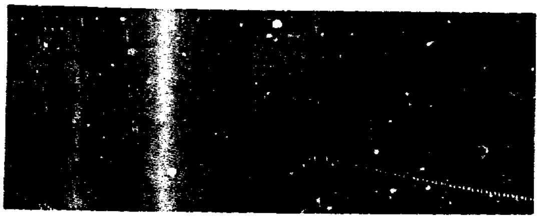

SPEECH INTELLIGIBILITY IN NAVAL AIRCRAFT RADIOS

Microphones and man-worn equipment are not major contributors to degraded intelligibility; speech processing is indicated to achieve improvement

J.C. Webster and C.R. Allen   Research and Development   2 August 1972

Sponsored by the Office of Naval Research ONR Task Number NR 213-089

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13. ABSTRACT

A study was made to determine how speech intelligibility in naval aircraft radio communications is affected by cockpit noise, by the microphone, helmet, and microphone used by the pilot, and by the vocabulary employed.

Using six standard word lists, speech-intelligibility tests were administered to 20 Navy enlisted men for 38 hours of listening. Cockpit noise in which the lists were recorded was both in-flight and simulated.

The talker and the speech-processing equipment are largely responsible for the quality of the transmissions. Cockpit noise, microphone, and man-worn gear have negligibly degrading effect upon intelligibility of the aircraft radio communications. Speech-processing is recommended to achieve improved intelligibility.

Recommendations are made for choosing optimum intelligibility tests for assessing military speech communication systems and for revising the Brevity Code words.

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Aircraft communications						
Voice radio						
Speech intelligibility						

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PROBLEM

Improve naval aircraft radio communications by determining how speech intelligibility is affected by cockpit noise, by the oxygen mask and helmet worn by the pilot, and by the vocabulary employed.

RESULTS

1. Using six standard word lists, speech-intelligibility tests were administered to 20 Navy enlisted men for 38 hours of listening sessions. Cockpit noise in which the lists were recorded was both in-flight and simulated.

2. Results are discussed with respect to individual and group listener differences; in-flight vs. simulated cockpit noise conditions; differences reflecting test-word list used; listener noise-level differences; talker conditions (including effects of background noise and oxygen mask) and phonetic confusions.

3. Tests showed that the equipment worn by speakers in the naval aircraft radio link (helmets and masks) and the transducers used account for very little of the degradation in speech intelligibility encountered in the total link. Rather, the quality of the speech is largely dependent upon the speaker and the speech processing in the transmitter.

4. The M-94A microphones and A-13A oxygen masks now in use in naval radio systems are satisfactory. There is a slight decrement in speech intelligibility due to the oxygen mask, but it appears to be primarily dependent on the user's adaptation to it.

5. The Modified Rhyme Test (MRT) of House, et al. as modified by Kruel, et al. was found to be the most acceptable speech intelligibility test; 95 percent of standard test sentences will be understood over a system that will pass 80 percent of the MRT words.

RECOMMENDATIONS

1. In future programs to improve aircraft radio communications, primary effort should be on speech-processing methods, in addition to altering microphones or oxygen masks.

2. Train prospective pilots to speak intelligibly when wearing oxygen masks in noise.

3. Standardize on some multiple-choice intelligibility test for determining the adequacy of military speech communication systems. The best test now available is the Modified Rhyme Test (MRT) of House, et al. as modified by Kreul, et al.

4. Set an MRT score of 80 percent or greater as the acceptance specification for speech intelligibility. This corresponds to an articulation index of 0.35 or better.

5. Use multisyllable words and/or multiword phrases in revising the Brevity Code word list.

ADMINISTRATIVE INFORMATION

Work was performed under RF 32.423.101, NR 213-089 (NELC B704) by members of the Human Factors Technology Division. The report covers intermittent work from February 1971 to June 1972 and was approved for publication 2 August 1972.

Appreciation is expressed to R. P. Kaufman who set up the recording equipment at MAVMISCEN, Pt. Mugu, and supervised the recordings of test words. Miss Elaine Schiller, Mr. Kaufman, and J. B. Rosenfeld set up and calibrated the equipment for the listening tests. Miss Schiller also compiled and randomized the Brevity Code word lists for the tests, which were administered by Mr. Kaufman, Mr. Rosenfeld, and P. Moreno.

The authors are greatly indebted to many colleagues in the fields of communications and speech sciences. These included experts in other Naval facilities, related USAF activities, and development companies, who contributed information through consultations and through relevant literature they made available.

The Naval Missile Center, Pt. Mugu, California, is working extensively in evaluating new noise-attenuating equipment (helmets, oxygen masks, earphones, earmuffs) and microphones. D. Robertson, T.V. Blattel, and W. Engbrecht of MAVMISCEN were helpful in making their facilities available for recording the test words used, and in exchange of information.

Dr. C. E. Williams, J. W. Greene, and J. R. Forstall at the Naval Aerospace Medical Institute in Pensacola, Florida, were helpful in assuring minimum overlap of related BUMED and NAVAIR programs with the present study. They made available four of their recent reports which are relevant and contributed substantial background information on both equipment and intelligibility.

Major D. C. Gasaway, BSC, USAF, of the USAF School of Aerospace Medicine supplied pertinent reports, updated the authors on current USAF problems of noise and radio intelligibility, and contributed his personal services for recording the test words.

Mr. Geoffrey Allen of the Royal Air Force contributed documents concerning effects of cockpit noise and protective equipment on speech intelligibility – an outcome of RAF studies of excessive cockpit noise in their Phantom aircraft.

In the early phases of the study, many persons were identified as being especially knowledgeable in the general problem area of speech intelligibility in aircraft radios. Most of these are listed as authors in the list of references, with brief annotations regarding their contributions. A few who are not so listed but contributed information and assistance are:

R. T. Camp, Jr., Basic Sciences Dept., U.S. Army Aeromedical Research Unit, Fort Rucker, California
Dr. E. C. Johnson, Naval Air Development Center, Warminster, Pa.
Dr. J. W. Black, Speech and Audiology Dept., Ohio State University
E. Massengil, Naval Air Systems Command
Dr. C. T. Morrow, Advanced Technology Center, Inc., Dallas, Texas
Dr. G. Tolhurst, University of Massachusetts
R. Seltz, Naval Air Test Center, Patuxent River, Md.

CONTENTS

Tables

Exhibit

Illustrations

INTRODUCTION

Command control on Navy ships and aircraft depends to a major extent on the effectiveness of their communications systems. Demands on these systems increase as new weapons systems and tactics are introduced and ambient noise levels become higher. Too often, voice intelligibility is only marginal. The study reported here addresses this critical problem – specifically, intelligibility of naval aircraft radio transmissions. In this context, the factors that affect speech intelligibility can be broken down into four major categories: those associated with (1) the person sending the message, (2) his equipment, (3) his environment, and (4) the message content.

Personal factors known to degrade speech intelligibility include regional dialects, poor enunciation or vocal articulation habits, and inadequate training in the special procedures and phraseologies associated with the equipment or the mission.

Equipment or design features are known to degrade intelligibility by creating noise and distortion and by their requirements for restricted bandwidths which are not amenable to the best message transmission. Reducing noise and increasing bandwidths are expensive, and tradeoffs between expense and intelligibility are serious considerations. Distortion often results from speech-processing schemes which are introduced to overcome noise or to make more efficient use of available power. Distortion of another sort is created by life-support equipments necessary for high-altitude flight, such as the oxygen mask worn by crew members of high-performance aircraft. This enclosure over the mouth and nose creates an unnatural cavity in which to talk.

Environmental conditions known to degrade intelligibility are ambient acoustic and electrical noise, diversion by competing tasks (like flying an airplane, or tracking on a radar scope), and stress.

Message parameters which degrade intelligibility include large vocabularies, reports of unusual events with seldom-used words or phrases, and short words or phrases vice grammatical sentences and polysyllabic words.

An extensive testing program was undertaken to measure the speech degradation caused by (1) acoustic cockpit noise and its interaction on speaking (microphone) and listening, (2) the oxygen mask, and (3) the vocabulary employed in operational messages. Subsequent sections describe the test program and present a detailed analysis of the results, as they relate to the quality of naval aircraft radio communications.

MESSAGE CONTENT STUDY

In preparation for the intelligibility tests, useful "real world" information on the content of military aircraft radio communications was obtained from recordings of operational transmissions.

A four-man team from NELC* working on four different but related problems rode USS ENTERPRISE (CVAN 65) from Pearl Harbor to Subic Bay to Yankee Station. These men took four small Craig cassette tape recorders with special adapters to bridge into the pilot's microphone-earphone radio-intercom lead. Recordings were made aboard an E2 which intercepted essentially all unencrypted radio transmissions of combat aircraft flying over the Republic of Vietnam (RVN). These recordings cannot be used for quality analysis, because of rather bad own-aircraft radar interference, but the content has been transcribed and is presented in a companion document.**

Another set of messages were recorded directly in the cockpit of an aircraft in combat over the RVN. A transcript of these, with altered call signs, appears in the Appendix. As in the case of the E2 recordings, the transcripts of these recordings are of interest primarily for their word content and are devoid of the features that come only with hearing the messages. There are certain changes in voice level, pitch level, and speaking rate that accompany the reporting of a surface-to-air-missile (SAM) on the way up, etc. Detailed physical measurements of these vocal parameters are beyond the financial and time limits of this problem, but a few excerpts of the messages are to be re-recorded later for a short tape report.

A valuable contribution was made by Major Gasaway, USAF, who furnished a list of words extracted from many hours of radio and interphone message recordings made on USAF aircraft. These messages had been recorded in-flight by Major Gasaway and compiled with the aid of Technical Sergeant J. F. Boyer, Jr., USAF. The lists included both single and coupled words. At NELC the lists were edited and collated with the USN Brevity Code list, for comparison with the words in five standard tests used routinely in speech intelligibility tests. The editing consisted of combining, as one entry, words used as both nouns and verbs, singular and plural forms of nouns, and verbs of different tenses. For example,

bank, banks, banked

were listed as

bank(s)(ed).

The combined lists (a total of 1769 words) are very useful in showing the relevance of the Brevity Code words to "real world" messages Tables 1A-B are sample pages from the combined list,*** and table 2 provides a statistical summary of the words in the total list.

---

*J. C. Webster, F. G. Henry, LT G. B. Woodring, Jr., USN, and ACC C. A. Smith, USN.

**NELC Technical Document 191, Compendium of Speech Testing Material and Typical Noise Spectra for Use in Evaluating Communications Equipment, by J. C. Webster (in preparation)

***To keep this report from being unduly long, many of the word lists including the complete list of USAF words are compiled separately in NELC Technical Document 191 cited above.

EXPLANATION OF CODING IN TABLE 1:

Symbols appearing in columns 2, 4, and 6 denote word-frequency counts (occurrences per million words), from Thorndike, E. L. and Lorge, I. (1952) and inclusion in one or more of the five word tests used in the study, as follows.

First symbol (occurrences per million words):

AA = at least 100 occurrences/million words

A = between 50 and 100 occurrences

Numerals 1 through 49: designated number of occurrences under 50

– = not counted.

The second through the sixth symbols in these columns indicate that the word is included in one or more of the following word lists:

Letter = Word List

P = Egan's Phonetically Balanced Words

F = Fairbanks Rhyme Test

M = Modified Rhyme Test of House, *et al.* as modified by Kruel, *et al.*

V = Clarke's Vowel Test

D = Voier's Diagnostic Rhyme Test

Thus the word "bit" as it appears on the list may be identified as follows:

Word appears oftener than 100 times per million words

AA,P, F,M,V,D – Voiers's Diagnostic Rhyme Test

Clarke's Vowel Test

and appears in

Modified Rhyme Test

Fairbanks Rhyme Test

Egan's Phonetically Balanced Words

TABLE 1. SAMPLE PAGES FROM AIRCRAFT COMMUNICATION WORD LIST.*

A. ONE-WORD LIST

a	AA	bag(ged)	AA	blur(red)	8
ABORT(ING)	–	ball	AA,P,V	board(s)	AA
add	AA,P	ban	2,M	boat(s)	AA,V
AFFIRM	10	band	A,V	bog(ged)(gy)	9,P
AFFIRMATIVE	3	bang	14,F,M	BOGEY	
aft	4	bank(ed)	AA	bolts	27,P
aid(s)	A,P	bar	A,P	bomb(s)	13,D
aim(ed)	A,P	BARCAP	–	book	AA,P,F,M
air	AA,P	bare	A	boom	19
AIRBORNE	–	barge	12,P	boost	2,P
aisle	12	barn	45,P	boot	37
ALFA	–	base(d)	AA,P	bore	A,F
all	AA,P	bat	19,P,M,D	born	AA,F
alley	13	BATTERY	19	botch(ed)	–
alp	–	batch	3	both	AA
ALTITUDE	14	bay	AA,P	bounce(d)	10,P
am	AA,P	be	AA	bound	A,V
an	AA	beach(ed)	A,M	BOWWAVE	–
ANCHORED	26	beam	42,P,M	brace	17,P
ANYCAP	–	beat(s)	AA,F,M,D	brakes	23
and	AA,P	been	AA	branch	AA
ANGELS	47	BELLHOP	–	BRAVO	1
ANGLE	30	bend(s)	48,F,M,V,D	break	AA
any	AA	best	AA,P,F,M	bridge	AA
APPROACH	A	bet	23,P,V	brief	A
apt	22,P	big	AA,P,F,M	bright	AA
arc(s)	9,P	bind	39,P,V	brim	13
arch(ed)	34,P	BINGO	–	bring	AA
are(n't)	AA,P	bird(s)	AA,V	brink	8
arid	AA	bit	AA,P,F,M,V,D	brisk	9
ARK	7	black	AA,P	broad	A,V
arm(ed)(s)	AA,P	blade(s)	32	broiled	9
as	AA,P	blare	2	broke	A
ask(ed)(s)	AA,P	blast	31	brown	AA
ASPRO	–	blaze	42	BROWNIE	6
ASSUME	A	bleak	9	budge(d)	4,P
at	AA,P,V	bleed	16	build	AA
AUTOCAT	–	blind	A,P	bulge	5
AWAY	AA	blow	AA	BULLMOOSE	–
aye	16	blob	–	bum	6
		block	A	bury	–
BABS	–	blow(n)	AA	burn(ed)(t)	AA
back	AA,P,F,M	blue	AA	burst(s)	A
bad	AA,P,M,V,D	bluff	12,P	bus	9,P,M

---

*Letters in lower-case appear in AF list only; lower-case and underlined, in Brevity Code only; in capitals, in both AF list and Brevity Code. See preceding page for explanation of symbols in columns 2, 4, and 6.

TABLE 1 (Continued).

A. ONE-WORD LIST (Continued)

bust	13,P,F,M	bye	1	calm(ed)	A
BUSTER	–			came	AA,F,M
but	AA,P,M	cab	15,P	camp	AA,P
buzz(ed)	16,P	cage	30,P,F	can('t)	AA,P
by	AA,P	call(ed)	AA,V	cap	A

B. TWO- AND THREE-WORD GROUPS

air borne
air brake
air line
air plane
air speed
air start
aisle seat
alls calm
ANY FACE
arm guns

bank left
bank right
base leg
BENCH MARK
BAY RUM
big blow
BINGO FIELD
BINGO STATE
blade pitch
bleed air
block time
boards out
bomb bay
bomb run
brake out
break left
break off
break right
break up
bright light
brisk wind
build up
burned out
buss box

call back
call sign
calm sea
calm wind

CEASE REPORTING
change speed
charge guns
chase plane
clear air
cloud deck
cloud layer
coast line
code book
code three
creep by
crew rest

DAVEY JONES
day break
DECK CLEAR
DECK FOUL
dense fog
dim lights
dive time
dog leg
dome light
down hill
down wind
drag chute
draw fire
drink fuel
drop down
drop tanks
dry tank(s)
dump fuel
dump stores

EASE TURN
east bound
east side
EMERGENCY SPACE
exit time

face mask

face plate
fan jet
far side
fast cruise
FEET DRY
FEET WET
fill tanks
first class
five G's
flame out
flaps down
flaps up
flat tire
flight deck
flight path
flight plan
flood light
fly at
FLYING AT
form left
form right
form up
four miles
FREE LANCE
freeze line
front side
fuel dump
fuel feed
fuel flow
fuel gauge
fuel pod
fuel pump
full flaps
full speed
fuze box

G-force
gas gauge
gear down
gear up

glide path
good by
ground fire
gun fire
guns free
guns tight
half flaps
hand crank
hatch closed
head wind(s)
heads up
high boost
high gain
high pitch
high side
high tide
high wind
hold course
hold fire
hold line
home plate
home stretch
hook down
HOTEL FIRE
hot mike

ice berg
iced up
I GO
in range
IN THE DARK
I STAY

join up
joy stick

keep clear
keep pace

lap belt

TABLE 1 (Continued)

B. TWO- AND THREE-WORD GROUPS

lead ship
left flank
left side
left turn
light haze
light mist
light rain
light snow
link up
live fuze
locked down
low boost
low pitch
low run
low side
low tide

MACK NO
MACK YES
main gear
main switch
marsh land
mid course
mild chop

new course
next turn
no joy
north bound
north east
north west
nose gear

off course
on course
ON THE CLOCK
on top
ON STATION
ON TARGET

TABLE 2. STATISTICAL COMPARISON OF USN BREVITY CODE AND USAF WORD LISTS*

Type Word(s)	Frequency (and percent) of Occurrence per Million				
	>100	50-99	1-49	<1	Σ
USAF	508(41)	173(14)	529(42)	39(3)	1249(100)
Brevity Code	50(18)	26(9)	129(48)	67(25)	272(100)

Number of Syllables per Single Word

	1	2	3	4	5	Different Suffixes
USAF	1221	28	–	–	–	402
Brevity Code	88	148	29	6	1	40

Number of Syllables for 2- and 3-Word Groupings

	2	3	4	5
USAF	222	–	–	–
Brevity Code	26	17	5	1

---

*It is not always possible to make the total number of words agree with the totals in table 3. For example, ABORT and ABORTING are listed as two words on table 3 but as one word in table 1.

The operational recordings and the USAF list just noted provide a baseline for any realistic attempt to understand and improve the speech-intelligibility problem in naval aircraft radio communications.

DETAILS OF RECORDINGS

The two talkers were Major Donald M. Gasaway (DG), USAF, and Douglas Robertson (DR). Both of these men have had graduate training in speech and audiology, are experienced talkers, and have had many hours of flight as observers in operational military aircraft. The four conditions in which they talked were no-noise/no-mask (Q,NM), no-noise/mask (Q,M), noise/no-mask (N,NM), and noise/mask (N,M).

A standard USN dynamic microphone (M-94A) was used, usually mounted in oxygen mask A-13A, which fastens to the aviator's protective helmet, USN APH-6A. In all the recordings the speakers wore the APH-6A, with the H-87 earphones in place to monitor their own voices. For the no-mask condition they held the microphone within a quarter-inch of their lips.

