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PRELIMINARY CRITERIA FOR INTERNAL ACOUSTIC ENVIRONMENTS OF ORBITING SPACE STATIONS

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ABSTRACT

Preliminary criteria are proposed for maximum desirable, and, where appropriate, minimum, ambient noise levels inside manned orbiting space stations. A general approach has been used to estimate desired acoustic levels considering: criteria for allowable interference due to noise, the level of interference produced by noise, the type of activity involved and the type of inhabited zones inside an orbiting space station. Every effort has been made to utilize available and applicable information on the effects of acoustic environments on man in this unique situation. Although acoustic criteria can be defined with reasonable accuracy based on interference with speech, the longer-range and more subjective effects of annoyance levels in a shirt-sleeve environment for a "captive" crew become difficult to assess. The criteria proposed, therefore, are preliminary only and subject to validation under conditions representative of space travel.

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1.0 INTRODUCTION

Preliminary effort is underway at the Marshall Space Flight Center, NASA, on design concepts for manned orbiting space stations. A necessary part of this effort is the consideration of the allowable or desired internal acoustic environment within which the "captive" crew must function. At least one case of "noise annoyance" in a spacecraft has already been observed in a recent Apollo flight. In this case, a noisy internal ventilating fan was turned off at the discretion of the crew to eliminate an annoying fan noise. Fortunately, a substitute method of ventilation was feasible for the crew involving a make-shift use of their cooling air hoses from their personal "air conditioning packs." Clearly, this represents a simple but real example of a systems problem involving interaction of man, his support equipment and his acoustic environment. In this particular case, human ingenuity provided a quick-fix which prevented any significant interference with the flight mission. However, by extrapolation to the case of an orbiting space station, where cost and weight of support equipment become greatly magnified as crew size and flight duration increase, it is not difficult to recognize that a rational and systematic effort is required to insure compatibility of flight equipment and acoustic environment for the crew of a space station.

As a first step in this direction, it is desirable to establish preliminary criteria for the maximum acoustic environment desired for internal spaces of a space station. In certain situations on a spacecraft, criteria for a minimum acoustic environment can also be required (i.e., sound level from an audible warning signal). In either event, such criteria can be applied to particular design configurations of space stations and their flight support systems to establish noise specifications for structure and equipment. Thus, the purpose of this document is to propose preliminary acoustic criteria for orbiting space stations which can be utilized in preliminary stages of system design and specification.

Due to the unusual nature of the working conditions covered and the lack of definitive data on related acoustic environment effects for many of these conditions, the criteria are necessarily preliminary and are subject to change as more information becomes available. Nevertheless, sufficient data are available, particularly in the area of allowable acoustic noise during voice communication, to provide a rational guide for preliminary system design. If this document can provide this type of preliminary design guide for the orbiting systems designer, it will have met its objective.

1.1 What is Covered by the Acoustic Criteria?

Maximum background noise levels are specified in Section II for the following types of zones within a hypothetical space station.

- Command and Control Areas
- Laboratory Workshop Areas

- Mess and Recreation Areas
- Sleeping Quarters
- Auxiliary Equipment Rooms

It is recognized that separate criteria would not be required for this many zones for space stations likely to be considered now. However, one objective of this preliminary report has been to establish a basic framework which may be used for the development of more detailed criteria in the future. These maximum noise levels are proposed to prevent significant noise interference with routine activity of the crew. With the exception of isolated auxiliary equipment rooms, the noise levels specified are well below those associated with potential hearing damage.

In certain situations, it may be desirable to maintain a minimum background noise level to insure speech privacy or to avoid a subjectively unpleasant environment of excessive silence. This minimum level criterion will normally be inherently satisfied by an acceptable noise level generated by internal ventilating equipment.

Preliminary criteria for minimum sound levels from audio warning devices are also specified. In this case, distinct and easily recognizable audio warning signals, such as fire or cabin pressure alarms, must stand out above the residual background noise.

Finally, preliminary criteria are proposed for acoustic absorption treatment inside the space station. These criteria are given to insure a desirable communication environment and, at the same time, provide a reasonable degree of internal noise control. Some of the factors which should be considered in developing detailed acoustic design specifications are also discussed.

1.2 How Are the Criteria Specified?

For steady state noise, maximum noise levels are specified in terms of octave band sound pressure levels, using the preferred octave band center frequencies. (See Appendix for explanation of terminology.) An alternate method is also indicated for specifying the criteria based on the maximum noise level as read on a standard Sound Level Meter using the A frequency weighting, dB(A).

For transient noises, the criteria are specified in terms of duration and allowable peak noise level.

Minimum sound levels are specified in the same fashion. In the case of audio warning devices, the criteria are given in terms of the minimum increase in sound level over the background noise which should be produced by the warning device.

Criteria for acoustic absorption treatment are given in terms of the total absorption in Sabins (i.e., ~ absorption coefficient x surface area in sq. ft).

The following section presents the proposed acoustic criteria in the form outlined above. The basis for these criteria is discussed in detail in Section 3. This includes a summary of a brief pilot experiment conducted to provide preliminary verification of the proposed criteria for maximum desired sound levels. Finally, a summary and recommendations for further study are given in Section 4.

2.0 CRITERIA

The following criteria are specified to achieve a desired acoustic environment inside manned orbiting space stations during extended zero-g flight missions. It is assumed that crew members are operating in essentially a "shirt-sleeve" environment without space helmets.

2.1 Maximum Desirable Levels

Wide-Band Noise

Steady-state wide-band (random) noise levels should not exceed those specified in Table I. These maximum levels correspond, approximately, to the single-number acoustic criteria specified in Table II. The value for the weighted sound pressure level as read on a standard Sound Level Meter with the A scale, dB(A), is based on typical spectra for machinery noise.

Pure Tones

Maximum sound pressure levels of pure tone components superimposed on the wide-band ambient noise shall not exceed the limits specified in Table III.

Occasional Transient Noises

Duration Less Than 30 Seconds - The allowable peak sound pressure level of the transient should be no more than 10 dB above the levels specified in Tables I and III.

Duration Greater Than 30 Seconds - The transient sound should be treated as a steady-state noise and the average sound pressure level limited to the values specified by Tables I and III.

Repetitive Transient Noises (Cyclic)

Period of Noise On-Noise Off Cycle Less Than 2 Seconds - Apply Tables I and III based on the peak sound pressure level of the repetitive transient noise.

Period of Noise On-Noise Off Cycle Greater Than 2 Seconds - Apply Tables I and III based on the arithmetic time average of the on-time sound level plus off-time sound level of the transient and steady-state noise levels.

