e. A-Weighted Sound Level (dB(A)) -- A single event sound level which has been filtered or weighted to discriminate against the low and high frequency extremes to approximate the auditory sensitivity of the human ear.

f Octave Band -- All of the components, in a sound spectrum, whose frequencies are between two sine wave (pure tone) components whose ratio of frequencies exactly two, ie. separated by an octave,

4. DISCUSSION. Today's large, jet-powered, air-transport airplanes present few speech-interference problems for flight crews. However, propeller or rotor driven aircraft, regardless of the power plant used, have noisier cockpits for several reasons. Much of the propeller or rotor noise energy lies in lower frequencies, which are much more difficult to attenuate than high-frequency sounds. In nonpressurized aircraft, constructian permits air leaks that are both sound transmitters and sound sources; propeller and rotor tips can travel at or near Mach 1, which means, in some flight configurations, small sonic booms constantly bombard the aircraft. In addition, techniques for minimizing sound production or sound transmission require the addition of physical mass to the system, and where payload determines the value or utility of the aircraft, adding enough mass to reduce noise, can cost severely in payload. Streamlining can be very costly in new design costs (to remove air leaks) and it may also require major changes in production methods. Some of these methods require additional weight which reduces utility.

a. Outside the aircraft, noise spectra vary greatly as a function of aircraft size and type and the variety of powerplant, but the interactions of those spectra with the sound-insulation properties of the various airframes generally lead to strikingly similar spectra on the inside. Cockpit noise studies have shown the spectral shapes of cockpit noises vary only slightly from one type of fixed-wing aircraft to another,

b. The primary energy in those noises lies in the low frequencies, ranging mostly from 100 to 300 Ha, with a rapid decrease as frequency increases. This spectral canfiguration may peak at different sound levels for different airplanes. The overall sound intensity varies from about 70 dB(A) to more than 100 dB(A). Generally, the quietest cockpits are found in jet aircraft; the noisiest are found in open cockpit airplanes such as those used for aerial application in agriculture and in some small military jets that use afterburners.

c. Within a general class of aircraft (for example, light, single-engine airplanes), the variations in cockpit noise level among airplanes of a single type may be about as large as the variations found among all the types within the class. Age and history seem to be important determinants of the cockpit noise level as much as the original design. Therefore, little is to be gained by looking at a single sound spectrum from a single airplane as if it were typical of its type and would remain typical of its type.

d. The following sections present an overview of a means to assess the level of cockpit speech interference due to noise and methods to measure and improve cockpit communications.

(1) <u>Speech Interference Level.</u> This AC utilizes a noise interference metric known as the preferred-frequency speech interference level (PSIL). The PSIL is an average of the unweighted noise sound pressure level of three octave bands at 500, 1000 and 2000 Hz and relates to an "A" weighted decibel measurement (dB(A)). The PSIL has been accepted as a suitable predictor for a much more complex measure of speech intelligibility known as the articulation index (AI). The AI ranges from 0.0 to 1.0 with an increasing value indicating a more perfect communication. The Armed Forces maintain that for communications approximately 3 feet apart, an AI between 0.2 and 0.3 represents an acceptable minimum intelligibility level. The maximum PSIL for AI=0.2 is 83 and for AI=0.3 is 78. The FAA believes that in cockpits with noise levels above 88 dB(A) (PSIL=78), efforts should be made to aid communications by use of one or more of the methods discussed in this AC. The evolution of speech intelligibility research and the development of criteria regarding speech interference is covered in sane detail in appendix 1.

(2) <u>Cockpit Noise Measurement.</u> A portable sound level meter (SLM) which indicates the sound output in "A" weighted decibels (dB(A)) is recommended for the measurement of cockpit noise.

(a) A quick noise survey of the cockpit can be made by observing the sound level for approximately 20 seconds while the aircraft is in stabilized flight. One or two repeat readings are recommended to average the data. Readings should be taken in the takeoff, approach, cruise and descent modes of flight so that a comprehensive noise picture is obtained.

(b) If the above tests indicate a noise problem or a borderline noise problem exists, additional noise measurements should be taken and recorded, as discussed in appendices 2 and 3. Recording noise levels is desirable as this will allow a more complete noise analysis to be made. In addition, a sample calculation of PSIL is shown in appendix 4.