SIMULATED NOISE

Simulated cockpit noise was prepared at the Naval Missile Center, Point Mugu, California, using General Radio Random Noise Generator 1390-B. The noise was shaped to conform to the spectrum of composite jet aircraft cockpit noise (fig. 1) determined by Sutherland and Gasaway (1971) from extensive data of Gasaway (1970).* Figure 2 is a block diagram of the equipment used in making the recordings. The noise was played back at an A-weighted sound-pressure level of 110 dB at the position of the microphone (without the mask in place), in an AIC booth which had been adapted to be semireverberant.

---

*Figure 1 includes an estimate from Blattel and Engbrecht (1971) of the spectrum at the talker's ears when he is wearing the USN APH-6A helmet; they used the same talkers, noise, and helmets in an evaluation of a modified oxygen mask and a different microphone and found an overall helmet attenuation of about 15 dB.

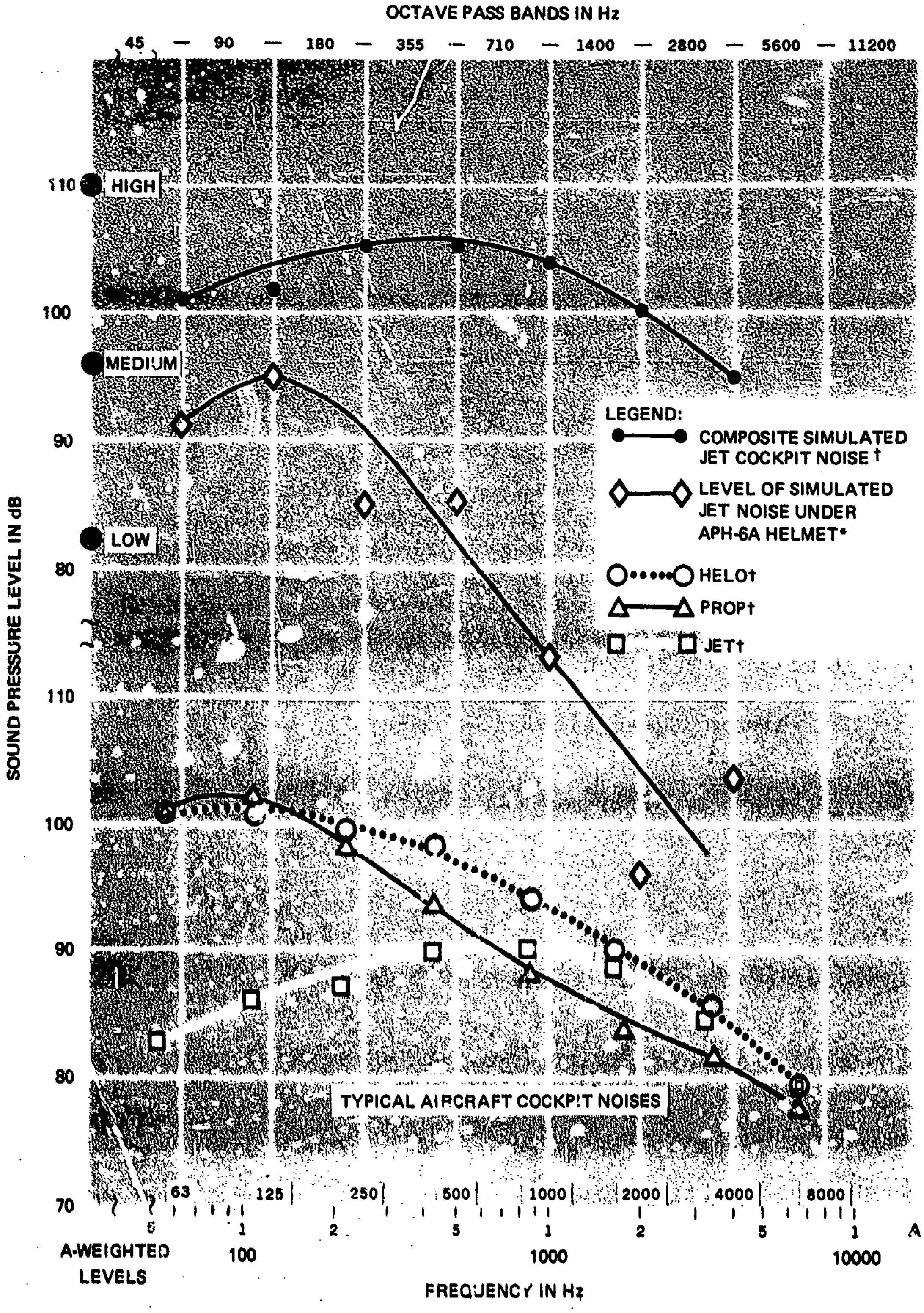

Figure 1. Octave-band and A-weighted levels of typical aircraft cockpit noise. Lower three curves, typical spectra in cockpits of jet, propeller, and rotary-wing aircraft. Upper curves, ●——●, highest jet aircraft noise in the cockpit and △——△, at the ears of the pilot. Data from [†] Sutherland and Gasaway (1971) and [*] Blattel and Engbrecht (1971).

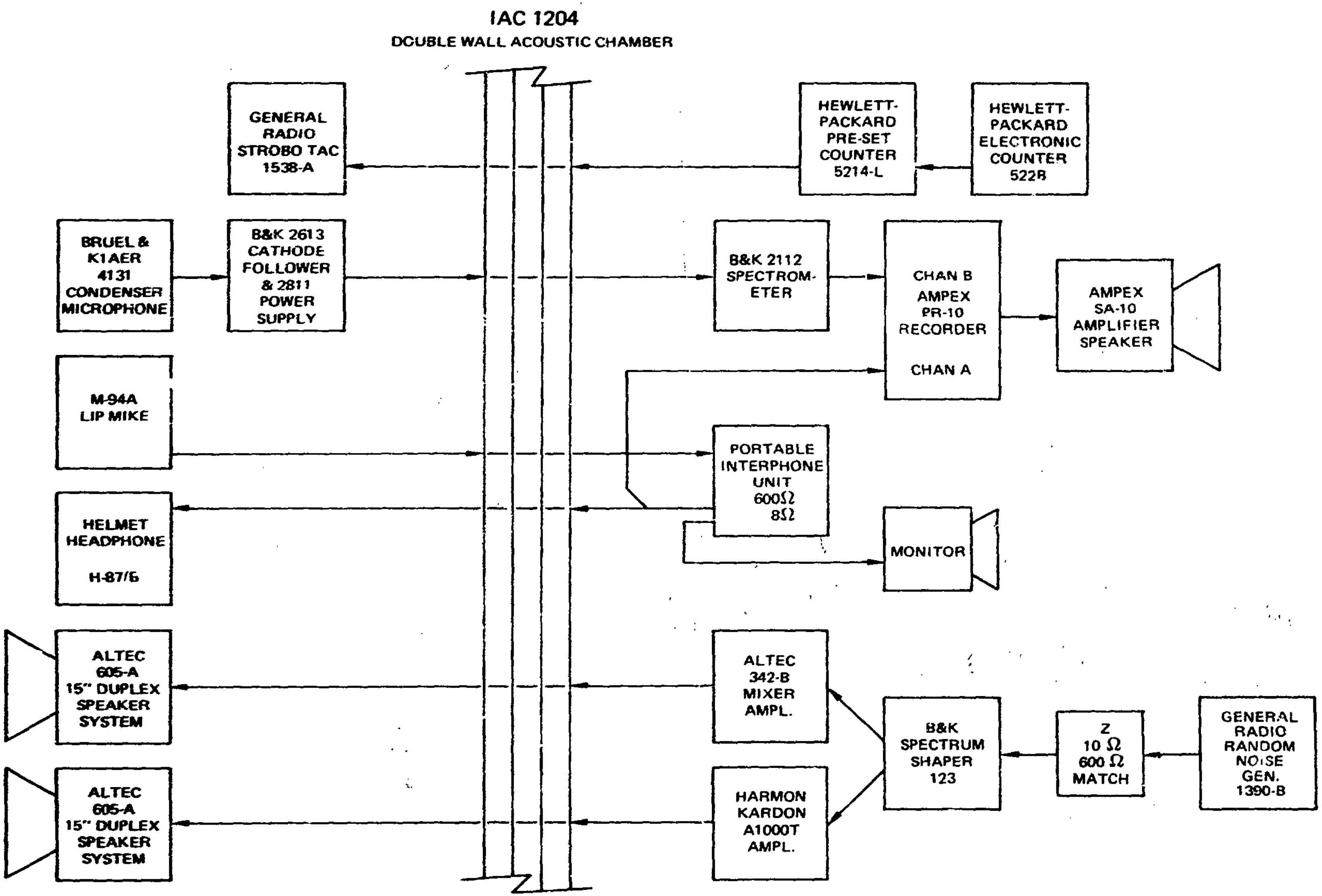

Figure 2. Block diagram of the equipment used at the Naval Missile Center to record word lists in simulated cockpit noise.

DETAILS OF TEST PROGRAM

TEST MATERIALS

The speech-intelligibility tests were carefully chosen from the great number now available. It was essential that speech degradation be measured in a manner that would be reliable (repeatable), valid (relevant to the tasks involved), and diagnostic (pointing to areas where improvement can be expected). Furthermore, for maximum usefulness the tests should be capable of cross-relation to tests that have been used extensively in the past and/or by other investigators and, if possible, related to physical measures of speech and noise levels at the listeners' earphone or at a loudspeaker.

A study was made of many candidate tests and of a series of 150 abstracts on speech tests and testing methods by Clarke, et al. (1965), and consultations were held with many colleagues of the authors in the field of audiology. The tests finally chosen were as follows. (The letter abbreviations indicated for each will be used throughout the remainder of the report; abbreviations in brackets were used for table 1.)

1. Egan's lists of 1000 monosyllabic, phonetically balanced (PB) [P] words (20 lists of 50 words).

2. A pilot's vocabulary test prepared at NELC, incorporating the ICAO (International Civil Aeronautics Organization) phonetic alphabet (ref. 34) (Alfa, Bravo, . . . Zulu), the numerals "zero" through "niner," and appropriate Brevity Code words (ref. 1). The latter are words agreed upon for use as substitutes for other words, phrases, or concepts, such as Roger (meaning "I have received your message") and Angels ("My present altitude is..."), etc. The pilot's vocabulary test, which will be referred to as BREV, comprises eight lists of 41 words, or a total of 328 words.

3. The multiple-choice Modified Rhyme Test (MRT) [M] by Kreul, et al. (1968), based on a similar list assembled by House, et al. (1965); consists of six lists of 50 words, or 300 words.

4. The Fairbanks Rhyme Test (FRT) [F], a multiple-choice rhyme test consisting of five lists of 50 monosyllabic words, or 250 words.

5. Voier's Diagnostic Rhyme Test (DRT) [D], consisting of four lists of 58 words, or 232 words.

6. Clarke's vowel or medial-position Phonetically Balanced Rhyme Test [PBRT(M)] [V], consisting of 300 phonetically balanced words assembled by Clarke (1965) to test medial vowels, in contrast to other rhyme lists which test initial (Fairbanks) or initial and final (Kreul, et al. and House, et al.) consonants.

The rhyme tests were chosen because they not only have proved to be as reliable as other tests (and require less training of listeners) but because they can be analyzed to tell what particular aspects of the English language are primarily responsible for reduced overall scores. This should prove invaluable if new phraseologies are the primary hope for significant improvement in overall effectiveness.

The MRT, DRT and PBRT were used in three ways: (1) to find the degree of degradation due to noise and oxygen mask; (2) to compare with two older standard tests – Egan's Phonetically Balanced Word Test and Fairbanks Rhyme Test – and with a new pilot's vocabulary test; and (3) to compare variations in intelligibility that occur when talking is done in simulated cockpit noise with those encountered in actual flight.

The word lists, answer sheet forms, and phonetic composition of tests other than the BREV test are not included in this report, but can be found in a companion document (NELC Technical Document 191, in preparation), which is intended to be a handbook of common speech tests, with directions for administering them. The BREV test is included (table 3) because it was especially assembled for this study.

The two talkers read randomized lists of the five standard word tests and the Brevity Code list, with the noise and mask conditions shown in table 4. The words were spoken in synchronism with a flashing light which established a 4-second interval for the PB words, a 3-second interval for the Brevity Code words, and a 1.5-second interval for all other lists. For the PB words the talkers spoke the carrier phrase, "You will write the word ________ now." For all other tests they merely read off the item number. Before each list was recorded they identified themselves, the equipment they were using and wearing, the ambient noise level, and the exact word list. This allowed them time to adopt a comfortable talking level and gave the recording technician time to establish a proper (-4 VU peak) recording level. Occasionally two or more pronunciations were given on a single word and in a re-recording process preceding the listening tests a selection was made of the most typically American pronunciation.

For these simulated-noise recordings, the talkers monitored themselves aurally by use of the H-87 earphones in their helmets and did NOT view any type of meter. This informal monitoring method kept the recordings realistic in terms of how pilots actually use the system and resulted in greater variations in word level than are usually found in this type of testing routine. In general the levels dropped throughout the list. This realism probably accounts in great part for the unusually large dispersion of listener scores, as will be discussed later.

IN-FLIGHT NOISE

To obtain in-flight recordings for the tests, the two talkers rode as observers (one in an A3 Sky Warrior and the other in an F4J Phantom) and recorded randomized lists of the PB, BREV, FRT, DRT, PBRT, and MRT words. The word lists and the aircraft maneuvers during which they were recorded are shown in table 5. For these in-flight recordings, the words were read off as fast as possible and the proper interword spacings were added in the re-recording process.

TABLE 3. NELC ADAPTATION OF USN BREVITY CODE WORD LIST (PHONETIC ALPHABET AND NUMERALS ADDED).

1. ABORT
2. ABORTING
3. AFFIRM
4. AFFIRMATIVE
5. AIRBORNE
6. ALTITUDE
7. ANCHORED
8. ANYCAP
9. ANGELS
10. ANGLE
11. ANY FACE
12. APPROACH
13. ARK
14. ASPRO
15. ASSUME
16. AUTOCAT
17. AWAY

18. BABS
19. BARCAP
20. BASE
21. BATTERY
22. BAY RUM
23. BELLHOP
24. BENCH MARK
25. BENT
26. BINGO
27. BINGO FIELD
28. BINGO STATE
29. BIRD
30. BLIND
31. BOGEY
32. BOWWAVE
33. BREAK
34. BROWNIE
35. BULLMOOSE
36. BUSTER

37. CAP
38. CAPREP
39. CAUTION
40. CAVU
41. CEASE REPORTING
42. CHARLIE
43. CHASE
44. CHECK
45. CHERUBS
46. CHICKS
47. CHOPPER
48. CIGAR
49. CLARA
50. CLEARED
51. CLUTTER
52. COCKROACH
53. CODE
54. CONDITION
55. CONFUSED
56. CONTACT
57. CONTINUE
58. COVER
59. CREW
60. CROSSING

61. DADCAP
62. DANGER
63. DAVEY JONES
64. DAYRECCO
65. DEAF
66. DECIMAL
67. DECK CLEAR
68. DECK FOUL
69. DECOY
70. DELTA
71. DETACH
72. DITCH
73. DITCHING
74. DIVERT
75. DOLLY
76. DRONE
77. DUCKBUTT
78. DUD
79. DUMBO

80. EASE TURN
81. ELEVATOR
82. EMERGENCY
83. EMERGENCY SPACE
84. ENGAGE
85. ESTIMATE
86. EVERGREEN

87. FADED
88. FAMISHED
89. FEAR
90. FEET DRY
91. FEET WET
92. FERRET
93. FEW
94. FINAL
95. FLY AT
96. FLYING AT
97. FOX
98. FRAME
99. FREE LANCE
100. FRIENDLY
101. FUEL

102. GADGET
103. GATE
104. GEIGER
105. GERONIMO
106. GOBLIN
107. GOODYEAR
108. GRANDSLAM
109. GRAPHIC
110. GUESSER
111. GUNS FREE
112. GUNS TIGHT
113. GYRO

114. HARD
115. HAWK
116. HEADING
117. HEADS UP
118. HECKLERS
119. HELOT
120. HELP
121. HIGH
122. HOLD
123. HOLDING
124. HOMER
125. HOTEL FIRE
126. HOSTILE
127. HUGO
128. HUNTSMEN
129. HUSH

130. IDENT
131. IDENTIFY
132. I GO
133. INTERFERENCE
134. IN THE DARK
135. INTRUDERS
136. I STAY

137. JUDY

138. KEEPER

139. LAMPS

TABLE 3 (Continued).

140. LAND
141. LAUNCH
142. LAZY
143. LEFT
144. LEVEL
145. LIFEGUARD
146. LIGHTS
147. LINER
148. LINK
149. LOCAP
150. LOST
151. LOW

152. MACK NO
153. MACK YES
154. MAKER
155. MANY
156. MAPPO
157. MAYDAY
158. MEDIUM
159. MERGED
160. MIDDLEMAN
161. MIDNIGHT
162. MINUS
163. MIXUP
164. MUSHROOM

165. NANCY
166. NEGATIVE
167. NIGHTCAP
168. NIGHTRECCO
169. NOCOP
170. NODUF
171. NO JOY
172. NORMAL
173. NOT

174. O'CLOCK
175. OCTOPUS
176. OKAY
177. ON STATION
178. ON TARGET
179. ON THE CLOCK
180. ORANGES
181. ORBIT
182. ORBITING

183. PAN
184. PANCAKE
185. PARROT
186. PARTNER
187. PEDRO
188. PIGEONS
189. PLAYBOY
190. PLUS
191. PLUTO
192. POGO
193. POINT
194. POPEYE
195. PORT
196. POSITION
197. POUNCE
198. PREP CHARLIE
199. PRONTO
200. PUNCH
201. PURPLE

202. RAID
203. RAMROD
204. RANGE
205. RAPCAP
206. READY
207. RECCO
208. RECKON
209. RELIABLE
210. REPORT
211. RESCUECAP
212. RIALTO
213. RIGHT
214. ROUTE

215. SAINT BERNARD
216. SALVOS
217. SAPPHIRE
218. SAUNTER
219. SAY
220. SCAN
221. SCENE COMMANDER
222. SECTOR
223. SCRAMBLE
224. SCRUB
225. SECURITE
226. SEE YOU
227. SHADS
228. SHECAT
229. SICK
230. SINGLE
231. SITREP
232. SHIP
233. SKIP IT
234. SKUNK
235. SKYROCKET
236. SLINGSHOT
237. SMOKER
238. SNOOPER
239. SOUR
240. SPLASHED
241. SPLITTING
242. SPOTTER
243. SPOOFER
244. SQUAWK
245. SQUAWKING
246. STARBOARD
247. STATE CHICKEN
248. STATE LAMB
249. STATE TIGER
250. STATE WEAPONS
251. STEADY
252. STEER
253. STOP
254. STRANGER
255. STRANGLE
256. STRIKE
257. SUBCAP
258. SWEEP
259. SWEET

260. TALLY-HO
261. TARCAP
262. TARGET
263. TASP
264. TIED ON
265. TIPS
266. TOOL
267. TOUCH
268. TRACK
269. TRACTORS
270. TRADE
271. TRAILOR
272. TRANSPONDER
273. TRIDENT
274. TROT

275. UNABLE
276. UNKNOWN

277. VECTOR
278. VERY
279. VISIBILITY

TABLE 3 (Continued).

