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INTRODUCTION

This document represents a compendium of information on literature surveys of human reaction to aircraft environmental variables conducted by the University of Virginia during the period January 1971 through June 1973. The data presented has for the most part been extracted from existing in-house and memoranda reports. The variables considered are motion, noise, temperature and pressure. The report is broken down into chapters for each of the environmental variables and criteria proposed based on the existing literature.

CHAPTER I

Motion

A. General

The effect of motion (linear acceleration, angular rotation and angular acceleration) on humans can be classified into three general areas--effects on performance, effects on subjective comfort, effects on motion sickness. These are purposely treated seperately since the ranges of motion which begin to have an effect in each of these areas, can be, and usually are, different. For a commercial vehicle environment, one is not interested in pushing toward the upper limits of degradation in any of these areas, and, since the degradation of comfort occurs prior to the onset of motion sickness, that area will be emphasized. Effects on performance have gotten much attention and these are well summarized in the Bioastronautics Data Handbook (1973) and Grether, 1971. This document will cover the area of subjective comfort.

B. Selected Experiments

The information displayed in the accompanying table is meant to give the reader a ready reference to the type of testing that has been done in the laboratory and in the field on subjective response to motion. This list is highly selective, but does represent a cross section of the experiments done to date. As can be seen from the table, most of the work has been done in the frequency range of 1-30 hz with the input being sinusoidal and in the vertical direction. The first ten investigators did laboratory simulations while the last three did field testing. The details and results of these tests can be obtained by referring to the original articles or one of the review articles indicated.

Normally two references are given, an indirect reference(s) which refers to the review article(s) in which the data appeared, and a direct reference which indicates the original reporting of the work. Complete citations are given in the bibliography.

INVESTIGATOR	DATE	# OF SUBJ.	TYPE OF SUBJ.	# OF PTS.	NAMES OF POINTS	FREQUENCY RANGE	TYPE OF INPUT	DIRECTION	SUBJECT POSITION	REF. INDIR.	REF. DIR.	COMMENTS
Reiher & Meister	1931	10	NA*	6	0-Imperceptible 1-Barely Percep. 2-Distinctly Disa. 3-Slightly Disa. 4-Disagreeable 5-Unbearable	3-7 cps	sinusoidal	vertical	standing & lying	140, 48, 13		
Jacklin & Liddell	1933	100	Male, age 17-27	3	Perceptible Disagreeable Uncomfortable	1-7 cps	sinusoidal	vertical	sitting on hard chairs	140, 48, 86, 13	73	in ref. 73 perceptible is as you feel you are moving or distant objects are
Meister	1935	15	NA	6	Same as above	1-70 cps	sinusoidal	vertical	standing	140		duration 8 min.
Dieckmann	1947	NA	NA	4	Imperceptible to slightly uncomf. Slightly uncomf. Very Disagreeable Intolerable	NA	NA	NA	NA	140, 13		established fatigue constants
Goldman	1948	Varied 14-100	NA	3	Perceptible Unpleasant Intolerant	1-70 cps	sinusoidal	varied	varied	140, 110	48	averaged information from 7 sources
Gorill & Snyder	1957	NA	Aircrewman	5	Threshold of Perception Definitely Per. Annoying Maximum Cont. Operation Intolerable	3,4,6,8 10 & 30 cps	sinusoidal	vertical	sitting in aircraft ejection seat	140, 110, 86		approx. range of points 1).01-.02g 2).02-.08g 3) .1-.25g 4) .4- .8g 5) .7-1.5g
Ziegenreicher & Magid	1959	10	NA	1	Limit of Tolerance (not discomfort)	1-15 cps	sinusoidal	vertical	seated on plywood seats	140, 110, 86		subjects looking for limit of physical harm
Parks & Snyder	1962	16	Physically fit males	4	Definitely per. Mildly annoying Extremely annoy. Alarming	1-27 cps	sinusoidal	vertical	seated on aircraft seat	140, 13	61	bounded also by 0-just barely per. & 5-limit of physical control, ref.61 has good comparison graph

*Not Available

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INVESTIGATOR	DATE	# OF SUBJ.	TYPE OF SUBJ.	# OF PTS.	NAMES OF POINTS	FREQUENCY RANGE	TYPE OF INPUT	DIRECTION	SUBJECT POSITION	REF. INDIR.	REF. DIR.	COMMENTS
Chaney	1964	10		4	Same as Parks & Snyder	1	sinusoidal	vertical	sitting	140, 110	21	different approach subjects controlled frequency until desired level reached
Urabe, Koyama, Iwase	1966	40	Male college students	4,5,2	Sensibility to centrifugal force 0 no sense 1 a little sense 2 clear sense 3 strong sense Feeling 0 1 2 3 4 comf. uncomf. Judgement 0 allowable train ride 2 unallowable	constant acceleration	ride thru curves	lateral	sitting, standing	16	139	special train run on freight tracks
Miyoshi, Sakamoto	1965	panels of 10	Men		Same as above	1-5 cps	sinusoidal	lateral	sitting	16	100	laboratory testing
Matsudaira	1960	40	College students	5	Very uncomfor. Slightly uncomf. Noticeable Just Sensible Insensible	constant acceleration		longi-tudinal	sitting, standing	16	92	passengers faced both forward and sideward in trains
Urabe, Nomura	1964	50	College students	4,5,2	0-no feeling 1-indistinct feel. 2-distinct feel. 3-strong feel. 0-4 line 0-uncomfortable to 4-uncomfortable Judgement 0-permissible comf 1-not permissible comfort	constant acceleration & jerk		longi-tudinal	sitting or standing in uncrowded and crowded cars facing forward & back	16	138	study forces produced by change of speed of trains

C. Annotated Bibliography

Below is an annotated bibliography of selected review articles in the area of subjective response to motion (vibration). It is felt that they, in general, will provide the most rapid means of becoming familiar with the work done in this area of the general problem of the effects of motion on human beings. In addition to the summary paragraphs, a measure of value as a review article is indicated in parentheses at the conclusion. Both figure and reference numbers are self-inclusive and refer only to the chapter in which they are cited.

Beaupeurt, J. E., Snyder, F. W., Brumaghim, S. H. and Knapp, R. K. "Ten Years of Human Vibration Research." The Boeing Company, Wichita, Kansas, D3-7888, August 1969.

Reviews ten years of research in whole-body, low frequency vertical vibration. The results of twelve studies are presented - five in which the objective was to define and quantify human subjective reactions to vibration and seven in which vibration was a baseline condition for evaluation of sensory-motor task performance. Subjective response studies keyed on the identification of acceleration levels with the verbal labels "perceptible," "mildly annoying," and "alarming" and used 15 vibration frequencies ranging from 1 Hz to 27 Hz. The acceleration levels are comparable to those reported by other investigators in vibration research; and where major differences were noted, they are discussed in the report. Generally, subjective responses were consistent and reliable. Consistency of results in the subjective reaction studies is in contrast to the variability in results of the sensory-motor effects studies. Tracking performance and speed and accuracy of control movements are degraded under vibration. Similarly, reading of smaller numerals is degraded by vibration, while speech intelligibility and auditory performance are not significantly degraded under the conditions of the tests. Physical effects of vibration are discussed in terms of the relationship between frequency of vibration and body sensation. (Fair)

Brumaghim, S. H., "Subjective Response to Commercial Aircraft Ride: Passenger Ride Quality Testing," The Beoing Co., Wichita, Kansas 67202---Presented at the International Symposium on Man-Machine Systems, 8-12, Sept. 1969: Transport Systems and Vehicle Control

Vibration testing program to determine airline passenger reaction to vibration environments typical of large commercial aircraft. Seven ride quality vibration tests conducted in 1968. Principal problem was to determine acceleration labels in the vertical and lateral directions that people find objectionable. Further questions: what is the relationship between human reactions to vertical and lateral vibration to single and combined frequency vibration?--to single and combined axis vibration? Interest confined to reactions in the frequency range of 0.20 to 7.0 Hz. Results: increasing sensitivity to vertical vibration as frequency increased from 1.0 to 7.0 Hz, with the greatest sensitivity in the 4.0 to 7.0 Hz range. Subjects found most sensitive to lateral vibration in the 1.0 to 3.0 Hz range with a nearly linear decrease in sensitivity as frequency of lateral vibration increased from 3.0 to 7.0 Hz. Assuming a linear model of human response to vibration, reactions to combined frequencies of vertical vibration were predicted from knowledge to reactions to component frequencies alone. A fit of the linear model to combined axes (vertical and lateral) vibration was not as clear. Possible applications of results include their use in design of advanced stability augmentation systems to optimize passenger transport ride quality. Need for further testing to substantiate and to extend results of the 1968 ride quality test program discussed. (Fair)

Bryce, W. D., "A Review and Assessment of Criteria for Human Comfort Derived from Subjective Responses to Vibration," National Gas Turbine Establishment, Report No. R286, 1966.

A review of numerous articles on the subjective response to vibrations. Discusses the effects of seat restraints on lateral and horizontal vibration response. Attributes similarities obtained between responses to vertical and restrained horizontal motion to common biomechanical mechanism. Covers frequency range of 1-100 Hz. (Fair)

Carstens, J. P. et al., "Literature Survey of Passenger Comfort Limitations of High-Speed Ground Transports," United Aircraft Corp., East Hartford, Connecticut, 1965, Department of Commerce.

A survey article of environments, and criteria for passenger comfort in all modes of transportation. In addition to vibration, which makes up the largest portion of the paper, the factors of pressure changes, atmospheric contamination, noise, visual disturbances and steady acceleration are reviewed. Author presents many criteria of other investigators as well as his own; however, he does not attempt to explain the differences and/or inconsistencies in these data. The environmental data is somewhat limited and should only be used for crude estimates. (Good)

Clarke, N. P., Mohr, G. C., Brinkley, J. W., Henzel, J. H., et al., "Evaluation of Peak vs. RMS Acceleration in Periodic Low Frequency Vibration Exposures," Aerospace Medicine, 36(11), November 1965, 1083-89.

Subjects exposed to vibration with varying peak and RMS accelerations and frequencies to explore the relative importance of these parameters in determining the effect of the vibration produced by turbulence in low altitude high speed flight. Various RMS acceleration levels and frequency content, pairs of periodic vibration exposures having the same RMS, but different peak accelerations were evaluated using both a subjective severity rating and a measure of vibration induced hand motion. The higher peak acceleration of the various pairs having the same RMS values was subjectively rated more severe in 32 of the 40 observations. But, when attempting to hold the hand in a fixed position during vibration the induced deviations from the null point expressed either as average or peak to peak errors depend more on RMS acceleration and frequency than on peak acceleration. (Good)

Fernstrom, R. W., Jr., Gechwind, R. T. and Horley, G. L., "Cross-Country Speed and Driver Vibrational Environment of the M60 Main Battle Tank," AMCMS Code 5543.12.28208.06 Tech. Memo 7 65, July 1965, 43pp. USA Human Engineering Labs., Aberdeen Proving Ground, Md.

Phase II---Determined the maximum g load the driver would accept. Results of first phase show that all subjects bodies responded to g environments, especially vertical g's, in about the same way. Results of phase II; subjects have widely differing RMS g and amplitude distributions. Computed correlation between RMS g and vehicle speed for both transverse and longitudinal channels. Linear regression technique (RMSg on speed) then used to obtain mathematical expressions describing the relationship for each course (test). (Fair)

Gebhard, J. W., "Acceleration and Comfort in Public Ground Transportation," Johns Hopkins University Applied Physics Lab., Report to Department of Transportation, February 1970.

An interesting compendium of data on acceleration effects in urban transportation systems (trains, trolley cars, etc.). The emphasis is on constant acceleration effects rather than vibration. An extensive description of the work done on ability to keep equilibrium (stand) in the presence of longitudinal acceleration and deceleration is presented and the effect of jerk is analyzed. It is noted that increasing the jerk enables the subject to maintain equilibrium at higher accelerations. A second area described in detail is the work done on lateral acceleration through use of train data on curves and automobile data. Emphasis on most work to data has been on perceptibility - some on comfort - and little or none on acceptability. (Good)

Goldman, D. E., "A Review of Subjective Responses to Vibratory Motion of the Human Body in the Frequency Range 1 to 70 Cycles per Second," Naval Medical Research Institute, National Naval Medical Center, Bethesda, Maryland, March 16, 1960.

This article represents one of the earliest attempts at establishing vertical vibration criteria for identifying subjective response. The author uses three levels of response - perception, discomfort, and tolerance. This paper is primarily of historical interest. (Fair)

Guignard, J. C., "Human Response to Intense Low-Frequency Noise and Vibration," Proc. Inst. Mech. Engrs. 1967-8, Vol. 182, pt. 1. No. 3.

The author states that the frequency dependent effects of mechanical vibration on human comfort and working efficiency are now clearly recognized, as are the effects of airborne noise on hearing. Vibration and intense noise at very low frequencies can also provoke disturbing non-auditory symptoms which are as yet ill understood. The paper reviews current problems in this field and mentions the work of the International Organization for Standardization which is aimed at defining limits of acceptable human exposure to vibration and intense noise.

The lower the frequency the less important becomes the distinction between routes of transmission of vibration energy to the body. Airborne sound of sufficient intensity and low frequency (below 100 Hz) can enter the body by direct absorption through the surface apart from the ear and so excite non-auditory sense organs. The ultimate physiological effect of such noise is essentially similar to that of whole-body mechanical vibration. (Fair)

Hanes, R. M., "Human Sensitivity to Whole-Body Vibration in Urban Transportation Systems: A Literature Review," Johns Hopkins University Applied Physics Lab., Silver Spring, Maryland, May 1970.

Ninety references are reviewed. The emphasis given is to studies that involve subjective estimates of vibration severity and to original experimental data as contrasted with derived recommendations. Found that major portion of the relevant data comes from only a few studies in which the results have been largely divergent. (Good)

Harris, C. S. and Shoenberger, R. W., "Human Performance During Vibration," Report from "Autonetics and Office of Naval Research Joint Symposium on Visual and Display Problems of High Speed Low Altitude Flight, Anaheim, California. 3-5 March, 1964." Proj. 1710, Task 171002, AMRL TR 65 204, Nov. 1965, 23 pp. USAF Aerospace Med. Research Labs, WPAFB, Ohio

Discusses the experimental approaches to the study of human performance during vibration. In addition, the characteristics of mechanical bodily responses to vibration at different frequencies are discussed, and human performance studies of the effects of vibration are compared with recommended long time tolerance curves.

Hornick, R. J. and Lefritz, N. M., "A Study and Review of Human Response to Prolonged Random Vibration."

Determines the effects of long duration, random vibration characteristic of low-altitude, high-speed (LAHS) flight aircraft on human performance, physiological, biodynamic and tolerance responses. Stimulation at 0.10, 0.15 and 0.20 RMSg with a shaped power spectral density from 1 to 12 while engaging in LAHS control tasks. Results related to what has already been done in LAHS flight. (Fair)

Janeway, R. N., "Vehicle Vibration Limits to Fit the Passenger," SAE Preprint 160, Presented at SAE National Passenger Car and Production Meeting, March, 1948.

Develops criteria for passenger comfort criteria in terms of safe limits during sinusoidal vertical vibration. Considers three ranges of frequency; 1-6 Hz, 6-20 Hz, and 20-60 Hz, as governed by three separate requirements - constant maximum jerk, constant maximum acceleration, and constant maximum velocity respectively. (Good).

Lee, R. A. and Pradko, F., "Analytical Analysis of Human Vibration," Mobility Systems Laboratory, SAE #68001

Method to determine analytically the response of the human being to vibration is developed. Method uses a parameter called "absorbed power." Advantage of absorbed power as a measurement criterion is that it has physical significance---places vibration severity on an absolute scale and is applicable in time of frequency domain. Human physical response is presented in the linear range, disagrees with von Gierke's impedance model. Rate of flow of energy becomes the parameter that characterizes the interaction of the vibrating human and the environment. Energy flow takes place as a result of the complex damped elastic properties of the anatomy. This energy flow has been designated as average "absorbed power." (Good)

LeFevre, W., "Ride and Vibration Data Manual---SAE J6a." December 1965, 28 pp. Society of Automotive Engineers, Inc.

Includes a graphical presentation of damped vibrating system characteristics aimed at applications to vehicle ride and vibration problems. Gives picture of the scope of the problem. (Good)

Linder, G. A., "Mechanical Vibration Effects on Human Beings," Aerospace Medicine, August 1962, p. 939.

This paper is a review of the literature on the effects of mechanical vibration on man. Although containing some information of the physiological responses of human beings, it is mainly concerned with physiological, psychophysical and performance data. Identifies areas in the displacement-frequency domain of concern for each of the above. (Good)

Parks, D. L., et al., "Human Reaction to Low Frequency Vibration," The Boeing Co., Wichita, Report No. 1 on Contract NONR 2994(00), July 1961, Clearinghouse Distributor AD261 330.

Although primarily a description of an experimental program in effects of vertical vibration by the authors, this report also contains a limited review of several other investigator's work. Large differences exist between the authors' work and similar research by others, particularly in the frequency range of 8 to 15 Hz. These differences are attributed to test configurations and supports and to subject orientation. (Good)

Shurmer, C. R., "Passenger Comfort in Hydrofoils," Human Factors Group, British Aircraft Corp. Ltd., Guided Weapons Division, Filton, Bristol.

Review of existing information on the vibration environment of current passenger vehicles, attempts to describe the vibration envelope acceptable to passengers. (Good)

Van Deusen, B. D., "A Study of the Vehicle Ride Dynamics Aspect of Ground Mobility," Vol. II, Human Response to Vehicle Vibration. Final Report, Contract DA 22 079 eng. 403, Contract Rep. 4, 114, Order 400, March 1965, 71 pages. HSA Engineer Waterways Experiment Station, Vicksburg, Miss. (Chrysler Corp., Detroit, Michigan).

Summarizes the exisitng literature in the area of human response to vibration and interprets it in the vehicle environment context. Comparisons are made among the shake table approaches to determine human response to vibration as a function of frequency. Several examples or ride comfort studies in actual vehicle environment are also discussed. Discusses problem of magnitude estimation and both ratio judgement and cross-modality techniques are suggested as approaches. Appendices give applications of the above in cross-country environment. (Excellent)

D. Proposed Criteria

This section of the report is an assessment of the state-of-the-art of the relationship of motion (primarily vibration since the great bulk of the work relates to this aspect) to the subjective response of human beings. The data presented takes the form of a set of tables and figures giving the criteria and experiments of other investigators and the criteria proposed based on the present study. The recommended comfort limits presented are somewhat conservative. It is felt that the wide variation in both magnitudes and trends in subjective reaction to motion reported by various various researchers requires a conservative approach to criteria at this date. This variation can be seen in Figure 1 where one experimenter finds levels intolerable that another finds not even mildly annoying, another's perceptible is unpleasant in still another worker's findings. This discrepancy is representative of all the data to date and the semantic differences in the scales does not account for the variance. Some of the inconsistency is traceable to the type of experiment - most is not. At best one can only state that it is imperative that future testing be of a much more systematic nature delving into not only the motion input, but the experimental method and conditions, psychophysical responses and psychological responses.

Perhaps even more distressing is the need to extrapolate this existing simulator data to field conditions when such poor agreement is seen to exist in the simulator data. That criteria are needed is not disputed, in fact, many individuals and groups have proposed such criteria based on past experience. Hence, we will synopsize these criteria and propose our own to be applied to first generation STOL type aircraft. The motion considered will be divided into vertical, lateral, and longitudinal motion and we will not

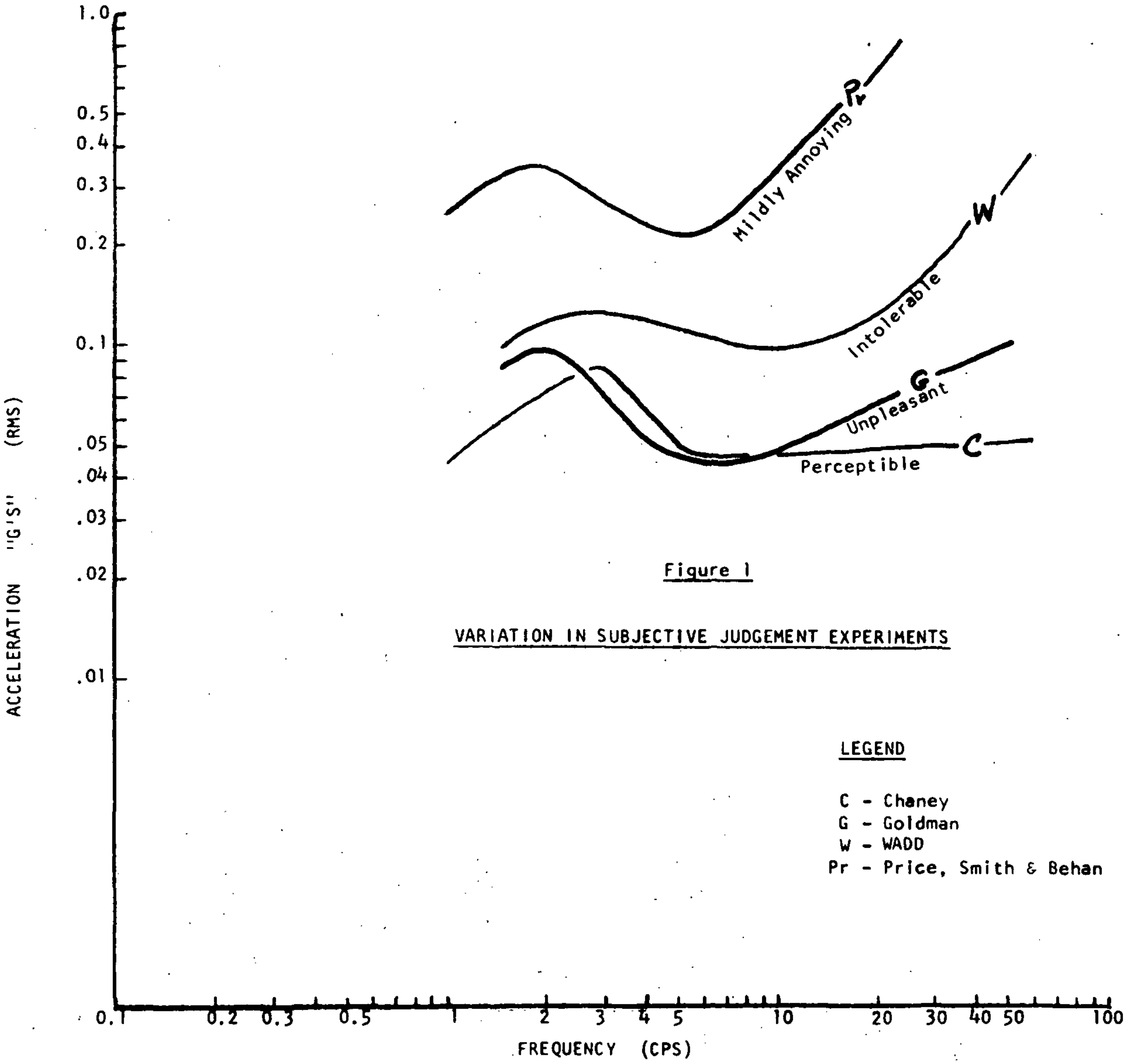

Figure 1

VARIATION IN SUBJECTIVE JUDGEMENT EXPERIMENTS consider angular motions (this is due to the lack of data on subjective response to angular motion).