Transient Noises in Sleeping Quarters

Due to sleep-disturbance effects of transient noises, the peak sound level, in dB(A), of occasional transient noise levels in sleeping quarters should not exceed +6 dB above the ambient background level, measured in dB(A).

2.2 Minimum Desirable Levels

Ambient Background Levels

For Mess and Recreation Areas and Sleeping Quarters, it is recommended that the minimum ambient noise level should exceed a level that is 10 dB below those specified for corresponding areas in Table I. This minimum requirement achieves a desirable privacy effect in living quarters by masking out extraneous or undesired noise.

Audio Warning Devices

Average sound pressure levels of audio warning devices, such as fire or cabin pressure alarm signals, should be greater than the ambient background noise by the levels specified in Table IV. Such devices should ordinarily consist of one or more complex tones reproduced with some form of amplitude or frequency modulation.

2.3 Acoustic Treatment of Interior Walls

For work spaces which utilize fixed intercom systems mounted on the structural enclosure, the average acoustic absorption of the space, including the furnishings and occupants, should exceed the value given below for the frequency range of 500 to 2000 Hz.

$$a \geq D\sqrt{V}\text{, Sabins}$$

where D = average distance between talker and microphone in feet

V = volume of space in cubic feet

2.4 Requirements for Acoustic Specifications

Design specifications for the acoustic performance of internal equipment, structure, and furnishings for space stations which comply with the criteria contained herein shall include

- Maximum sound power levels in octave bands for equipment
- Required sound transmission loss for structural walls which enclose high-noise level areas
- Measurement procedures in accordance with accepted industry practice
- Requirement for engineering reports demonstrating compliance with the appropriate specification

Military Specification MIL- . ~906A, 11 July 1966, may be used as a guide for preparation of such detailed design specifications.

TABLE I

CRITERIA FOR MAXIMUM OCTAVE-BAND SOUND PRESSURE LEVELS OF STEADY-STATE WIDE-BAND AMBIENT NOISE INSIDE ORBITING SPACE STATIONS
(In dB re: 0.0002 Microbar)

Octave Band Center Frequency (Hz)	Level A (1)	Level B (2)	Level C (3)
31	70	75	105
63	64	67	100
125	57	61	95
250	52	56	90
500	48	53	85
1000	46	51	83
2000	44	48	82
4000	42	46	80
8000	42	46	80

(1) Applicable to: Command and control areas.
Lab workshop areas during delicate experiments.
Sleeping quarters.

(2) Applicable to: Lab workshop area during routine activity.
Mess and recreation areas
Manned auxiliary equipment rooms.

(3) Applicable to: Unmanned auxiliary equipment rooms requiring occasional entry for maintenance.

TABLE II

APPROXIMATE SINGLE NUMBER ACOUSTIC CRITERIA FOR ORBITING SPACE STATIONS

Level (See Table I)	Speech Interference Level, PSIL①	Noise Criteria, NC	dB(A)
A	46	45	54
B	51	50	58
C	83	83	91

① The average of the octave band levels at 500, 1000 and 2000 Hz.

TABLE III

MAXIMUM LIMITS OF PURE TONE COMPONENTS OF AMBIENT NOISE LEVELS INSIDE SPACE STATIONS

Frequency of Pure Tone (Hz)	Sound Pressure Level of Pure Tone Alone Minus Octave Band Sound Pressure Level of Wide Band Noise Alone, in Octave Containing Pure Tone
200-500	+ 2 dB
500-1600	- 5 dB
1600-4000	- 11 dB
4000-8000	- 5 dB

TABLE IV

MINIMUM LIMITS FOR SOUND PRESSURE LEVELS OF AUDIO WARNING DEVICES INSIDE SPACE STATIONS

Center Frequency Range of Audio Warning Device (Hz)	Sound Pressure Level of Audio Warning Signal Minus Octave Band Level of Background Noise in Octave Containing Warning Signal Tone
200-500	+ 20 dB
500-1600	+ 20 dB
1600-4000	+ 14 dB
4000-8000	+ 20 dB

2.5 Maximum Allowable Levels

The preceding specify the maximum desirable sound levels for orbiting space stations. These represent conservative values chosen to insure a realistic but comfortable noise environment on board such craft. If it is not feasible to achieve these desired levels, higher sound levels could be specified which may still be acceptable. However, the degree of acceptance is necessarily a subjective quality which can only be established by tests under realistic conditions with representative (astronaut) subjects. In any event, it is recommended that maximum allowable sound levels shall not exceed those specified for levels A and B in Table I (or II) when the latter are increased by 13 dB. All other criteria in Section 2.1 shall be applicable to those modified levels.

3.0 BASIS FOR CRITERIA

The following outlines the basis for development of the preliminary acoustic criteria for manned space stations given in the preceding section. General qualitative considerations and pertinent data utilized in developing the criteria are discussed along with a summary of comments on this problem which were obtained through personal contact with several authorities in this field.

3.1 General Considerations

As a starting point in developing the criteria, a matrix was constructed of the types of space in an orbiting space station versus the type of normal activity in these spaces. The types of space, identified in Table I, are:

- Command and Control Areas
- Lab Workshop Areas
- Mess and Recreation Areas
- Sleeping Quarters
- Auxiliary Equipment Rooms

The types of related activity considered were:

- Voice Communication
  - Indirect communication over wire or RF links with personal intercom sets (e.g., - lip microphone and ear insert earphones)
  - Indirect communication over wall-mounted intercom sets
  - Direct face-to-face communication.
- Non-Vocal Activity
  - Visual monitoring
  - Mental activity (problem solving)
  - Manual activity
- Rest and Relaxation

For each type of space and appropriate activity, consideration was then given to the allowable degree of noise-induced interference with the activity. The possible degree of interference was assumed to range over five levels given by

1) Complete disruption
2) Severe disturbance
3) Significant distraction

4) Occasional annoyance
5) No effect

Finally, with each of these possible levels of interference, criteria for criticality of interference were assigned as follows:

CRITICAL - Presents danger to life or safety of mission.

NON-CRITICAL - No immediate danger to life or safety but possible reduction in achieving mission objectives.

ACCEPTABLE - Minor hindrance in completing activity.

Based on this cursory analysis, the following guidelines were established:

a) Only ACCEPTABLE (according to the above definition) levels of interference should be allowed.

b) Noise levels causing an interference more than OCCASIONALLY ANNOYING (see Item 4 above) would be unacceptable.

c) The types of activity which will tend to set desirable noise levels will be:

- Maximum Levels - Voice communication in all areas, either over fixed intercom systems or by face-to-face communication.