280. WARNING RED
281. WARNING WHITE
282. WARNING YELLOW
283. WATCH
284. WAVE OFF
285. WEAPONS FREE
286. WEAPONS TIGHT
287. WEATHER
288. WELL
289. WHAT LUCK
290. WHAT STATE
291. WHICH TRANSPONDER
292. YELLOW JACKET
293. YELP

PHONETIC ALPHABET AND NUMERALS

1. ALFA
2. BRAVO
3. CHARLIE
4. DELTA
5. ECHO
6. FOXTROT
7. GOLF
8. HOTEL
9. INDIA
10. JULIETT
11. KILO
12. LIMA
13. MIKE
14. NOVEMBER
15. OSCAR
16. PAPA
17. QUEBEC (pronounced Kay-beck)
18. ROMEO
19. SIERRA
20. TANGO
21. UNIFORM
22. VICTOR
23. WHISKEY
24. X-RAY
25. YANKEE
26. ZULU
27. WUN
28. TWO
29. THU-REE
30. FO-WER
31. FI-YIV
32. SIX
33. SEVEN
34. EIGHT
35. NI-NER
36. ZERO

TABLE 4. DISTRIBUTION OF WORD LISTS AMONG TALKER CONDITIONS IN SIMULATED NOISE.

Environmental Condition*	PB	FRT	MRT	DRT	PBRT	BREV
			Talker, Douglas Robertson (DR)			
1 (Q,NM)	1,9,17	1-1,5-3	1A,2F	111E,F,G,H	1,8	7,8
2 (Q,M)	2,10,18	2-1,1-3	1B,2E	113CA,-,-	5,4	5,6
3 (N,NM)	3,11,19	3-1,2-3	1C,2D	116E,F,G,-	9,6	3,4
4 (N,M)	4,12,20	4-1,3-3	3A,3B	112E,-,-,-	2,10	1,2
			Talker, Donald Gasaway (DG)			
1 (Q,NM)	5,13,1X	4-2,1-3	1D,2C	111A,B,C,D	2,9	1,2
2 (Q,M)	6,14,2X	3-2,2-3,	1E,2B	112A,C,-,-	6,3	3,4
3 (N,M)	7,15,3X	2-2,3-3	1F,2A	116A,C,-,-	10,7	5,6
4 (N,M)	8,16,-	1-2,5-3	3C,3D	113G,E,-,-	5,4	-,8

*Q = Quiet, N = Noise, M = Mask, NM = No mask

TABLE 5. WORD LISTS RECORDED IN FLIGHT AND FLIGHT PROFILE FOR RECORDING.

Actual F4J Noise; Talker, DG:

PB	Condition
11	Climb 28 to 35 kft
12	Normal cruise 35 kft
13	Normal cruise 35 kft
14	Normal cruise 12 kft
15	High cruise 22 kft
16	Normal cruise 35 kft
17	Level 19 kft
18	Normal cruise 22 kft
19	High cruise 12 kft
20	Climb 12 to 22 kft
DRT	
111C	Normal cruise 12 kft
111D	Descent from 20 kft
111G	Normal cruise 35 kft
111H	Normal cruise 35 kft
112C	Descent 33 to 22 kft
112D	Takeoff 6 kft/min.
112G	Warmup
112H	Normal cruise 22 kft
113B	Descent 21 to 12 kft
113C	Probe out on descent 35 to 22 kft
113G	High cruise 22 kft
113H	Normal cruise 12 kft
Exp. Mask	
113H	Normal cruise 12 kft
116C	Idle power grd.
116D	Climb 17 to 21.5 kft
116G	Normal cruise 12 kft
116H	Normal cruise 35 kft

MRT	Condition
3A	20 kft cruise, defog on
3B	High cruise 22 kft
3B	Normal cruise 35 kft
3C	Normal cruise 12 kft
3E	Normal cruise 22 kft
3F	High cruise 22 kft

BREV	Condition
5	Climb 17 to 22 kft
5	Normal cruise 34.9 kft
6	Normal cruise 22 kft
7	Probe out descent 35 kft to 22 kft
8	High cruise 22 kft
8	Normal cruise 35 kft

Actual A3 Noise; Talker, DR:

DRT	Condition
112C	Normal cruise
112D	
112G	
112H	
113C	
113D	Normal cruise

TEST SUBJECTS

Listeners for the tests were twenty Navy enlisted men who were paid volunteer subjects for Project PING. The objective of Project PING was to determine an acceptable level of short, cyclic, multifrequency tone bursts (pings) in terms of deafness risk. The subjects, who had been selected as having normal hearing, were exposed to over 100,000 pings over a 30-day period. They were tested continuously to assure that they had no abnormal temporary auditory threshold shifts, and tests were run to detect any effects of the program on their sleep and performance. The men lived in a barracks for about eight weeks.

Participation of these men in the speech intelligibility study was therefore only a part of the many behavioral performance tests in which they were engaged. For Project PING purposes, they had been divided into two equal groups, called ALFA and BRAVO. Both these groups were made available for the speech tests six days a week, alternating between one ½-hour and two ½-hour sessions a day, for a total of 36 hours. On the double-session days, the speech tests were fitted into a schedule of: addition problems, speech tests, psychological questionnaires, rest, speech tests, and dinner.

LISTENING TEST PROCEDURES

Playback equipment and the earphone listening network used in the speech tests were compatible with other Project PING instrumentation (fig. 3). Otherwise the only restriction imposed on the speech tests was that the overall listening (noise) levels not exceed the ping levels. The noise level at the ear was kept constant at 80 dB SPL, and the speech peaks were adjusted to yield scores of about 50 percent on the MRT words. For the listening tests, the speech levels were at -3, 0, and +3 dB with respect to the established level for 50-percent MRT scores. The speech level for the speech-to-noise differential of 0 dB was in fact 80 dB, so that when speech and noise were measured simultaneously the A-weighted level increased from 80 dB, on the background noise alone, to 83 dB for the speech peaks in the presence of the background noise.

Before each test, and while the subjects were wearing the helmets, a check was made to assure that the sound-pressure level was at the prescribed listening condition of 80 dB(A). The precalibrated attenuation was then set to give a -3, 0, or +3 dB speech-to-noise differential, according to a randomization schedule.

The levels just mentioned are representative of preferred pilot listening levels according to data of Sutherland and Gasaway (1971). The results of their study are plotted in figure 4. They had 65 pilots adjust the level of recorded aircraft radio transmissions when listened to under ten conditions of ambient noise: quiet, and three levels each of three types of aircraft noise. The jet, propeller, and helicopter noises and levels chosen were typical and represented the quietest, noisiest, and average cockpit levels as reported by Gasaway (1970a). When 15 dB is subtracted from each of the levels they used to account for the attenuation of the APH-6A helmet

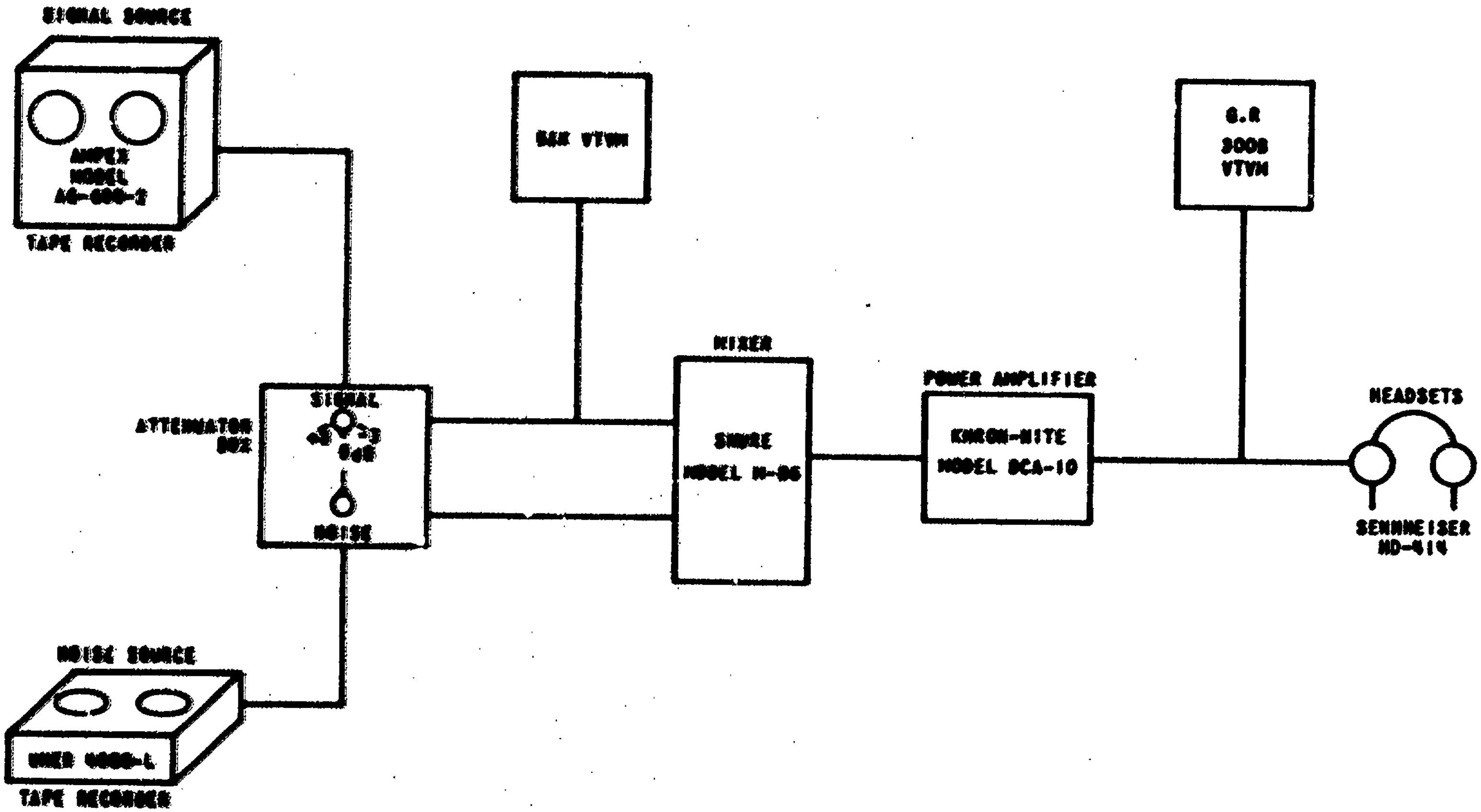

Figure 3. Block diagram of the equipment used in the listening tests.

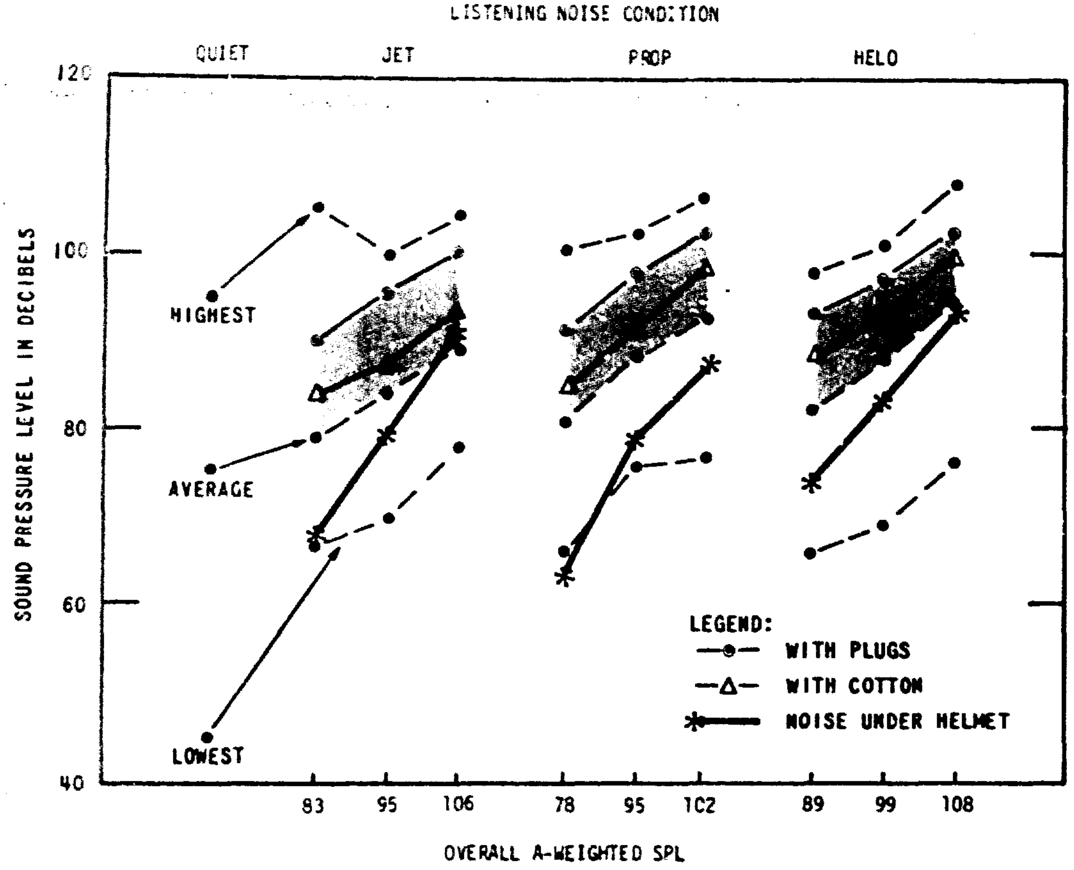

Figure 4. Preferred listening levels [from Sutherland and Gasaway (1971)] for quiet, jet, prop, and helo noise conditions at minimum, average, and maximum observed levels for these types of aircraft. Shaded area represents increased average listening level when wearing V-51 earplugs vs. open ear. The line roughly bisecting the shaded area represents the average listening level when wearing dry cotton in the ears. The highest and lowest listening levels of the 65 pilots are also plotted.

and associated sonic earcups, the levels shown on figure 4 result.* Note, for example, that when the average jet cockpit noise level at the ear is about 80 dB, as measured on the A-weighting network of a sound level meter, the average preferred listening level is 84 dB. So the preferred listening level in 80 dB(A) noise is about one dB greater than the highest (+3) level used for the listening tests in this study.

For Project PING purposes, intelligibility tests, in quiet, were given before and after the PING sequence (of 30 days), and at selected periods within the PING sequence the tests were given in noise. For the major results of this study the listeners were trained on Egan's (1948) 1000

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*The 15 dB figure is taken from figure 1 which represents the noise and levels used to make the recordings used in this study and is corroborated in general by the results of Attwood and Maslen (1970a) and Forstall (1968).

phonetically-balanced words and the 328 Brevity Code (and phonetic alphabet) words during the PING sequence. The tests of major interest in this study were conducted after the PING sequence stopped. Even so, the listening noise-level limit of 80 dB(A) was continued.

The ALFA group of test subjects listened to five word tests (PB, BREV, MRT, FRT, and DRT) which had been recorded in simulated noise by the two talkers under four talker conditions. The BRAVO group listened to the same tests, except for the FRT, which had been recorded in flight, and to Clarke's PBRT(M) test as recorded by both talkers in simulated cockpit noise.

One of the major criticisms of the Egan PB lists of 1000 words is the enormous learning time required of the listeners. Listeners must be at a learning plateau, preferably the top asymptote, to reliably reflect effects of test variables. To this end the following training procedures for the PB words and the Brevity Code words were carried out.

The subjects were first required to write the 20 distinct PB lists and 328 Brevity Code words as they were spoken and spelled by a live talker and simultaneously written on a blackboard in front of the subjects. Two different live talkers shared equally in reciting the word lists. The second presentation of the 20 PB lists and 328 Brevity Code words was in the form of a spelling test. A third presentation resulted from the correction of the tests, whereby the papers were exchanged among and graded by the subjects as the talker repeated the words and spelling. All wrongly spelled words, including those resulting from phonetic confusion, were collected and administered as a second spelling test. These retested words were again checked in the aforementioned manner and a last spelling test conducted with the misspelled retested words. Following this sequence a fourth and final word delivery was made through the test apparatus by first presenting one-half of the PB and Brevity Code words without noise and the remaining half with a S/N differential of 0 dB at a noise level of 80 dB(A) SPL; the subjects wrote all words.

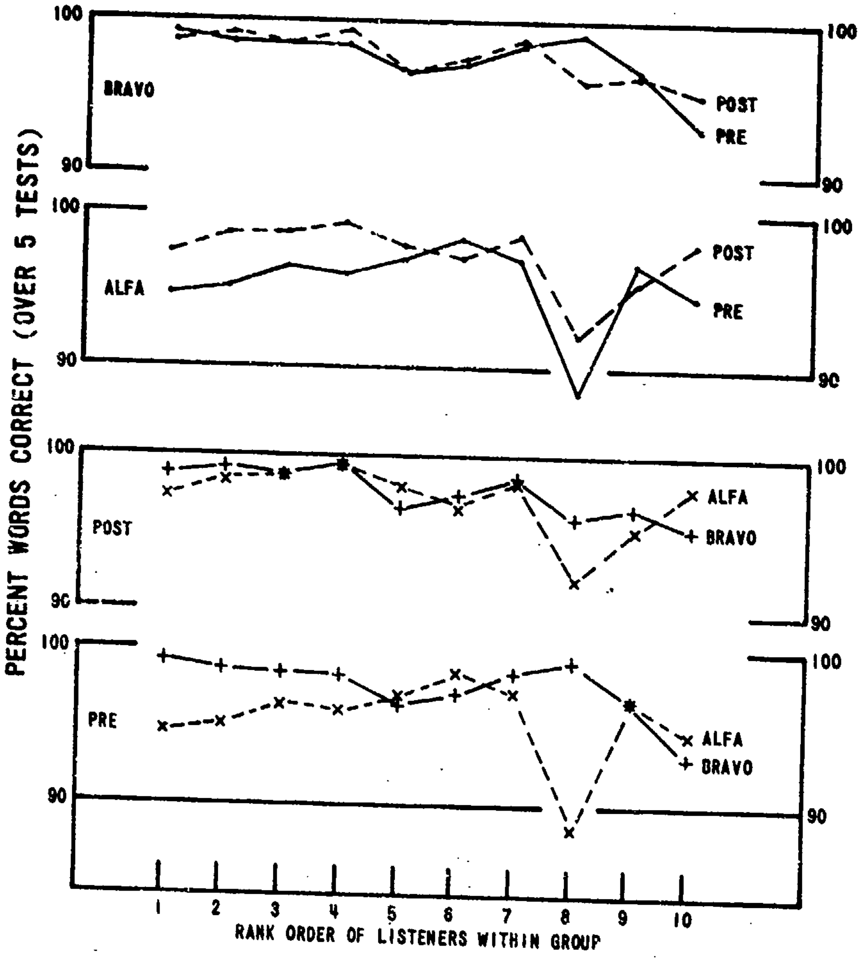
At the conclusion of the elaborate training on the PB and BREV words, the counterbalancing experimental listening sessions on all six tests commenced.