(3) <u>Methods to Improve/Aid Cockpit Communication.</u> When the noise level in the cockpit, exceeds 88 dB(A) (PSIL=78), the noise will be of sufficient magnitude as to interfere with normal cockpit communications, i.e. voice and radio. Therefore, efforts should be made to aid communications. The following methods are suggested to improve the signal (voice)-to-noise ratio, which will enhance the intelligibility of cockpit communications. Appropriate FAA approvals must be obtained for any type design changes resulting from any of the following methods employed:

(a) Decrease the cockpit noise level.

(i) Use of door seals

(ii) Acoustical insulation.

(b) Increase the voice signal levels or modify the signal-to-noise ratio.

(i) Increase the gain of intervening audio amplifiers. (reference TSO-C50c, Aircraft Audio and Interphone Amplifiers)

(ii) Use of electronic headsets, noise cancelling or boom microphones and intercom systems. (reference TSO-C57b, Aircraft Headsets and Speakers (for Air Carrier Aircraft) and TSO-C58a, Aircraft Microphones (for Air Carrier Aircraft))

(iii) Appropriate use of hearing protectors.

(iv) Move the flight crewmembers closer together.

e. Appendix 5 discusses in detail the advantages and disadvantages of the methods described above to improve cockpit communications. The overall objective of the modification should be to improve the intelligibility of communications. The minimum goal should be to achieve an articulation index (AI) of 0.3, identifiable by a PSIL of 78 or a measured noise level of 88 dB(A) or less.

f. Regardless of the method used to aid communications care should be taken to assure that aural warnings (i.e. overspeed, stall, and landing gear) can be heard with or without the communications aid in place.

M.C. Beard
Director, Aircraft Certification
Service, AIR-1

APPENDIX 1

QUANTIFYING SPEECH INTERFERENCE

Several researchers have contributed landmark studies of the ways in which noise can interfere with the understandability or intelligibility of speech. It has been demonstrated that the frequencies necessary for 100 percent intelligibility of a speech signal cover the range from about 300 Hz to about 7000 Hz.

A measure of that portion of the speech intelligibility range that is available in a specific communication situation is known as the articulation index (AI). The AI was developed by French and Steinberg and is a number falling between 0 and 1.0.* AI accounts for the level and spectra of ambient noise, and describes the relative ease or difficulty of a particular communication situation. An AI of 1.0 is considered perfect, with lower values indicating communications of lesser quality.

* French, N.R. and Steinberg J.C., "Factors governing the intelligibility of speech sounds," Journal of Acoustical Society of America, 19, 90-119, 1947.

Researchers have devised a set of relationships between AI and speech intelligibility for several sorts of speech test materials ranging from nonsense syllables, in which the content is quite unpredictable, to sentences, which are, comparatively, perceptually redundant--if you hear part of a sentence, you have a reasonably good chance to guess correctly what the rest of it is.

In 1947, Beranek published a report that serves as a further basis for determining how noise interferes with speech.* The speech interference level (SIL) is an average of the octave-band noise levels at some preselected set of center frequencies. In his original proposal, Beranek used the three octaves running from 600-4800 Hz. Later work, primarily by Webster and by Klumpp and Webster, showed that the inclusion of different frequency bands in the averages leads to AI predictions that are accurate for different communication conditions.** Thus, an average of the octave band levels at 500, 1000, and 2000 Hz seems well suited for predicting an AI of 0.2; i.e. a minimal communication environment. An average of 500, 1000, 2000, and 4000 Hz corresponds fairly well with an AI of 0.5 and an average of 1000, 2000, and 4000 Hz seems to go with an AI of 0.8. The 500, 1000, and 2000 Hz SIL has come to be known as the preferred-frequency SIL (PSIL), and it is often closely related to a dB(A) measurement of the same noise, though the relationship is not perfect.

*L. L. Beranek, "The design of speech communication systems," Proceedings of the Institute of Radio Engineers, 35, 880, 1947.