- Minimum Levels - Rest and relaxation in mess and recreation areas and sleeping quarters.

In addition to these guidelines for the normal acoustic background noise, it is clear that criteria for any audio warning signals must insure a clearly recognizable alerting signal that stands out over the ambient noise levels.

Finally, it was felt desirable to establish the acoustic criteria in terms of readily measurable quantities and to utilize, to the greatest extent possible, available data or information from related studies.

3.2 Basis for Maximum Allowable Levels

Human response to a noise environment can involve the following effects, listed in approximate descending order according to level of the noise. (See Reference 1 for a more detailed review.)

- Biophysical damage
- Sensation of auditory pain
- Impairment of motor or visual activity
- Permanent or temporary loss of hearing
- Interference with voice communication
- Subjective annoyance
- Sleep interference.

For the crew of an orbiting space station operating in a shirt-sleeve environment, it is not possible to take advantage of the significant noise attenuation offered by space helmets. Thus, only the three lowest levels of human response to noise, namely, interference with voice communication, annoyance, and interference with sleep, need be considered. All of the other forms of response only become significant at higher noise levels which would not be acceptable. This is illustrated clearly in Figure 1 where it is shown that the threshold for significant interference with voice communication falls well below thresholds for other effects not involving communication.

Wide Band Noise

Most of the studies on interference of acoustical noise with voice communication have been conducted either under laboratory conditions or in conventional office areas. Procedures for predicting the intelligibility of speech in a noise background range from rather elaborate calculation methods to simpler, single number criteria. Representative sources from the wealth of literature on this topic are contained in References 5 through 7. For application to orbiting space stations, it was considered more realistic to utilize the results from an extensive study carried out on noise interference and acceptability on board naval vessels (Reference 2). The essential result of this study was to show that the average background noise level on board ships, which is judged acceptable by the crew, could be specified either as a

- Speech Interference Level at Preferred Octave Band Frequencies (PSIL) of 64 dB, or

- Sound Level on the A Scale of a Standard Sound Level Meter of 71 dB(A).

The Speech Interference Level is simple to calculate but is limited to a consideration of average octave band sound levels over a portion (350-2850 Hz) of the audio frequency range. The "A" weighted sound level is more accurate since it represents a frequency-weighted sound level covering almost the entire audible frequency range. The octave band sound levels upon which this study is based are shown in Figure 2. While these spectra for Navy ships contain more low frequency noise than one would anticipate from, say, small ventilating fans on orbiting space stations (Reference 8), it is anticipated that typical acoustic spectrum shapes in the latter, considering all the potential noise sources from auxiliary equipment, will, in fact, be similar to those in Figure 2.

The results of Reference 2, summarized above, have been used as a basis for specifying maximum allowable sound levels on board orbiting spacecraft. However, these levels are considered to be significantly higher than desired for this unique situation.

3.3 Basis for Maximum Desirable Levels

A more conservative approach leading to desirable rather than allowable levels has been adopted by comparing the average octave band sound levels measured on Naval ships (Reference 2) with other criteria for desired noise environments. As shown in Figure 3, the average noise level in office and sleeping areas on Navy ships corresponds to approximately the NC 60 Noise Criterion curve or an overall weighted sound level of 68 dB(A). However, Beranek (Reference 5) suggests that the maximum acoustic environment for offices should not exceed a Speech Interference Level of 55 dB or a noise criterion of NC 55. One specification for the maximum noise levels in orbiting workshops, proposed by NASA (Reference 21), lies near an NC 55 criterion in the speech frequency range. This is also shown in Figure 3. A lower level would be desirable.

Subjective Evaluation of Desired Levels

In order to test the response of persons to noise levels in the range indicated in Figure 3 (NC 45-60), the following brief subjective judgment test was conducted. A broad band random noise spectrum, shaped in accordance with NC curves, was generated in a room approximately 10 feet by 10 feet. Four subjects were asked to record their reaction to these acoustic environments. The noise levels evaluated corresponded to "A" weighted sound levels of 48, 54, 58, 64 and 68 dB(A). The reactions to these levels are summarized in Table V.

The 68 dB(A) level corresponds to the average level measured on-board Naval ships. This level required a raised voice for communication over 3 to 6 feet, and was distracting or annoying. The 58 dB(A) level was judged to be quiet or moderately noisy, required no extra vocal effort to communicate over 3 to 6 feet, and had only a slightly disturbing effect on the ability to concentrate. This level corresponds to a Noise Criterion curve of NC 50 and is slightly below the maximum level suggested for office space by Beranek. Also Webster and Lepor, Reference 2, indicate that a noise level of approximately 50 dB PSIL is acceptable for normal voice level communication (see Figure 4).

Therefore, a maximum desirable level corresponding approximately to an NC 50 criterion, or 58 dB(A), was adopted for the steady state acoustic environment for lab workshop areas, mess and recreation areas, and manned auxiliary equipment rooms. A 54 dB(A) level, (NC 45), was judged to be very quiet or quiet, and to have no effect or only slight effect on mental activity. According to Figure 4, this level should allow voice communication in a normal voice over about 12 feet. This level was therefore selected as desirable for command and control areas, lab workshops during delicate experiments,

TABLE V

HUMAN REACTION TO BROAD BAND NOISE SPECTRA
SHAPED ACCORDING TO NC CRITERIA
(Table lists number of subjects responding as indicated[a].)

Sound Level (dBA)	NC (Approx.)	Subjective Noisiness Rating				
		Very Quiet	Quiet	Moderately Noisy	Very Noisy	Intolerably Noisy
48	40	4	-	-	-	-
54[b]	45	1.5	2.5	-	-	-
58	50	-	3	1	-	-
64	55	-	1	3	-	-
68	60	-	-	-	2	2

Sound Level (dBA)	NC (Approx.)	Face-to-Face Communication[c]			
		Normal Voice	Raised Voice	Shouting	Impossible
48	40	4	-	-	-
54[b]	45	4	-	-	-
58	50	4	-	-	-
64	55	3	1	-	-
68	60	-	4	-	-

Sound Level (dBA)	NC (Approx.)	Interference with Concentration or Problem Solving			
		No Effect	Slight Distraction	Annoying	Marked Distraction
48	40	4	-	-	-
54[b]	45	2	2	-	-
58	50	1	[illegible]	-	-
64	55	-	2	2	-
68	60	-	[illegible]	2	1

a) Pilot test with 4 adult subjects in 10 ft by 10 ft room. Noise spectrum closely matched NC weighting within ± 1 dB from 31.5 to 8000 Hz.

b) Average of two tests.

c) Average talker-listener distance, 5 ft.

and sleeping quarters. These two levels are compared in Figure 3 with the previously mentioned NASA specification and the Navy data.