Vertical

There is more data on subjects exposed to vertical motion than any other direction. Nearly all of the experiments have used single component sinusoidal inputs. Figure 2 illustrates many of the criteria published to date as well as the one here proposed. As can be seen, there is over an order of magnitude variation in the low frequency range with somewhat better agreement above six cycles/sec (omitting Park's data). Some of the differences lie in the semantic scales used, others in the choice of experiments on which they are based. From a study of these as well as other data the hatched curve is proposed as a conservative criterion. The extrapolation below about 1 cps is dangerous at best, however, from physiological considerations[80,170] it is felt a horizontal extrapolation is best.

Transverse

For transverse vibration a similar synopsis to that above is shown in Figure 3, where the proposed criterion for STOL aircraft is once again given by the hatched line. Although the proposed limit is significantly lower than the limit for the vertical direction there is considerable disagreement on this point[130,131,142,168] in the literature, however, this seems the most reasonable at present. In the case of transverse motion, there is also a need for a criterion on the limit of steady state acceleration - as would be experienced in maneuvers. It would seem appropriate to apply the knowledge obtained in cars and trains during rides on curved roadways and tracks respectively.[116,193,274]

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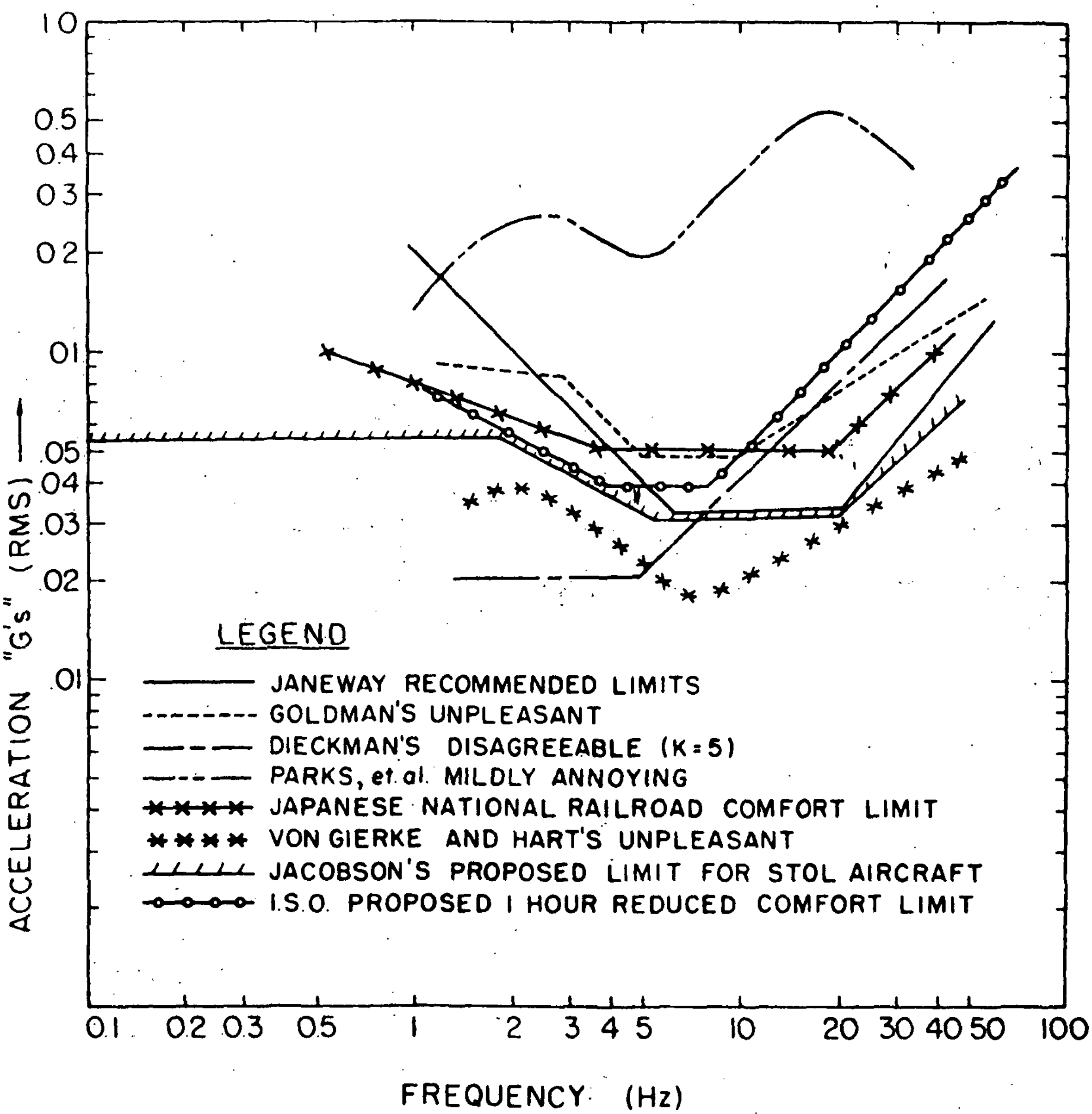

Figure 2. VERTICAL VIBRATION CRITERIA

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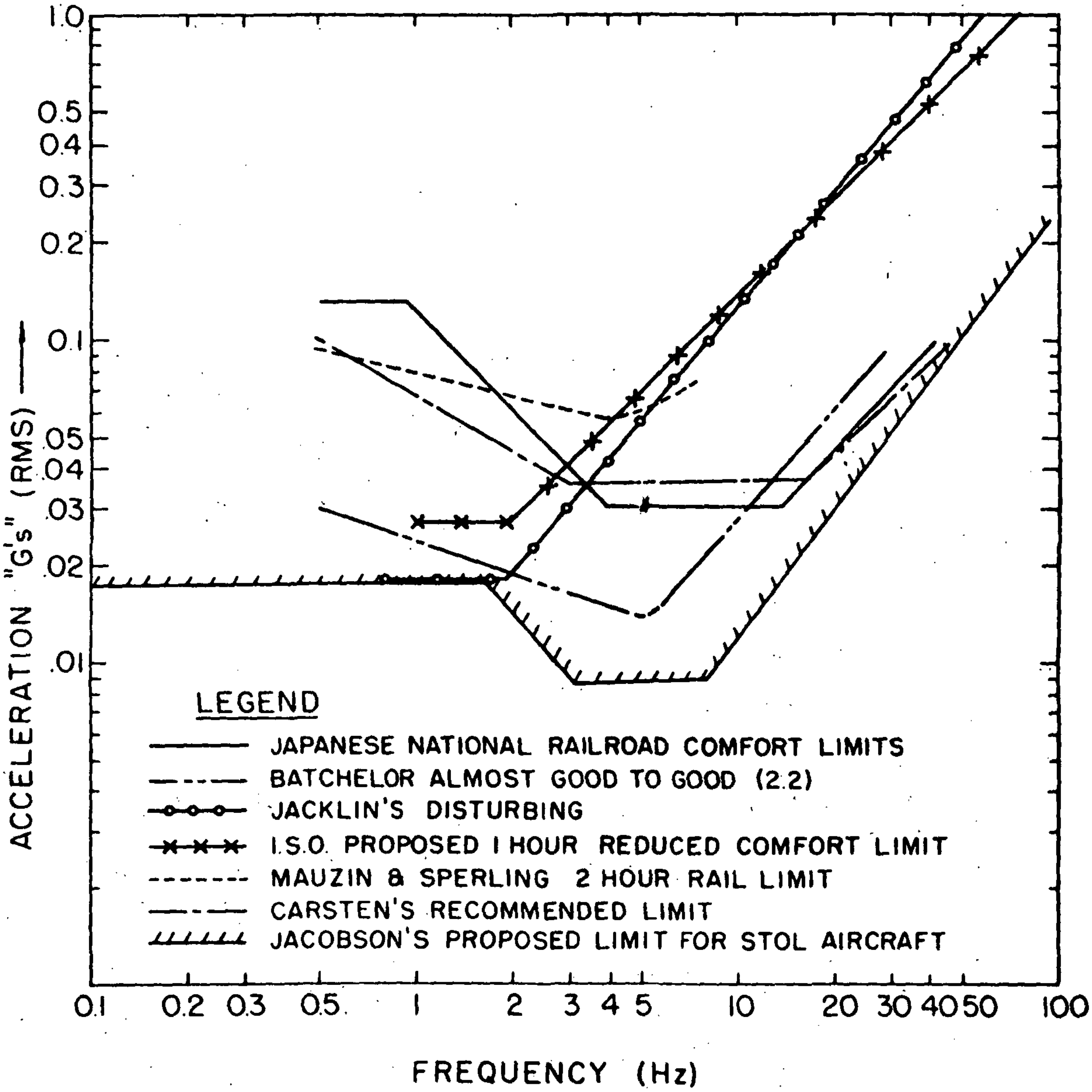

Figure 3. TRANSVERSE VIBRATION CRITERIA

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The data of Urabe, Koyama and Iwane is typical and is given in the table below as a proposed criterion for lateral accelerations and their rates of change ("jerk").

TABLE I

LATERAL ACCELERATIONS

Quality Rating	Percent Passengers	Characteristics of Lateral Acceleration (g)	Jerk (g/sec)	Acceleration Duration (sec)
Comfortable	90	< 0.22	.07	No Limit
	95	< 0.12	.05-.06	No Limit
Acceptability	90	< 0.12	0.05	No Limit
	95	< 0.07-0.08	0.03-0.04	10-20 (for maximum values)

Longitudinal

Very little data is available on subjective response to motion in the longitudinal direction. What data is available tends to support the use of the same criterion for longitudinal as for lateral motion.[30] This approach is adopted here until such time as more data is obtained to better isolate the differences which may exist.

As for steady-state acceleration (or deceleration) the values indicated below are representative of the state-of-the-art.[164,185,280] It is important to realize that the type of seat restraint, environment, duration, and other factors can play a significant role in altering these values.

Allowable Values of Longitudinal Accelerations

Acceleration or deceleration - 0.13 "g"

Jerk - 0.3 "g"/sec

There are three other items worthy of discussion - effects of duration of exposure, effects of combined motions, and, effects of environmental variables.

Exposure Duration

Surprisingly little has been done in this vital area. The ISO standards have made an attempt to include the effects of time as is seen in Figure 4, but recent studies have indicated these may be too optimistic.[116,119,252] No definitive statement can be made at this time suffice it to say that the proposed criteria for vibrations in the vertical, lateral and longitudinal directions were arrived at with an exposure time of thirty - sixty minutes in mind.

Combined Motions

The literature is almost devoid of any experimental data on subjective response to multi-axis stimulation. Several authors have postulated methods to be used for combined inputs ranging from vector summation[98] to weighted sums of various types[39,82] to power spectra methods.[239] At this time there is no evidence to favor one method over the other and all that can reasonably be said is that combined motions will tend to be worse than each of the components taken alone.

Effects of Other Environmental Variables

The study of the response of humans to motion can be misleading if an account of all the environmental factors during testing is not undertaken. Just as motion in combined directions changes the subjective response of a subject, so does other environmental inputs (such as

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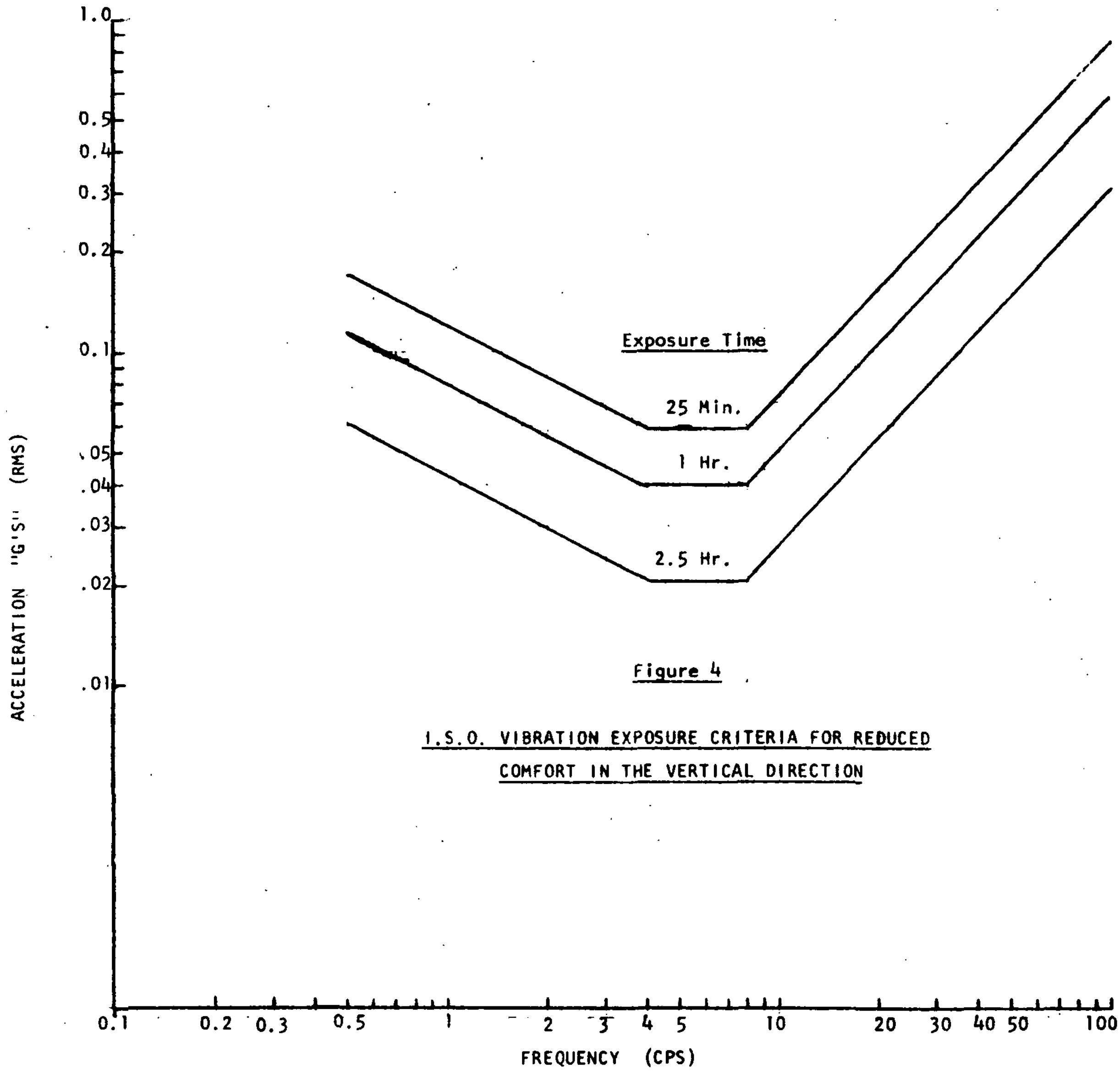

Figure 4

I.S.O. VIBRATION EXPOSURE CRITERIA FOR REDUCED COMFORT IN THE VERTICAL DIRECTION temperature, noise, pressure, etc.). Combining the effects of environmental inputs to determine an overall index of "comfort" has been virtually ignored. Here we point out that many of the discrepancies in simulator data, as well as field data, may well be attributable to lack of understanding of these influences. Future studies should attempt to identify these other environmental factors so that their effects on the response to motion can be determined.

E. Bibliography/References (Vibration)

The bibliography presented here provides the complete citations for the classifications given in Section A of Part I. As stated previously, this is by no means a complete bibliography and is in fact only a fraction of the total document file assessed to date (more than 500 documents).

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CHAPTER 2

NOISE

A. General

The investigation of the effects of noise on sedentary subjects in a closed space with emphasis on passengers on an aircraft suffered from a lack of information. The research on effects of noise fills volumes, but the emphasis is on community acceptance rather than passenger acceptance, making it difficult to apply to this study. However, in most cases, the information in this paper deals with these studies and uses their findings on the assumption that the noise level relation to comfort of subject is independent of the location of the subject. Accordingly, the findings of this paper will be only guidelines until the psychological effects of location are found and correlated. The time period of this chapter includes articles appearing in the literature through 1970.

In the measurement of noise levels, one finds that there exists a great number of scales and measurements that can be used depending on the characteristics of the noise under examination. In Tables I and 2, 37, one sees most of the presently accepted methods of noise measurement. Of all these methods the two most frequently used in measuring aircraft noise are the Perceived Noise Level and the A Weighted Sound Pressure Level. The effects of frequency have been added to these scales by the use of equal loudness contours (figure I)21.

The effort to construct equal loudness contours leads to breaking the frequency content into octave bands (figure 2, 30 and figure 3)5 and, since loudness is affected by the direction of incident, this is also included in some equal loudness contours (figures 4 and 5)29. It should be noted that this brings out one of the main problems in a study of comfort levels of noise. Sex and age have a large effect on the frequency weighting as seen in figure 6 (sex) 29 and figure 7 (age) 30.

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Table I

SCALES USED FOR MEASUREMENT OF NOISE
DATUM POINTS. UNITS

p_i = sound pressure in i-th band or frequency
p_j = *sound pressure at judged equality*
p_t = threshold sound pressure for specified condition
p_o = reference pressure for sound pressure level
w_i = weight factor = 1 at 1 kHz; function of frequency and level
Δ_i = 20 log w_i
δ_i = 1 for a maximum member in a summation, otherwise
= 0.3 for octave bands, 0.15 for third-octave bands

m ⟶ physical measurement (or calculation) a ⟶ arithmetic mean level
j ⟶ judged sensation t ⟶ limit function

1j	Loudness Datum: p_o = 0.001 dyne/cm^2 Unit: loudness unit	$L = 20 \log (p_{700}/p_o)$ Fletcher (1923)
2m	Loudness (level) Datum: p_o = a threshold sound pressure Unit: sensation unit	$= 30 \log [\Sigma(w_i p_i/p_o)^{2/3}]$ Fletcher and Steinberg (1934)
3j	Audiometer reading Datum: noise threshold of buzzer in WE 3A audiometer Unit: "arbitrary scale" (sensation unit)	$= 20 \log (p_j/p_o)$ Lemon (1925)
4m	Sensation level (formerly loudness) Datum: p_{oi} = a threshold pressure Unit: transmission unit (TU)	$= 10 \log [\Sigma\, p_i^2 \,/\, \Sigma\, p_{oi}^2]$ Steinberg (1925)
5m	Loudness *Datum:* p_o = *thresholdat 700 c/s* r = 1 to 3 Unit: "unit"	$= (10r^2/3) \log [\Sigma(w_i p_i/p_o)^{2/r}]$ Steinberg (1925)
6j	Lautstärke ("physical measure") Datum: p_t ⟵ 1 Wien Unit: Wien	$= p_j/p_t$ Barkhausen (1927)
7m	Lautstärke ("sensation measure") Datum: p_t = threshold for buzzer Unit: phon	$= (10/3) \log (p/p_t)$ Barkhausen (1927)
8m	Phonic Level Datum: p_o = 1 dyne/cm^2 Unit: sensation unit	$\phi = 20 \log (p/p_o)$ Fletcher (1929)
9j	Deafening Level (Noise Level) Datum: P_t for three warble tones Unit: *decibel*	$= 20 \log (p_j/p_t)$ Fletcher (1930)
10m	Noise Level (sound level) Datum: p_o = 0.00045 dyne/cm^2; 30-dB weighting Unit: *decibel*	$= 10 \log \Sigma(w_i p_i/p_o)^2$ Galt (1930)
11j	Equivalent Loudness Datum: 0.0002 dyne/cm^2, free wave, 1000 c/s Unit: British Standard phon	$= 20 \log p_j/p_o$ B.S. 661: 1936
12m	Sound Level Datum: 10^{-16} watt/cm^2 ⟶ P_o = 0.0002 dyne/cm^2; a wt Unit: decibel	$SPL = 20 \log [\Sigma(w_i p_i/p_o)^2]$ ASA Z 24.3 - 1936
13m	Equivalent loudness Datum: p_o = 0.0002 dyne/cm^2 Unit: phon	$E.L. = 20 \log (\Sigma\delta_i/p_o)$ King (1941)
14a	Articulation Index Datum: natural zero Unit: pure number	$AI = \sum_1^{20} [(S_i - N_i)/30]/20$ French and Steinberg (1947)
15a	Speech Interference Level *Datum:* 0.0002 dyne/cm^2 Unit: decibel	$SIL = \sum_1^{3} L_i/3 = 10 \log [(p_1 p_2 p_3)^{2/3}/p_0^2]$ Beranek (1947)

Table I (continued)

16m	Loudness (equivalent tone) Datum: $p_o = 0.0002$ μbar Unit: sone	$= \Sigma\,(w_i p_i/p_o)^{2/3.32}$ Mintz and Tyzzer (1952)
17t	Noise Criterion Level Datum: 0.0002 μbar Unit: decibel	$NC = (L_i + \Delta_i)_{max}$ Beranek (1956)
18m	Loudness level (with inhibition) Datum: 2×10^{-4} dyne/cm^2 $\quad r = 1$ to 4 Unit: phon	$L_N = 33.2 \log [\Sigma S_i (1.4 w_i\, p_i/p_o)^{2/r}]$ Stevens (1961)
19m	Perceived noise level Datum: 0.0002 microbar Unit: PNdB	$PNL = 33.2 \log [\Sigma S_i (w_i\, p_i/p_o)^{2/3.6}]$ Kryter (1959)
20m	Lautstärke (*spread of loudness) Datum: 2×10^{-5} N/m^2 Unit: $phon_{GD}$; $phon_{GF}$	$L_{NGD} = 33.2 \log [\Sigma (w_i p_i^*/p_o)^{3.6}]$ Zwicker (1960)
21a	Articulation Index Datum: natural zero $\quad \Sigma\, w_i = 1$ Unit: pure number	$AI = \Sigma\, w_i\, (S_i - L_i)/30$ Kryter (1962)
22m	Speech Privacy Datum: $p_o = 0.0002$ microbar Unit: decibel	$-10.5 > \Sigma\, w_i\, (S_i - N_i) = S_A - N_A$ Young (1965)
23m	Impulse Sound Level Datum: $p_o = 20$ μN/m^2; A weighting Unit: decibel	$L_{AI} = 20 \log [\Sigma\, w_i\, p_i/p_o]$ DIN 45633-2 (1968)

Table II

SCALES FOR DURATION-SENSITIVE NOISE LEVELS

DATUM POINTS. UNITS.