**J. C. Webster, "Relations between speech-interference contours and idealized articulation-index contours," Journal of the Acoustical Society of America, 36, 1662, 1964; J. C. Webster, "Noise and Communication," in D. Jones and T. Chapman (editors), Noise and Society, London: Wiley in preparation; R. G. Klumpp and J.C. Webster, "Physical measurements of equal speech-interfering navy noises," Journal of the Acoustical Society of America, 35, 1328, 1963.

The maximum PSIL for communications approximately 3 feet apart for an AI of 0.2 is 83. The maximum for an AI of 0.3 is 78. As will be shown below, these two AI's represent the range of acceptable minimum intelligibility levels. Therefore, when a cockpit has a noise level above a PSIL level of 78, talkers and listeners can 'be expected to have some voice-communication problems. This prediction can be modified slightly by the fact that, in many cockpits, the pilot and copilot can 'be more or less than 3 feet apart. However, in the cockpits of aircraft likely to be relatively noisy, i.e. small aircraft, crewmembers would probably be seated at distances between 2 and 3 feet apart.

The messages that are expected to be transmitted in aviation communications come from a prescribed vocabulary. However, even when that vocabulary is ignored, the messages are spoken in context, which usually means that they are more intelligible. The Armed Forces have set acceptable levels of performance for communications equipment, and those performance levels can be transformed into AI values: they range from 0.25 to 0.3. The Air Force, for example, defines an 80 percent score on a rhyme test as passing and a 70 percent score as conditionally passing. In figure 1, it can 'be seen that the 80 percent criterion is almost exactly 0.3 and that the 70 percent criterion is very close to 0.25.

Navy and Army limits of acceptability are approximately the same as the Air Force%. Webster and Allen specified an 80 percent rhyme test score as (the Navy fence) the lowest acceptable value*. They reasoned that "95 percent of standard test sentences will be understood over a system that will pass 80 percent** of rhyme test words. Following identical reasoning, the FAA believes that, short of measuring human performance on rhyme tests in cockpit-noise environments, the choice of AI=0.3 is both reasonable and acceptable. This AI equates to a PSIL of approximately 78 at a distance of 3 feet.

*J. C. Webster and C. R. Allen, "Speech intelligibility in naval aircraft radios,** <u>Naval Electronics Laboratory Center Report</u>, TR 1830, 1972.

Relation Between AI and Various Measures of Speech Intelligibility

From ANSI S3.5-1969

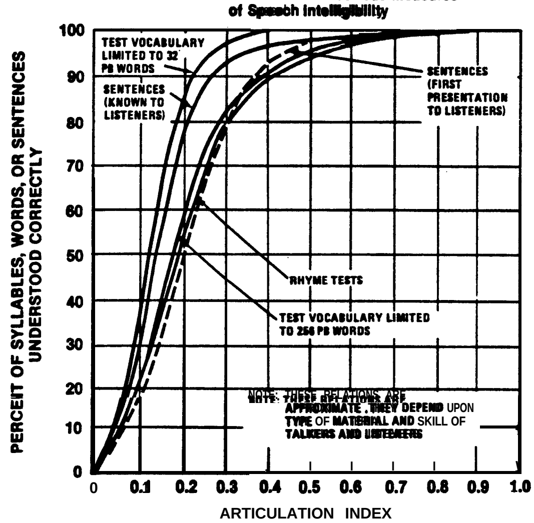


FIGURE 1

The following table also corroborates the relationship between the various test results and Articulation Index:

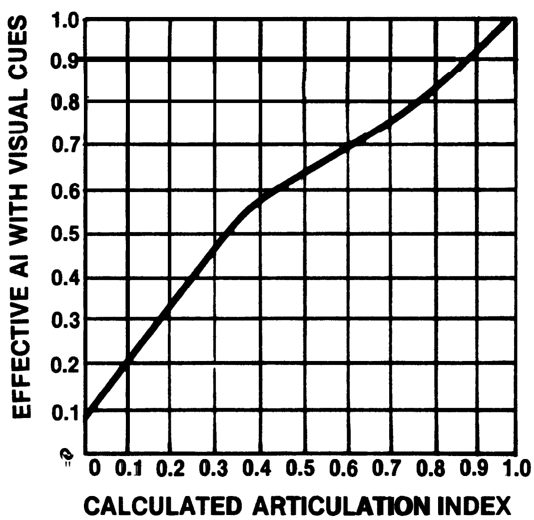
Table 1. Expected Word or Sentence Scores for Various Articulation Indices (AI)