In summary, the results of Reference 2 have been used to establish criteria for maximum allowable steady state noise levels. Lower, maximum desirable levels have been established on the basis of: limited subjective tests (Table V), criteria for voice communication in a normal voice (Figure 4), and recommended noise criteria for office areas proposed by Beranek (Reference 5).

The approximate equivalent single-number criteria, given in Table II, provide a basis for comparison of the criteria levels given in Table I with other studies. The compatibility of these criteria levels for communication with various types of equipment can be analyzed from the information in Figure 4 and Tables II and VI. The latter shows that for a level of 50-70 dB(A), direct face-to-face communication is satisfactory. Note that the poorest communication system is invariably the squawk-box or fixed intercom system.

It is worth noting that the Speech Interference Levels associated with the two lowest criteria levels in Table I (A and B) are much lower than typical values inside cockpits of aircraft. These range from PSIL $\simeq$ 79 to 101 with an average PSIL of 86 (Reference 12). For unmanned auxiliary equipment rooms, the basic criteria levels have been increased to 91 dB (see Level C, Table I). This represents an approximate upper bound for direct voice communication and would be acceptable for only short durations for maintanenace operations (Reference 2).

Pure Tones

The studies of noisiness of complex sounds which combine random noise and pure tones have been utilized to establish allowable levels for pure tones (Reference 11). The criteria identified in Table III have been selected so that any pure tone components would not be expected to increase the Perceived Noise Level of the background noise by more than 1 PNdB (see Appendix for explanation of PNdB). This conservative restriction on pure tones was selected to avoid the particular annoyance associated with a pure tone in a background noise which must be tolerated for a long time.

Occasional Transient Noises

For occasional noises less than 30 seconds duration, it can be expected that voice communications will not be significantly influenced if an increase in level of no more than 10 dB is allowed. This increase in noise will cause a talker to raise his voice level for this period of time to overcome the background level. For passive listening situations, a 10 dB increase in noise will reduce communication efficiency somewhat. This loss should ordinarily be acceptable for a short time. If necessary, this relaxation of the criteria might be eliminated in command and control areas where communication is more critical.

TABLE VI

COMMUNICATION CAPABILITIES IN FIVE LEVELS OF NOISE TYPICAL FOR ON-BOARD NAVY SHIPS USING VARIOUS COMMUNICATIONS FACILITIES (ADOPTED FROM REFERENCE 10)

Communication Facility	Noise Level Ranges, dB(A) (2)				
	50-70	70-90	90-110	110-130	> 130
Face-to-Face	Speakers may be separated by more than 3 feet	Some effort required for good communication to be maintained over 1 to 3 feet	Maximum satisfactory communication distance is 1 foot	Very difficult to impossible	Impossible
Conventional IC Squawk Box	Satisfactory to difficult	Unsatisfactory	Impossible	Impossible	Impossible
Conventional IC Telephone	Satisfactory to slightly difficult	Difficult to unsatisfactory	Press-to-talk and acoustic booth needed	Special transducers needed	Impossible
Flight Deck Radio	Satisfactory but cumbersome	Satisfactory but cumbersome	Satisfactory	Satisfactory	Inadequate (lacks mike noise shield)
Loudspeaker	Any	Good quality speaker needed for adequate intelligibility	Must be inside helmet or ear protector	Inadequate	Inadequate
Special MOMCOMS Microphone (1)	No special mike needed for satisfactory communication	Any microphone satisfactory, including earphone used as mike and bone contact	Any mike. If earphone used as mike, put under ear protector. If bone contact, under helmet.	Proper transducers achieve adequate intelligibility	Adequate using proper transducers
Special MOMCOMS Earphone (1)	Any phone satisfactory	Any	Any, except bone conductors	Special circuitry achieves adequate intelligibility	

(1) MOMCOMS - Special Type of Personal Intercom Systems Designed for "Man-on-Moon Communication."
(2) Sound Level as Read on Standard Sound Level Meter with (A) Scale.

It was assumed that increased voice levels and reduced communication in the presence of transient noises longer than 30 seconds could not be tolerated. Thus, such a noise is treated as steady state and is limited by the criteria in Tables I and III.

Repetitive Transient Noises (Cyclic)

A repetitive series of noise bursts, with a cycle time less than 2 seconds, occur too rapidly to allow a talker to adjust his voice level to compensate for the higher ambient noise (Reference 13). Thus, the peak sound level of the noise burst must be limited to the levels specified in Tables I and III.

For cycle times greater than 2 seconds, a talker can adjust his voice level accordingly for reasonable changes in level. For the listener, studies have shown that the masking effect of such a noise for these repetition rates, is approximately the same as a steady noise with a constant sound level equal to the arithmetic time-average of the on-time noise level and off-time noise level of the combined steady state and repetitive noise (Reference 14). Thus, this time-averaged noise level should be limited to the values specified in Tables I and III. For example, a repetitive 4 second burst of noise with an octave band level at 500 Hz of 56 dB which repeats every 10 seconds combined with a steady-state octave band level of 42 dB would correspond, approximately, to a steady state noise level of $[56 \times 4 + 42 (10-4)]/10 = 47.6$ dB. This level would just fall below the limit in this band for Level A, Table I.

Noise Level in Sleeping Quarters

The sleep-disturbance effect of noise has been found to have a threshold of about 65 dB(A). This is the basis for selection of maximum allowable steady-state noise in sleeping quarters as defined in Section 2.5 (References 13 and 20). For transient noises, a level of 50 dB(A) has been found to cause a 50 percent probability of awakening or shifting to a shallower sleep (Reference 20). The criteria for maximum desirable levels in sleeping quarters of 54 dB(A) falls within this range. Lacking any definitive data on the change in level above a steady background which causes sleep disturbance, it is assumed that a transient peak no more than 6 dB above the background is acceptable. This is intended to apply to transient noises which might occur frequently during a period of sleep for a crew member.