For the people who scored these final tests, no special instructions were necessary for the multiple-choice tests, FRT, MRT, PBRT, and DRT. For the PB and BREV tests the scorers observed the usual precautions that spelling per se was not the criterion of correctness: "aisle" was acceptable for "isle," etc.

TEST RESULTS

LISTENER DIFFERENCES

As part of the Project PING overall test plan, baseline data were required on all personnel on all tests they were subjected to. For the word tests one example of each of five word tests – PB, BREV, MRT, FRT, and DRT – was played back with no background noise added at the listening end. Examples from each of the two talkers in three of the four talker



	ALFA (×)	Δ	BRAVO (+)	Δ
1	LAGGER	2.8	COOPER	(0.4)
2	LAUTZ	3.6	HOLNER	0.4
3	LONDO	2.4	RIGSBY	0.0
4	WOODWARD	3.6	SCHMIDT	1.2
5	LESLIE	0.8	BAILEY	0.0
6	DAVIS	(1.2)	MAHFOUZ	0.4
7	SEBASTIAN	1.2	OWENS	0.4
8	FERRER	3.6	KIRTZ	(3.2)
9	TYREE	(1.2)	MILLIGAN	(0.4)
10	JACOBUCCI	3.6	WOOD	2.4

Δ = PRE-TEST SCORE MINUS POST-TEST SCORE (QUIET)

Figure 5. Baseline (before and after PING exposure, in quiet) word (consonant) scores for each individual in both the ALFA and BRAVO groups. Data points are average scores taken over one example of each type of word test (PB, BREV, MRT, FRT, and DRT).

conditions (involving simulated cockpit noise and the wearing of an oxygen mask) were used.

The results are shown in figure 5. The order (rank) in which each individual within the groups is listed represents his overall proficiency in the full series of tests given over the whole 60-day period. That is, over the longer series of tests, Lagger and Cooper got the highest composite scores and Jacobucci and Wood the lowest The only major deviation from these ranks in the baseline data is Ferrer in the ALFA group. He apparently has comparatively more difficulty listening to words in quiet (baseline) than he does in noise (all other tests). Ferrer was in fact the only minority race member (Chicano) and had difficulty on all behavior tests involving proficiency in the English language.

GROUP DIFFERENCES

There is some indication that the BRAVO group as a whole gets higher word scores in quiet than the ALFA group: six higher scores, one equal score, and three lower scores on the PRE tests; and six higher, two equal and two lower in the POST tests. Since all scores are so close to perfect and the differences so slight, statistical significance tests were not run.

The ALFA group which showed lower PRE test scores exhibited the greatest amount of improvement on the POST tests, as would be expected.

Nothing of significance is evident. In terms of the objectives of PING, no decrement in listening to words in quiet accrued during the listener's PING exposure.

The lower portion of figure 6 shows the listeners' scores on all other tests and is in fact the basis for the rank ordering of individuals in figure 5. Here, the "comparison" curve represents each group taking exactly the same tests as for the baseline data, except that: (1) noise was added at the listener's ears to reduce scores into meaningful regions for evaluation, (2) the recordings of only one talker (DG), and (3) only two types of word lists (PB and MRT) were used, and (4) both in-flight and simulated talker conditions were used. These results definitely show the BRAVO group to be the superior group (10 out of 10 when compared rank-to-rank, and 7 out of 10 when compared any-man-to-any-man). The average superiority of the BRAVO group is 6 percentage points.

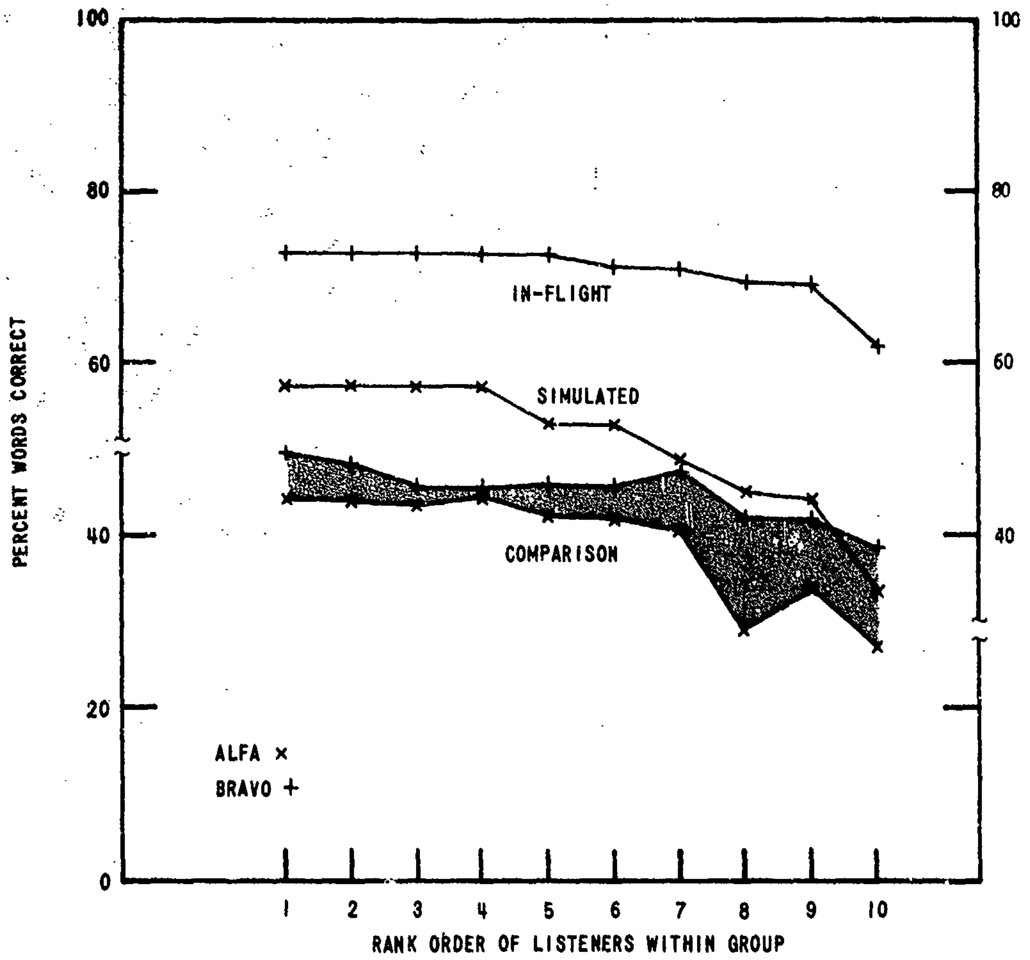


Figure 6. ALFA/BRAVO comparison scores for PB and MRT word lists read in noise. Data points are averages of talker DG's recordings of 12 lists (6 PB and 6 MRT) over three listener noise conditions (-3, 0, +3). Half of the lists were recorded in-flight and half in simulated cockpit noise. The upper pair of curves shows the difference in listener scores between the in-flight and simulated words.

IN-FLIGHT VS. SIMULATED NOISE

Comparison between groups is important because a major objective of this study is to show the simulated tests to be at least as difficult as the in-flight tests. The results in the upper portion of figure 6 definitely show this to be the case, since the in-flight average score is 70.6 and the simulated, 50.8. Of this difference of 20 points, no more than 6 can be attributed to the difference between the ALFA and BRAVO groups.

Further evidence of the fact that words recorded in-flight are more intelligible than those recorded in simulated cockpit noise is shown in figure 7. Scores from two word lists were used – PB and MRT – and on both tests and for both ALFA and BRAVO groups the in-flight results indicate about 20 percentage points more intelligibility.

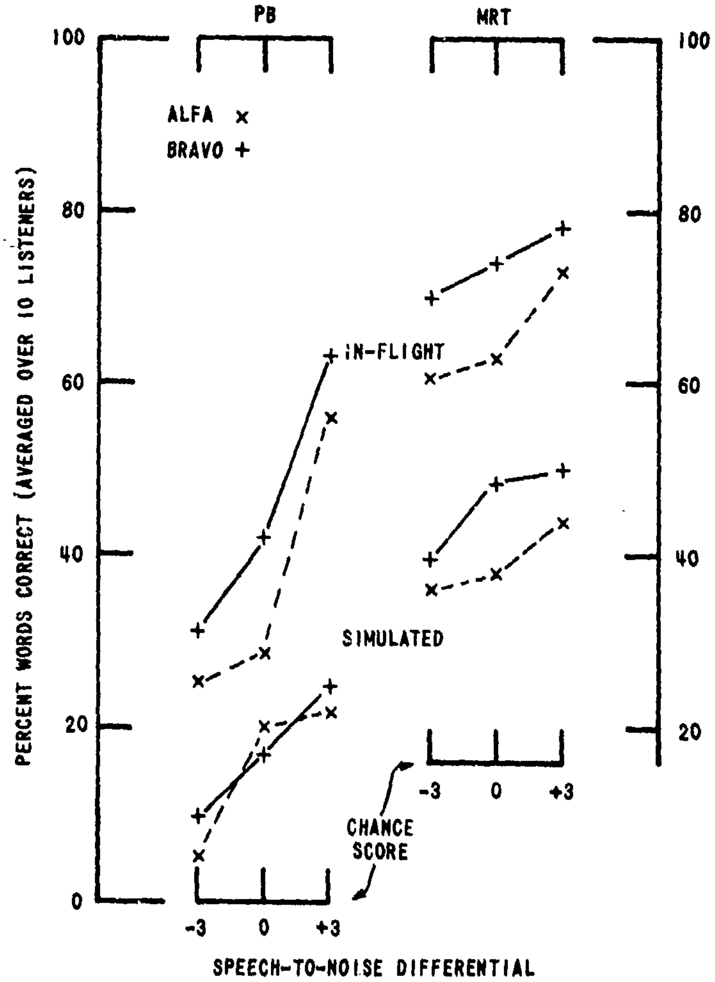


Figure 7. Percent of words correct for PB and MRT word lists recorded in-flight by DG in an F4J and in simulated F4J cockpit noise as determined by the ALFA (simulated) and BRAVO (in-flight) groups.

WORD-LIST DIFFERENCES

Figure 8 shows the average test scores for both ALFA and BRAVO groups averaged over all other (except baseline, fig. 5, and comparison, figs. 6 and 7) listening-test conditions. General trends are evident: as the chance score increases so do the observed listening scores; the BRAVO group obtained better scores than the ALFA group at every comparable point; with two exceptions the scores increase as the speech-to-noise differential increases; and the vowel intelligibility (PBRT) score is greater than consonant intelligibility (MRT, FRT, DRT) scores.

Taking a few liberties with the actual data points, best-guess lines (generally bisecting the results of the two groups and following known principles of increasing scores with increasing relative speech levels) are drawn which show the PB words to be the most difficult; PB rhyme words

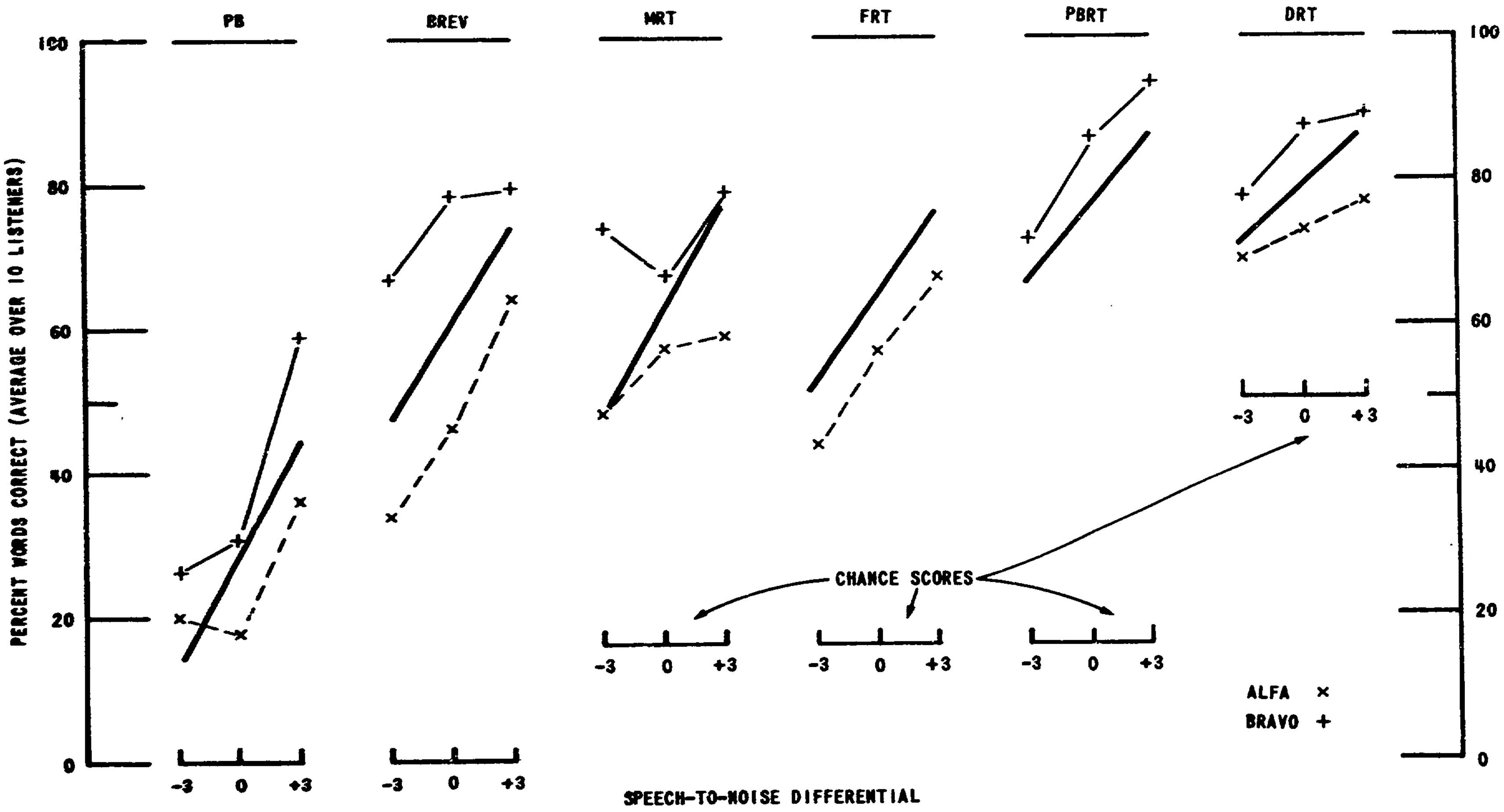


Figure 8. Percent of words correct on all six tests as listed along the top for all talker conditions combined and as determined by the ALFA and BRAVO groups. Each data point represents an average of at least four word lists over ten listeners. The smooth uni-sloped lines are best guesses as to true scores had a larger sampling of tests been given.

the easiest, and comparable to the DRT; and the MRT, FRT, and Brevity Code words approximately equal in difficulty.

TALKER CONDITION DIFFERENCES

Results of the ALFA group listening to five types of word lists recorded by the two talkers under four talker conditions at three speech-to-noise differentials are shown in detail in figure 9. These are the data from which the ALFA data in figure 8 are derived. The symbol code for the eight talker conditions is shown at the upper left. Note the great discrepancy of the data points for any one listening condition. This is due to many factors: differences in the inherent intelligibility between the two talkers, among the four noise/oxygen-mask talker conditions, and among different word lists within the same type of test; and changing attitudes of the listeners over the 60-day period in which they were confined for Project PING purposes.

The effects of talker conditions can be identified in the following manner: deviations from the average at any single listening condition are tabulated for each of the eight talker conditions (two talkers over four conditions). The average deviation is then determined, as plotted at the lower right in figure 9.

The following facts result from the talker-condition analysis: DR is inherently the more intelligible talker (except in noise with no mask where apparently he does not raise his voice level as much as DG does). DR's scores fall with any change from the no-noise, no-mask condition. Adding noise or donning the mask gives about the same decrement. In noise, donning the mask causes no further decrement in intelligibility. DG's scores drop appreciably whenever he dons his mask either in quiet or in noise. DG shows increased intelligibility in noise with or without mask; apparently he raises his voice level sufficiently to overcompensate for the noise. It should be noted that the oxygen mask attenuates the ambient acoustic noise reaching the microphone about 6 dB. For example, in evaluating the noise attenuation of many oxygen masks Attwood and Maslen (1970b) find values of about 6 dB when the expiratory valves are closed, and on the A-13A model, the one used by USN and by the talkers in the present study, they found that "opening the expiratory valve...had little effect on the (6 dB) attenuation..."

If the talker-condition corrections are applied, the range or spread of the data points in figure 9 decreases by 5.4 percentage points. Because of the nature of the arithmetic correction there is no change in listener condition scores when averaged over all word lists and listening levels, but selected points do change by 4 to 5.6 units; for example, the +3 BREV score increases by 5.6; the +3 MRT scores decrease by 4; and the -3 DRT scores increase by 3.9. It is these corrected scores that are plotted in figure 8 for the ALFA group.