PERCENT INTELLIGIBILITY

Articulation Index	Phonetically* Balanced Test	Modified** Rhyme Tests	Sentence* Test
0.2	22	54	77
0.3	41	72	92
0.35	50	78	95
0.40	62	86	96
0.50	77	91	98
0.60	85	94	98
0.80	92	98	99

*From Kryter and Whitman (1963)
**From Webster and Allen (1972)

Assuming that pilots can communicate visually with each other, an AI of 0.3 actually can be elevated to 0.47 as indicated by the following chart (figure 2).



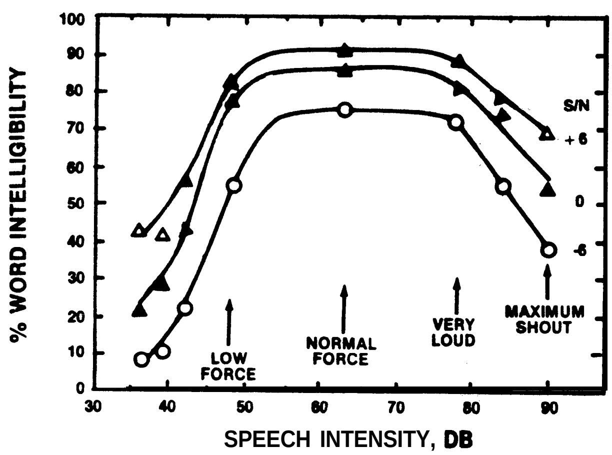
Relation between calculated AI and effective AI for a communication system wherein the listener can see the lips and face of the talker (Sumby and Pollack, 1954).

FIGURE 2

Thus, an AI of 0.3, if aided by visual cues, can raise the intelligibility level to approximately 98 percent (as shown figures 1 & 2). However, visual communication, while it can improve intelligibility, requires the persons to look directly at each other. This full-face orientation in the cockpit 'between the pilot and copilot is an unusual occurrence. Cockpit noise levels in many rotorcraft and propeller-driven airplanes, especially the piston-engine types, can possibly exceed the maximum practical PSIL values noted above.

If one considers the distance between the heads of a pilot and copilot to be 3 feet, then in a noise field whose intensity exceeds a PSIL of about 90 (about 97 dB(A)), vocal effort cannot overcome the intelligibility problem created by the noise. First, shouted speech is not as intelligible as speech produced with less effort (see figure 3). Second, in that much noise, human vocal systems are, on the average, just about at the limit of their loudness. (Reflexively, talkers raise their voices in order to be heard above the background noise. In this instance, though, where noise levels are quite high, the reflex cannot lead to more intense speaking levels: the vocal system has already reached its physiological end point.) When PSIL = 90, AI approaches zero as does intelligibility--that PSIL condition is unacceptable at a 3-foot distance.

FROM: Pickett, J.M.: Limits of Direct Speech Communication in Noise. J. Acoust. Soc. America, vol. 30, no. 4, Apr. 1958, pp. 278-281.



Relations between speech intelligibility in noise and vocal force. Vocal force measured as speech intensity one m from lips in a free field. Parameter, over-all signal-to-noise ratio, db. Noise, 70 db, flat spectrum.

FIGURE 3

APPENDIX 2

COCKPIT NOISE MEASUREMENT

TEST SETUP

Measurement in the cockpit should be made at the typical head location of each flight crewmember. The microphone should be placed at the representative ear position on the side where speech communication is normally received and moved around slightly to obtain a spatial average of noise at the head position. Whenever possible, the measurement shall be made with the crewmember absent from his location so as to minimize interference and shielding effects. During the measurements care should be taken not to hold the microphone close to a sound-reflecting or sound-refracting surface. A common recommendation is to stay at least one foot away; in practical use, a 6-inch distance is probably adequate,

TEST CONDITIONS

The aircraft interior should be in a fully furnished configuration for its intended use (passenger, cargo, other) with tie downs, carpets, seats, curtains, interior trim panels, etc., installed. Systems used for providing conditioned air (i.e., pressurization, cooling, heating,) should be operational. Cabin pressure should be noted so that adjustments for differences in air pressure may be made, if necessary. Cabin pressure can affect noise measurements taken on the ground or inflight. The difference between these measurements is about 0.25 dB(A). On sane aircraft, windows can be open during flight and could adversely affect the noise level in the cockpit. If this case exists this condition should also be tested.