1. Composite Noise Rating
   Datum: $p_o = 0.0002$ microbar
   Unit: decibel

   $CNR = L_{eq} + C_{bk} + C_{other}$

   Pietrasanta, Stevens (1958)

   $$L_{eq} = L_{max} + 10 \log (t_e/T) \quad (1a)$$

   t_e = effective duration

   T = sampling time

2. Mean Annoyance Level
   Datum: 0.0002
   Unit: decibel

   $L_{eq} = m \log [\Sigma 10^{L_i/10m} \Delta t_i/T]$

   Koppe, Matschat, Müller (1966)

   $$L_{eq} = L_{max} + 10m \log t_e/T \quad (2a)$$
   $$p_{eq}^2\, T^m = p_{max}^2\, t_e^m \quad (2b)$$
   $$t_e = p_{max}^{-2/m} \int p^{2/m}\, dt \quad (2c)$$

3. Sound Exposure Level
   Datum: $p_o^2\, t_0 = (20\ \mu N/m^2)^2$ (sec)
   Unit: decibel

   $L_{AE} = 10 \log [\Sigma\, 10^{L_A/10} \Delta t_i/t_o]$

   Young (1968)

   $$L_E = 10 \log [\int p^2 dt/p_o^2\, t_o] \quad (3a)$$
   $$L_E = L_{eq} + 10 \log (T/t_o) \quad (3b)$$
   $$L_{max} = L_E - 10 \log (t_e/t_o) \quad (3c)$$

4. Integrated Perceived Noise Level
   Datum: $p_o^2\, t_o = (20\ \mu N/m^2)^2$ (0.5 sec)
   Unit: $PNdB_t$

   $IPNL = 10 \log [\Sigma\, 10^{PNL_i/10} \Delta t_i/t_o]$

   Kryter (1968)

5. Equivalent (or Effective) Perceived Noise Level
   Datum: $p_o^2\, t_o = (0.0002\ \text{microbar})^2 (0.5\ \text{sec})$
   Unit: $E_d PNdB_t$

   $E_{0.5sec}PNL = 10 \log [\Sigma\, 10^{PNL_i/10} \Delta t_i/d]$

   Kryter (1968)

   $$E_d PNL = IPNL - 10 \log (d/0.5) \quad (5a)$$

6. Effective Perceived Noise Level
   Datum: $p_o^2\, T_o = (20\ \mu N/m)^2$ (10 sec)
   Unit: PNdB

   $L_{EPN} = 10 \log [\int_{-x}^{x} 10^{L_{PN}/10}\, dt/T_o]$

   ISO/TC43(Sec-443)520[Nov 1968]

   $$L_{EPN} = IPNL - 13 \quad (6a)$$

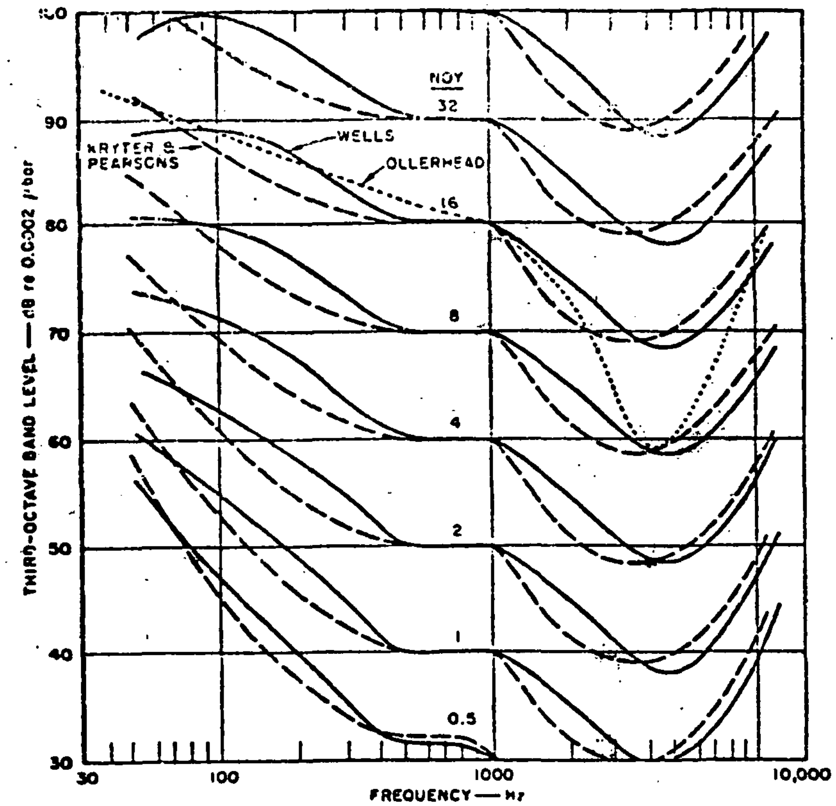

Figure 1. Family of normalized equal noisiness contours found by Wells (solid lines), proposed by Kryter and Pearsons (dashed lines) (5) and contour (adjusted downward by 4 Noy to aid comparison) found by Ollerhead (15). After Wells (24). (From Ref. 21)

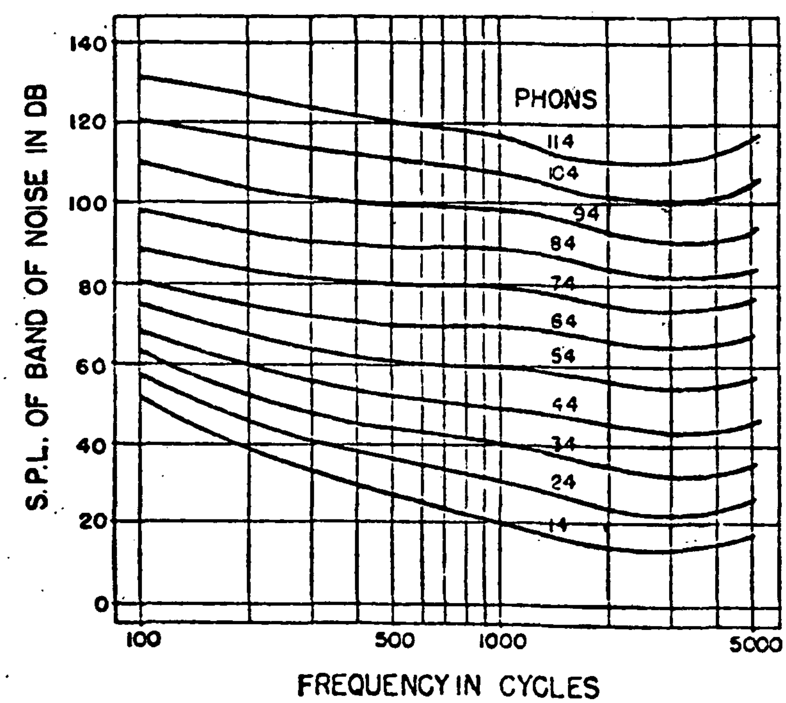

Figure 2. Equal-loudness contours for relatively narrow bands of random noise. The center frequency of the band is shown as the abscissa and the numbers on the curves are phons (Irwin Pollack, "The Loudness of Bands of Noise," Journal of the Acoustical Society of Am., Vol. 24, Sept. 1952, (From Ref. 30)

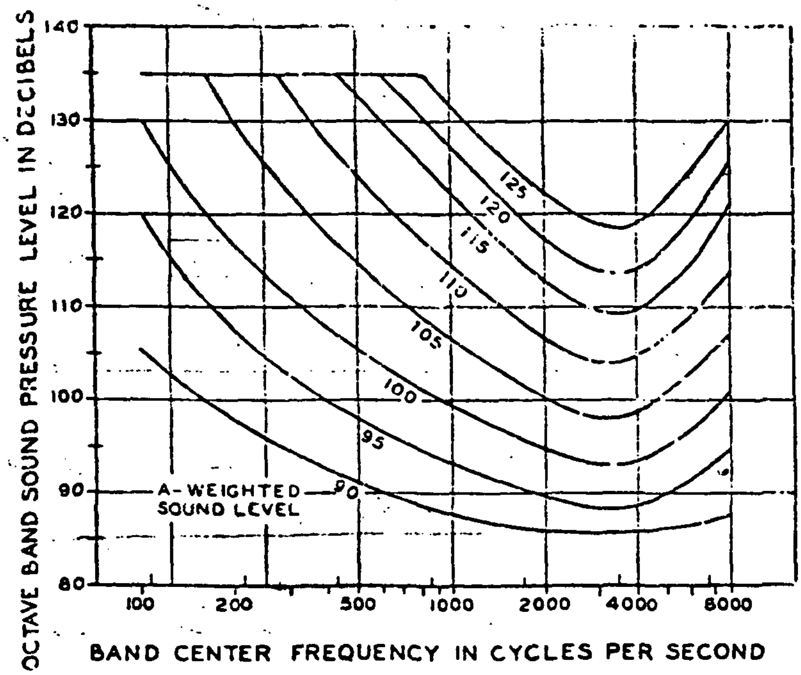

Figure 3. Equivalent sound level contours. Octave band sound pressure levels may be converted to the equivalent A-weighted sound level by plotting them on this graph and noting the A-weighted sound level corresponding to the point of highest penetration into the sound level contours. This equivalent A-weighted sound level, which may differ from the actual A-weighted sound level of the noise, is used to determine exposure limits from Table I. (From Ref. 5)

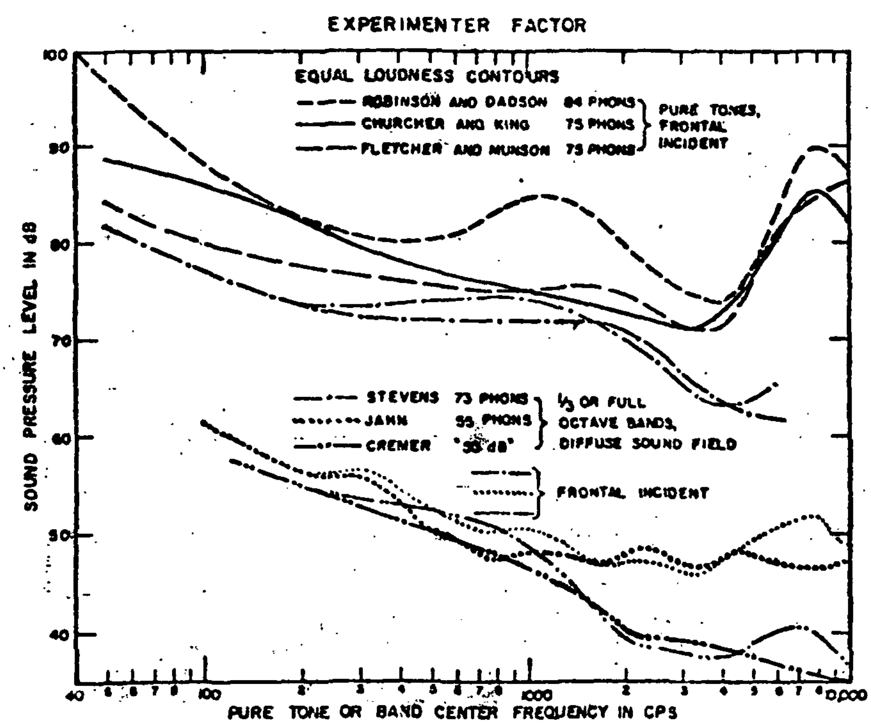

Figure 4. Equal loudness contours for tones (after Robinson, Dadson, 1956). (From Ref. 29)

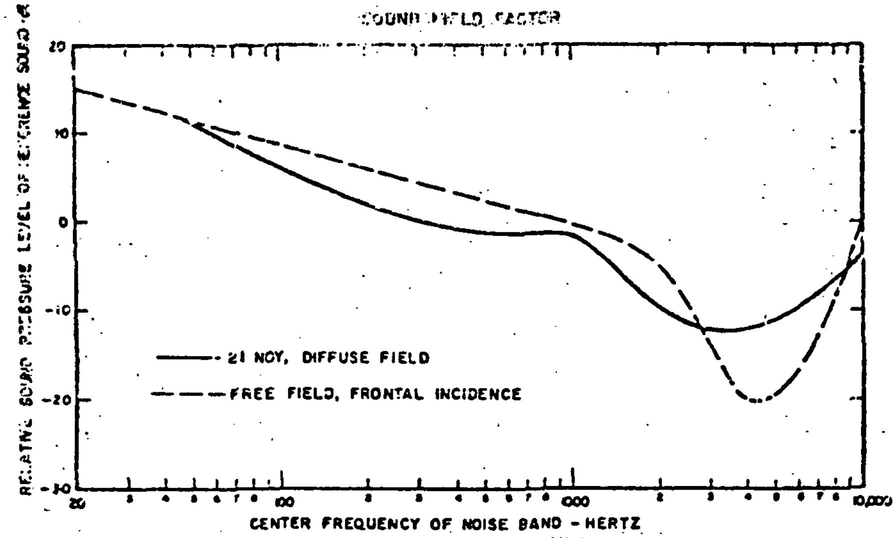

Figure 5. Equal noisiness contours for bands of noise. (From Ref. 29)

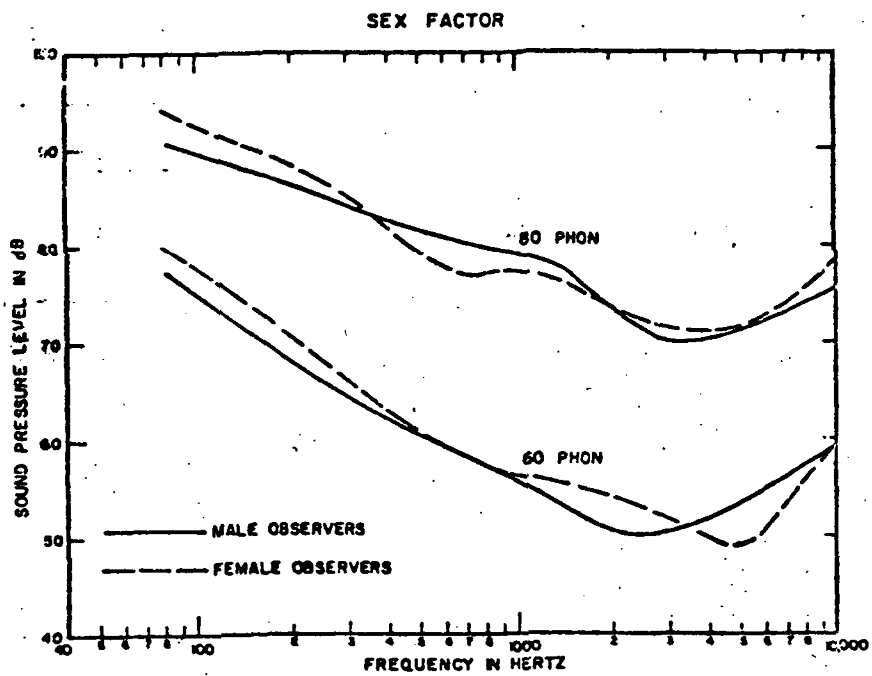

Figure 6. CBS Laboratories equal-loudness contours, octave bands of pink noise. (From Ref. 29)

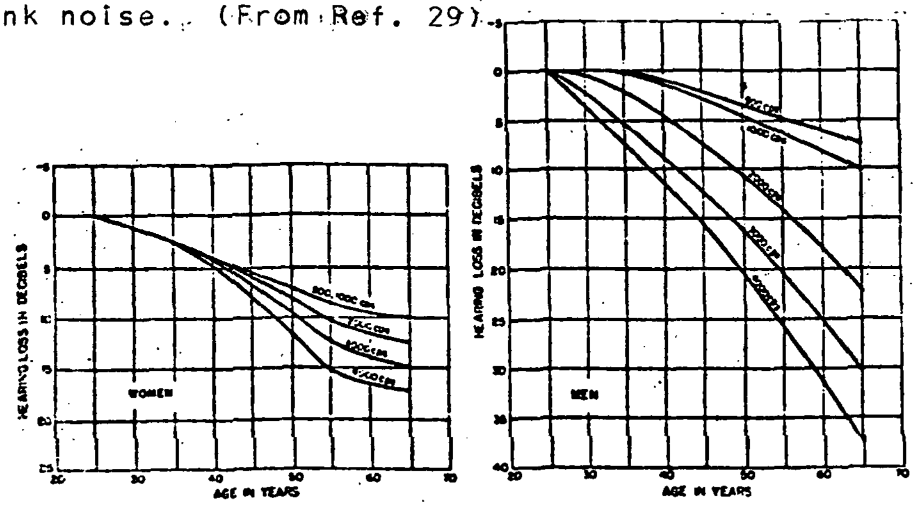

Figure 7. Presbycusis curves for women and men. These sets of curves show the average shifts with age of the threshold of hearing for pure tones (ASA Subcommittee Z24-X-2, "The Relations of Hearing Loss to Noise Exposure," New York, 1954, pp. 16-17)(From Ref. 30)

Other factors which influence equal loudness measurements are the effects of tones and comparison of broad band noise to pure tone noise (figure 8)10. The duration of a noise has been investigated, and several methods devised for studying time dependency, including the development of new noise level scales (Table 2) and relations to existing Perceived Noise Level (PNL) and Sound Pressure Level (SPL) (figures 9)21 and 10)25 scales. Other problems encountered include the amount of insturction given to the test subjects and the differences in individual adjustment to the loudness of a noise (figure 11 (figure 11)29. At this point it seems that both the PNL and SPL (A weighted) scales with octave band filters should be used in the study of passenger acceptance of aircraft noise (see figure 12, 21 for a comparison of these scales).

When one tries to set comfort levels corresponding to noise levels for passengers on aircraft using data from test subjects on the ground, an important factor is left out of the test - fear associated with a noise. This fear arises from noises whose source cannot be determined and noises that do not fit the pattern of preceeding noises. Also, people feel differently about the same noise depending on the relative importance of the cause. Thus, the effects of these problems need further investigation and the results added to existing information before a complete comfort scale can be constructed.

In the construction of the comfort scale there exists one area which will be independent of psychological factors, that is, the physiologically dangerous/damaging noise level. This noise level varies depending on the number of recurrences in a twenty-four hour period - the more frequent the noise, the lower the limit. Botsford, 5 has done research in this area and Table 3 gives limits for different noise durations and recurrence times. Here the minimum is eighty-nine decibels (A weighted SPL) for an eight hour exposure.