The BRAVO group listened primarily to in-flight recordings and their listening scores are shown in figure 10 (the trend lines were shown in fig. 8). The results reflect two major differences between the in-flight and the simulated noise recordings: (1) the words recorded in-flight are more

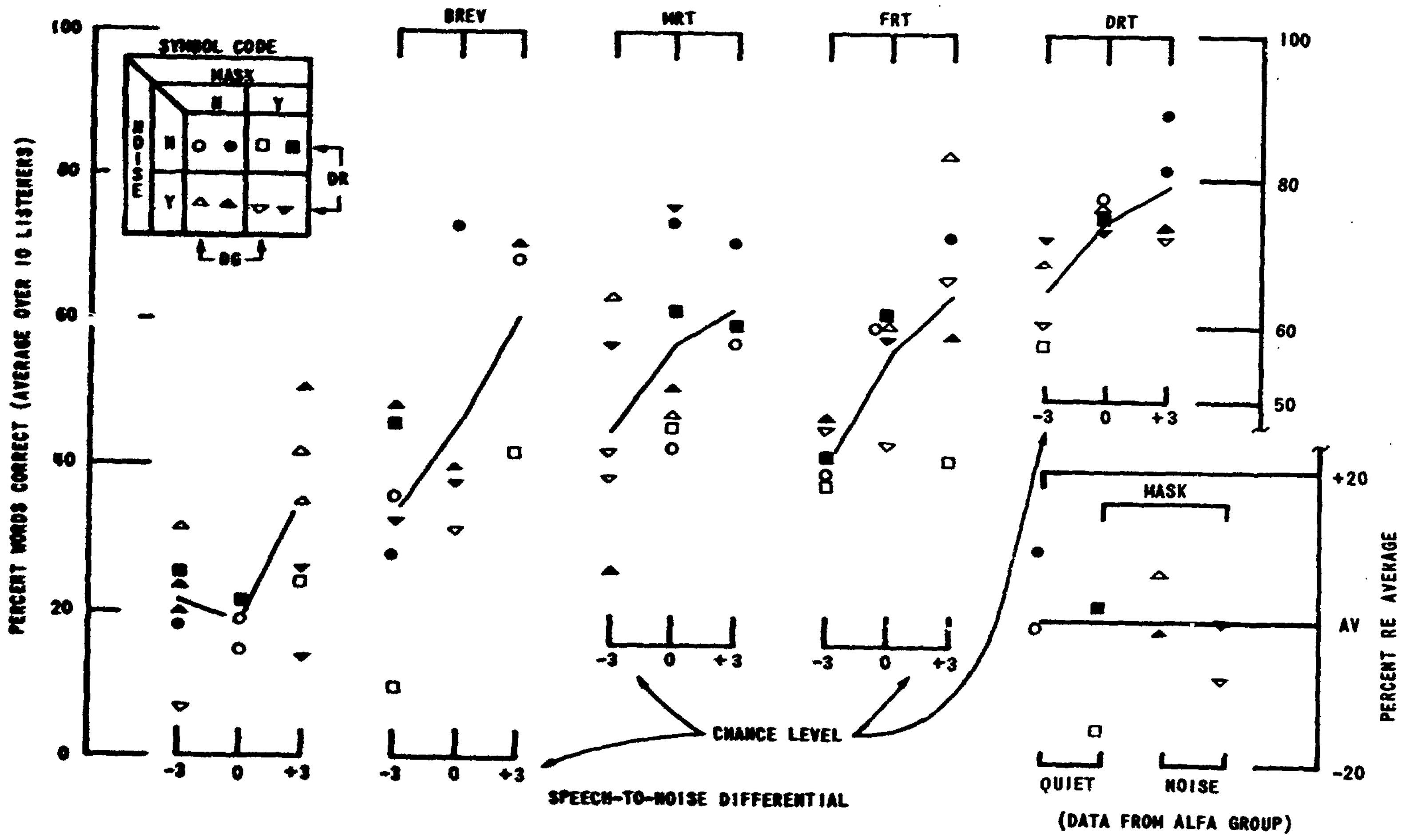


Figure 9. Percent of words correct for the five tests listed across the top for the three listener speech-to-noise differentials listed along the abacissa for each of eight talker conditions (by symbol code listed at the upper left). At the lower right are average deviations of the talker condition scores from the average.

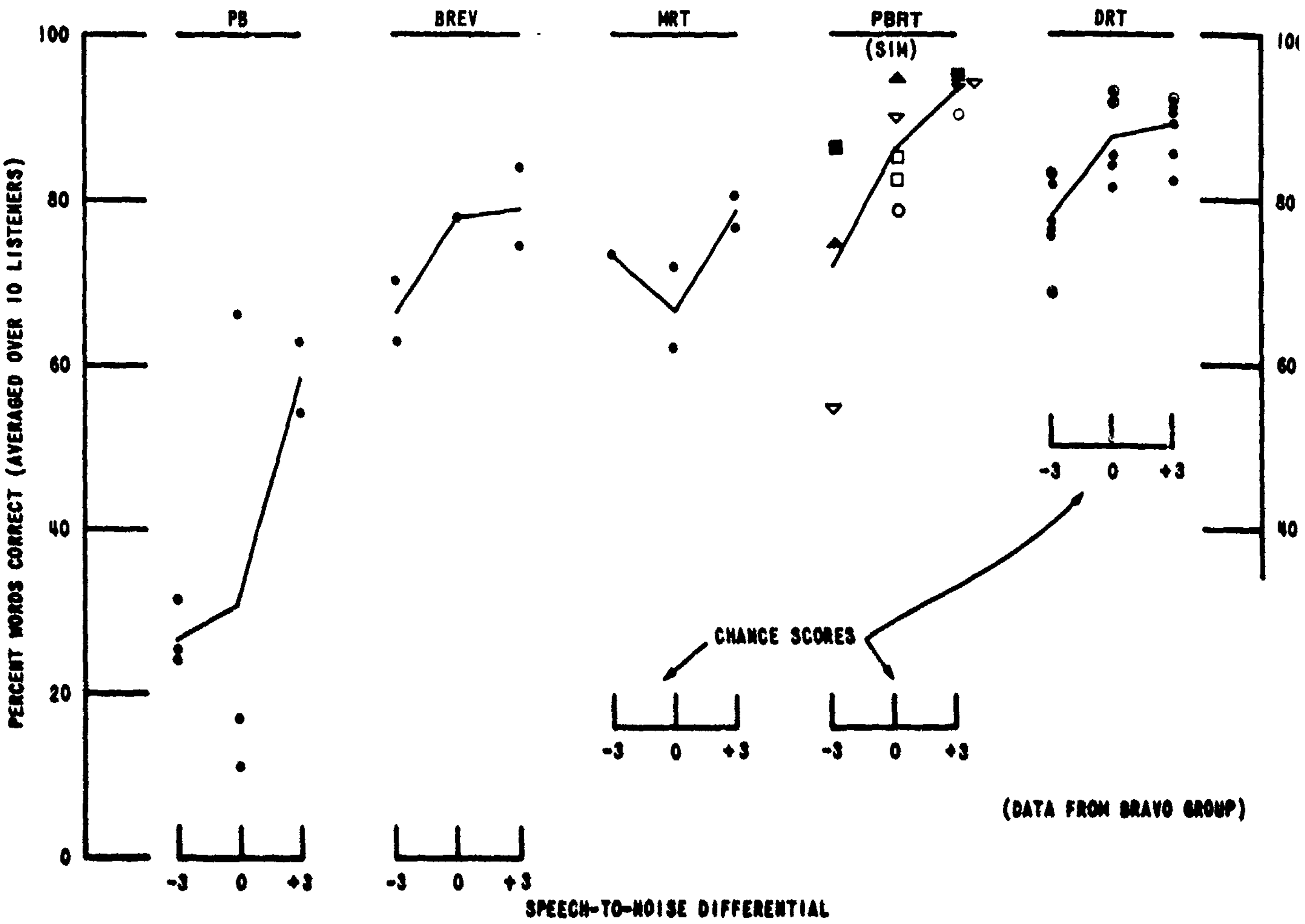


Figure 10. Percent of words correct for the five tests listed across the top for the three listener speech-to-noise differentials listed along the abscissa. All tests except the PBRT were recorded by DG in an F4J in flight. The PBRT tests were recorded by both talkers under simulated noise conditions. The symbol code is the same used in figure 9.

intelligible (see also figs. 6, 7, and 8) and (2) the dispersion of data points is less (with the one exception at the 0 speech-to-noise differential for PB's). Hindsight examination of the three word lists at 0 for the PB's shows that the lists which resulted in the two abnormally low scores were pronounced extremely fast while the high-scoring list was pronounced at a slower (normal) rate. (The time between words was always 4 seconds regardless of the speed at which the words were pronounced.)

The PBRT words were recorded by both talkers under four simulated noise-mask conditions. The results show high intelligibility and less dispersion than the other simulated recordings listened to by the ALFA group. (One reason for lack of dispersion is the fact that all scores are high, and as scores approach 100 percent they have no place to spread to.) It can certainly be said that vowel intelligibility is considerably higher than consonant intelligibility, a fact already shown by Clarke and so well known as to require no extensive bibliographic references.

PHONEMIC CONFUSIONS

Two types of error (confusion) analyses will be considered: errors in the Brevity Code words and those in the Diagnostic Test phonemes.

Tables 6 and 7 show representative errors in the Brevity Code words. Note that the phonetic words BRAVO, CHARLIE, HOTEL, INDIA, and QUEBEC and the numerals SEVEN and SIX are among the most intelligible words. MIKE and TWO are among the least intelligible along with PARROT, STEER, ASSUME, IDENT, and SPLITTING. In general, single-syllable words are less intelligible than multisyllable words or two- or three-word phrases. Words with the same vowel sound or prosodic (time pattern) features are those most often substituted for missed words, e.g., six, pick, sit for SICK, affirm and obtain for ASSUME, and sad cap and bad cap for DAD CAP.

TABLE 6. MOST OFTEN AND LEAST OFTEN CONFUSED BREVITY CODE WORDS.

Words Missed 15-20 Times of 20:

20	parrot	
	sick	six(6) fix(2) pick(2) lick, kick, quit, sit
	crew	through(2) two(2) true(2) cruel
	sweet	sweep(5) weak(4) wheat(3) week(2)
19	pan	can(2) tang(2) end(2) tan, ten, aim
	streer	fear(10) hear(6) cheer, feel
18	lamps	lamp(4) lance(3) mumps(2) thanks, land
	tips	kiss(5) tits(3) kick, six, cook, ship
	link	limp(3) linch(2) lame(2) limit
17	prep charlie	pre charlie(6) rep charlie, map charlie
	dolly	gallons(3) dollars(2) bow wave, valley
	oranges	argue(6) bread(3) corn, are, you
	assume	affirm(3) obtain(3)
	liner	nine(6) final(3) lion, finer
16	dad cap	sad cap(3) bad cap(2)
	ident	item(2) I went, Ivan, I go, idle
	mike	mite(4) quite(3) mice, mine

Words Missed 0-5 Times of 20:

0	weapons light
	ramrod
	Bravo
1	seven
	lifeguard
	St. Bernard
	state chicken
2	warning red
	charlie
	octopus
	state tiger
	hotel
	india
3	six
	strike
	ship
	mushroom
	mack no
	Quebec
	rialto
	in the dark
	cigar
	purple
4	ready
	bingo state

TABLE 6 (Continued).

Words Missed 15-20 Times of 20:			Words Missed 0-5 Times of 20:	
15	tar cap	rap cap, hub cap, hard cap	5	scramble
	famished	family(4) pattern, salmon, phantom		contact
	splitting	split, slip, flip, skip it		what state
	two(2)	tube, food, thu		medium
				x-ray

TABLE 7. PHONETIC ALPHABET AND NUMERAL ERRORS WHEN EMBEDDED WITH BREVITY CODE WORDS.

ALFA	7	delta, ego	1	6	warm, roam, walk
BRAVO	0	----	2	15	tube, food, thu
CHARLIE	2	cherubs	3	7	marie
DELTA	9	bellcap, skullcap	4	10	go way(2) bowwave, no way
ECHO	7	recco, tonto, mappo, nickle	5	8	gyro, siren, spy ring
			6	3	mixed, fixed
FOXTROT	9	hot shot(4)	7	1	eleven
GOLF	7	dog, dull, doll, god	8	11	state, hate, gate, ache
HOTEL	2	propel	9	12	mine, minus
INDIA	2	----	0	6	hero, helo, kilo
JULIETT	11	----			
KILO	10	helo(t) (4), hugo(2) pluto			
LIMA	10	signal(2) midnight(3) seamen, demon			
MIKE	16	mice, mite(4), quite(3) mine			
NOVEMBER	17	----			
OSCAR	10	ox, ashtray			
POPPA	8	popeye(3) project			
QUEBEC	3	pay up			
ROMEO	11	radio, rodeo, romance			
SIERRA	11	----			
TANGO	7	echo, bingo, mack no, hugo			
UNIFORM	7	airborne, windstorm			
VICTOR	12	sector(3), vector, whisper			
WHISKEY	12	whistling			
XRAY	5	----			
YANKEE	10	----			
ZULU	7	bingo(2) field			

Table 8 shows the ten Diagnostic Test word pairs that were most often missed under each of the three listening speech-to-noise conditions. Note that the aircraft radio system is particularly vulnerable to making distinctions between the consonant V and either B or F; between F and TH, T, or H; between B or V or M; and between T and K, P, or TH.

Figure 11 shows that EE (beat) is the worst context vowel and EH (bet) the best. If the listening conditions are good it is easy to distinguish M, N, and NG (nasals) from all other consonants but in bad listening conditions the "sibilation" and "voicing" attributes contribute the most to intelligibility. When new Brevity Code words are needed these facts should be kept in mind.

TABLE 8. MAJOR CONFUSIONS AMONG WORD PAIRS.

Word Pair	Speech-to-Noise			Word Pair	Speech-to-Noise		
	-3	0	+3		-3	0	+3
VON/BON	X	X	X	MAD/BAD	X		
VEE/BEE	X		X	MEAT/BEAT	X		
VOX/BOX			X				(2)
			(6)	MET/NET*		X	
FIN/THIN*	X		X				(1)
FORE/THOR		X		NAB/DAB	X		
FOUGHT/THOUGHT		X					(1)
FAD/THAD*			X	HIT/FIT	X		
			(5)				(1)
VEAL/FEEL	X	X		GOT/DOT		X	
VAULT/FAULT		X					(1)
			(3)	JOCK/CHOCK		X	
CAUGHT/TAUGHT*	X						(1)
KEY/TEA		X	X	THICK/TICK		X	
			(3)				(1)
PENT/TENT	X			SHAD/CHAD			X
PEAK/TEAK*			X				(1)
POOL/TOOL			X	ZOO/SUE			X
			(3)				(1)

Summary of Consonant Confusions:

F/TH	5	B/V	6	T/K	3	(V/B	6)
F/V	3	B/M	2	T/P	3	(V/F	3)
F/H	1			T/TH	1		
	9		8		7		(9)

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*Are generally difficult; not a peculiarity of this system

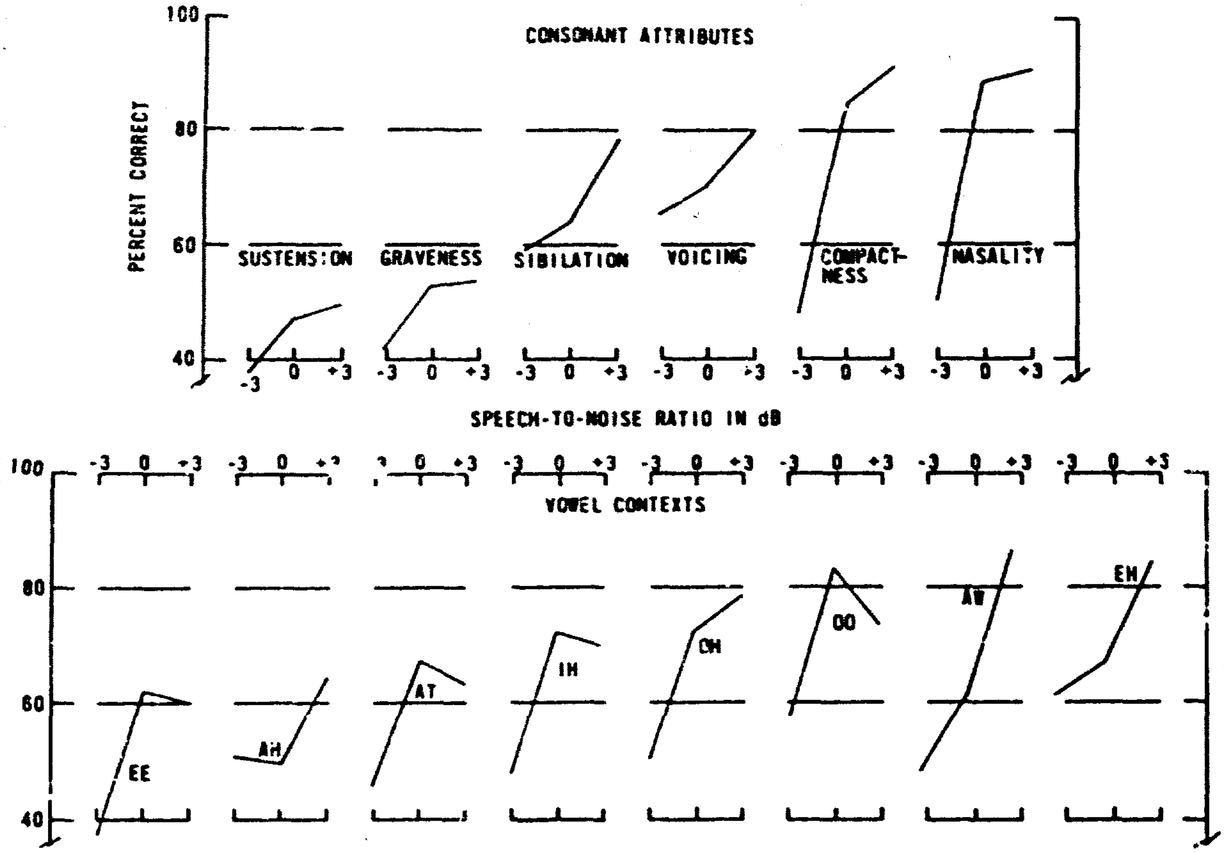


Figure 11. Diagnostic rhyme test scores (corrected for guessing) from in-flight recordings for the BRAVO listener under three speech-to-noise listening conditions. Diagnostic scores on all other figures are not corrected for guessing and this explains the gross difference in scores.

DISCUSSION OF TEST FINDINGS

EFFECTS OF MAN-WORN EQUIPMENTS ON INTELLIGIBILITY

The results of the study show quite conclusively that the man-worn equipment at the input (talking end) of the naval aircraft radio link in 110 dB(A) jet cockpit noise is not responsible for much, if any, of the decrement in speech intelligibility encountered in the total link. For example, the results in figure 5 show that the words recorded in simulated cockpit noise but heard in quiet are at least 95 percent intelligible; as shown in figure 6, scores on words recorded in flight are even more intelligible than words recorded in simulated cockpit noise (when both are heard in noise).

EFFECTS OF THE TALKER IN COMMUNICATION

The tests definitely demonstrated that the effects on intelligibility of cockpit noise and oxygen mask are dependent upon the talker. The talker with the most in-flight experience, the Air Force major (DG), showed a drop-off of about 15 percentage points when using his mask in either quiet or noise, but showed a 9-percentage-point increase in intelligibility when in noise. He is apparently adept at adapting his voice or speaking style to the noisy environment. The talker who was more experienced, but had less communicating experience in flight, showed smaller decrements with donned mask (in fact a slight increment in noise) but showed consistent intelligibility losses when talking in noise. This implies a learning or training factor that should probably be investigated further with trainee pilots.

CHOICE OF TEST MATERIALS

An important outcome of the study was what was learned about choice of test materials for evaluating naval aircraft radio speech-communication intelligibility and the equipment it involves. The findings may be briefly summarized as follows.