3.4 Basis for Minimum Desirable Levels

Ambient Background Levels

To achieve the desired effect of acoustic privacy in living areas, it was desirable to establish a minimum level for background noise in mess and recreation areas and sleeping quarters. Webster has found that this privacy effect is an important factor in the acceptability by Navy shipboard personnel of their acoustic environment (Reference 13). The relatively high ambient level, compared to normal living areas, tends to mask out undesirable speech and activity "noise" of other closely adjacent crew members thus providing some degree of personal isolation. It has been found that speech privacy is primarily dependent on the relative level between the undesired speech sounds and the steady background noise (References 5 and 15). If the background noise level in these areas does not fall below a level 10 dB lower than specified in Table I, it is estimated that an adequate degree of "acoustic" privacy can be maintained.

Audio Warning Devices

Immediate detection of an audio warning signal such as a fire or cabin pressure alarm is essential. The values given in Table IV for the recommended increase in audio warning level over the background noise have been selected to insure this feature. These relative increases in level are required to achieve approximately a 10 PNdB increase in Perceived Noise Level (Reference 11).

3.5 Basis for Acoustic Treatment of Interior Walls

It is well known that the intelligibility of speech reproduced in a large room decreases as the reverberation time and volume of the room increases (References 16 and 17). However, for typical volumes of compartmented areas in space stations, the reverberation times, T_R is given approximately by

$$T_R = 0.049\ V/a$$

where

V = volume in cubic feet

a = total acoustic abosrption in Sabins

= (surface area in sq. ft) (average absorption coefficient)

This time will ordinarily be less than 1 second and speech intelligibility of reproduced speech should not suffer any significant decrement. The controlling acoustic parameter, in this case of small (less than 10,000 cu. ft) volumes, is the speech to noise ratio. A 3 dB speech to noise ratio will reduce the intelligibility to about 84 percent of the value in the absence of noise (Reference 17).

On the other hand, the intelligibility of speech which is picked up or broadcast from a microphone in a room seems to vary in a somewhat different manner as a function of the room volume V, reverberation time T_R, and distance D between the microphone and talker (Reference 18). In this case, it has been found that intelligibility decreases as a liveness parameter L increases where

$$L = 1000\ T_R^2\ D^2/V$$

and all dimensions are in feet and time in seconds. Data have been obtained on the change in intelligibility of speech recorded in rooms with varying "liveness" and played back through a VHF radio link over earphones to a panel of listeners (Reference 19). The listeners consistently judged the intelligibility highest and preferred the quality of the speech recorded in the most "dead" room ($L \rightarrow 0$). This was particularly true when a high level masking noise was added to the listeners acoustic environment. Very significant decrements in intelligibility were found when the source room had a liveness (L) of 1.0.

This limited information provides some guidelines for acoustic treatment of relatively large work spaces in an orbiting space station where communication with other areas would be by means of common two-way loudspeaker-microphone intercom systems which do not require keying by the talker. Assuming a liveness value of 1 should not be exceeded, the preceding two expressions may be combined to indicate the desired amount of acoustic absorption in a room equipped with these types of open intercoms for efficient communication to other areas. The result is

$$a \geq 1.55\ D \sqrt{V}, \quad \text{Sabins}$$

where

D = average distance between talker and microphone-speaker in feet

V = room volume in cu. ft.

For example, assume an 8 ft by 10 ft by 12 ft room with D = 5 ft, V = 1000 ft and a = 246 Sabins. Since the total surface area is 616 sq. ft, an average absorption coefficient α (total absorption in Sabins)/(area in sq. ft) should be greater than 0.4. The reverberation time for the source room, in this case, would be

$$T = \frac{(0.049)\ (1000)}{246} = 0.2 \text{ sec}$$

This indicates that the requirement for acoustic absorption, based on desirable voice pickup intelligibility leads to a fairly "dead" room design. The high value of acoustic absorption called for is considered excessive, from a practical standpoint. For preliminary design purposes, it is proposed to reduce it arbitrarily by 50 percent so that the minimum acoustic absorption in workshop areas equipped with open intercom systems is:

$$a \geq D \sqrt{V}, \quad \text{Sabins}$$

where D, in feet, may be taken as typically 1/2 the average span of the room for wall-mounted intercom units. This is the criterion indicated for acoustic treatment of such rooms in Section 2. Note that high level masking noise in the source room will tend to eliminate the significance of this liveness criterion. However, the ambient noise level in a room containing internal noise sources decreases inversely as the absorption increases. Thus, adherence to the suggested "liveness" criterion for acoustic absorption also tends to provide a reasonable value of absorption from the standpoint of internal noise control.

3.6 Basis for Acoustic Specification Requirements

Several basic requirements are suggested to insure that adequate documentation and engineering design are carried out by a contractor in response to the acoustic design requirements imposed by this document.

3.7 Influence of Modified Atmosphere Inside Space Stations

If the atmosphere inside an orbiting space station is significantly different from sea level conditions, two important effects can occur which have a bearing on interpretation of the noise criteria in this document.

1) Sound power output of internal noise sources can change

2) Speech intelligibility may be affected.

The first effect is due to the change in the acoustic impedance (ρc) of the medium. Both theory (Reference 22) and experiment (Reference 23) show that significant changes in sound power output will occur in a reduced or modified atmosphere. The limited experimental data were obtained inside a simulated space capsule and indicated an average reduction of 14 dB in noise level generated by internal equipment when cabin pressure was reduced from sea level to 0.32 atmospheres. However, this reduction varies with frequency and the type of noise source, as predicted by theory (Reference 22). Thus, any specification for maximum noise output of space station equipment must include a consideration of the change in noise output with ambient atmosphere.

During a recent 56-day simulated space mission test, it was noted that speech intelligibility was affected by the artificial atmosphere employed (Reference 24). The test atmosphere was composed of 30 percent helium and 70 percent oxygen. The pressure was equivalent to an altitude of 27,000 feet. Principal results from physical and subjective evaluations indicate: 1) word intelligibility was satisfactory as long as the ambient noise level, in the speech frequency range, was below the level of speech; 2) the fundamental frequencies of speech were relatively unaffected by the helium-oxygen atmosphere; and 3) speech quality did deteriorate with increased duration of exposure to the 30-percent helium mixture. This study suggests that in a helium-oxygen atmosphere, it may be necessary to pay particular attention to the noise level in the speech frequency range.

To summarize, the criteria contained herein are based on speech-to-noise levels that would exist in the actual atmosphere in an orbiting space station. Although criteria for maximum desirable and allowable levels are based on data obtained under sea level conditions, the results from Reference 24 indicate these criteria should still be valid for typical atmospheric conditions inside space stations.