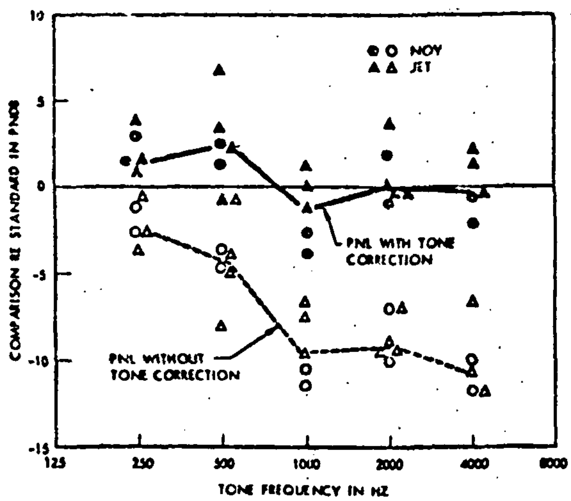

Figure 8. Judgements of equal noisiness for single tone and broadband noise (comparison) vs. broadband noise (standard). (from Ref. 10)

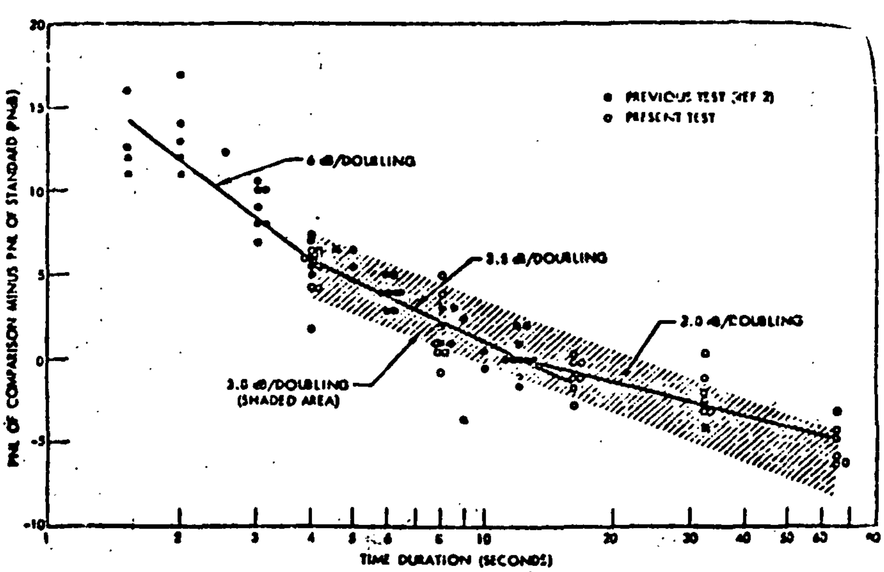

Figure 9. Summary of equally acceptable noises of various durations (combined tests 1.5-64 seconds). (from Ref. 21)

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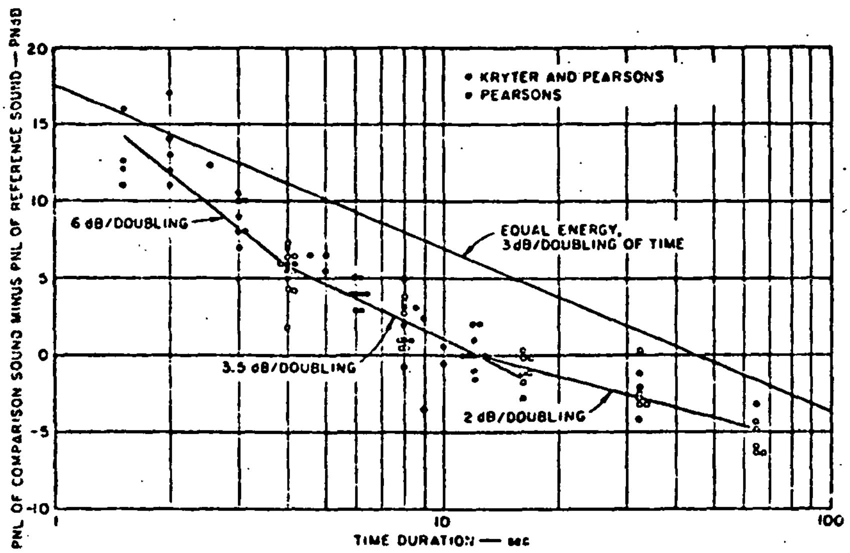

Figure 10. Showing relative effect upon PNL of changing duration of a noise relative to a duration of 12 secs. After Kryter and Pearsons (5) and after Pearsons (16). (from Ref. 25)

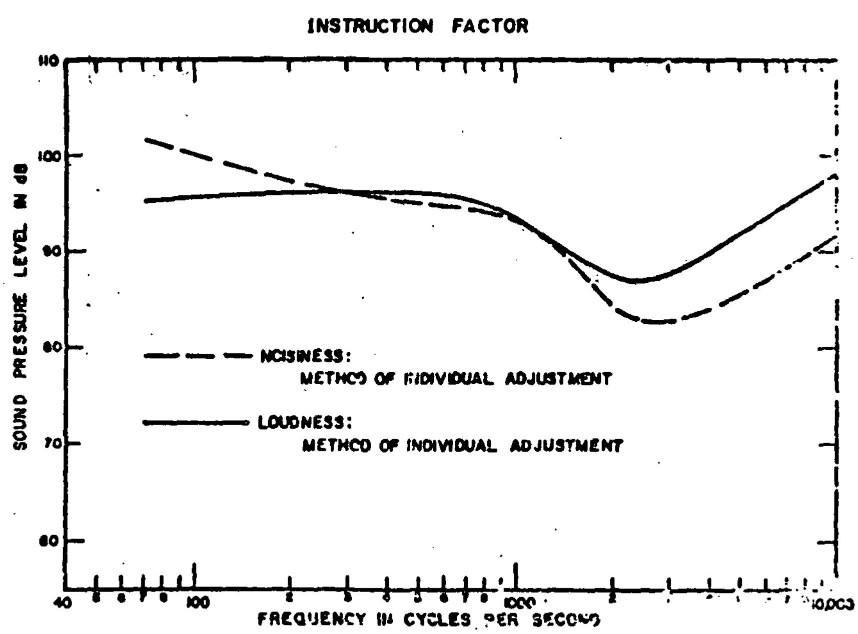

Figure 11. Equal loudness and equal noisiness method individual adjustment (after Kryter and Pearsons, 1963). (from Ref. 29)

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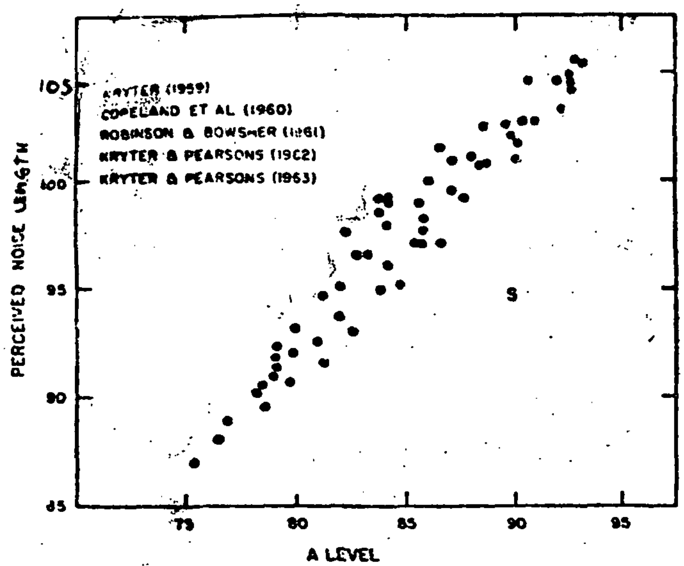

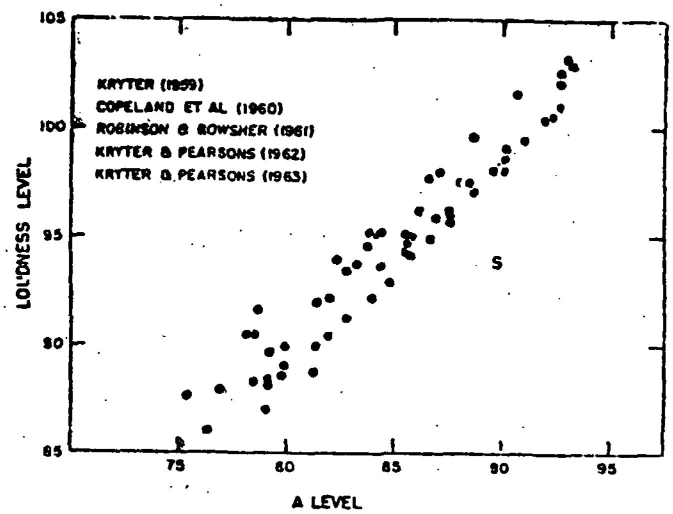

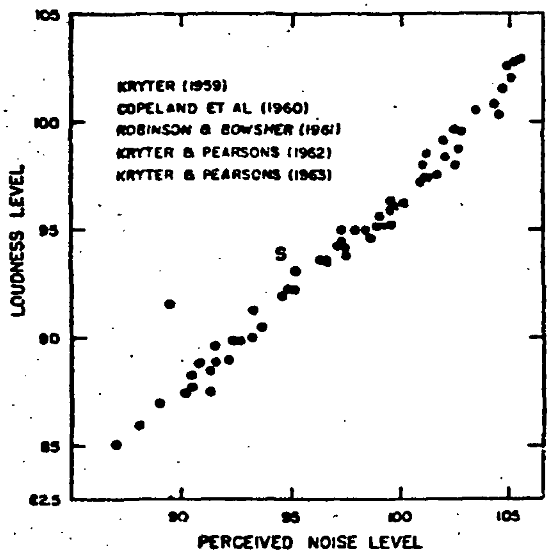

Figure 12. Scattergrams for comparing A-Level, Loudness Level, and Perceived Noise Level. (from Ref. 21)

Table 3

ACCEPTABLE EXPOSURES TO DANGEROUS NOISE

To use the table, select the column headed by the number of times the dangerous noise occurs per day, read down to the average sound level of the noise and locate directly to the left in the first column the total duration of dangerous noise allowed for any 24 hour period. It is permissible to interpolate if necessary.

Total Noise Duration Per Day (24 hours)	Number of Times Noise Occurs Per Day						
	1	3	7	15	35	75	160 up
8 hrs.	89	89	89	89	89	89	89
6	90	92	95	97	96	94	93
4	91	94	98	101	103	101	99
2	93	98	102	105	108	113	117
1	96	102	106	109	114	125	125 (1½h)
30 min.	100	105	109	114	125		
15	104	109	115	124			
8	108	114	125				
4	113	125					
2	123						

A-Weighted Sound Levels

B. Selected Annotated Bibliography

Both the figure and reference numbers are self-inclusive and refer only to the chapter in which they are cited.

Alford, B. R., Jerger, J. F., Coats, A. C., Billingham, J., French, B. O. and McBrayer, R. O. "Human Tolerance to Low Frequency Sound," presented at the 7th Annual Session of the American Academy of Opthalmology and Otolaryngology, November 14-19, 1965, Chicago, project supported by NASA Contract NAS 9-2468.

Explored the human physiological alterations during exposure to intense sound below 22 cps produced by sinusoidal pressure fluctuations (pure tones by a piston and crank assembly, which varied the volume) of the test chamber---intensity of the pure tones produced ranged from 119-144 dB sound pressure level (SPL). Monitored EKG and respiration (by impedance pneumogram), monitored auditory thresholds before, during, and after exposure to the stimuli.

Bolt, Beranek, and Newman, Inc., Cambridge, Ma. "Some Factors Influencing Human Response to Aircraft Noise: Masking of Speech and Variability of Subjective Judgements," June 1965, 72 p. FAA-ADS-42. IR-15387. AD-617 935.

Statistics of the variability of subjective judgements of loudness and noisiness of pure tones and complex sounds as studied in the laboratory and in the field presented. Analysis of possible sources or causes of this variability made in terms of test/retest reliability differences among subjects. Type of sounds judged, and experimental method used in obtaining judgements, possible contributors to variability of judgements. This is due to differences in the size of the external ear and the thresholds of auditory sensitivity at different sound frequencies for different age groups. Word intelligibility tests at various intensity levels administered to a crew of trained listeners in the presence of recorded noise from jet and propelier-driven aircraft. The noise was that which would be present outdoors and in a house as the result of engine run-up operations and aircraft flying overhead shortly after takeoff and prior to landing. Methods of measuring or evaluating aircraft noise predict the results of the speech tests in the following order of merit, from best to worse: 1) articulation index (AI); 2) and 3) perceived noise level in PNDB and speech interference level (SIL) (SIL and PNDB appear to predict the masking of speech about equally well); 4) noise criteria (NC); 5) overall SPL, A scale; and 6) overall sound pressure level, C scale.

Canada, Defense Research Medical Laboratories, Toronto, "Noise Survey, CSR-110 Aircraft," October 1962, 11 p. (DRML Technical Memo No. 244-6) IF-769. AD-297-898.

Survey of the noise generated by the engines of the CSR-110 (Albatross) aircraft. Inside the aircraft the noise was composed of sound energy in the low frequencies with overall SPL ranging from 110 dB at the radar operator's position to 103 dB at the rear of the aft compartment. On the ground at a distance of 100 ft from the aircraft, the significant sound energy in the noise was in the frequency range 37.5 to 300 at idling power. Overall SPL ranged from 90-119 dB. All persons regularly exposed to this noise should participate in a hearing conservation program which requires use of proper voice equipment.

Guignard, J. C. <u>Noise</u>, in Gillies, J.A. ed., <u>A Textbook of Aviation Physiology</u>, Pergamon Press, 1965, 895-967.

Comprehensive review of noise in aviation, where noise is defined as "any sound that is unpleasant, loud, harsh, or distracting." Reviews physical nature of sound and the principles of noise measurement. Table summarizing representative levels of equivalent and relative loudness for sounds ranging from rustling leaves to a large rocket engine at 100 yards presented. Techniques of noise measurement and analysis are discussed. Noise as sources, including the aircraft itself, air-field equipment, etc.---sound propagation through air under various meterological conditions is compared---the physiology and microanatomy of the ear are described, and the effects of noise are assessed. Psychology of noise also considered, but it is emphasized that while for many people various sounds are annoying, an exact definition of annoyance and its nature is difficult to formulate---principles of noise suppression in aviation and equipment used for this purpose are examined.

Harris, C. S. and Shoenberger, R. W. "Combined Effects of Noise and Vibration on Psychomotor Performance," Aerospace Medical Research Laboratory, Aerospace Medical Division Air Force Systems Command, WPAFD, Ohio, AMRL-TR-14 (BME 0051) Project 7231, Task 723101

Tracking performance and reaction time to the appearance of a light (red) and disappearance of a light (green) of highly trained Subjects measured. Noise = 85 or 110 dB and noise exposures combined with 0.25G vertical vibrations at 5 Hz---duration at each exposure was 19 minutes. Vibrations found to have an adverse effect on both the horizontal and vertical tracking tasks and on reaction time to both sets of lights. Noise had a significant effect, both with and without vibration, but only on the vertical part of the tracking task. On vertical tracking, the effect of noise was additive to that of vibration with both noise and vibration presented simultaneously - 110 dB + .25 G @ 5Hz.

Ioseliana, K. K. "Effect of Vibration and Noise and Ability to Do Mental Work Under Conditions of Time Shortage," Environmental Space Sciences, 1(2), March-April 1967, 144-46. (Translated from Kosmicheskaya Biologiya i Meditsina, 1(2) 79-82, March-April 1967).

Task---continuous counting at a set rate method while working. Analysis of the mistakes during vibration. Determined the effects of vibration and noise separately.

RESULTS: Ability to do mental work reduced during exposure to noise alone an average of 50%. Combined exposure to vibration and noise decreased amount to 33-50% and was stable. In first minutes after switching off the combined stimuli, although some improvement in the quality of the work took place, initial productivity not fully restored. 70% of decrement due to vibration, 30% due to noise---but vibration causes persistent disturbances of mental activity.

Jerison, H. J. "Effects of Noise on Human Performance," Journal of Applied Psychology, 41, No. 2, 1959, 96-101.

Experiment I: Purpose---check previously reported results that performance on a prolonged vigilance task was poorer in noise than in quiet.

Experiment II: Noise and complex mental counting. Subjects working in high energy noise fields cannot keep an accurate count of how far they had gone in a repetitive task. Found severe decrement with 110 dB noise level.

"Implication is that for short, spurt-like efforts, no performance decrements in noise need be expected---sustained performance, however, and the task not intrinsically challenging, effects of the sort reported here are likely."

King, P. G. "Auditory Perception in Aircrew," in Gillies, J.A. ed. A Textbook of Aviation Physiology, Oxford, Pergamon Press, Ltd., 1965, 968-88.

Review of the measurements, techniques, and the standards involved in auditory perception in aircraft personnel. Although considered obvious, the need for the members of an aircrew to have good hearing is emphasized. Show that, in practice, a pilot who is required to hear speech in a background of noise is unlikely to make use of a greater range of speech frequencies than that from 500-3000 Hz. The clinical and audiometric techniques of examining hearing acuity are described, and three different tests administered by the RAF are evaluated and compared. Risk to hearing and acoustic trauma are shown to depend on factors which include age, individual susceptibility, and nature and intensity in excess of 95 dB can be hazardous to hearing. Measures to reduce the risk of hearing loss are reviewed in particular the RAG Mark III ear defender is described and illustrated---use of audiograms described.

Kryter, K. D. "An Example of 'Engineering Psychology': The Aircraft Noise Problem," Presidential Address presented to the Society of Engineering Psychologist at the meeting of the American Psychological Association, Washington, D. C., September 1967.

Three criteria for aircraft noise levels:

a) PNdB - basic unit for measuring the sound from aircraft and other sources in terms of its most probable "annoyance" effect on people. Found by making calculations on octave band or one-third octave band sound pressure level measurements of a sound. Effects on annoyance or the "noisiness" of a sound in terms of pure-tone content and duration of a sound can also be evaluated by "corrected" PNdB units

b) Composite noise rating (CNR) = PNdB - 12 + 10 $\log_{10} N$

c) See also Noise and number index (NNI)
NNI = PNdB - 80 + 15 $\log_{10} N$

Little, J. W. and Mabry, J. E. "Human Reaction to Aircraft Engine Noise," A69-12766, The Boeing Company, Seattle, Washington, Sound and Vibration, November 1968.

Evolution of EPNL (effective perceived noise level) and its possible constraint on engine design and a new approach to subjective evaluations are significant areas discussed. Although field-test studies have an element of realism, since judges are exposed to actual fly-overs, control of the noise is limited. This leads to confusion in interpretation of results as found in the interaction of the location variable and the noise level variable therefore:

a) Avoid category scaling using word descriptions; results are dependent on the words used and the range of noises investigated.

b) Establish a reference noise as a means of anchoring the judgements.

c) Establish an approach that combines laboratory control---in particular, control of the noise parameter---and the realism of living situations

Community acceptance related to average peak noise level and to the number of times the noises occur gave rise to a concept called Noise and Number Index (NNI). Change in annoyance with number of events was given as 15 log N.

PURE TONES: Presence of pure tones caused increased annoyance not accounted for by PNL. Pure tone correction, i.e., ratio of pure tone to noise level is important.

Mohr, G. C., Cole, J. N., Guild, E. and von Gierke, H. E. "Effects of Low Frequency and Infra Sonic Noise on Man," Aerospace Medicine, 36, 1965, 817-24.

Investigated noise environments in the 1-100 Hz frequency range. Subjects exposed for two-minute periods to high intensity, broad-band, narrow-band and pure-tone low frequency noise. Effects of these exposures on cardiac rhythm, hearing threshold, visual acuity, fine motor control, spatial orientation, speech intelligibility and subjective tolerance were observed. Exposures up to 154 dB in the 1-100 Hz range were achieved. Range of human exposure to infrasound was extended from 20-40 dB above prior documented experience. Both objective and subjective responses of the Subjects demonstrated that short-duration exposure to low frequency noise up to 150 dB is well within human tolerance limits. Exposures above 150 dB elicited responses indicating the limiting range of subjective tolerance and reliable performance was being approached.

Stone, R. B. "Cockpit Noise Environment of Airline Aircraft," Aerospace Medicine, 40, 1969, 989-93.

Noise level surveys were carried out in the cockpit of the M404, DC6, F27A and J, F227, CV600, L188, B720, B727, B707, and DC9. Octave band analysis during a number of regimes of flight indicate cruise and high speed descent were the noisiest portions of flight. Compared to speech interference criterion many of the currently operated turboprop exceed damage risk and cause communication between pilots to be carried out at a near shout. Source of the noise is air movement around the aircraft nose and windshield, radio and instrument component noise, engine component and in the jet prop the noise associated with propeller operation. Chose five hours as the average length of exposure.

Tobias, J. V. "Cockpit Noise Intensity Fifteen Single Engine Light Aircraft," Aerospace Medicine, 1969, 963-69.

15 populated aircraft tested for the noise intensity present during normal cruising operations at 2,000, 6,000 and 10,000 feet MSL. Compared with currently accepted DRC (damage risk criterion) curves, the noise levels found even in the quietest plane tested could be damaging---use earplugs.

U. S. National Aeronautics and Space Administration, Langley Research Center, Langley Station, Virginia, "Some Effects of Spectral Content and Duration on Perceived Noise Level," April 1963, 53 p. TN-D-1873, IR-979, IR-2687

Equal noisiness contours and tables for the audible frequency range up to 12,500 Hz presented for use in the calculation of perceived noise level. Results presented for judgements by 250 subjects to determine the effects of duration on the perceived noise level of aircraft sounds.

C. Proposed Criteria

From the general discussion in section A the comfort zone is set at the level at which normal conversation can be maintained without extra effort. This level seems to be between 50 and 60 decibels octave noise level (figure 16) and between 80 and 90 decibels PNL (figure 13 and 14). Thus, the maximum level for comfort can be established as 70 decibels PNL broad band or as 60 decibels SPL in any octave band.