The quantitative scores shown in figure 8 fall into three groups, by tests:

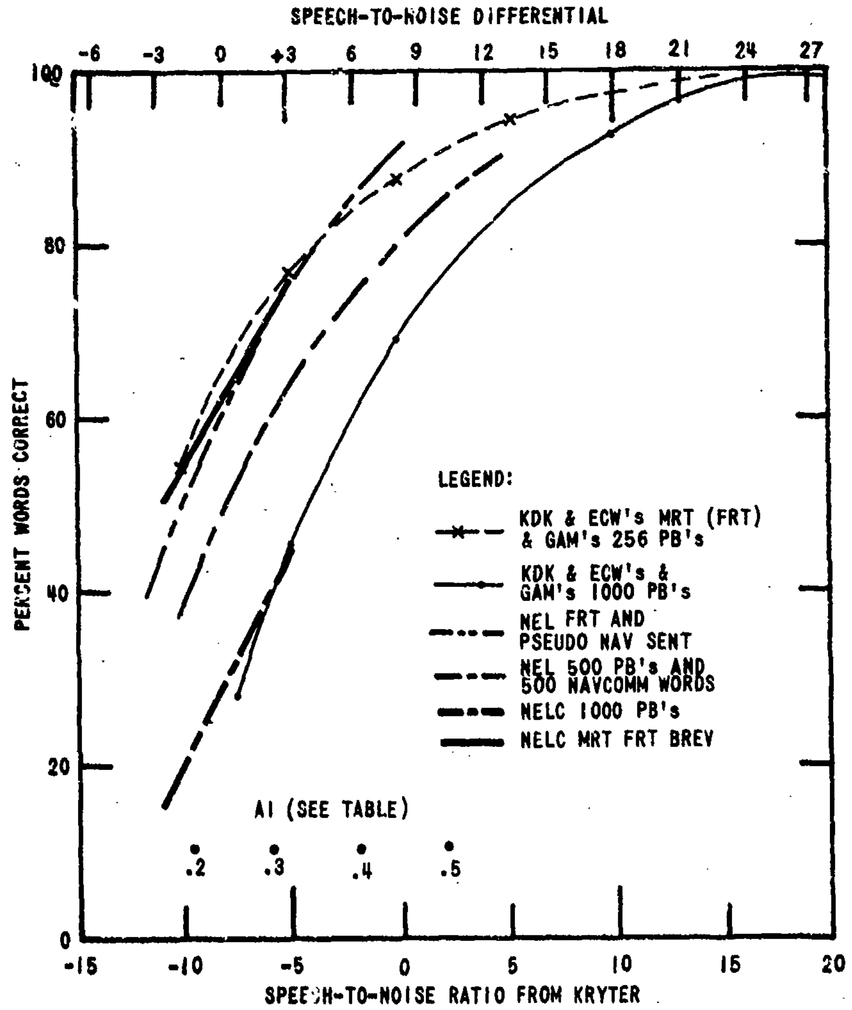
1. PB, average scores about 30 percent;
2. BREV, MRT and FRT, average scores about 60 percent;
3. PBRT and DRT, average about 80 percent.

Without considering any mitigating circumstances, these results indicate that Egan's phonetically balanced (PB) words are too difficult. The words require too much training of listeners and result in scores that are too low and thereby depress the morale of the subjects. The PB test, therefore, is judged to be unsuitable as a test material in assessing military communication systems.

Conversely, the PBRT (vowel or medial position) and DRT words (in the test format used) are too easy to produce meaningful results.

The MRT and FRT lists appear to be equally difficult and at the same difficulty level as that of the Brevity Code words. The MRT requires no training time for listeners and gives results equivalent to the FRT (used extensively in past work at NELC) and the Brevity Code words used by pilots. It should therefore be the standard speech intelligibility test for naval aircraft communication systems. Since 95 percent of standard test sentences will be understood over a system that will pass 80 percent of the MRT words (an AI of 0.35), an MRT score of 80 percent should be the acceptance criterion for military communication systems.

The conclusions drawn from the results of the NELC listening tests were compared with other studies which cross-compared the same tests. Figure 12 plots these results, incorporating the averages shown in figure 8. The two heavy, linearly sloped lines represent (1) the smoothed PB scores and (2) average of the BREV, MRT, and FRT scores, which are in fact nearly identical. The major results of Kryter and Whitman's (1965) summary figure are juxtaposed to equate their 1000-word PB scores to those of Miller, et al., and in figure 12 this is shown as a single line which joins to the NELC data with a good continuity of slope. Kryter and Whitman show that their MRT scores coincide with Miller, et al.'s, 256-word PB score (once the 1000-word PB scores have been juxtaposed); and Kryter and Whitman then juxtapose the Nickerson, et al., data on the FRT to



*AI	*PB	MRT	*SENT
0.20	22	54	77
0.30	41	72	92
0.35	50	78	95
0.40	62	86	96
0.50	77	91	98
0.60	85	94	98

* FROM KRYTER ET AL. (1963)

Figure 12. Comparison of NELC word-test results [including those of Montague (1960)] with those reported by other experimenters – K. D. Kryter and E. C. Whitman (1965), who include the data of G. A. Miller, G. A. Heise, and W. Lichten (1951). Relationships between some of the tests and the AI (articulation index) are shown at the bottom and right of the figure. FRT refers to Fairbanks Rhyme Test; PB to Egan's phonetically balanced words, either 256, 500, or 1000 of them; MRT to Kreul et al's variation of House et al's Modified Rhyme Test; and BREV to Naval Brevity Code word tests.

coincide with their MRT scores. In figure 12, the scores of Kryter and Whitman (MRT), Miller, et al. (256-word PB), and Nickerson, et al. (FRT) are shown as a single line. The fact that the data (1) show the MRT and FRT scores to be equivalent and (2) show such good agreement between the MRT/FRT/BREV data and Kryter and Whitman's MRT/FRT/256-word PB data when matched (juxtaposed) on 1000-word PB scores is fairly conclusive proof that, for 1000-word PB scores between about 20 and 50 percent, MRT (and FRT, BREV, and 256-word PB scores) scores are roughly 30 percentage points higher.

The remaining comparison data plotted in figure 12 are from Montague (1960). Montague compared 500 PB words to 500 Naval Communication Words (NCW), to FRT, to Harvard Sentences [Hudgins, et al. (1947)], and to Pseudo Naval Communication sentences. Montague found "No significant difference...between the NCW and PB lists ($t = 0.5517$, $df = 180$, $t_{0.01} = 2.5758$)." He also found that the FRT scores and Pseudo Navy Sentence scores did not differ significantly. Two trend lines from Montague's data are plotted in figure 12: (1) his 500-PB word and 500-Naval Communication word scores as a single line and (2) his FRT/Pseudo Naval Sentence scores.

Concerning the choice of testing materials, there are apparently some valid reasons for considering sentences or phrases since it can be argued that these are more typical of actual usage. However, it is apparent in the radio transcription (Appendix) that often the crucial aspects of the messages are relatively context-free: Note ". . . Jumper 1, verify heading 140 . . . Roger, passing 170 for 140. . . Jumper 1, speed and angles as desired, check your switches safe. . . 1, switches safe. . . 1, your bogey 226 at 19. . . 1, your bogey 224, 11, break, port 220...," etc.

In other flying routines perhaps the messages have more of a sentence context. But the redundancy built into the context of the normal English sentence cannot be counted on to get a marginally intelligible message through to naval pilots flying combat missions. However, since Giolas, Cooker and Duffy (1971) have shown the synthetic sentence lists (SSL) developed by Jerger, Speaks, and Trammell (1968) to be essentially free of redundancy, these sentences should be considered in further testing programs of this type.* In particular, comparison scores between the SSL and MRT should be determined.

Since it is quite evident that the score on a speech intelligibility test is dependent on (1) the number of words in the test vocabulary, (2) the number of possible responses on the answer sheet, (3) the context within which the words are used (in isolation vs. in sentence), etc., some measure is needed which is not dependent on all these variables. Such a measure is the articulation index (AI), which is based on speech-to-noise differentials in selected bandwidths.

The AI is not always easy to measure or calculate (see Kryter, 1970), and in any case the relationship between AI and at least one standard intelligibility (articulation) test is necessary. One such relationship between the AI and 1000-, 256-, and 32- word (equivalent of sentence) PB scores is tabulated in Kryter, et al. (1963), as illustrated in figure 12. Since sentence scores exceeding 95 percent correspond to AI's of greater than 0.35, AI values of 0.35, 0.4, and 0.5 have been suggested by various people as being the criteria of intelligibility for an adequate speech communication system. In round numbers an MRT score of 80 percent or better, or a 1000-word PB score greater than 50 percent, should suffice for a military communication system.

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*Examples of these synthetic sentences can be found in NELC Technical Document 191 (in preparation).

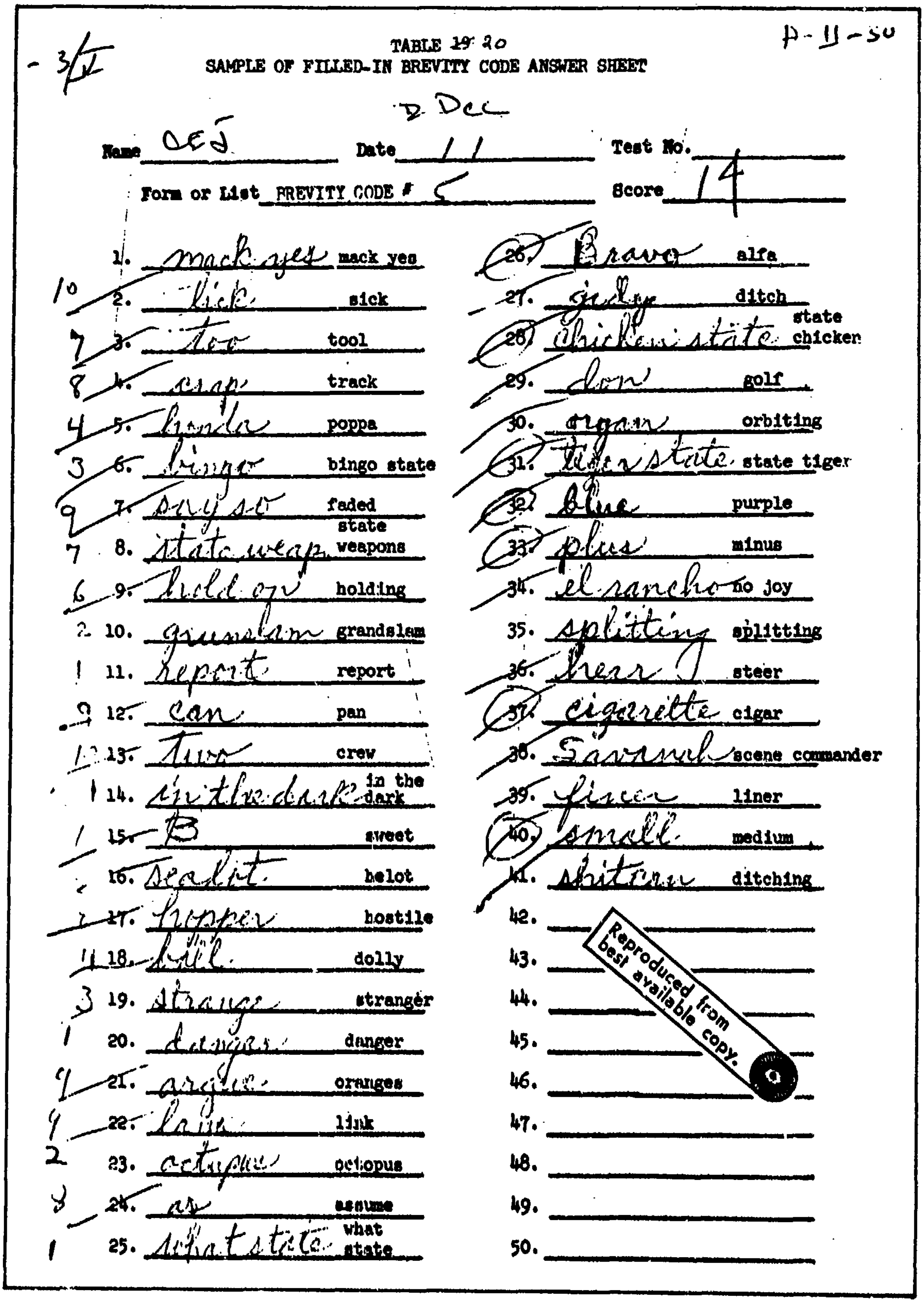
One reason it is difficult to evaluate speech communication systems in terms of physical measures is the difficulty of specifying a speech (and sometimes a noise) level. For example, the 44-percent, 1000-word PB score of Kryter and Whitman corresponds to a speech-to-noise ratio of -5 dB. In the present study the 44-percent point corresponds to an S/N of +3, and for Miller, et al. (1951), the corresponding S/N is listed as +4. This is a complex subject which includes considerations of the bandwidth in which the speech and noise are measured, the shaping network of the measuring instrument (A- vs. C-weighting of a sound-level meter), the ballistics of the measuring instrument, etc. Many of these factors are affected by type of speech processing (which is discussed in the following section), type of noise, etc. The point is, it is often easier to measure the speech intelligibility than it is to measure physical parameters and calculate the AI. This points up the value of all the relationships shown in figure 12. If the AI is known, the intelligibility of any type of word or sentence can be found; and if any reliable test score is known the AI can be estimated. So specifications can be written in either form.

In this regard it cannot be overemphasized that a test with a known response set should be used unless an inordinate amount of time can be spent on training listening teams.

Concerning Brevity Code word confusions, two factors emerge: (1) bisyllabic words and/or phrases of two or more words should be chosen for greater inherent intelligibility and (2) "write-down" tests should not be used on this type of testing program unless the highest motivation can be maintained. Exhibit 1 is an actual copy of one sailor's answer sheet for the BREV test. Note his use of opposites, "plus" for MINUS (No. 33); free-association words, "bravo" for ALFA (26), "blue" for PURPLE (32), "chicken- and tiger-state" for STATE CHICKEN (28), and STATE TIGER (31), "cigarette" for CIGAR (37), etc. These results show (1) he really heard the item (and he was given credit), (2) he was bored or otherwise affected by the testing routine, and (3) he was highly uncooperative as a paid volunteer test subject. Incidentally, this subject was ranked as number 10 in his group even though on the baseline tests, figure 5, he scored well above rank 10. In many cases he tried only a few items in a difficult test and left blanks for most items.

Debriefing remarks from this man, and others, indicated that the copy-down (nonmultiple choice) tests were the least desirable.

EXHIBIT 1. SAMPLE OF FILLED-IN BREVITY CODE ANSWER SHEET.



- 3/4 P-11-50

TABLE ~~19~~ 20
SAMPLE OF FILLED-IN BREVITY CODE ANSWER SHEET

D Dec

Name OEJ Date 11 Test No. ______

Form or List BREVITY CODE # 5 Score 14

	1.	mack yes	mack yes
10	2.	lick	sick
7	3.	too	tool
8	4.	crap	track
4	5.	honda	poppa
3	6.	bingo	bingo state
9	7.	say so	faded
7	8.	state weap.	state weapons
6	9.	hold on	holding
2	10.	granslam	grandslam
1	11.	report	report
2	12.	can	pan
12	13.	two	crew
1	14.	in the dark	in the dark
1	15.	B	sweet
	16.	sealit	helot
2	17.	hopper	hostile
4	18.	hill	dolly
3	19.	strange	stranger
1	20.	danger	danger
9	21.	argue	oranges
9	22.	lane	link
2	23.	octupus	octopus
8	24.	as	assume
1	25.	what state	what state
	26.	Bravo	alfa
	27.	jelly	ditch
	28.	chicken state	state chicken
	29.	don	golf
	30.	organ	orbiting
	31.	tiger state	state tiger
	32.	blue	purple
	33.	plus	minus
	34.	el rancho	no joy
	35.	splitting	splitting
	36.	hear !	steer
	37.	cigarette	cigar
	38.	Savannah	scene commander
	39.	fincer	liner
	40.	small	medium
	41.	shitern	ditching
	42.		
	43.		
	44.		
	45.		
	46.		
	47.		
	48.		
	49.		
	50.		

VOCABULARY USED IN MESSAGES

If it appears impractical or overly expensive to improve the cockpit environment (by reducing noise levels of future aircraft) and equipment (by modifying masks, microphones, earphones, and helmets and applying recent electronic speech-processing techniques), or to alleviate stress and distraction by competing tasks, then the remaining hope for improving communication effectiveness may be a change in the language phraseology used in the transmissions. This possibility will play a major role in the choice of intelligibility test to be used and the methods of collecting field data on phraseologies used in combat flights.

SPEECH PROCESSING

As indicated in the foregoing discussion, an important conclusion reached in this study is that the microphone and oxygen mask used by the pilot do not appreciably degrade intelligibility or quality of current aircraft radio transmissions. Efforts to enhance speech intelligibility should be directed to transmitter speech processing. This approach is justified by the fact that recording the audio on the aircraft intercom line before transmission by radio gave a signal of excellent quality, with the talker using an M-94A noise-canceling microphone in an A-13A oxygen mask. On the other hand, other operational recordings, made on the ground, showed evidence of peak clipping, which distorted vowels especially and brought up the noise level during pauses. Clipping can be helpful when properly designed, but in the case of inadvertent overload the frequency shaping is not correct for clipping, and there is no provision for suppressing noise during pauses. Therefore, when the transmitter audio gain control is set too high, which is very common in operation, the voice quality is impaired.

It is clear that if the signal on the aircraft intercom line is satisfactory but the signal out of the ground receiver is not, the problem must lie in the transmitter audio section, in the radio link itself (fading and additive noise), or in the receiver. Audio distortion in the receiver can sometimes impair quality somewhat, but it is not usually a serious problem because receivers are generally designed to supply considerably more audio power than is normally in use, so they are seldom operated near the overload point. Noise picked up on the radio link is definitely a problem; it always degrades quality except when the radio signal at the ground receiver is very strong. The transmitter audio section is probably the major source of difficulty. If the transmitter audio gain control is set too high, uncontrolled peak clipping produces distortion. If the gain is set too low, the carrier is not modulated fully and the effects of noise picked up on the link and acoustic noise at the receiver become more serious.

Both of the above problem areas – transmitter audio distortion and noise introduced on the radio link – can be addressed most effectively by proper speech processing applied to the microphone signal before it is fed to the intercom line. Without processing, the wide dynamic range of speech makes it impossible to find a setting of the transmitter audio gain control which is correct under all conditions. The following paragraphs discuss in detail why processing is needed and how it can best be applied.

Unprocessed speech makes very inefficient use of a radio link, primarily because of its wide dynamic range. Extensive experimental data from a variety of sources on the intensity and spectrum of speech are summarized by Meeker (1967). Briefly, the dynamic range considering rms sound pressure averaged over 1/8-second intervals is about 30 dB, extending from 18 dB below the long-term average to 12 dB above. Peak amplitudes cover an even larger range, since the peak pressure occurring within a 1/8-second interval exceeds the rms pressure averaged over the interval by about 10 dB. Thus if the transmitter audio gain is set to modulate 100 percent on the strongest sound (the back vowel aw), the weakest consonant (the unvoiced fricative th) will modulate only a few percent. Furthermore, the foregoing figures apply to a single talker exerting apparently constant vocal effort; individual talkers in the same acoustic environment may vary vary from 10 dB above to 10 dB below the level averaged over all individuals. The ambient noise level also has a major effect on vocal intensity – people talk louder in noise, and a man is capable of maintaining continuously an overall level 25 dB louder than normal conversation before being limited by painful voice fatigue.