If a tape recorder is used, the acoustic sensitivity calibration can be recorded during flight to establish the reference acoustic level for subsequent data processing and for comparison with the preflight recording of acoustic-sensitivity signals. Recorded noise levels should be measured cm the ground and inflight to establish the proper gain to be used for recording above the background noise levels. At least me reel of tape used during the test should have a recording of acoustic-sensitivity calibration signals.

Where possible measurements should be made when all aircraft operating conditions (such as altitude, airspeed and engine power settings) are stabilized. The aircraft cockpit noise should be tested in take-off, approach, landing, cruise, and descent at high speed.

On multi-engine aircraft the use of engine synchronization is optional depending on the test objectives. Installation and operation of engine synchronizers or propeller synchrophasers is frequently desirable for increased passenger comfort. Operation of such devices during acoustical testing is advisable if the test objective is to measure the optimum cabin environment. However, imperfect synchronizer operation my introduce very low frequency beats which compromise the data, so that intentional operation out of sync may be necessary. In such cases, the engines should be set to produce a known beat frequency high enough to allow reasonable length data records and minimize amplitude effects.

The following flight data should be observed and noted while the acoustic data is being obtained:

a. Flight Regime - takeoff, cruise, approach, landing, descent etc.

b. Airplane pressure altitude.

c. Airplane indicated airspeed and/or Mach number.

d. Propeller RPM (if applicable).

e. Engine power settings.

f. Synchronizer or synchrophaser operation.

g. External ambient air temperature.

h. Cabin pressure and temperature.

i. Cabin system operation modes.

DATA ACQUISITION

If tape recording is used, the record length at each location should be at least 2 1/2 times the data reduction integration period, but in no case less than 20 seconds. If audible beats are present the record shall include at least 3 complete beats. Sufficient precautions should be taken to ensure the data signals are not compromised by inappropriate tape recorded gain settings. Data should be recorded with the sound level meter in the flat mode (unweighted).

When portable sound level meters are used for direct measurement of sound pressure levels, (use the A-weighting network with SLOW response setting) the data to be reported shall be the maximum reading noted on the meter. When audible beats are present the meter should be observed for a period of time long enough to include at least three beats, and the maximum meter reading noted shall be reported. If the sound level meter has integrating capability where the time period is operator-controlled, the time period used shall be at least 10-20 seconds. If audible beats are present, the time period shall be sufficient to include at least 3 complete beats, but not less than 20 seconds.

DATA REDUCTION

Data reduction, from the recording, when employed, should be performed by time averaging data samples of at least 8 seconds duration. When audible beats are present, the integration period should be extended to include at least a three-beat period.

Sound pressure levels should be obtained for the eight-octave bands center frequencies from 63 Hz to 8 KHz. Overall sound pressures should be obtained by summing antilogarithmically the octave band data. Preferred speech interference level (PSIL) should be calculated by algebraically averaging the unweighted levels in the 500, 1,000, and 2,000 Hz octave bands.

Frequency weighting may be added to octave band sound pressure level data. The weighting function should correspond to that referenced in International Electrotechnical Commission (IEC) 651. Frequency weighted overall sound pressure levels are obtained by antilogarithmically summing the octave-band data after weighting is applied.

Presentation of the acoustical data should include at least the following information:

1. Overall A-weighted sound pressure levels at each measurement location.

2. Preferred speech interference levels at each measurement location.

APPENDIX 3

MEASUREMENT SYSTEM

A portable sound level meter (SLM) and a portable battery-powered FM recorder are recommended to measure cockpit noise. The SLM includes the microphone, amplifier, rectifier and a meter which gives a sound output directly in decibels. A connecting jack is provided so the amplifier output can also be recorded on a magnetic recorder for further study.