4.0 SUMMARY AND RECOMMENDATIONS

Preliminary criteria have been developed for the maximum desired and maximum allowable background noise levels inside orbiting space stations. Maximum levels were limited, primarily, by the necessity to maintain good conditions for voice communication. Additional factors, such as annoyance or interference with mental activity, were considered in developing criteria for desired noise levels which are about 12 dB below currently acceptable noise environments experienced on board Navy ships.

Criteria have also been suggested for minimum noise levels in certain areas to: provide conditions of personal privacy, or insure adequate recognition for audio warning devices, such as fire alarms. Recommendations are also made for the minimum acoustic treatment inside work spaces to insure desirable conditions for communication. Finally, some of the factors are considered which should be included in a noise specification prepared in compliance with these criteria.

Many of the specific levels cited in these criteria are based on very limited data or on reasonable estimates and should be verified more thoroughly. In particular, the desirable noise levels should be validated under conditions which closely simulate a space station environment and preferably with potential or experienced astronauts as subjects. Additional studies could also be conducted under less complex conditions to verify some of the detailed criteria for intermittent noises, sleep disturbance levels and acoustic "liveness" conditions of work spaces.

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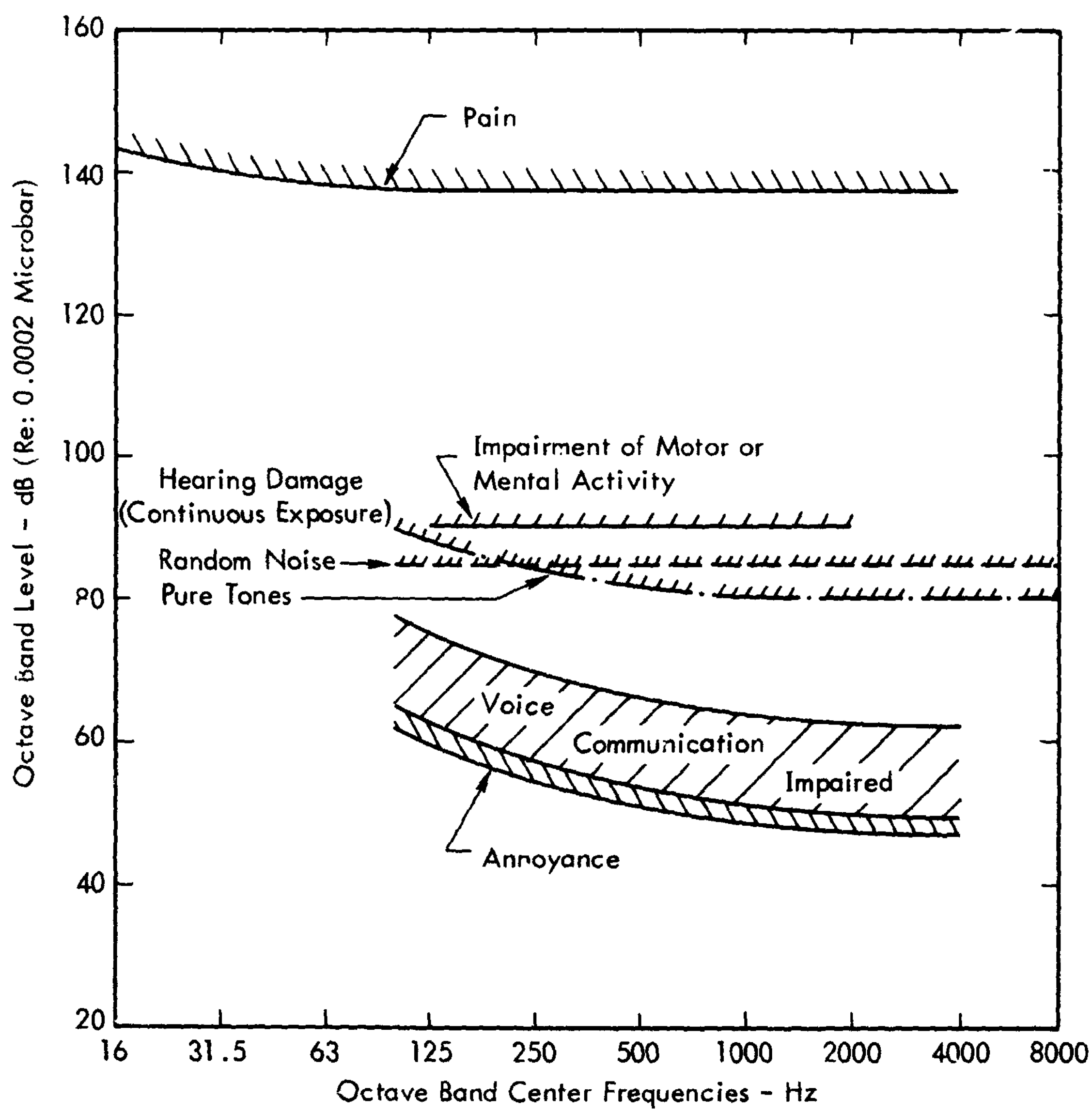

Figure 1. Approximate Threshold of Responses of Humans to Ambient Noise (Compiled from Data in References 1 through 4)

