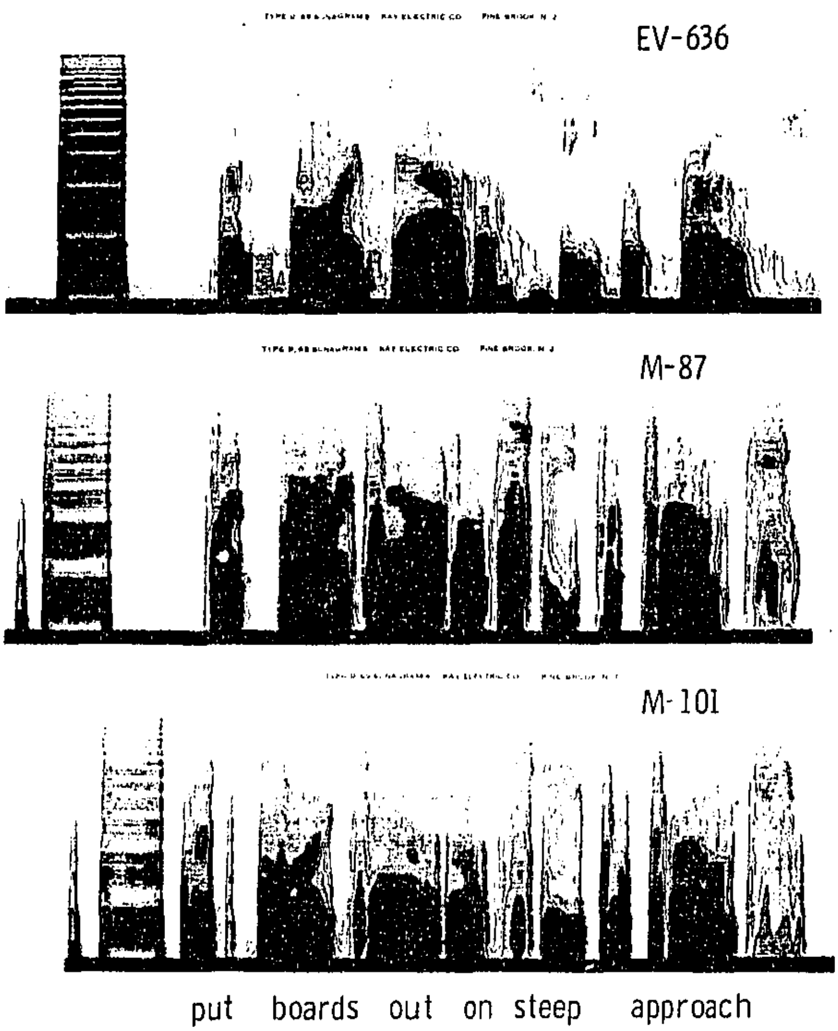

Figure 6. Comparison of voice prints obtained using three transducers and standard logarithmic (frequency) Sonagraph analysis with amplitude contours (6-dB contour).

The phrase reported in this study was selected only to illustrate that acoustic alterations do occur. These samples were recorded in quiet surroundings, so noise that commonly accompanies speech is absent.

Figure 7 shows a phonetic transcription of the phrase. The acoustic elements most altered by the lip microphone are identified (underlined). Vowels and diphthongs are not significantly affected; of the consonants, the voiceless ones are most altered.

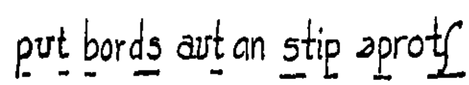

Figure 7. Acoustic alterations (underlined) that occur when speech is picked up at the lips with either M-87 or M-101 microphone.

Table 1 lists the 24 consonants used in general American pronunciation (3). Consonants that receive the most alteration when picked up at the speaker's lips, are indicated by an asterisk. These alterations were identified by comparing each when uttered in frontal and final positions with the neutral vowel sound "ah." Although this study does not quantify details of the acoustic alterations, the voiceless consonants identified as stops, fricatives, affricates, and nasals are recognized as taking on a significantly different form of acoustic loading (or emphasis) from that encountered in normal conversational speech.

SUMMARY AND CONCLUSIONS

Speech samples recorded in aircraft reveal that many consonant sounds undergo significant acoustic alteration when picked up at the lips. When lip-position microphones are used, the amplitude representation of voiceless consonants differs from that of normal face-to-face speech. This initial study was prompted because the author noted that pilots who failed auditory standards for pure-tone hearing acuity and who also demonstrated less-than-normal speech discrimination when tested with standard articulation materials in the clinical setting, appeared to have little, if any, difficulty understanding speech signals delivered to their ears via standard electroacoustic communication systems. Since most pilots who have difficulty passing the pure-tone hearing standards have a high-tone hearing loss, the first phase of investigation was to identify the acoustic nature of speech received within aircraft. In accomplishing the initial aim, this research showed that acoustic alterations do occur in speech picked up at the lips, and suggests that this type of acoustic alteration may increase intelligibility after the

TABLE 1. CONSONANTS USED IN GENERAL AMERICAN ENGLISH

		Bilabial	Labio-dental	Inter-dental	Alveolar	Alveolo-palatal	Palatal	Velar	Glottal
Stops	voiced	b •			d •			g	
	voiceless	p •			t •			k •	
Fricatives	voiced		v •	ð	z •				
	voiceless		f •	θ •	s •				h
Affricates	voiced					ʒ			
	voiceless					ʃ •			
Nasals	voiced	m			n	dʒ		ŋ	
	voiceless					tʃ •			
Glides	voiced	w •					r j		
	voiceless	hw •							
Lateral	voiced				l				
	voiceless								

• Consonants acoustically altered when picked up at the lips.

listener has learned to accurately process the signals. The degree of enhancement must now be explored; this will be approached by recording standard speech-discrimination test materials at a distance of 6 inches (15.24 cm) and at the lips, and then presenting this material to rated personnel with normal and abnormal pure-tone hearing acuity.

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