The level of comfort still remains low for the design of an aircraft since these levels may have to be exceeded. Thus, other points on the comfort scale should be found that would be tolerated by the passengers. This acceptable zone can be placed between 70 and 80 decibels PNL as indicated by figures 13, 14 and 16. This leaves two zones between 80 decibels PNL and 90 decibels SPL which should be included in the noise comfort scale. If the 90 decibel SPL in converted to PNL by the use of figure 12, the danger threshold appears at 100 decibels PNL. Therefore, the division between the 'noisy' to 'annoying' zone can be taken as 90 decibels PNL. The comfort scale so constructed appears in figure 17.

This scale appears to agree with noise levels from different sources as indicated by figures 18 and 19 (4). If the duration and tone corrections are made, then the results of a field study should agree with this scale unless the psychological effects of flight cause a lowering of the noise level limits.

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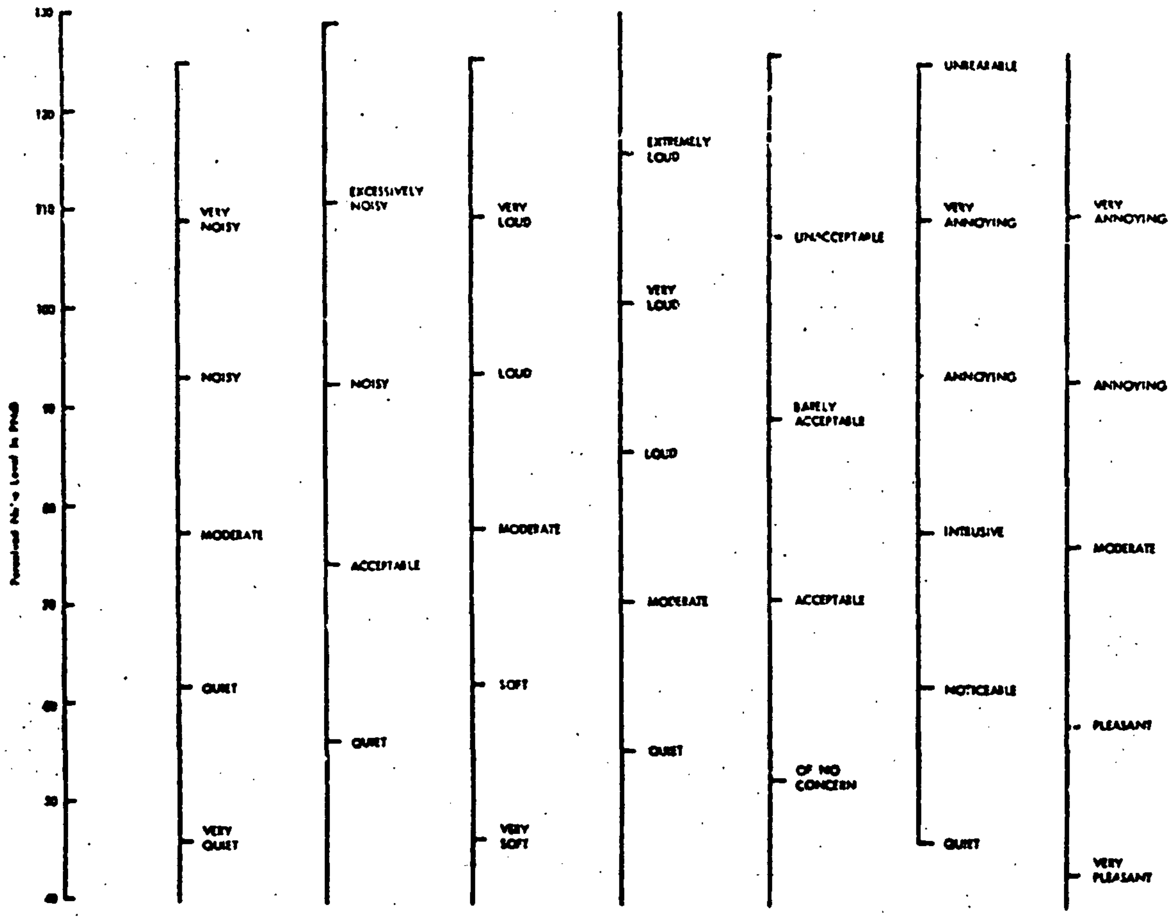

Figure 13. Judged equivalent scale ratings for stimuli employed in all laboratory test sessions.

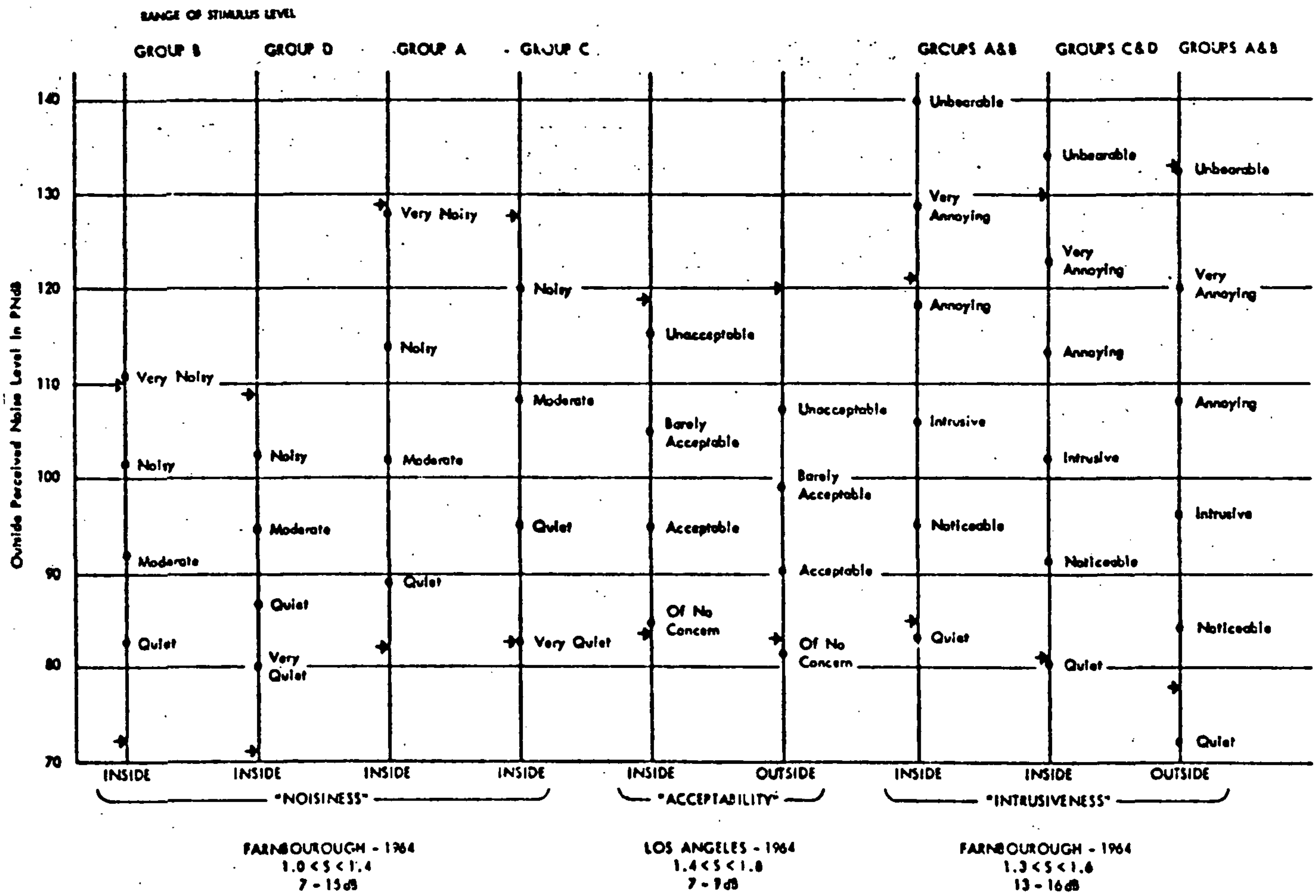

Figure 14. Comparison of results of several category scale judgements (arrows indicate range of noise levels during experiments).

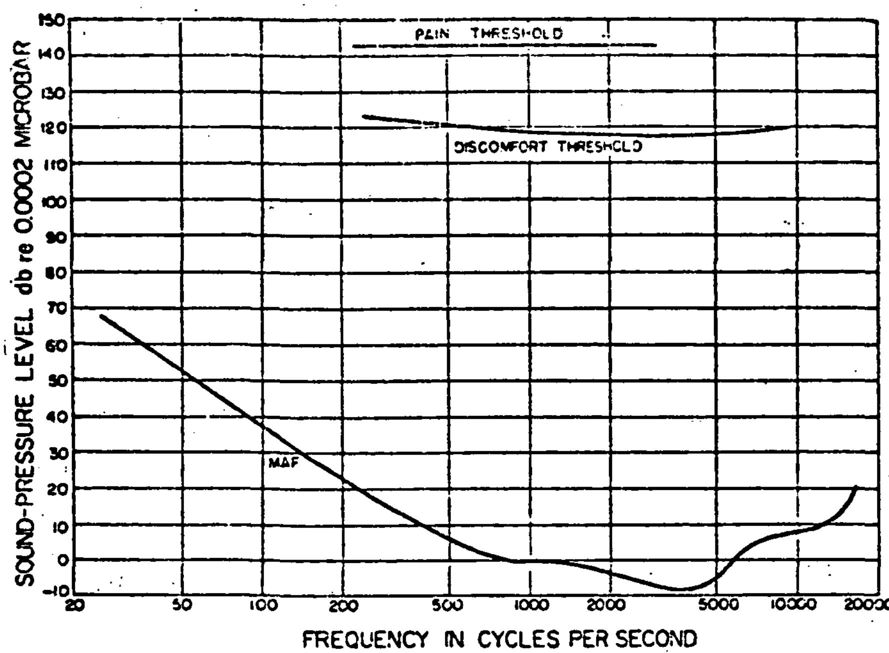

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Figure 15. Thresholds of bearing and tolerance.

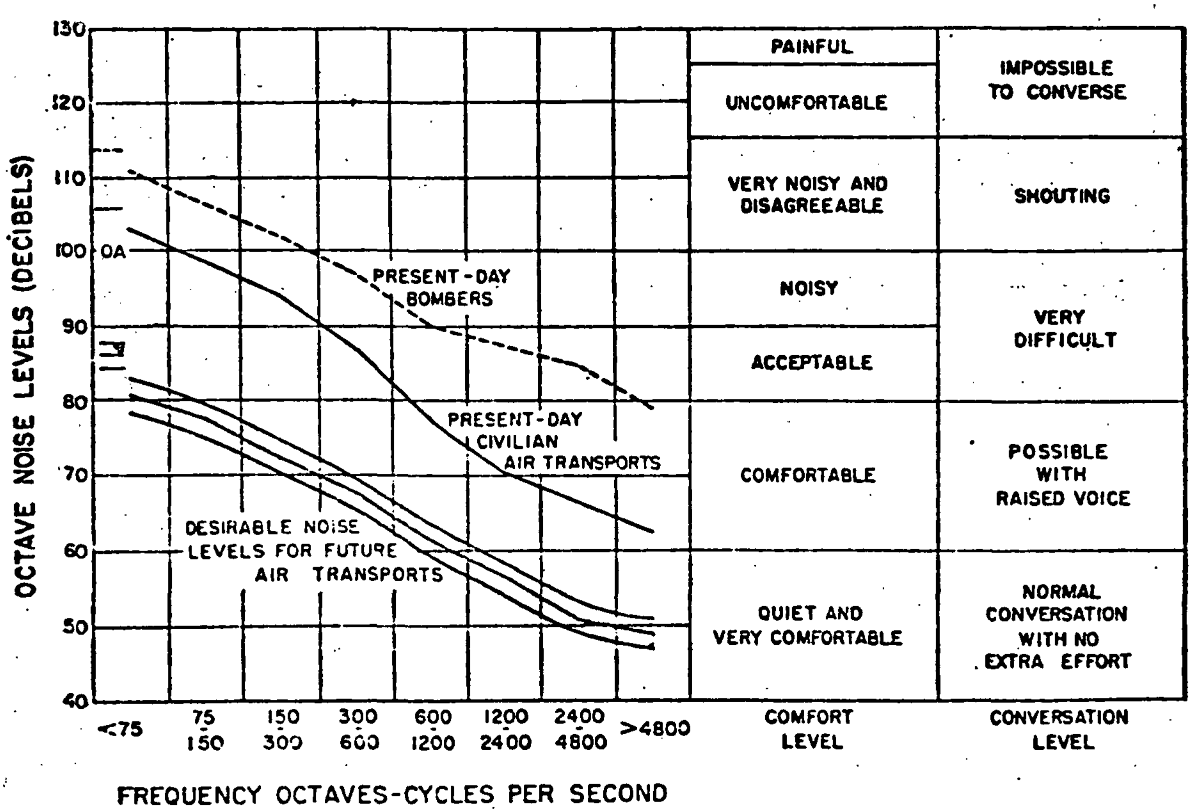

Figure 16. Average noise levels for contemporary aircraft compared with desirable levels. The comfort and conversation (at a distance of 3 ft.) levels of military and civilian aircraft are much higher than the desirable levels for commercial air transports. (From Reference 3).

Comfort	1
Acceptable	2
Noisey	3
Annoying	4
Unacceptable	5

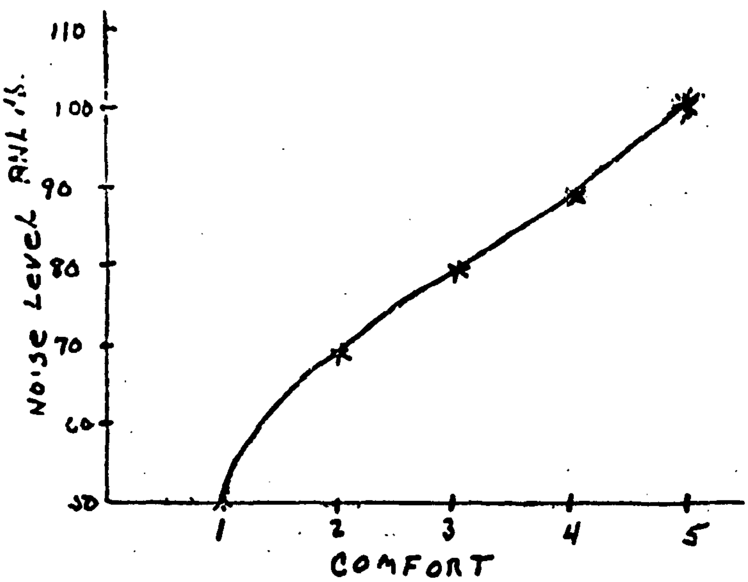

Figure 17. Comfort Scale

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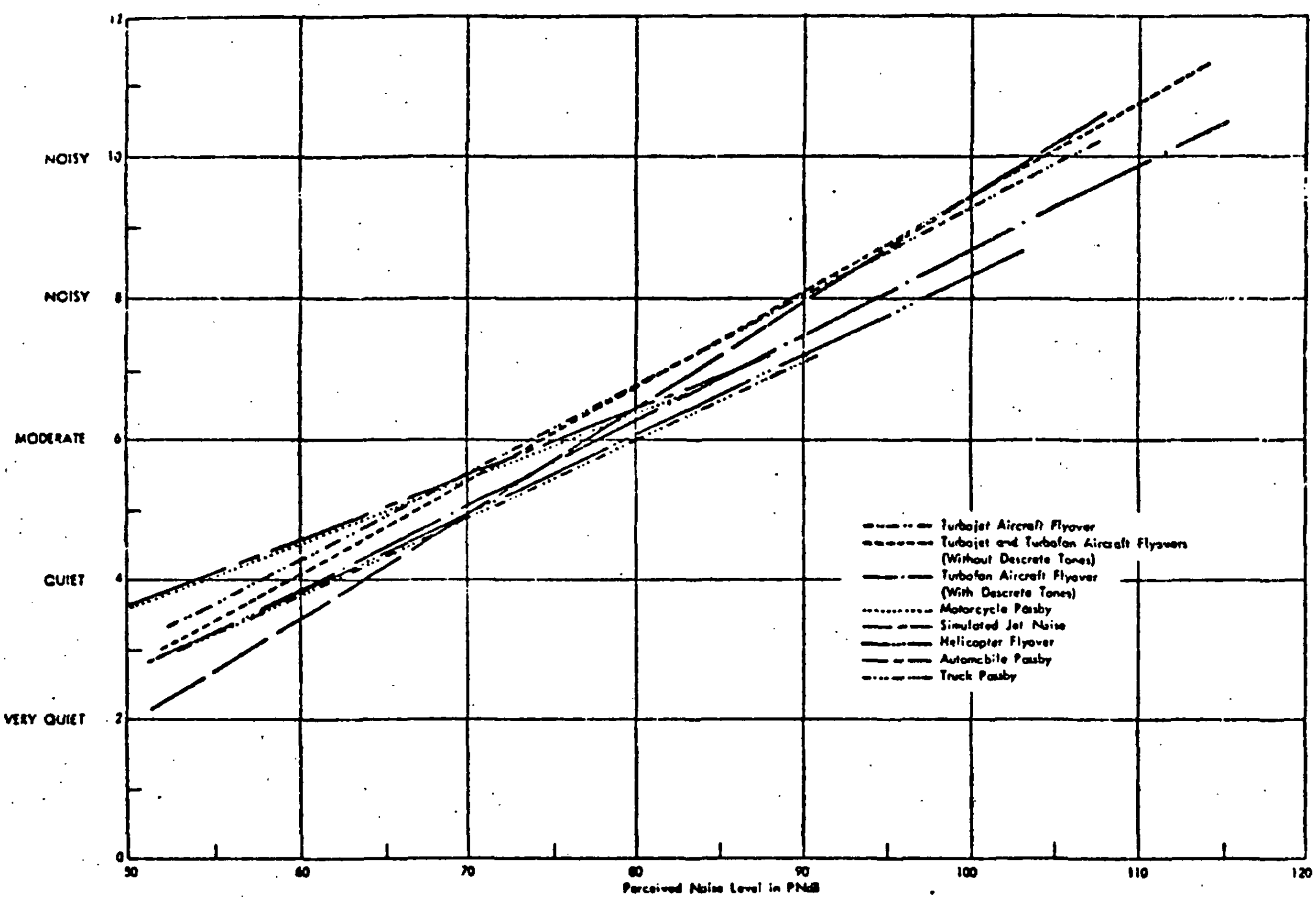

Figure 18. Mean noisiness rating vs. perceived noise level (adjusted for duration and discrete tone content) of noise stimulus groups for all laboratory test sessions.

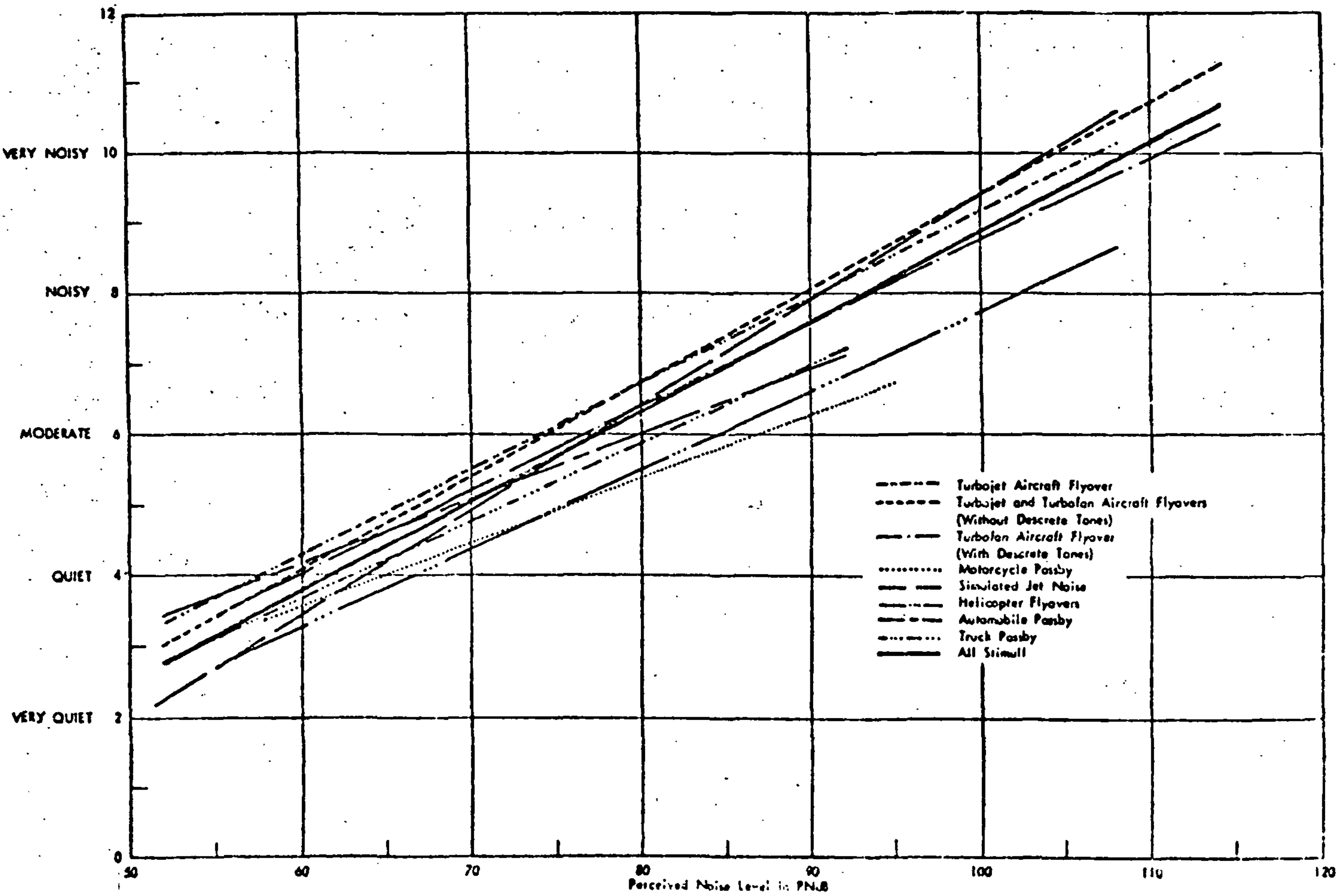

Figure 19. Mean noisiness rating vs. perceived noise level of noise stimulus groups for all laboratory test sessions.