Most sound level meters also include weighting networks selected by a panel switch. The "flat" position sums all frequencies evenly. The "C" position is almost the same as "flat" and one or the other may be omitted on cheaper instruments. The "A" and "B" weightings are designed to approximate the ear's response and to give a truer approach to loudness of complex sounds. (The "B" scale is little used today, while the "A" weighting is used extensively. The designation "dB(A)" or, less properly, "dBA", indicates the reading with the "A" weighting.)

More expensive meters include, either as an attachment or internally, a series of band pass filters, usually of one octave width. Eight such bands will cover the usual measurement range of 50 to 10,000 Hz. Such filters provide a convenient means for a quick evaluation of the frequency structure of a complex sound.

In order that sound level meters made by different manufacturers will agree adequately when measuring various sources, their characteristics are specified by the International Standards Organization (ISO) and American National Standards Institute (ANSI). This-includes the characteristics of the weighting networks and the meter damping, as well as the overall accuracy. Sound level meters are divided by ANSI standards into several groups: Type 1 or "Precision" meters; Type 2, or "General Purpose," Type 3, or "Survey,*' and Type S or "Special Purpose." Type 1 meters meet the rigid tolerances for Precision meters and provide filtering and impulse measuring options. A Type 1 meter is recommended for evaluating cockpit noise.

A high quality FM tape recorder should be used to record the noise in the cockpit. Good results can be obtained from a portable battery-p-red system. Several manufacturers now advertise high quality cassette recorders for instrumentation use.

The sound level meter or the recording system, if recordings are made should be calibrated using a PISTON-PHONE, or other calibration instruments, before and after the test data is recorded. These calibration devices are available from manufacturers of sound level meters and measurement microphones. It is designed to fit tightly on the microphone, with adapters for various microphone sizes, and it produces a tone of accurately known sound pressure at the microphone diaphragm at one or more standard frequencies, A set-screw is usually provided in the sound level meter to standardize its output.

A calibration signal is particularly necessary when the microphone is used with amplifiers other than a standard sound level meter or when a recorder is used. This "end-to-end" calibration should be made both at the beginning and end of a test run, and at any other time where there is a possibility that the system gain may have been changed.

It is important in all test operations to maintain an accurate log of all conditions: microphone placement, weather conditions if outdoors, system channel connections (if more than one channel), all attenuator and calibrated amplifier gain settings, time of day and date, source and distance from source to microphone, etc. When a tape recorder is used, the log information should be recorded vocally on the tape.

While the PISTON-PHONE calibrator is an essential part of any acoustic measurement program, it does not give an adequate check of microphone, amplifier and recorder frequency characteristics. The instrumentation and procedures required for full calibration are beyond the scope of this discussion, but some provision should be made for periodic recalibration of system components by the manufacturer or by a reliable and well-equip@ standardization laboratory.

CALIBRATION

A preflight sensitivity check should be used to adjust the gain of the sound level meter to match the output of the acoustic calibrator as adjusted for atmospheric pressure. A "warm-up" time of at least 1 minute should be allowed before checking the sensitivity of the sound level meter. If a tape recorder is used, the sensitivity checks shall also be recorded.

If an in-flight acoustic sensitivity check is used, it should be taken when the aircraft has reached the desired cruise altitude and the aircraft's internal pressure is at the desired value. The indicated sound pressure level of the output of the acoustic calibrator should be noted; the gain of the sound level meter should not be adjusted in flight if the indicated level is not the same as the acoustic calibration level obtained before takeoff. If necessary, cabin pressure should be noted so that adjustments for differences in air pressure may be made.

APPENDIX 4

EXAMPLE CALCULATION OF PSIL

$$PSIL = \frac{L_{500} + L_{1000} + L_{2000}}{3} \; *$$

Octave Band Cntr. Freq.	T.O. Power Avg. Meas. Data	Normal Cruise Power Avg. Meas. Data	Approach Power Avg. Meas. Data
63	106.2	103.0	102.8
125	114.5	111.6	110.0
250	110.0	109.2	100.5
500	99.1	95.8	86.5
1000	84.6	80.1	73.9
2000	81.2	78.4	73.2
4000	76.9	73.8	74.8
8000	76.1	74.1	73.7
db(C)	116.2	113.8	110.9
db(A)	104.3	102.7	96.6
PSIL	88.3	84.7	77.9

From the above it can be seen that the takeoff and normal cruise power noise levels exceed a PSIL of 78 and speech interference can be expected in the cockpit in those flight regimes. The db(A) in all three flight regimes also exceed the recommended level of 88.