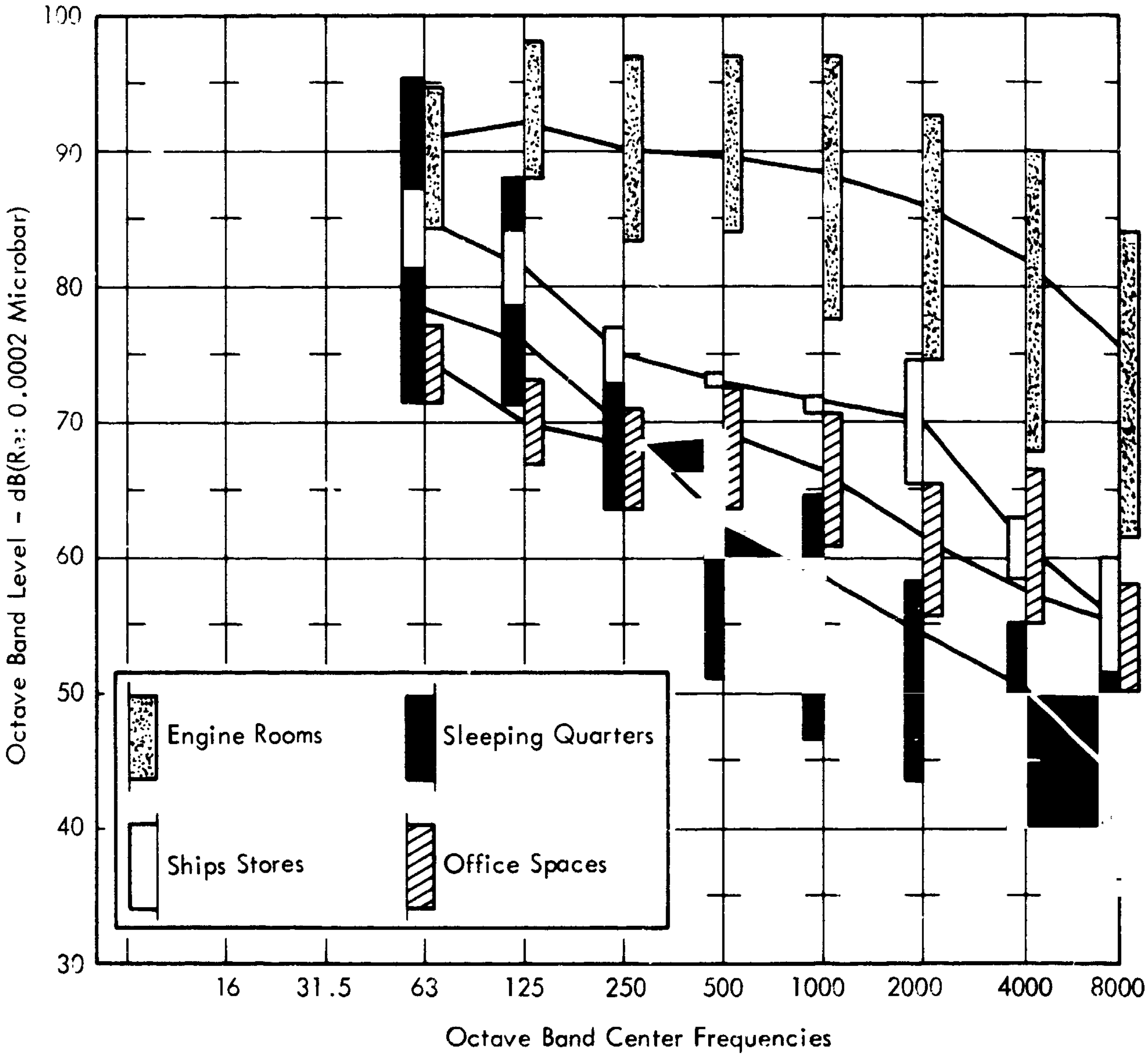

Figure 2. Typical Octave Band Sound Levels Measured On-Board Navy Ships. (From Reference 2).

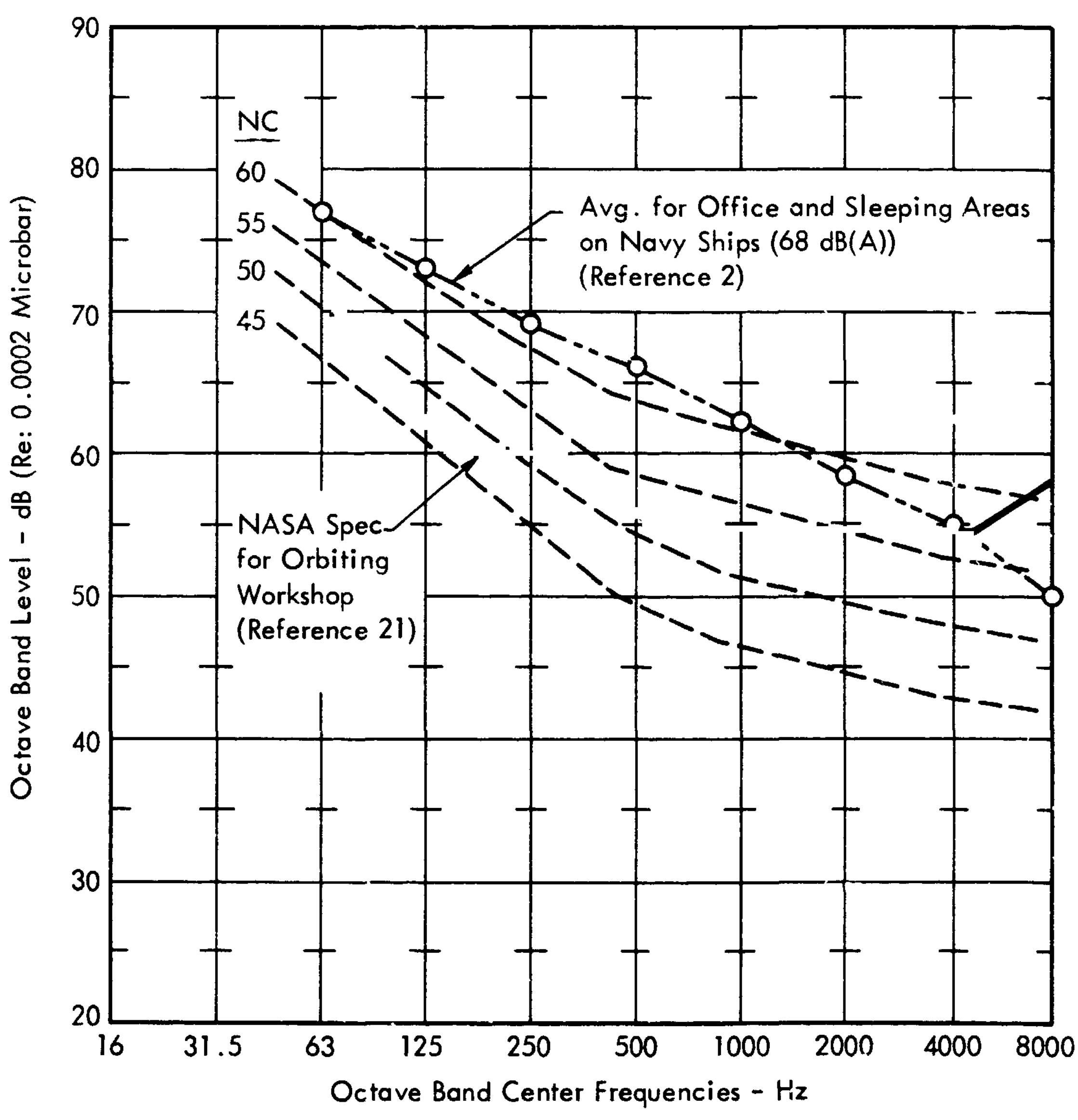

Figure 3. Comparison of the Existing NASA Spacecraft Noise Specification with Noise Criterion Curves