D. Bibliography

An extensive bibliography can be found in Kryter, K. D. "The Effects of Noise on Man," Academic Press, 1970. These will not be repeated here.

1. Alford, B. R., Jerger, J. F., Coats, A. C., Billingham, J., French, B. O. and McBrayer, R. O. "Human Tolerance to Low Frequency Sound," presented at the 7th Annuel Session of the American Academy of Opthalmology and Otolaryngology, project supported by NASA, Contract NAS 9-2468, Chicago, November 14-19, 1965.

2. Arkadyevskiv, A. A. "Combined Effect of Vibration and Noise on the Human Organism," WPAFD, Ohio, Foreign Technology Division, Air Force Systems Command, AD 415672, Oigiyena i Sanitariya, No. 10, 1962, 25-28. (prepared by Translation Division Foreign Technical Division).

3. Bolt, Beranek, and Newman, Inc., Cambridge, Ma. "Some Factors Influencing Human Response to Aircraft Noise: Masking of Speech and Variability of Subjective Judgements," FAA-ADS-42, IR-15387, AD-617 935, June 1965, 72 pp.

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CHAPTER 3

TEMPERATURE

A. General

In any investigation into the effects of temperature one is confronted with a great number of variables. One must decide which of these variables to include in his investigation. If one considers only the physical variables directly connected with temperature, there still remain many complex interactions of these variables. This is the cause of so much variation in the research that has been conducted in this area. Also, due to the large number (figure 1 (16)) and complexity of interaction among variables there has been little progress in the effort to write a thermal comfort equation.

There exist three main methods for heat exchange between the environment and the human body. These are evaporation, convection and radiation, and each is affected differently by the various physical factors. (figure 2(21)).

Another problem encountered in trying to write an equation to predict the thermal comfort is that under ideal conditions there will be some people who will not be comfortable. It has been found that a maximum of 80 percent of the people can be comfortable under the best conditions (16, 17). This problem is caused by individual differences in heat production, body size, age, sex, clothing and other lesser physiological factors as represented in figure 3(1). Thus, any standards developed for thermal comfort deal with this percentage instead of with all persons.

There has only been one widely used standard developed that sets limits on all the physically changeable variables, that is the ASHRAE Standard 55-66 (figure 4 and 5). The use

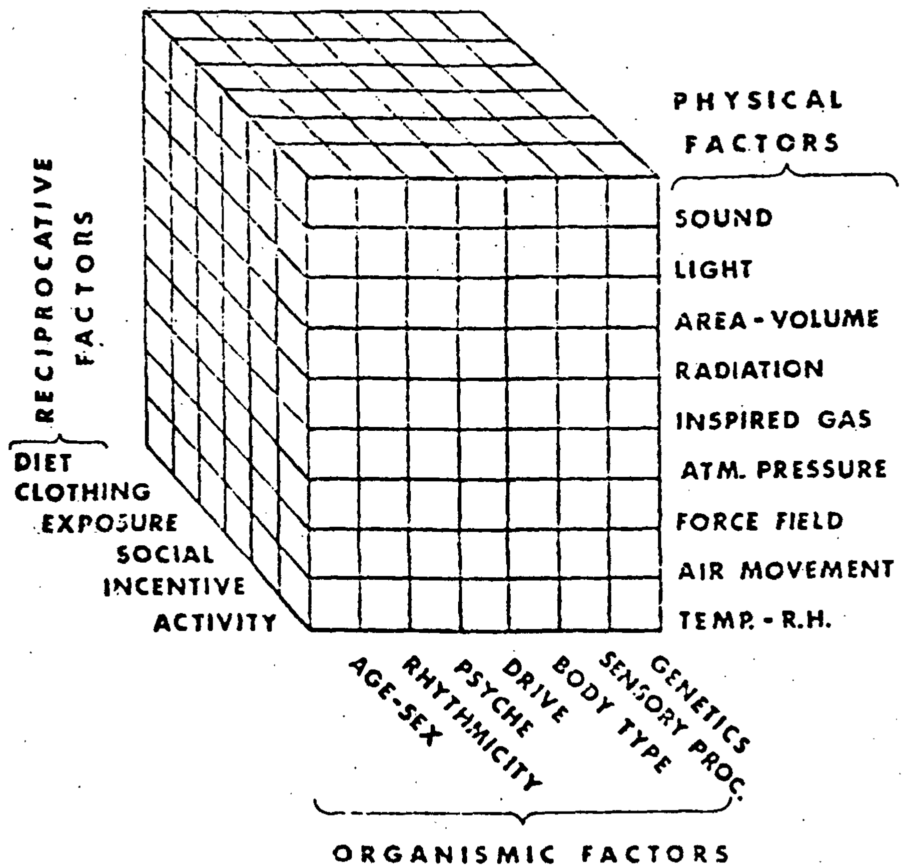

Figure 1. Three-dimensional representation of various factors to be accounted for in seeking thermal comfort.

Physical Factors	Evaporation	Convection	Radiation
Air Temperature	+	+	
Air Movement	+	+	
Relative Humidity	+		
Mean Radiant Temperature			+
Body Area		+	
Effective Radiant Area			+
Area of Evaporative Surface	+		
Mean Skin Temperature		+	+
Available Moisture for Evaporation	+		

Figure 2. Methods of heat exchange and their governing Physical Factors

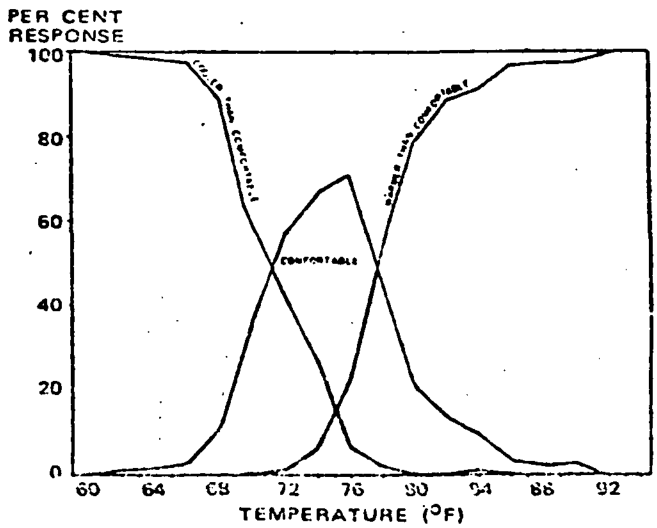

Figure 3. Result of test to determine range of satisfaction with ambient temperatures.

ASHRAE STANDARD 55-66

This standard specifies the environmental conditions that will provide year-around thermal comfort for most people, normally clothed, engaged in sedentary or near sedentary activities. The limits on the specifications have been based on the current state of knowledge of environmental physiology, comfort research and commercial practice. This standard replaces the Code of Minimum Requirements for Comfort Air Conditioning (1938).

Section 1.0 Purpose and Scope

1.1 This standard specifies desirable and generally acceptable thermal environmental conditions for comfort of sedentary and slightly active, healthy and normally clothed people in the United States and Canada.

1.2 This standard does not specify the non-thermal environmental factors such as ventilation rates, noise, illumination, etc.

Section 2.0 Definitions

2.1 Air Conditioning-the process of treating air so as to control simultaneously its temperature, humidity, cleanliness, and distribution to meet the requirements of the conditioned space.

2.2 Thermal Comfort-that condition of mind which expresses satisfaction with the thermal environment.

2.3 Thermal Environment-those characteristics of the environment which affect the heat exchange of people. They are air temperature, humidity, and velocity and surface temperatures.

2.4 Comfortable Thermal Environment-an environment in which at least 80% of normally clothed men and women living in the United States and Canada while engaged in indoor sedentary or near sedentary activities would express thermal comfort. (See Chapter on Physiological Principles in the ASHRAE Guide and Data Book.)

2.5 Dry-Bulb Temperature-the temperature of a gas or mixture of gases indicated by an accurate thermometer after correction for radiation.

Figure 4. ASHRAE Standard 55-66.

2.6 Wet-Bulb Temperature-thermodynamic wet-bulb temperature is the temperature at which liquid or solid water, by evaporating into air, can bring the air to saturation adiabatically at the same temperature. Wet-bulb temperature (without qualification) is the temperature indicated by a wet-bulb psychrometer constructed and used according to specifications.

2.7 Relative Humidity-the ratio of the mol fraction of water vapor present in the air to the mol fraction of water vapor present in saturated air at the same temperature and barometric pressure; approximately, it equals the ratio of the partial pressure or density of the water vapor in the air to the saturation pressure or density, respectively, of water vapor at the same temperature.

2.8 Mean Radiant Temperature (MRT)-the temperature of a uniform blank enclosure in which a solid body or occupant would exchange the same amount of radiant heat as in the existing non-uniform environment.

2.9 Air Velocity-a quantity which denotes the instantaneous time rate and direction of air motion.

2.10 Occupied Zone-the region within a space between a level 3" above the floor and the 72" level and more than 2' from the walls or fixed air-conditioning equipment.

Section 3.0 Environmental Conditions for Thermal Comfort

3.1 Dry-Bulb Temperature

3.1.1 The dry-bulb temperature shall be between 73 and 77° F at any point within the occupied zone, and at any time, when MRT is approximately equal to the dry bulb temperature.

3.1.2 The dry-bulb temperature may exceed the range given in 3.1.1 if necessary to provide compensation for MRT deviations as specified in 3.3.

Figure 4. ASHRAE Standard 55-66.

3.1.3 The rate of change of dry-bulb temperature at any point in the occupied zone shall not exceed 4 deg/hr if the peak to peak variation in the temperature cycle is two or greater within the limits stated in 3.1.1.

3.2 Relative Humidity

3.2.1 The relative humdity shall not exceed 80 percent at any point in the occupied zone. (For many reasons other than for thermal comfort, the relative humidity should not fall below 20 percent.)

3.2.2 The rate of change of relative humidity at any point in the occupied zone shall not exceed 20 percent/hr if the peak to peak variation of the humidity cycle is 10 percent or more within the limits stated in 3.2.1.

3.3 Mean Radiant Temperature

3.3.1 When the mean radiant temperature in the occupied zone differs from the dry-bulb temperature, the dry-bulb temperature shall be reduced 1.4 F for each 1.0 F mean radiant temperature elevation above air temperature and vice versa.

3.3.2 The MRT correction shall be considered applicable only for mean radiant temperatures between 70 and 80 F.

3.3.3 When excessive local radiant effects are present from surfaces which are considerably above or below the room air temperature, compensation shall be provided.

3.3.4 The rate of change of mean radiant temperature at any point in the occupied zone shall not exceed 3 deg/hr if the peak to peak variation of the MRT cycle is 1.5 F or more, within the limits stated in 3.3.3

3.4 Air Velocity

3.4.1 The air motion in the occupied zone shall not exceed 45 fpm and shall not be less than 10 fpm at any time.

Figure 4. ASHRAE Standard 55-66

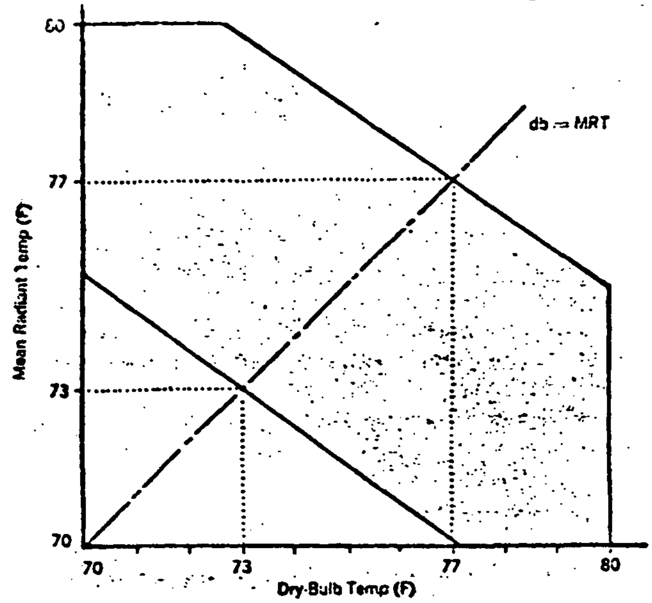

Figure A. The shaded area shows the permissible "comfort zone" relating dry-bulb air temperature and mean radiant temperature.

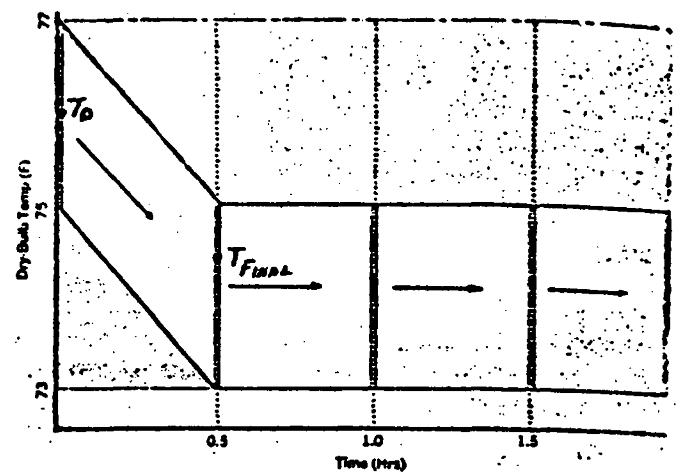

Figure B. The light area shows the permissible "comfort zone" of dry-bulb air temperature as it changes as its fastest rate with time at a single location in the occupied zone, when the dry-bulb air temperature is equal to the mean radiant temperature at time zero (shaded area comfort zone, white area is maximum rate of change).

(Figure 5. Graphical Representation of ASHRAE Standard 55-66)

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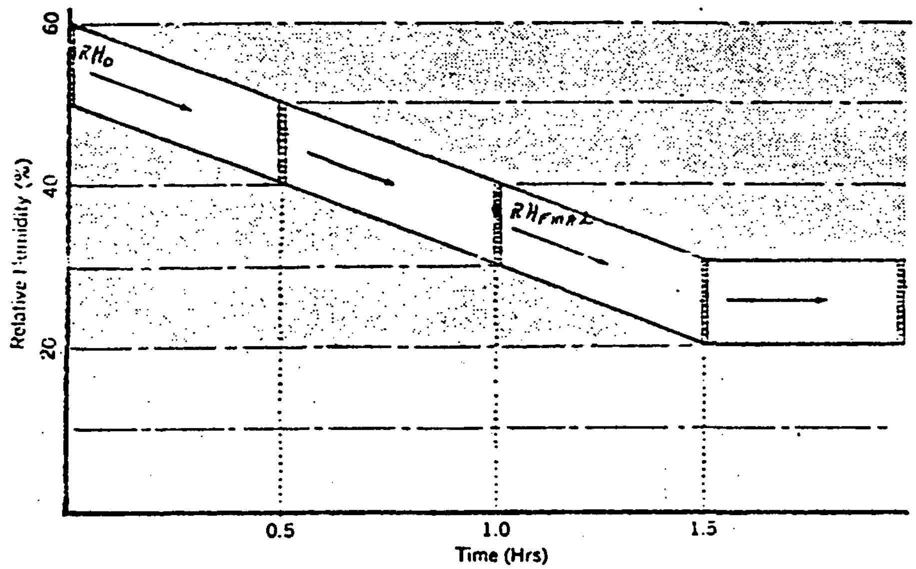

Figure C. The light area shows the permissible "comfort zone" of relative humidity as it changes at its fastest rate with time at a single location in the occupied zone (shaded area comfort zone, white area is maximum rate of change).

(Figure 5. Graphical Representation of ASHRAE Standard 55-66)

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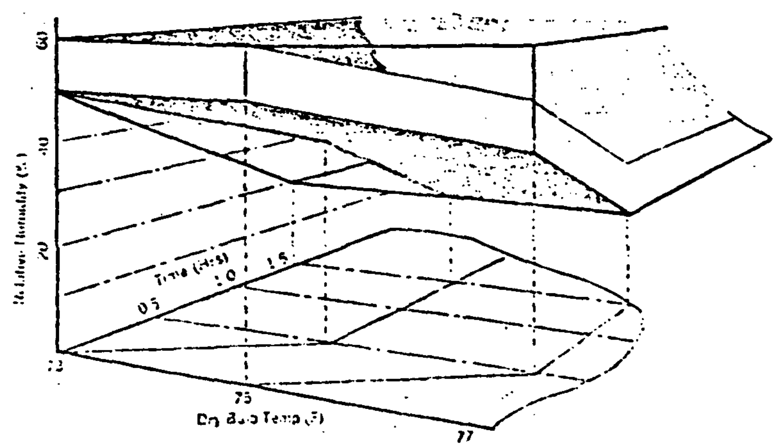


Figure D. Permissible "comfort zone" when both dry-bulb air temperature and rh change at their fastest rate with time.

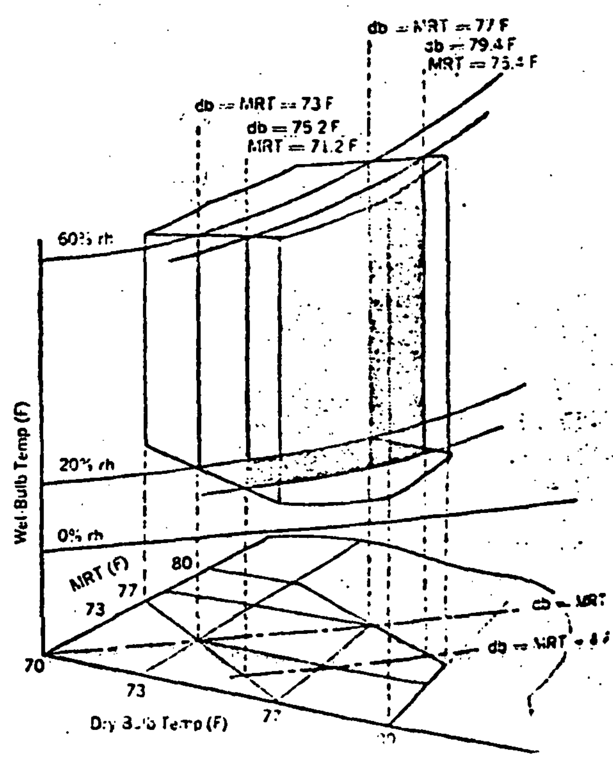


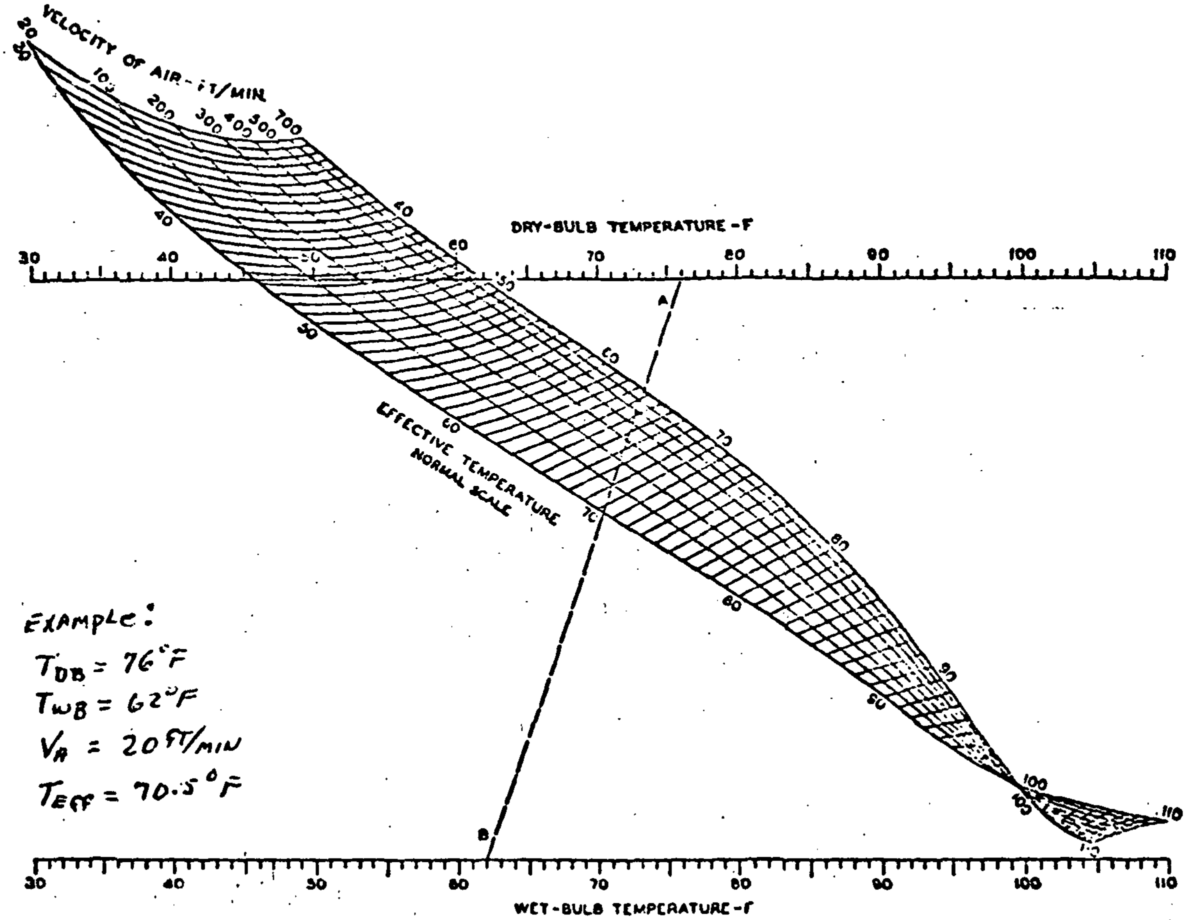
Figure E. The permissible "comfort zone" is represented by any combination of dry-bulb air temperature, mean radiant temperature and rh which falls within the truncated hexagonal parts shown, any time, at any point in occupied zone.