* L is the noise level (flat) at the specified octave band center frequency.

APPENDIX 5

MODIFICATIONS OF SIGNAL-TO-NOISE RATIOS

An easy speech intelligibility concept to grasp is that the louder the speech is in comparison to the background noise, the easier it is to understand. obviously, there are practical limits to the concept, but through most of the range of audible sound pressures, this statement about the speech-to-noise or the signal-to-noise ratio (S/N) is true. Where both speech and noise are extremely quiet or extremely intense, nonlinearities arise. For the cockpit-noise situation, one may confront a degree of high-intensity nonlinearity.)

An improvement in S/N, then, will serve to improve the intelligibility of speech.

The most direct approaches call for an increase in absolute signal level or a decrease in absolute noise level. One may also try to create relative differences between the signal and the noise levels.

The difficulty with trying to decrease cockpit noise levels at the source has already been discussed. However, it should be noted that noise attenuation materials are available for light aircraft. The use of inflatable door seals and acoustic blankets can reduce interior noise levels. Nevertheless, the most effective option may be to increase signal levels or modify the relationship between signal and noise.

Signal levels can be increased by increasing the gain of an intervening amplifier (for electronically transmitted communications), or by moving the talker and listener closer together. Research has shown a deterioration of intelligibility with an extremely weak or strong vocal force.

Hearing protectors for aviators can provide protection against hearing loss that results from noise exposure and improves speech intelligibility. They perform the intelligibility improvement task in two ways. The lesser of these is that they lower the overall intensity of the sound that enters the human auditory system into a middle range of sound pressures where the system operates optimally. (Note that hearing protectors do not remove sound; they only decrease its intensity). The other way is selective filtering which can be effective in some noise environments.

Sane precautions are necessary, though, before one elects to use hearing protectors for the purpose of improving voice communication. First, a well-sealed, well-fitted protector is necessary. Second, some auditory functions are changed by the introduction of hearing protectors into the transmission system. For example, some people report a decrease in the ability to make fine pitch discriminations, many people report a decrease in the ability to judge the azimuth of a sound source, However, the human auditory system rapidly accommodates itself to environmental change of all sorts, so one can assume that with a bit of practice these functions can be brought back into the normal range. Third, because one adjusts one's vocal effort to overcome the

U.S. Department
of Transportation
Federal Aviation Administration

Advisory Circular

Subject: COCKPIT NOISE AND SPEECH INTERFERENCE BETWEEN CREWMEMBERS

Date: 3/22/89
Initiated by: AIR-120

AC No: 20-133
Change:

1. PURPOSE. This advisory circular (AC) provides information about the relationship between flight crew cockpit voice communication and cockpit noise levels. Guidance, on speech interference levels, noise measurement and measurement systems, and methods to improve cockpit communication, is provided for those manufacturers, Owners or operators who believe cockpit noise may be a problem on their aircraft. This guidance material is relevant to the operation of all types of civil aircraft.

2. BACKGROUND.

a. Many modem aircraft provide comfort, convenience, and excellent performance. At the same time that the manufacturers have developed more powerful engines, they have tried to give the occupants better noise protection and control, so that many of today's aircraft are more powerful, yet quieter than ever. Still, the levels of sound associated with powered flight are high enough in same aircraft to raise concern about the effect these noise levels may have on direct voice communication between flight crew members.

b The National Transportation Safety Board (NTSB) investigation of an accident involving a twin-engine, small airplane, concluded that the cockpit noise levels of that particular airplane were loud enough to interfere with direct voice communication. In the opinion of the NTSB, this communication interference could have affected crew coordination and contributed to the accident. The NTSB also believes that poor crew communication, because of high cockpit noise levels, may have contributed to other accidents.