In addition to the data summarized by Meeker (1967), there are some field data (final recordings of pilots in fatal crashes) which suggest that normal levels may be considerably exceeded under severe stress. If intelligibility is to be maintained in these final agonizing seconds (and this is often the only clue to the cause of a crash), the communications system must be capable of handling louder signals than laboratory measurements might indicate. It is true, on the other hand, that low-level vocal effort will not normally be used in aircraft noise, but it may be used by a maintenance man setting levels before a flight. A communications system must be designed to handle all contingencies, so one may conclude that a total dynamic range of some 60 dB is not unreasonable.

One would expect from these facts that some form of speech processing for dynamic range compression would be a standard feature of all military voice radio equipment. This is not the case; the AN/ARC-27, ARC-51, ARC-52, and ARC-58 transceivers have no processing except for some rf compression in the ARC-58 and simple peak clipping without proper frequency shaping in the ARC-27. The AN/AIC-10 intercom does have automatic gain control (agc) with slow attack and very slow release, which is useful to compensate for intensity differences among speakers, variations in microphone position and sensitivity, effects of altitude, etc., but does nothing to improve the vowel-to-consonant ratio, which ranges up to 28 dB. The consonants, though relatively weaker, are essential to the intelligence transmitted. For example, in this and other studies it has been shown that in monosyllabic words the vowel sound is often understood but the proper consonant is not. Note for instance the most common confusions for TIPS in table 19, namely KISS* (5), TITS* (3), KICK, SIX, SKIP, and COOK.

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*For psychiatrists, it might be pointed out that these tests were performed by 20 healthy young sailors confined in a barracks for 60 days.

Parenthetically, it is interesting that an equally important element of intelligibility found in this study was the prosodic (time pattern) features of multisyllable or multiword phrases. For example, for IDENT the confusions were ITEM (2), I WENT, IVAN, I GO, and IDLE; and for NO JOY the confusions were OUTLAW, HELL JOY, OUT JAW, and OUT GOING. A successful speech processor must maintain cues to these frequency and intensity time-variation patterns.

It is believed that speech processing has great potential for increasing the effectiveness of voice radio communication. Extensive experimental data from a number of sources (see Bibliography) have shown that proper processing of the voice signal can give an increment of intelligibility under difficult conditions equivalent to a transmitter power increase of 10 times. This improvement applies to a single talker in a constant acoustic environment, and even so it can easily mean the difference between satisfactory communication and a marginal or unusable circuit.

The principal kinds of speech processing are (1) frequency shaping, (2) automatic gain control, slow (to control overall level) or fast (for syllabic compression), (3) peak clipping of the baseband audio signal, and (4) peak clipping of a single-sideband (SSB) version of the voice signal which is demodulated back to audio after clipping. Combinations of these methods can often be used to advantage. A great deal could be said about the relative merits of these schemes and combinations of them, but the authors have concluded, on the basis of their own experience and an acquaintance with the literature of the last 25 years, that the most promising system for the aircraft radio application is carefully designed frequency shaping followed by infinite peak clipping of an SSB version of the speech, with a quieting tone injected into the clipper that is automatically adjusted to suppress the noise between syllables without eliminating weaker speech sounds.

The system suggested avoids most of the drawbacks of other methods. Peak clipping of the baseband signal can work very well under proper conditions, but it has two difficulties. It inherently generates odd-order harmonic distortion, and when the response of the circuitry following the clipper is not flat to well below the frequency range of speech (and it is not in current equipments) the resulting phase shift upsets the phase relations among these harmonics so that the flat tops of the clipped waveform are tilted. That is, the phase shift "unclips" the signal to a certain extent and partly cancels the improvement from clipping. This problem cannot be solved in an add-on device but requires extensive changes to the transmitter. The other difficulty is that clipped audio is not suitable for use with single-sideband transmitters such as the AN/ARC-58. The envelope of an SSB signal bears little resemblance to the audio waveform it represents, and it turns out [Kahn (1957), Squires and Bedrosian (1960)] that clipped audio produces a peaky SSB signal, so that much of the improvement in peak-to-average ratio is lost.

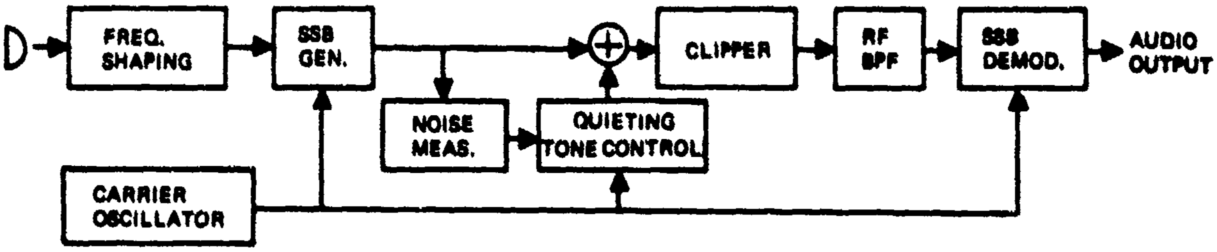
Automatic gain control can be useful in the absence of other processing, as in the AN/AIC-10 intercom. Slow agc controls overall level, but does not improve vowel-to-consonant ratio. Fast agc, or syllabic compression, is more effective, but it cannot usually be made fast enough to avoid suppression of a weak consonant following a loud vowel [Kahn (1957)], and without special circuitry it produces an annoying "pumping" effect with a rise in noise during pauses. Properly designed infinite clipping with noise-suppression controls the speech level with little need for agc and thus sidesteps these problems. (Because of the very wide potential dynamic range of the input signal from the aircraft microphone, it may nevertheless prove desirable to include a small amount of slow agc preceding the clipper, simply to reduce the range of a signal level which must be handled by the clipping and noise-suppression circuitry.)

All speech-processing methods generate some distortion, but SSB clipping is much superior to baseband clipping in this respect. It produces no harmonic distortion, and its intermodulation distortion is considerably less than that of baseband clipping. As a result, it avoids the irritating harshness and mushiness characteristic of clipped audio. It is commonly claimed in the literature that clipping degrades intelligibility (1) when the speech-to-noise ratio at the microphone is poor or (2) when conditions are ideal so that no noise is introduced either at the microphone or on the radio link. Recent experimental work shows that neither effect occurs with correct frequency shaping before the clipper. In any case, the speech-to-noise ratio of the microphone output can be expected to be good, since this study has shown that present-day microphone-mask combinations give good quality speech with relatively low noise.

The chief drawback of SSB clipping is circuit complexity, but with modern circuit design and the availability of suitable linear integrated circuits this is no longer a serious problem.

As a follow-on to the study reported here the authors suggest development of an add-on microelectronic processor unit to be built as part of the microphone cable assembly or mounted inside the intercom. Output of the processor would be an audio signal of nearly constant amplitude, independent of how loudly the talker speaks, and with the weak consonants brought up to the level of the vowels. Noise during pauses would be suppressed, which improves intelligibility slightly, eliminates a source of annoyance in ordinary clipping, and greatly improves the operation of VOX circuits in gear which has them, such as the AN/ARC-58. The unit would be compatible with current aircraft intercoms and radio equipments, including both uhf AM and hf SSB transceivers. It should be equally useful in shipboard or ground systems.

The following simplified block diagram shows the essential components of a speech processor using SSB clipping. After frequency shaping



(discussed below) the audio voltage from the microphone is applied to an SSB generator which produces a single-sideband, suppressed-carrier signal at some convenient frequency, say 30 kHz. The background noise level is measured during pauses in the speech, and its intensity controls the amplitude of a quieting tone (at the suppressed carrier frequency) which is applied to an infinite peak clipper along with the SSB signal. The limiter-capture effect ensures that sounds weaker than the quieting tone are suppressed at the clipper output. Clipping generates harmonic and intermodulation distortion, but harmonics of an SSB signal are remote in frequency from the signal band and are easily removed by a simple bandpass filter. All of the even-order and some of the odd-order intermodulation products are also filtered out, so that only those odd-order products which fall within the bandwidth of the SSB signal remain. This feature accounts for the superiority of SSB clipping over other processing methods; it accomplishes instantaneous compression of dynamic range with a minimum of distortion. The filtered SSB signal is then demodulated back to audio.

The frequency shaping before the clipper is critical in any clipping scheme. Thomas and Niederjohn (1970) have shown experimentally that the optimum shaping is a pre-emphasis curve with 12 dB/octave slope, 3 dB down at 1100 Hz. Optimally pre-emphasized, infinitely-clipped speech, with noise added after clipping to give a speech-to-noise ratio of 0 dB, gave an intelligibility score of 90 percent. Under identical conditions, differentiated/clipped speech, recommended in the classic study by Licklider and Pollack (1948), gave a score of 65 percent. Unprocessed speech of the same average power scored 40 percent. (If the comparison had been made on the basis of equal peak instead of average power, unprocessed speech would have scored even lower because of its higher peak-to-average ratio. The peak comparison is more realistic, since an AM transmitter is limited to 100 percent modulation on peaks.)

The intelligibility of optimally-filtered/clipped speech in the presence of no deliberately introduced noise was 97 percent, which shows that clipping need not degrade intelligibility under ideal noise-free conditions. All of the above data were obtained with baseband audio clipping, but it seems certain that results with the same pre-emphasis preceding SSB clipping would be at least as good.

Many investigators have found that heavy clipping improves intelligibility only when the speech-to-noise ratio at the microphone is good. Clipping is not usually recommended when the speech signal itself is noisy, as when the talker is immersed in an intense acoustic noise field. Thomas and Ravindran (1971) have shown that this is not the case for optimum pre-emphasis before the clipper. Their results were as follows, using speech-to-noise ratios at the microphone of 0 dB, 5 dB, and 10 dB:

	Intelligibility (%)		
SNR:	0 dB	5 dB	10 dB
Unmodified speech	40	65	80
Optimally-filtered/clipped speech	47	82	96

These data show that clipping *is* somewhat more effective with a clean signal to work on, but it still gives some improvement with a very noisy signal.

The reason for the superior intelligibility with Thomas's optimum pre-emphasis is interesting. Thomas (1968) has shown that the second formant of a voiced phoneme is the principal determinant of intelligibility; the first formant is relatively unimportant. The spectrum of speech is such that the first formant is much stronger than the second, so that in a clipper the limiter-capture effect causes the first formant to partially suppress the second. In addition, the harmonics of the first formant generated by baseband clipping fall on top of the second formant for some sounds and tend to mask it. Both of these effects are prevented by a pre-emphasis characteristic which ensures that the second formant predominates at the clipper input.

One problem with any infinite clipping system is that during pauses the background noise is brought up to the same level as the speech. This is annoying to the listener, and it degrades intelligibility slightly by its effect on the perception of certain phonemes. A stop consonant (/p/, /t/, /k/, /b/, /d/, /g/) consists of a burst of sound preceded by a brief silent interval and followed usually by an aspiration sound. If the silence is replaced by noise, recognition of the phoneme is more difficult. Voice-controlled transmit-receive switching (VOX), used in some SSB equipments including the AN/ARC-58, does not work when pauses are filled with noise, because it relies on a difference of intensity between speech and silence.

These difficulties can be avoided by injecting a "quieting tone" of superaudible frequency into the clipper along with the speech signal. Amplitude of the tone is made just larger than the noise, so that the limiter-capture effect causes the tone to suppress the noise during pauses, whereas when the speech signal is present it suppresses both noise and tone. This scheme was used by Licklider and Pollack (1948) and by Thomas and Niederjohn (1970) in their experiments. In the aircraft radio application, some method of automatic control of the quieting tone is needed, because the levels of both speech and noise may vary widely. One must measure the noise level and then adjust the quieting tone to exceed the noise by a small margin. Hellwarth and Jones (1968) developed an ingenious circuit for detecting the presence of speech over a 60-dB dynamic range, in the presence of a variable noise level, by measuring the noise intensity during pauses. Their circuit could be adapted to the problem of controlling the quieting tone.

There are four methods for generating a single-sideband, suppressed-carrier signal: the filtering method, which dates back to the earliest days of SSB; the "phasing" method described by Norgaard (1956a), which was patented by Hartley in 1928; the "third method" of Weaver (1956); and a fourth method developed by Saraga (1962). It is expected that the phasing method will be chosen for use in the processor because it is relatively simple and needs no bulky rf filters. Demodulation of the clipped SSB signal back to audio will also be done by the phasing method [Norgaard (1956b)]. This circuit configuration permits all the filtering to be done at audio frequencies using well-known active-RC circuits [Mitra (1969)], except for a simple rf bandpass filter following the clipper, which can also use an active-RC circuit since the requirements on its bandwidth are not stringent. The elimination of bulky LC, mechanical, or crystal filters commonly used in SSB systems makes the circuit compatible with the hybrid microelectronic technology, so that the entire processor can be built as a very compact unit.

A speech processor with all the features outlined – optimum pre-emphasis, infinite SSB clipping, and noise suppression – has never been built, so its performance cannot be predicted exactly. Experimental results with SSB clippers, however, permit an estimate of the effectiveness of the proposed unit. Ferrell (1958) observed an increase in articulation score from 56 to 75 percent when clipping was added on an actual radio link, with an accompanying 10 dB increase in the average power output of an SSB transmitter limited to constant peak power output. Craiglow et al. (1961) report an intelligibility threshold improvement of 8 dB for 20 dB of SSB clipping. "Intelligibility threshold is here defined to be the condition where connected discourse is just barely understandable in the presence of white noise limited to the same bandwidth as the signal." [Pappenfus et al. (1965)]. Ewing and Huddy (1966) report that 24 dB of SSB clipping improved articulation scores (Harvard PB words) under various signal-to-noise ratios from 0 to 50 percent, from 10 to 60 percent, from 25 to 70 percent, and from 50 to 90 percent. Several amateur radio operators, such as Squires and Clegg (1964), have observed that heavy SSB clipping is about as effective in producing intelligible copy as a 10-dB increase in power without clipping. The addition of optimum pre-emphasis and noise suppression would be expected to improve performance further.

In summary, speech processing is the most promising approach to improving aircraft radio equipment. The audio design in Navy voice radio transmitters has improved relatively little since World War II. Recent advances in speech-processing techniques, electronic circuit design, and microelectronics now permit a quantum jump in communication effectiveness to be achieved at low cost.

CONCLUSIONS

1. The equipment worn by speakers in the naval aircraft radio link (helmets and masks) and the transducer used account for very little of the degradation in speech intelligibility encountered in the total link. The quality of the speech is largely dependent upon the speaker and the speech processing in the transmitter.

2. The M-94A microphones and A-13A oxygen masks now in use in naval radio systems are satisfactory for the jet cockpit noise of present-day aircraft. There is a slight decrement in speech intelligibility caused by the oxygen mask, but it appears to be primarily dependent on the user's adaptation to it.

3. The Modified Rhyme Test of House, et al, as modified by Kruel, et al, was found to be the most acceptable speech intelligibility test; 95 percent of standard test sentences will be understood over a system that will pass 80 percent of the MRT words.

RECOMMENDATIONS

1. In future programs to improve aircraft radio communications, concentrate effort on speech-processing methods as well as on modification of microphones or oxygen masks. Consider development of an add-on microelectronic processor unit to be built as part of the microphone cable assembly or mounted inside the intercom.

2. Standardize on some multiple-choice intelligibility test for determining the adequacy of military speech communication systems. The best test now available is the Modified Rhyme Test (MRT) of House, et al., as modified by Kruel, et al.

3. Set an MRT score of 80 percent or greater as the acceptance specification for speech intelligibility. This corresponds to an articulation index of 0.35 or better.

4. In revising the Brevity Code word list, incorporate multisyllable and/or multiword phrases.

5. Train prospective pilots to speak intelligibly when wearing oxygen masks in noise.

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Determine exact magnitude of improvement in speech reception when ear plugs are worn in helicopter noise: 6 or 7 percentage points on modified rhyme test.

REVERSE SIDE BLANK

APPENDIX: TRANSCRIPTION OF OPERATIONAL NAVAL AIRCRAFT RADIO TRANSMISSIONS (MADE OVER RVN)

[I]Five zero six from zero three, all[II] engine instruments normal.[1]

Ah roger, I've got twenty-four. You've got a very slightly...

OK ah, five one five do you have me in sight [at] this time?[2]

Ah five one five I've[3,III] just lost you[4] in the haze.[5]

Ah roger, I'm climbing through 8000.

Bull Dog, all Sable Sacks[IV] feet wet. Check us in please.

Station checking in - you're broken,[V] say again.[6]

Roger, check events[VI] four hotel and india back through TOPAZ, would you please.[7]

Fighter aircraft on channel 4,[VII] let's go button 15, button 15.[VIII]

Yes, he is feet...[IX]

This is Viking,[8] point alfa, three two zero... out.[9]

(SILENCE)

*

[1] ------

[2] from side to side

[3] they

[4] ------

[5] heading

[6] in a second

[7] ------

[8] sacking

[9] alfa

*

[I] one

[II] our

[III] I have

[IV] Uh, Sable Sack

[V] ------

[VI] ------

[VII] Fighter a tadpole 204

[VIII] Let's get back at 15 to 15

[IX] Yes, he is speaking

*Note: This transcription was made by a Navy pilot (K.E.). Out of 333 phrases, 35 were missed or garbled, for a score of 89.5 percent correct.

Roman numerals identify transcription errors by a Chief Aircontrolman (C.S.) familiar with aircraft phraseology and communication procedure. He missed an additional 73 phrases, for a score of 67.6 percent correct.

Arabic numerals identify transcription errors by a trained listener (P.K.) not familiar with the phraseology. He missed 185 phrases in addition to those missed by the pilot, for a score of 33.9 percent correct. It should be noted, however, that P.K. listened first and when in doubt C.S. had P.K.'s transcript available. And K.E. had the corrected (by C.S.) transcript available. The relative scores of pilot, controller, and speech researcher therefore reflect, among other things, the order in which the men listened.

Transcription page 2

Five two one is alfa.[10,X] Jumper[11] one, give me one.

Ah, Snowflake this is Sly Fox one. We're detaching this time, over.[12]

Ah, roger. Ah, Sly one, I think, ah, Lucky one has already taken up, ah, your job, over.

Ah, Sly one, roger, Ah, Lucky one is that affirmative?

That's affirmative, I'm, ah, about, ah, 6 miles feet dry.

Ah, roger.

(SILENCE)

This is Snowflake, point alfa.