(Figure 5. Graphical Representation of ASHRAE Standard 55-66)

of this standard still remains very limited since it assumes that the subject is initially at thermal equilibrium with the environment. There has been some disagreement with the actual limits imposed by the standard (12, 20). Thus, many efforts have been directed at updating the 55-66 Standard rather than at trying to develop a new standard.

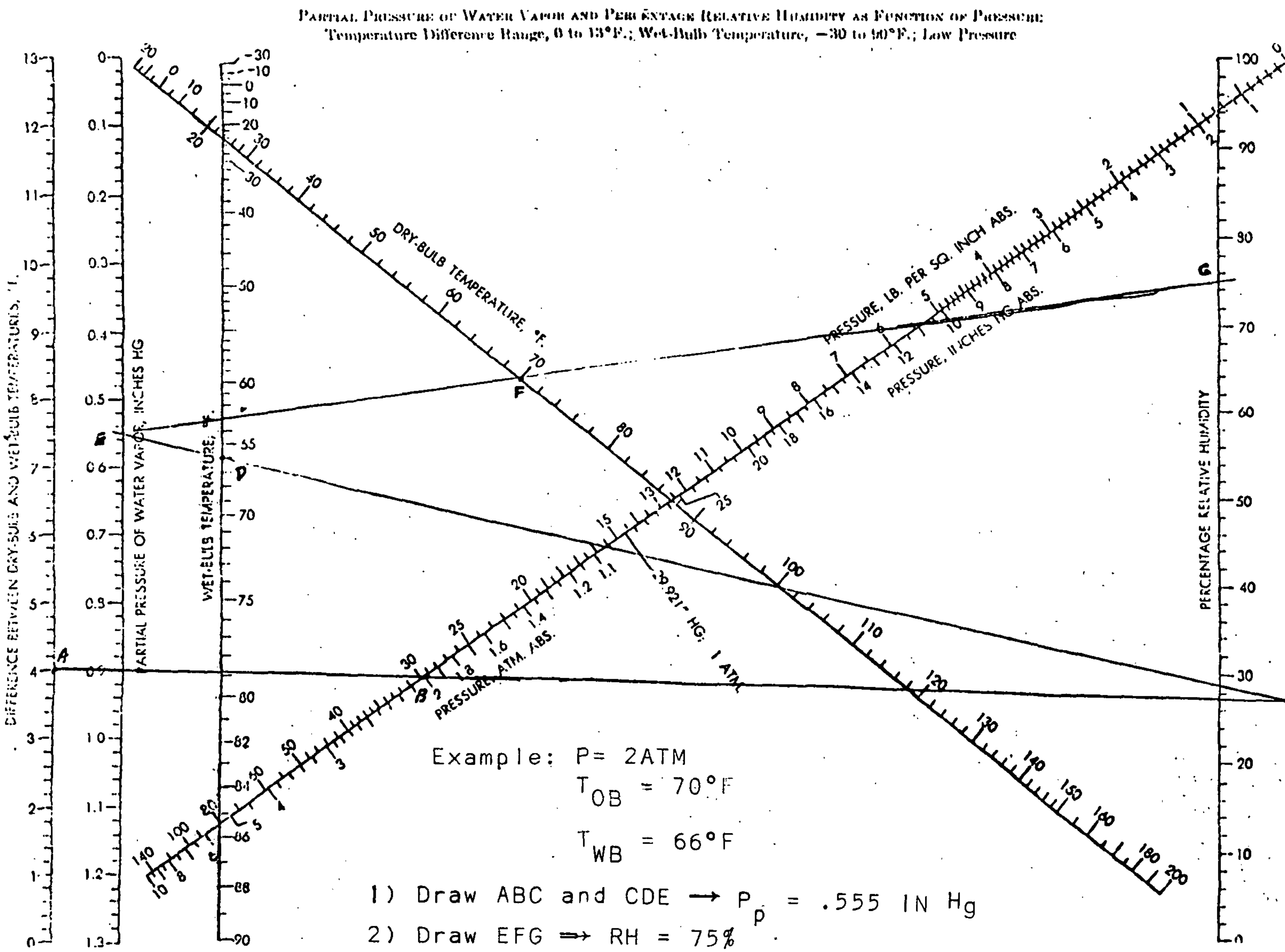
The efforts toward the building of a completely new standard stem from efforts to devise new methods for describing the thermal environment. This arises from the dependence of dry-bulb temperature, relative humidity, atmospheric pressure, wet-bulb temperature and ventilation rates. This interdependence of the variables is usually shown in monogram form, (figures 6, 7, 8, (1, 22, 29) and the effective temperature is then used in correlation with comfort of the subjects. Some of the efforts to relate comfort to the effective temperature are shown in figure 9 (1) which includes changes from winter to summer zones. This effort appears to have a bias to dry-bulb temperature and high percentage of comfort over a wide range of temperature which seems unfounded due to the lower percentages found in other research reports.

The insulating effects of clothing is another important factor which has entered into more recent studies, and which makes many previous studies practically useless, e.g., Weslow and Herrington (21) did a great deal of work using nude test subjects, but due to this condition their results cannot be readily applied. Seppanen, McNall, et al., (18) have done a recent survey on the insulating effects of different types of clothing. Also, they found that the clothing factor for men varies from .48 to 1.00 (clo) while range for women varies from .21 to 1.00 (clo) (figure 10), but that the average for both men and women falls at about .6 (clo) for yearly coverage.



A. Clothing: Customary indoor clothing. B. Activity: Sedentary or light muscular work. C. Heating Methods: Convection type, i.e., warm air, direct steam or hot water radiators, plenum systems.

Figure 6. Effective temperature chart showing normal scale of effective temperature, applicable to inhabitants of the United States under conditions stated.



Example: P= 2ATM
T_{OB} = 70°F
T_{WB} = 66°F

1) Draw ABC and CDE ⟶ P_p = .555 IN Hg
2) Draw EFG ⟹ RH = 75%

Go to Figure 8

Figure 7. Monogram for computing moisture content and temperature of air..

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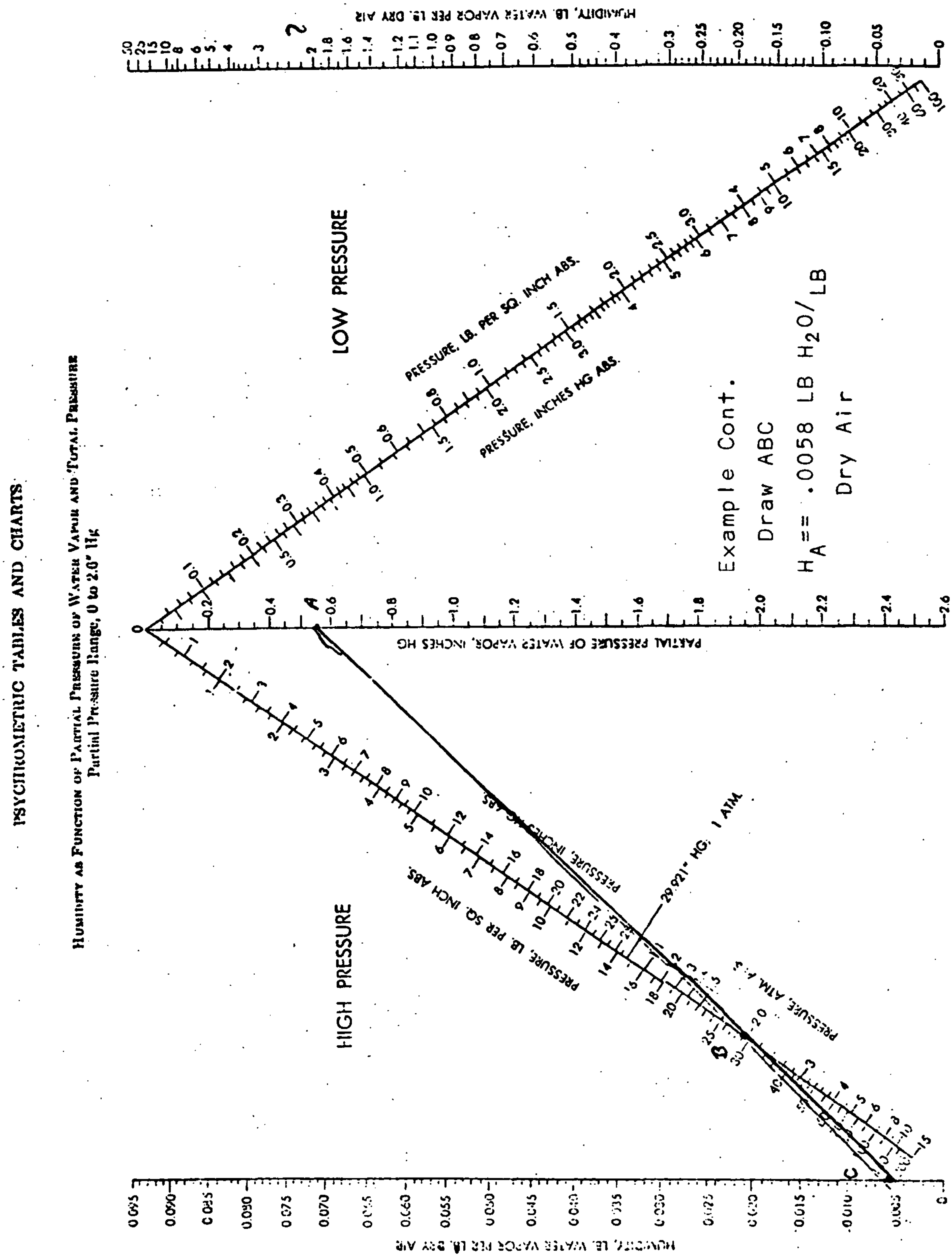

Figure 8. Monogram for computing pounds water vapor in air for given partial pressure.

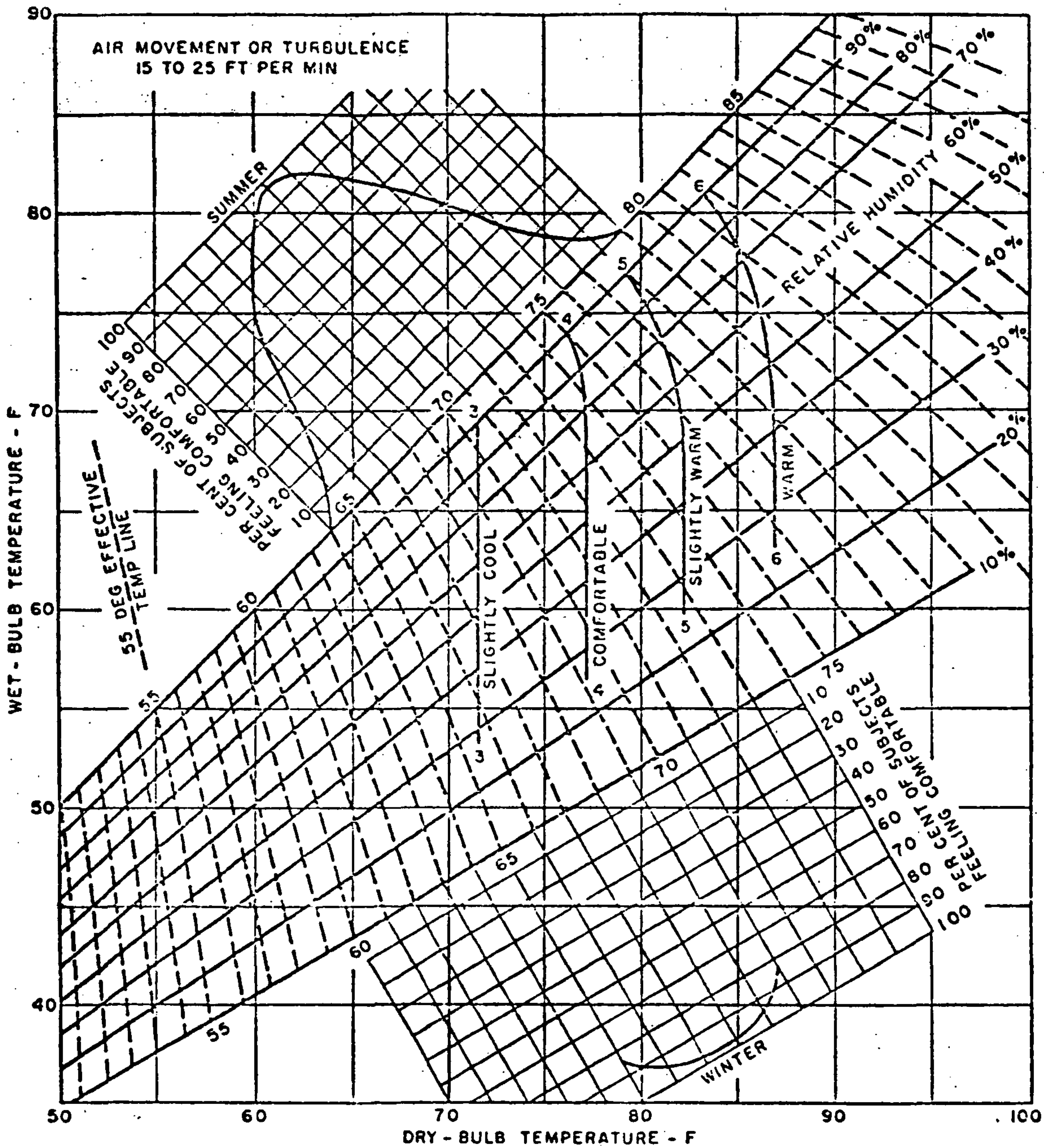

Figure 9. Revised ASHRAE comfort chart.

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Also, the effects of various air velocities on the effective clothing factor was investigated in the same study (figure 11, 12). Their average value of 0.6 (clo) has been used in other research (4). Another effort in the same area, but using a different approach was conducted by Nishi and Gagge (14). They worked with the permeation efficiency of water vapor for various clothing factors and at different air velocities. Their findings are more applicable for use in a mathematical model of a human subject than in actual field studies (see 4).

The effects of radiant energy exchange have been investigated in two noteworthy studies. Chrenko (3) studies the effects of hot floor surfaces on the comfort of test subjects. His method was to relate the floor temperature and the temperature of the soles of test subjects feet to the comfort of the subject. He found that for a comfortable response (vote) of the test subject the floor temperature could not exceed 77° F. He ends his report with a recommendation of a maximum value of 75° F for marginal considerations. The other study, McNall and Bibbison (11) produced a wider range of results.

The conditions that they investigated included hot and cold walls, and hot and cold ceilings. The neutral zone for radiant temperatures for various dry-bulb temperatures that they developed is shown in figure 13. The percentages of comfort votes for each series of test varied from 60 to 80% (see figure 14 for actual statistics). The results of all their tests were used for developing an equation for describing the thermal sensations for different radiant fields, (these results are tabulated in Table 4). There is only one point that decreases the reliability and validity of this study; they only used college age test subjects, thus the age factor is not included in the results.

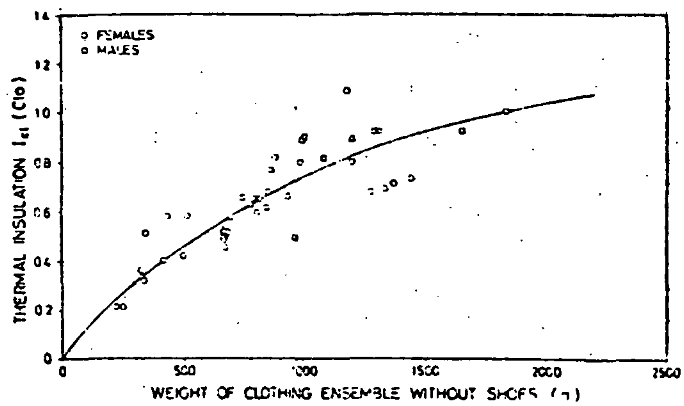

Figure 10. The thermal insulation value as a function of the weight for the different clothing ensembles tested in the present study at KSU.

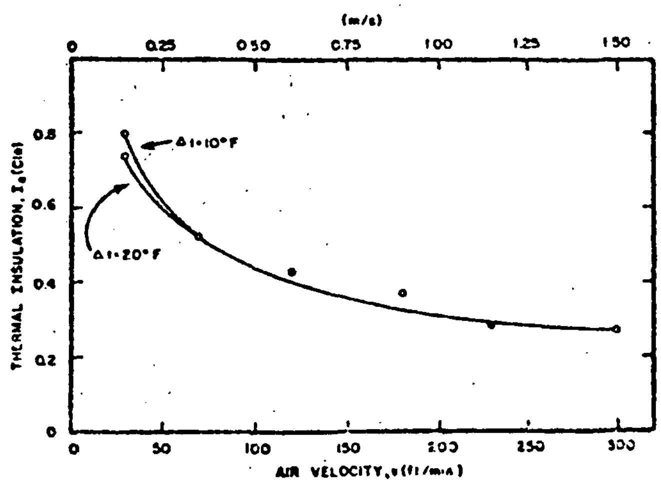

Figure 11. Effect of air velocity on I_a for nude manikin.

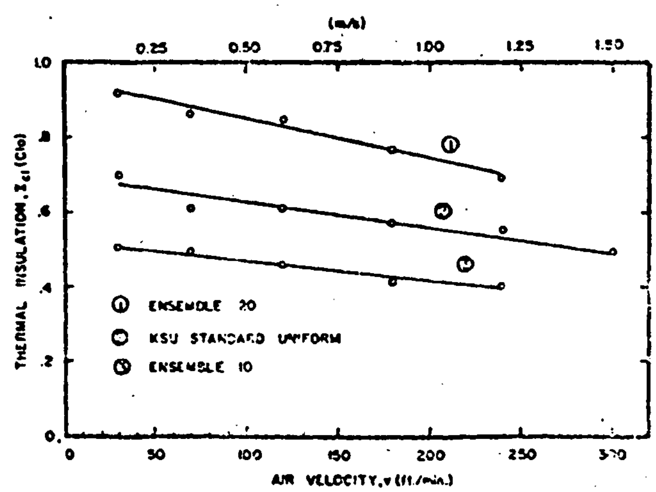

Figure 12. Effect of air velocity on I_{ct} for the KSU standard uniform and emsembles 10 and 20 from Table VII.

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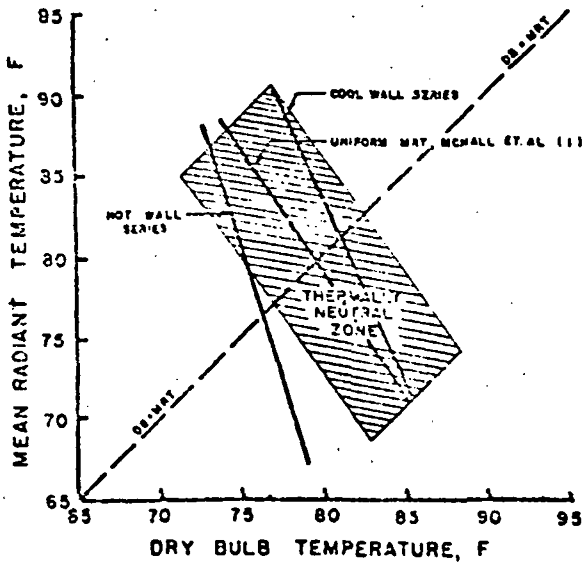

Figure 13. Lines of predicted thermal "neutrality" for the males and females of the cool and hot wall series and the uniform MRT series.