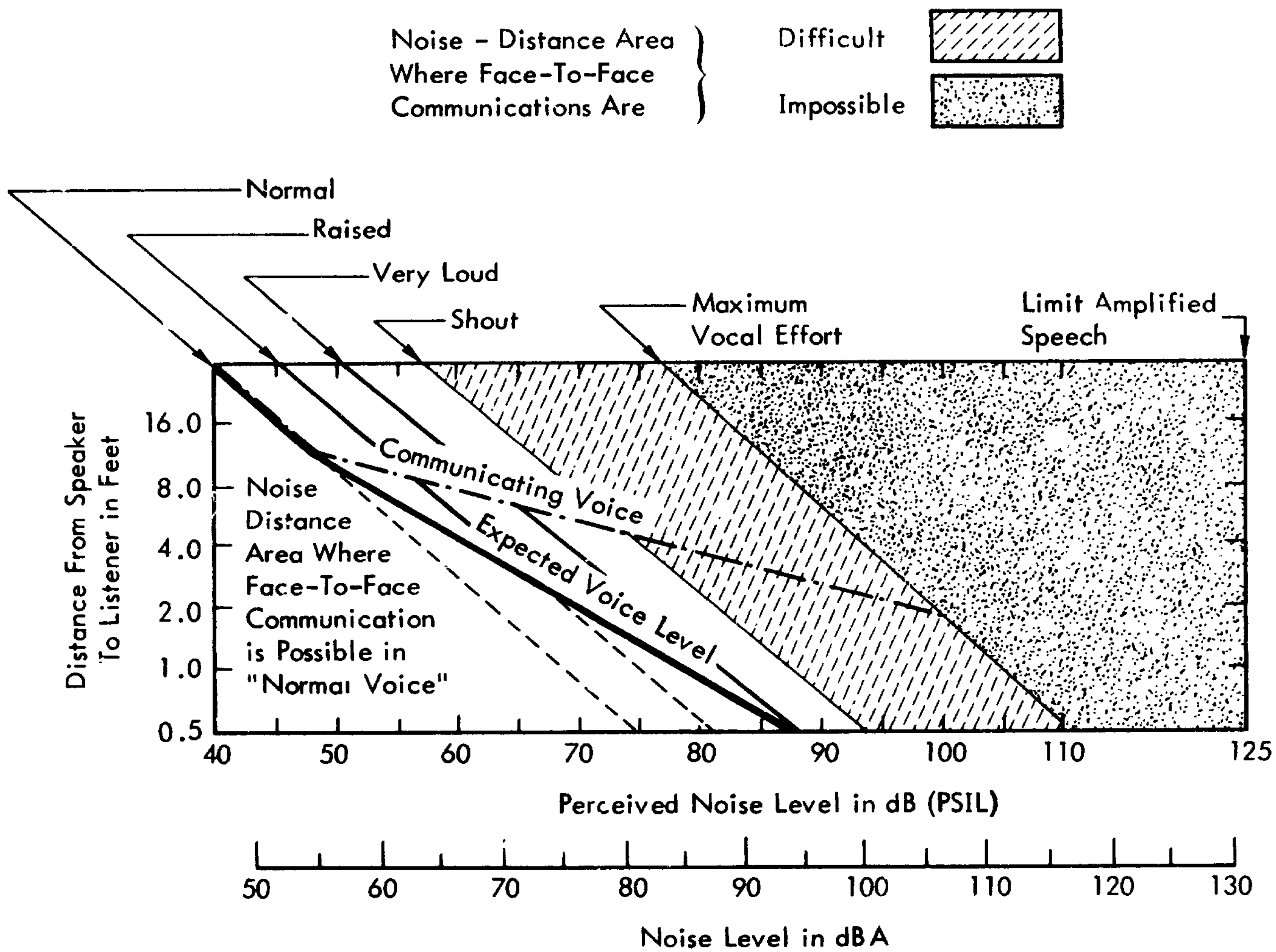

Figure 4. Voice Level Necessary for Satisfactory Face-To-Face Communication as A Function of Distance Between Listener and Speaker. The Expected Voice Level Line Indicates the Normal Compensation in Voice Level as a Function of Background Noise for Non-Vital Communication. The Communicating Voice Line Indicates the Typical Compensation in Voice Level for Vital Communication. (Adopted from Webster and Lepor, Reference 2.)

APPENDIX

ACOUSTICAL TERMINOLOGY

1. Sound Pressure Level

The sound pressure measured at a point is expressed as a sound pressure level (SPL) in decibels through

$$SPL = 20 \log_{10} (p/p_{ref})$$

where

p_{ref} = reference pressure, dynes/cm^2

p = measured effective pressure of the sound wave, dynes/cm^2

The effective sound pressure p is the root-mean-square value of the instantaneous sound pressure, averaged over an integrating time long enough to make its value insensitive to small changes in the length of the averaging time. The reference value p_{ref} = 0.0002 dynes/cm^2 (microbars) is customary and is used throughout this report.

2. Octave Band Sound Pressure Level

The octave band sound pressure level is the sound pressure, expressed as a sound pressure level (see above) as measured over a frequency interval equal to an octave (a two to one interval in frequency).

Preferred center frequencies for the octave bands are:

31.5 Hz	1000
63.0	2000
125.0	4000
250.0	8000
500.0	

3. dB(A)

The overall sound pressure level measured on the (A) frequency weighting scale of a standard Sound Level Meter conforming to ASA Standard S1.4 is identified in the units dB(A). The frequency weighting network utilized decreases the effective sound level of low frequencies, thus emphasizing the frequency content near 1000 Hz where the ear is most sensitive to annoyance and near the center of the frequency range that is important for speech communication.

4. Noise Criteria (NC) Contours

Empirically derived contours of constant noise interference have been developed which approximate the response of the human to noise interference. These contours vary in shape with sound level but also tend to de-emphasize low frequency energy reflecting human response to noise (Reference 5). The NC value for each contour is numerically equal to the Speech Interference Level (SIL). See Item 6.

5. Perceived Noise Level

Another widely used form of frequency weighted contours of sound level which are intended to predict the annoyance of noise. These contours have a more complex shape but also de-emphasize low frequencies (Reference 11). These contours are used to compute an overall Perceived Noise Level in PNdB.

6. Speech Interference Level

The average octave band sound pressure level in the three octave bands, 600-1200, 1200-2400, and 2400-4800 Hz (SIL) or in the three preferred frequency octave bands centered at 500, 1000, and 2000 Hz (PSIL) has been found to be a very useful parameter for predicting interference of noise with speech communication (Reference 5).