(SILENCE)

Snowflake clear alpha, one eight.[XI] Jumper[13] one, Cluster. Ah, this is[14] Snowflake, roger out.[15]

Ah, flight, ah, contrails high at two.

Ah, don't worry about it.

Jumper[16] two are you with me? That's affirmative.[17] Ah, roger.

(SILENCE)

Slider Blue we have a MIG.[18]

Ah, Snowflake, you want to pass to[19] the west to avoid key area.[20,XII]

[10] ------

[11] other

[12] off

[13] Pass this

[14] as

[15] ------

[16] put seek

[17] as promised

[18] follow up

[19] ------

[20] entry area

[X] Five four is also alfa

[XI] Snowflake go from out it

[XII] entry

Transcription page 3

Say again. Disregard.

Singer low, singer low, Lucky[21] two.

Ah, how low a singer?[22] Fast?
Roger, got it.....Ah, fast.

Anybody see anything?

OK, ah, Jumper[23] we got a SAM comin' up at, ah, two o'clock - low[24] - two o'clock low.

Should be comin' through the clouds in a minute. Goin' right through the flight[25] passing[26] you six o'clock. Right through the flight.[27] 'Nother one. Right.[28]

OK Jumper[29] one, how about[30] givin' me a little... Being tracked, being tracked!! Eject![31]

Two chutes, down there -- it's OK,[32] right in front.[33] OK, flight let's go down, let's go down. Jumper[34] two, fire.

Jumper[35] two, Cluster.

[21] I've

[22] ------

[23] Patson

[24] ------

[25] white

[26] ------

[27] white

[28] OK

[29] pacer

[30] right

[31] Retire four attacked retack enter

[32] Preshoot, now you're cooking

[33] approach

[34] pass

[35] pas a

Transcription page 4

Sly Fox four, ah, two chutes, good chutes.[36]

To the east,[37] this[XIV] is Red Prince[38]...**signal**[XIII] **five, six or Red Prince,** two good chutes.

One[XV] two zero, three two...fi...si....[39, XVI]

Ah, this is Snowflake,[40] target in sight at, ah, one thirty down,[41] popping up.

This is Sly Fox,[44] four. Both chutes[42] are heading[43] into the clouds, into the clouds..... Keep an eye on 'em.

OK fatbacks,[45,XVII] target's[46] about, ah, 1030 now.

Go[XVIII] feeder[47] mopex. Snowflake,[48] mopex mopex.

(SILENCE)

[36] two, two

[37] eat

[38] loud

[39] one two zero three two

[40] nutmeg.

[41] now

[42] shoots

[43] hovering

[44] quite good

[45] fat backs [called pitchrock by second listener]

[46] its

[47] keying

[48] nutmeg

[XIII] recon repodep

[XIV] ______

[XV] three

[XVI] five six of Red **Prince two good chutes**

[XVII] (see 45) Sly Fox

[XVIII] off

Transcription page 5

This[49] is Sly Fox four. Both chutes[50] disappeared[51] below the clouds. Sly Fox four is wai[ting].

Check your altitude Pete[52] so, you're low. Sable Sack[53] one is in.[54,XIX]

Sable Sack[55] two is in,[56] Chowder Hound five, in. You got thirty[XX] sevens. Sable Sack five is in.[57]

Jumper[58] one, Cluster. Sable Sack one is off. [Sable S]ack[59,XXI] two is off, tally ho.

(SILENCE)

---

[49] sis

[50] boswitch

[51] disappearing

[52] tile

[53] I'll haul back

[54] two ten

[55] I'll settle back

[56] his end. For

[57] looks like

[58] similar

[59] Sable Sack

[XIX] one to descend

[XX] hurkey

[XXI] ______

Transcription page 6

OK, Jumper one[60,XXII] you've..you've either got a shrike, cookin'[61] or you're letting out white smoke outa your...That's chaff.[62]

Ah, roger four, this is Snowflake...[Garbled transmission concerning Sly Fox four].

Jumper[63,XXIII] three, Cluster. Gotta piece[64]...ten...(starboard tire)[XXIV]

Ah, is that[65] Sly Fox four calling this?[66]
Jumper three, Cluster....fire[67]...if[XXV] you have Snowflake[68] in sight?
I have two fox[XXVI]... at three o'clock. Ah, two, do[69] you have the wreckage back there at our eight o'clock? Affirmative. OK, let's get a good mark on it. Roger.

[Sly]Fox[70] four you have the lead.[71] Roger.

Jumper[72] four, Cluster.
Sly Fox heading one one one. Recommend you get away from there[73] [garbled sentence ending].

[60] pop why there
[61] shirt change or
[62] ask champ
[63] fatso
[64] switcher start
[65] Ah, so
[66] hess
[67] fire if
[68] that think
[69] tooy
[70] Bus
[71] Yon go in
[72] fatso
[73] Let him get away tomorrow.

[XXII] Bouncer
[XXIII] Bouncer
[XXIV] Sly Fox retiring
[XXV] four do
[XXVI] I am still...fire

Transcription page 7

Start headin'[XXVII] out there, Jumper four. [Roger] four.

Not...Roger, roger.
Ah, Sly Fox one...about...This is Sly Fox one (or four), say again Snowflake.[XXVIII]
...Going into the clouds. You[XXIX] have the wreckage.[74] Ah, I may go back up there
'take a look... About two miles. Go back...Sable Sack[75] one, feet dry.

Three-oh-four,[XXX] let's go back in there[76] and take a look.

OK....crash...[garbled]... is that affirm? That's affirm...[77]
It's, ah, Sly Fox one zero four, one zero four.[78]

[Broken]...Ah, roger, ah, we're goin' there and take a look, ah, ah, we have the wreckage in sight; however, we did not, ah, we don't know where the chutes are. We didn't see them.

The chutes landed north west, about, ah, two or three miles from the wreckage.

...You're going too far in -- let's bring it back out.[XXXI]

Ah, I heard a beeper, ah, ah, Chowder Hound two.
Ah, did you hear the beeper, over?
Ah, Chowder Hound two, ah, negative, I did not.
This is Papa[XXXII] two, I heard beeper...beeper also.
Ah, Snowflake...Chowder Hound four, I heard a beeper about ah, a minute after the ejection. Lock on beeper.[XXXIII] Likewise.
Haven't heard anything since. Affirm.

[Garbled][XXXIV]...beeper about a minute after the, ah, plane went down.

---

[74] All of the wreckage.

[75] tell back

[76] Nah, I think I'll four and like to go back

[77] it's

[78] burned foot

[XXVII] Heading

[XXVIII] ______

[XXIX] I

[XXX] Sly Fox four

[XXXI] let's take it back out

[XXXII] Chowder Hound

[XXXIII] ______

[XXXIV] Heard

Transcription page 8

Five bravo's going[79] feet wet---Sable Sack[XXXV]...Ah, Sly Fox two reads you loud and clear. Ah, roger.

One...six[80,XXXVI] zero five, side[81] number. Roger six zero five break,[82] ah, Viking, Viking, Birthday Cake on secondary.

Snowflake roger.

Yeah,[83] I got him.

Slider[84] Blue, your vector three six[85] zero.

Slider[86] Blue, thank you.

Slider[87] Blue, bring [it] around[XXXVII] to zero one zero, range about[88] twenty.

Slider[89] Blue, acknowledge.

Slider Blue, say again.

Roger, your vector zero one...[XXXVIII]

Slider Blue, ah, say once again please [you] cut out.

Zero one zero, twenty, Blue. Thank you.

Sno-Snowflake, Birthday Cake is on [station].

SAM at twelve o'clock.

Cluster[90] away.

---

[79] steam

[80] one

[81] sight

[82] breakdown on Snowflake Snowflake Birthday Cake

[83] hell

[84] Polo

[85] fifth

[86] polo

[87] polo

[88] of

[89] polo

[90] that got

[XXXV] Switch two

[XXXVI] ______

[XXXVII] Bring down

[XXXVIII] ______

Transcription page 9

Twelve o'clock to who?

Second SAM in the air.

Ah, Rog, let's take 'er[91] to the, ah, right gang.[92]

Jumper[93] three, Cluster.

Your silo's[94] at three o'clock.

OK take her[95] down and in close to town.

OK, ah, we've got the, ah, third[96] SAM rising, ah, across the river.

OK from the north,[XXXIX] across the river.

Tally ho, Chowder Hound, let's start her down,[97] start 'er down.[XL]

Let's peel off.[XLI]

Fourth SAM rising east.

Stand by to pop up.

[Garbled]

There's another one ... twelve o'clock.

OK Sable Sack one is[98] in.

And there's a fifth one goin'[99] up.

There's another one. Let's go.

---

[91] was baker

[92] gay angle

[93] All set

[94] sight you

[95] baker

[96] first

[97] corra star down

[98] let's go

[99] gone

[XXXIX] ______

[XL] start down two all

[XLI] ______

Transcription page 10

[Garbled][100,XLII]...Chowder Hound.

Keep it high, keep it high,[101] Chowder Hound.

Roger high.

I'll tell you, we're gonna be slow, gang.

Pickle a little low and a little late.

There's another one low, Chowder Hound, another one low, keep it high-still low.[XLIII]

Roger got loose.

You OK Chowder Hound?

[Garbled] ... , ah, Sable Sack's in.

You still with me, ah, Chowder Hound four?

Affirm, I'm with you baby.

Let's go, let's dig it in,[XLIV] Chowder Hound, you're gonna be a little shallow.[102]

Watch the flack.

Chowder Hound four one breaking off.[103]

Henny Penny Viking shine ... [Garbled]

OK, ah, Chowder Hound three in.

Sable Sack six and seven, you OK?

Yeah.

It's out right on, ah, your three o'clock.

Still ... got tally ho.

Chowder Hound, ah, four one five, no joy.

Jumper three,[104] Cluster.

[100] Anchor there

[101] to the right, to the right

[102] give me an hour shell

[103] four I'm bring you

[104] alsatoy

[XLII] yank her back

[XLIII] to the right

[XLIV] Bring it in

Transcription page 11

Chowder Hound ... you gonna[XLV] run on the bridge? Watch your turn; twelve o'clock approximately.[105] Maybe.[XLVI]

Jumper four, Cluster. No joy.

This is Sable Sack one, I've got about four bird hits.

I'm at fifty-five hundred now.

Chowder Hound six, do you have me?

That's affirmative.[XLVII]

Sable Sack three, you with me?

Affirm.

[Garbled] ... I've got you ... got your feet wet?

Sable Sack three are you with me? Ah, roger.

Chowder Hound six from five are you with me?

Chowder Hound[106] ... Chowder Hound[107] five this is six, over.[XLVIII]

Ah, Jumper[108] five and six are you out?

Affirmative.

Chowder Hound[109] one 'n two feet wet.

Chowder Hound five and six are feet wet.

Jumper[110] three and four heading out.

Ah, rog, Jumper one and two are turning out at this time.

Say again,[111] Jumper one.

---

[105] fox baby

[106] far out

[107] far out

[108] far out

[109] far out

[110] Ahtsa

[111] see you

[XLV] to make a

[XLVI] ____

[XLVII] ____

[XLVIII] ____

Watch your AD's at, ah, eleven o'clock.

Tally ho.

Sable Sack five, are you wet with three?[112]

Sable Sack five, I've got two, ah, six and seven, come up.

Six is up.

Seven is ...[XLIX]

Chowder Hound three 'n four, you feet wet?

Three and four feet wet.

Roger, roger.

I'm getting a lotta thirty seven down there, Phil.

Sable Sack, let's go button niner.

Sable Sacks, wait[113] one. Understand all chicks feet wet?

Right.

Ah, this is Chowder Hound, affirm.[114] All birds feet [wet].[115]

[We haven't] heard from the Jumpers.

Jumpers one 'n two will be[116] feet wet in one minute.

Jumper three and four, feet wet.

Roger.

All Chowder Hound, feet wet.

All Lucky Devers[117] feet wet

---

[112] weapons free
[113] make
[114] seven
[115] seed--here
[116] zero beep
[117] round quivers

[XLIX] here

Transcription page 13

Roger.

And all Sable Sacks are feet wet.

"At's negative, Jumper two's[118,L] still feet dry.

Sable Sacks[119] (or throttle back again).

And Jumper one and two are going feet wet this time.

Roger. Sly Fox, are you feet wet?

Fee, ah, feet wet in about one minute.

Ah, roger.

Ah, Jumper two's[120,LI] feet wet.

Chowder Hound[121] six, feet wet.

Viking,[122] Viking, I hold all feet wet, but, ah, Sly Fox.

Ah, roger, this is[123] Snowflake going on channel nine.

Roger nine.

Watch the birds, Jumper[124] four.

Ah, tally ho this pass ... [garbled] (the SPADS are well below).

Three is enough, Bill.[LII]

Sly Fox one and two, feet wet.

Sly Fox one one four ... [garbled]

Button nine.[125]

[118] ascot and concert

[119] flowerback

[120] key's

[121] far out

[122] ------

[123] asses

[124] cloud

[125] down

[L] three

[LI] three

[LII] Pick

Transcription page 14

Button nine?[126]

We've got negative TACAN. You have the lead.[127]

Ah, rog.[128]

Viking, Slider Blue and Slider Green departing station for Pinto.[129]

Viking copy.

Viking, Penny seven seven nine, over.

Ah, Penny this is Viking, go.[130]

Ah, do[LIII] you hold all chicks feet wet?

Ah, roger all chicks are feet wet.

Ah, roger.

Flight, let's[LIV] go button[131] one.

Events[132] alfa, bravo, delta, echo, golf, and hotel.

---

[126] down

[127] key typewriter on the roof rog

[128] ______

[129] forward bleu and forward drain

[130] do

[131] back a

[132] ______

[LIII] ______

[LIV] A figment

Ah, this is Red Prince[133,LV], roger out.

Ah, Red Prince, Slider Blue.

Ah, Slider this is Red Prince,[134] go.

Ah, roger, Slider Blue in company with[135] Slider Green, events[136] two lima and[137] two kilo departing station for[138] Pinto.

Red Prince,[139] Red Prince,[140] Chowder Hound three zero five.

Two zero five, Red Prince go.[141]

This is Chowder Hound three zero five. Ah, two aircraft, three zero five three one zero from event two golf, on[142] your zero five zero, thirty five.

Roger, go eight.[LVI]

Up two one three.

Red Prince,[143] Red Prince,[144] Chowder Hound three zero two, over.

Affirmative, three zero five, you're clear.

Chowder Hound two[LVII] zero two, go.

Red Prince,[LVIII] Red Prince,[145] two zero five.

Button eight,[LIX] three ten.[146]

---

[133] cloud

[134] cloud

[135] ------

[136] against

[137] ------

[138] from

[139] cloud

[140] cloud

[141] come

[142] front of vent two cut off when

[143] cloud

[144] cloud

[145] cloud

[146] Psyching

[LV] Ah, check

[LVI] Marshall

[LVII] three

[LVIII] roger

[LIX] checking in

Transcription page 16

Chowder Hound three zero two, ah, checking out.

Chowder Hound three zero two, event two fox trot, to zero four zero, thirty one, squawking[147] normal.

Roger, go[LX] eight.

Red Prince, Red Prince,[148] Sly Fox one zero seven, over.

Roger Sly Fox, go.

Roger Sly Fox one zero seven, Sly Fox one one four, event two bravo, two bravo, on your zero one zero degree radial,[149] thirty one miles.

Ah, this is Red Prince.[LXI] Roger Jim you're cleared.[150,LXII]

Ah, roger thank you. Let's go button eight,[151] switch two.[LXIII]

Red Prince,[152] Chowder House[LXIV] three ... one five, over.

Roger Prince,[LXV] say your call sign again, over.

Chowder Hound three one five is event two hotel on your zero two five at thirty two.

Roger, go eight.

Ah Red Prince[153] ... one[LXVI] all chicks feet wet RTB.[154]

Ah Chowder Hound,[LXVII] you're cleared.

Chowder Hound roger, going eight.[156] ...zero five, over.

[147] sparking

[148] recon, recon

[149] radian, raid elk

[150] ------

[151] fight now

[152] ------

[153] cloud

[154] are

[155] ------

[156] aheik

[LX] ------

[LXI] ------

[LXII] ------

[LXIII] ------

[LXIV] power

[LXV] ------

[LXVI] check

[LXVII] roger

Transcription page 17

This is three zero five at three one zero. I'm on your three five zero at, ah, sixty. My low[157] state is, ah, three eight.

Three one one, up.

Three zero[158] five let's ....[159,LXVIII] three point eight.

Switch[160] to button[161] seventeen, over.

Roger going seventeen.

Slider[162] Green, Slider[163] Blue, you up?

Roger.

Pinto, Slider[164] Blue, over.

Slider[165] Blue, Strike[166] over.

Ah Roger, Strike. Slider Blue in company with Slider Green is inbound on your three five zero degree[167] radial, five four miles, angels ten.

Slider Blue has five thousand pounds give-away of fuel. Over to Slider Green.

Slider Green has six thousand give-away.

---

[157] below

[158] reasoner

[159] west they

[160] six

[161] one

[162] our

[163] four

[164] four

[165] four

[166] sight

[167] ------

[LXVIII] roger state

Transcription page 18

Three[LXIX] zero[168] five, roger angels[169] ten and five points to give away. Zero seven six points to give away. Switch to button[170] seventeen. I hold[171] you fifty two miles inbound.

Slider[172] Blue, wilco,[173] switching button[174] one seven.

Green copied.[175]

Pinto, Chowder Hound three one five.[LXX]

Chowder Hound three one five, Strike, over.

Three one five in company with three one one on your three five zero radial.[176] Estimate sixty miles, no DME. Low state is[177] four four. Each aircraft has one unexpended AGM forty five.

Three one five, Strike, roger state four point four. You're cleared[178] to switch button[179] seventeen [garbled] (...bingo this). Roger switching one seven.

Hello Pinto Strike, Chowder Hound three one six, over.

---

[168] ------

[169] angles

[170] one

[171] owe

[172] our

[173] all cons

[174] by

[175] breakup

[176] ------

[177] below status

[178] ------

[179] problem

[LXIX] ------

[LXX] ...strike over

Transcription page 19

Estimate[LXXI] three one zero. Ah, we're fifty miles out.[180]

And, ah, my low state is three six.
Roger three zero five. Report see me. Altimeter three zero zero five.

Roger.

Three eleven up.[181]

Nine nine,[LXXII] Pinto, new altimeter three zero zero four, three zero zero four.

Pinto Marshall,[182] Slider Blue, over.

Slider[183] Blue, Pinto, go ahead

Slider Blue in company with Slider Green on your three five zero degree radial, forty three miles, angels eight.[LXXIII] Slider Blue has five thousand pounds give-away. Slider Green has six thousand pounds give-away, over.

Roger, Slider Blue and Green, report see me.

Altimeter three zero zero five.

Slider Blue,[184] wilco.

Pinto,[185] Chowder Hound three one five.

---

[180] hour

[181] show up

[182] how full

[183] over

[184] ------

[185] ------

[LXXI] made

[LXXII] niner

[LXXIII] three