3. DEFINITIONS.

a. Noise -- Any sound which is undesirable because it interferes with speech and hearing.

b. Noise Spectra -- The description of noise sound waves by resolution of their components, each of different frequency and (usually) different amplitude and phase.

c. Frequency (Hz) -- The number of oscillations per second of a sine-wave of sound.

d. Decibel (dB) -- The unit in which the relative levels of intensity of acoustical quantities, such as sound pressure levels, noise levels and power levels, are expressed on a scale from zero for the average least perceptible level to about 130 for the average pain level.

noise one hears, hearing-protector wearers (since they hear less noise) usually don't speak loudly enough. Persons who wear hearing-protectors must train themselves to speak more loudly.

In most cockpits where noise is a problem, the noise spectrum tends to have the same shape as the average speech spectrum. As a result, one cannot count on selective filtering to improve speech intelligibility. Whatever changes are made in one spectrum will be made similarly in the other. The S/N stays about the same. Thus, in cockpits with similar noise and speech spectrums, the improvement in speech intelligibility for pilots and copilots who wear hearing protectors is probably limited to the small amount that arises from bringing signal intensities into the linear, middle frequency range where the auditory system works better.

A microphone may help some, because if it is held close to the mouth, it is somewhat like reducing the distance to the ear. Considerably more improvement in S/N can be obtained by using noise cancelling microphones in communication systems. The noise-cancelling microphone is built to accept sound from the front, the back, or the top. In a fairly homogeneous sound field, approximately the same ambient-noise wave form enters from both sides, serving to cancel much of the effect of the noise on the microphone diaphragm. A talker, though, directs his or her speech to one side only, so the cancellation effect for speech is far less than for noise--if the user understands the proper way to use the microphone. Covering the rear vents with the hand diminishes the cancellation effect. Holding the front of the microphone more than a few inches from the lips of the talker permits the speech to enter the back with nearly as much intensity as enters the front, thus cancelling speech as well as noise. Another potential loss of S/N improvement results from the reflex that leads a talker to speak with enough effort to be heard above the noise: if the talker expects to be heard (by the microphone) at a distance of 3 inches rather than 3 feet, he or she is likely to reduce vocal effort accordingly.

Miniature headsets have come into use among pilots in recent years. The headsets, which are worn over the ear, conduct sound to the microphone diaphragm via a hard, plastic tube that is hinged so that it can be moved about at will. Although these headsets are not noise-cancelling devices in the usual sense, the tip of the plastic tube can be moved so close to the talker's lips as to make a significant improvement in S/N over face-to-face communications in the same noise environment. Again, the likelihood of improvement is a direct function of how much vocal effort is exerted and of how close the tube is to the mouth; if the tube has been moved out of the way (as it needs to be for eating or drinking), any S/N improvement will be markedly diminished.

Some headsets are equipped with circumaural muffs which attenuate the cockpit noise and enhance the S/N for electronic communications. This type of ear muff furnishes some hearing protection and acts somewhat like an ear plug in normal cockpit voice communications. Headsets equipped with the better designed circumaural muffs may attenuate cockpit noise more that 20 dB. These headsets used with noise cancelling or boom microphones and an intercom system can substantially enhance the S/N and markedly improve crew communications.

Proper use requires holding the noise-cancelling microphone so that the vents are not blocked, holding it close to the mouth, and speaking as loudly as if the listener were a few feet away. When the microphone is used properly, it can make a significant difference in S/N.

It should be noted that increasing the gain of an amplifier or trying to do selective electronic filtering will make no useful change in the S/N; it will stay the same as it was at the face of the microphone whose sounds are being amplified or filtered. If the S/N is poor to begin with, amplifying both the speech and the noise cannot make the situation any better. Also, electronic filtering is no different in its effect than the acoustic filtering that a hearing protector does: if the spectrum of the noise and the spectrum of the speech are similar, selective filtering will not help.

Additional information on aircraft audio system characteristics and standards can be found in Radio Technical Commission for Aeronautics (RTCA), Document No. DO-170, "Audio Systems Characteristics and Minimum Performance Standards, Aircraft Microphones (Except Carbon), Aircraft Headsets and Speakers, Aircraft Audio Selector Panels and Amplifiers," January, 1980.