TABLE 4

REGRESSION EQUATION VALUES USED IN PREDICTING THE THERMAL SENSATION OF SEDENTARY SUBJECTS AND SUPPORTIVE STATISTICS

MODEL: $Y = Y + b_1 (t_a - \bar{t}_a) + b_2 (t_{mrt} - \bar{t}_{mrt})$

SERIES	SEX	EQ.	$\bar{Y}$	$\bar{t}_a$	$\bar{t}_{mrt}$	b_1	t_{b_1}	s_{b_1}	b_2	t_{b_2}	s_{b_2}	R^2	$s_{y.t_a, t_{mrt}}$	$\frac{b_1}{b_2}$	NO. OF SUB.
Uniform MRT	M+F	1	4.00	78.88	81.01	0.111	14.65***	0.009	0.077	8.75***	0.009	0.643	0.712	1.43	106
	M		4.03	78.88	81.01	0.099	8.16***	0.012	0.066	5.67***	0.012	0.629	0.651	1.51	80
	F		3.99	78.88	81.01	0.122	8.61***	0.014	0.088	6.53***	0.014	0.688	0.761	1.37	80
Cool Wall	M+F	2	3.97	80.69	80.77	0.121	8.87***	0.014	0.056	3.73***	0.015	0.637	0.747	2.16	100
	M		3.90	80.77	80.83	0.076	4.90***	0.015	0.040	2.34*	0.017	0.541	0.588	2.11	50
	F		4.03	80.61	80.70	0.165	8.72***	0.019	0.072	3.44**	0.021	0.773	0.739	2.32	50
Hot Wall	M+F	3	4.49	79.53	79.94	0.124	6.36***	0.020	0.035	1.68	0.021	0.521	0.857	–	70
	M		4.44	79.49	79.97	0.054	2.21*	0.024	0.058	2.39*	0.024	0.398	0.764	0.93	35
	F		4.54	79.57	79.90	0.194	7.49***	0.026	0.009	0.29	0.030	0.715	0.800	–	35

R^2 = Square of the Multiple Linear Correlation Coefficient

s_{b_i} = Standard Error of b_i

t_{b_i} = t Ratio = $\frac{b_i}{s_{b_i}}$

$s_{y.t_a, t_{mrt}}$ = Standard Error of Y for Given Values

Y = Thermal Sensation, ($\bar{Y}$ = mean Y)

t_a = Air Dry Bulb Temperature, ($\bar{t}_a$ = mean t_a)

t_{mrt} = Mean Radiant Temperature, ($\bar{t}_{mrt}$ = mean t_{mrt})

* = Significant at the 5% Probability Level

** = Significant at the 1% Probability Level

*** = Significant at the 0.1% Probability Level

b_i = Regression Coefficient

The effects of periodic fluctuations in the environmental variables has had very little research devoted to it. The only information available in this area are the ASHRAE Standard 55-66 and the research of Sprague and McNall (20). The research conducted by Sprague and McNall do not agree with that of the ASHRAE Standard. They studied the effect on comfort of both various periods and various amplitudes of fluctuating temperature (dry-bulb) and relative humidity.

Their results were given in comparison with the ASHRAE Standard as seen in figures 14-19. The same defect exists in this study as in that conducted on the radiant temperature investigation, the ages of the test subjects were all in the range of 20.5 years to 25 years of age. For this reason, the good points raised in the test are over-shadowed by this and since the only comparable results are those of the ASHRAE Standard it is felt that further research is needed to establish which of the limits should be followed. At best, the most strict part of both limits should be used.

If one prefers to use only a limited number of the variables used for describing the thermal environment, there remains one method that has not previously been noted. This method of describing the thermal environment is the temperature-humidity index (originally called the discomfort index) which was devised by the U. S. Weather Bureau. The temperature-humidity index, is found using the equation
T-HI = .4 (T_{DB} + T_{WB}) + 15.0, where T_{DB} and T_{WB} are the dry and wet-bulb temperatures in °F, has been used as a comfort scale. Most persons will be uncomfortable if the T-HI exceeds 79 and values of 86 are considered extreme (5).

The ventilation rates required for comfort have received little research along the limits imposed by the ASHRAE Standard which gives maximum and minimum values of 45 and 10 feet per minute respectively, and the Heating, Ventilating and Air

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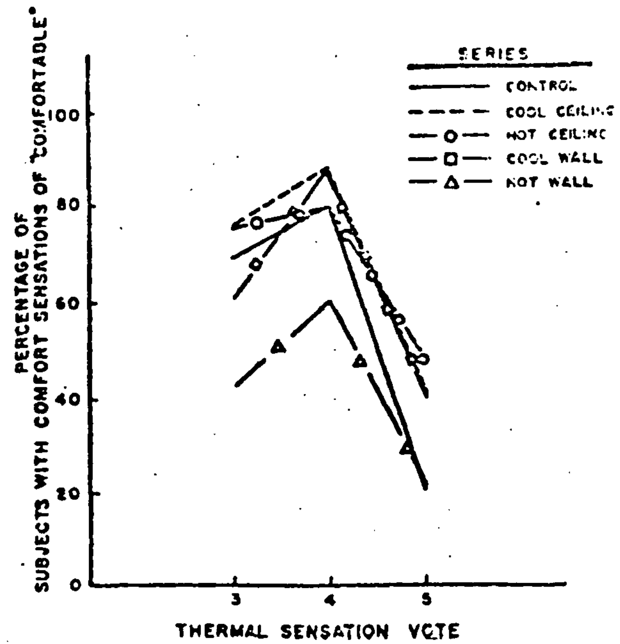

Figure 14. The distribution of comfort sensation votes of "comfortable" within the thermal sensation votes for sedentary subjects of all series conducted.

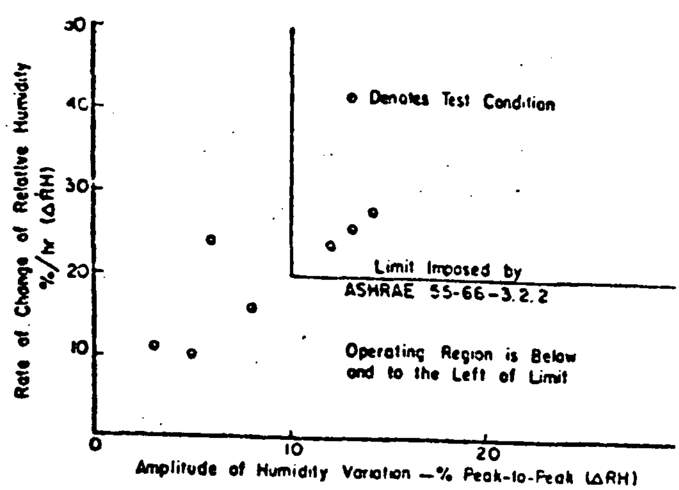

Figure 15. Test conditions for fluctuating humidity tests compared to the ASHRAE 55-66 Standard.

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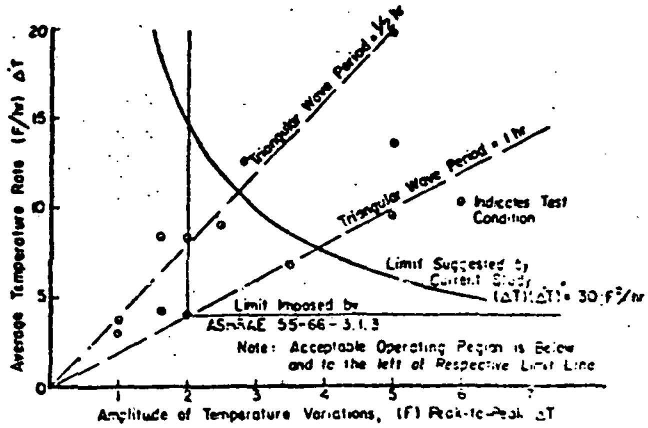

Figure 16. Test conditions and suggested thermal comfort limits limits for fluctuating temperature tests compared to the ASHRAE Standard 55-66.

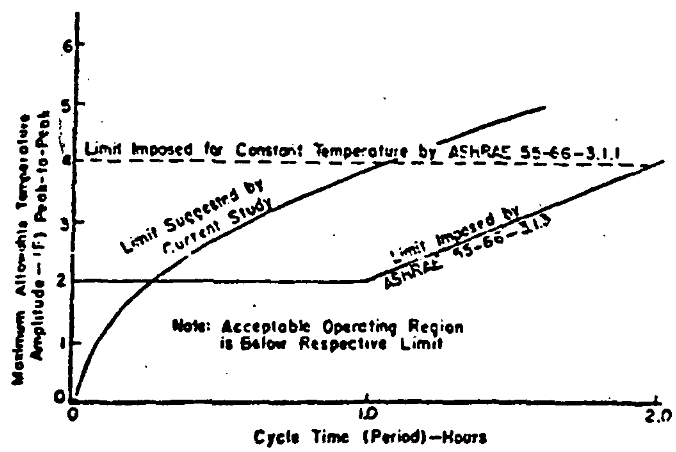

Figure 17. Suggested maximum temperature amplitude for thermal comfort versus cycle time for triangular wave temperature variations.

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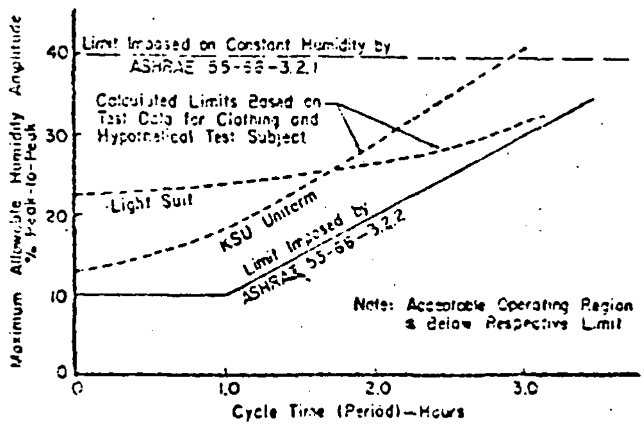

Figure 18. Suggested maximum humidity amplitude for thermal comfort versus cycle time for triangular wave humidity variations.

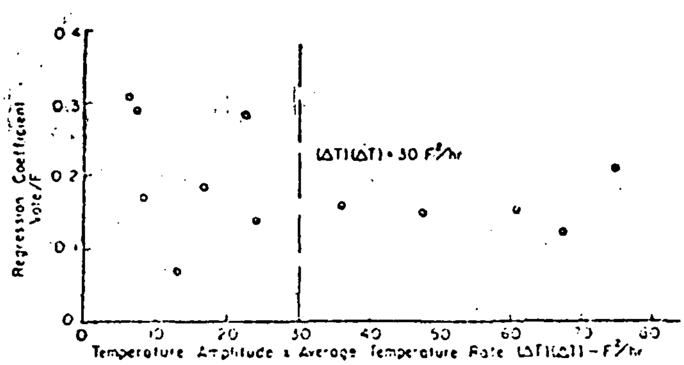

Figure 19. Regression coefficient (vote with temperature) versus temperature amplitude times average temperature rate for the fluctuating temperature tests.

Conditioning Handbook (8), which gives 15 feet per minute, minimum, and a maximum of 'less than drafts.' The values used in most researches investigated were from 20 to 25 feet per minute.

The efforts to describe man's thermal comfort started with the use of skin temperature and the relating factors. But due to the difficulty of determining the mean skin temperature for large groups of test subjects, other methods were later used. The use of skin temperature did have a relatively simple relation to comfort (21), so there have been recent efforts by Gagge, et al., (4) to relate back to this variable in a thermal environment study. Gagge, et al., built a mathematical model for a sedentary clothed man and wrote a computer program (see 4) that describes the thermal state of a test subject at the end of a one hour exposure. This model has a great number of advantages since it can be used for different metabolic rates, temperatures, humidities, clothing factors and other factors by making small changes in the program. The program could stand revisions to allow for changes in radiant temperature (it assumes radiant temperature equals dry-bulb temperature). The results from their program can be seen in figures 20, 21, 22, and 23. In figures 22 and 23 one again sees the effective temperature, but with slight modifications dealing with skin wetness.

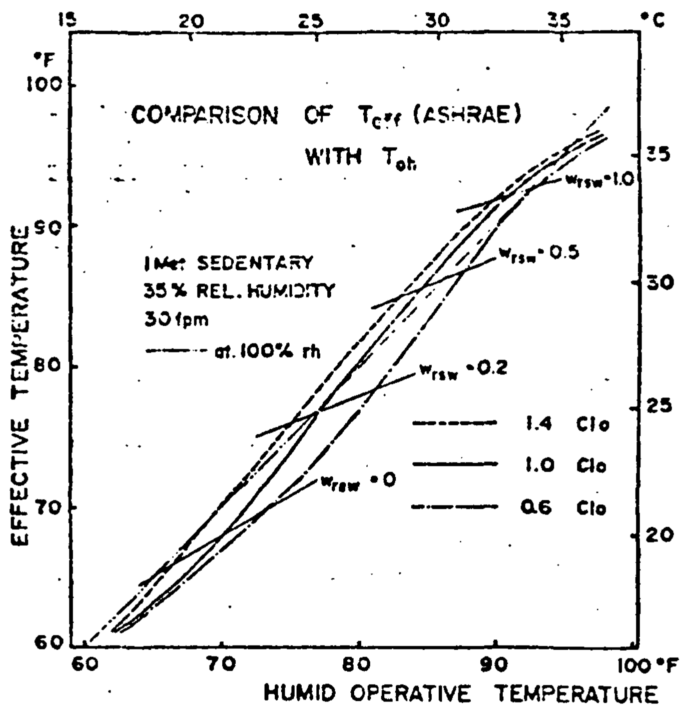

Figure 20. A comparison of the predicted human operative temperature with the current ASHRAE effective temperature scale for various clothing insulations.

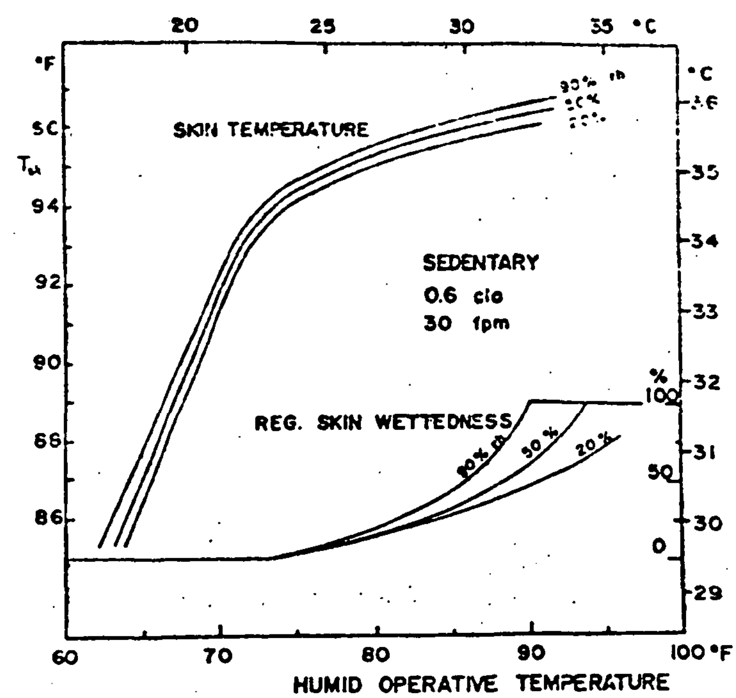

Figure 21. The relationship between skin temperature, regulatory skin wettedness, and humid operative temperature as predicted by our model.

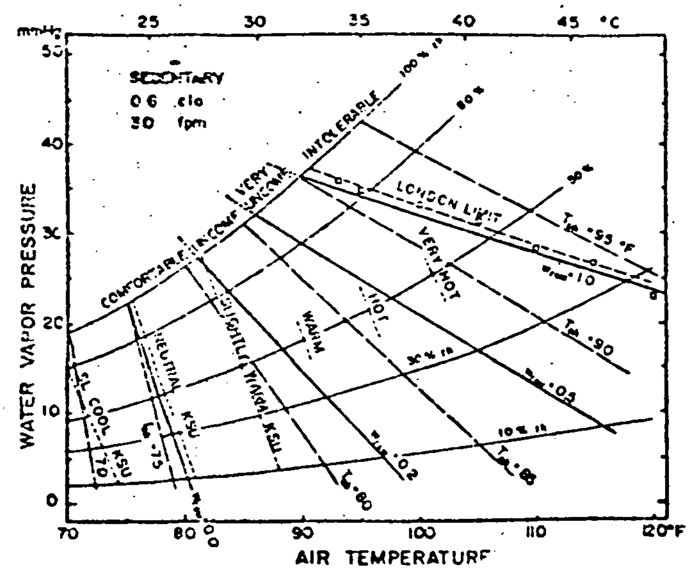

Figure 22. Loci of constant humid operative temperature and of constant wettedness are compared with KSU measurement of temperature sensation, the Pierce Laboratory observations of warm discomfort, and the "London" limit for heat tolerance.

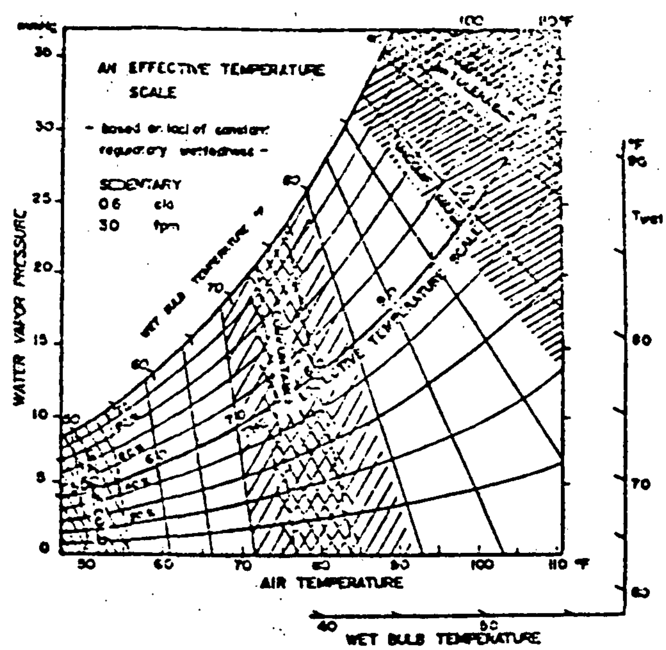

Figure 23. A new effective temperature scale based on loci of constant wettedness caused by regulatory sweating. The lightly shaded zone on the left represents "uncomfortably warm." The heavily shaded area is tolerable only for limited periods of exposure. This chart is drawn over the corresponding section of ASHRAE Psychrometric chart = 1.

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CHAPTER 4

PRESSURE

A. General

The investigation into the effects of atmospheric pressure and its time rate of change suffered from a lack of information since so little work has been done in this area in regard to comfort. Most of the information available on pressure deals with the critical pressures at which protective measures must be taken. These critical points and the ideal points are used to note possible ranges in the comfort zone. The major problem in stating limits on the pressure comfort zone arise from the fact that the zone changes for persons who are acclimated to different initial pressures; that is, a person living at sea level and a person living at an altitude of 3,000 feet would have different zones in which they would feel comfortable. In this paper, the initial condition is taken as sea level and any variation in this in a field study would induce a raising of critical points.

The critical altitude, at which point safety measures must be started, is established as being between 10,000 feet and 14,000 feet, when oxygen must be supplied. The reason is that the oxygen supply to the blood is decreased to the point of 85 percent saturation (2) which leads to dizziness in most sedentary persons. Most pressurized aircraft maintain a pressure differential that enables them to have a cabin pressure equal to less than 7,000 feet (5). These pressurized aircraft use the critical altitude pressure (14,000 feet for the Boeing 707) as the starting point for safety measures in cases of decompression in flight (4). In cases of decompression, the flight may be continued at 9,000 feet without ill effects on passengers. In cases where any exertion is taking place, these limits may be lowered (1), but since this paper deals with sedentary persons, this aspect of the problem was not investigated further.

B. Proposed Criterion

The critical limit at which discomfort becomes intolerable appears to be placed at an altitude of 10,000 feet and the ideal comfort altitude at sea level. The first major change between these points appears at an altitude of 5,000 feet where some people are affected by the oxygen deficiency (2). The next critical point appears at 6,500 feet which is indicated by ventilation and pulse increase. Other limits have been set for various medical illnesses (5). These altitudes include 6,000; 8,000; and 14,000 feet, at which point oxygen or pressurization becomes necessary.

These limits seem to establish a scale on which comfort could be measured, but lacking more detailed information, it is only a guideline for further study.

The time rate of change of pressure is an area in which a great deal of disagreement arises in its effects on comfort. One reason for this disagreement arises from the fact that rates of pressure change are given as rates of change in altitude. This leads to some misconception since a 100 foot change in altitude starting at sea level produces a greater pressure change than an equal altitude change starting at 1,000 feet above sea level. Present standards for the rate of change of pressure are given at a 300 foot per minute descent and a 500 foot per minute ascent for commercial aircraft (6). The unbearable point is stated by McFarland (3) as 1,000 feet per minute. McFarland also gives a luxury zone of from 0 to 100 feet per minute.

These critical points have been questioned, most notably by Waggoner (6), who stated that there was no difference found in a 700 foot per minute ascent and the recommended 300 and 500 foot per minute limits. Waggoner's studies were carried out for altitude changes from 0 to 7,500 feet. He did note, however, that persons instructed in methods of equalizing pressure differential in the ears had much less trouble than did persons not so instructed.

Since there is so little information in this area, the 300 feet per minute descent/500 feet per minute ascent should be followed until further investigations are made into the raising of these limits. A comfort scale in regard to time rate of change of pressure is not constructed since it would loose its usefulness due to the lack of sufficient data points.

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Both the figure and reference numbers are self-inclusive and refer only to the chapter in which they are cited.

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CONCLUSIONS

The research for this paper has shown a lack of necessary information for constructing reliable comfort equations using field and laboratory results only. The area of thermal comfort requires more work on building of a mathematical model of man to increase the practicability of determining the comfort equation. The effort to write comfort equations for pressure and noise requires additional field study and possibly the construction of a mathematical model of man's ear for study of both pressure and noise.

The comfort limits on the various parameters that were investigated are as follows:

	Vibration	Vertical direction, see Fig. 2 Chapter I Lateral direction, see Fig. 3 Chapter I
(1)	Dry-Bulb Temperature	Between 72 and 80° F when MRT equals dry-bulb temperature
	Rate of Change	Rate of change times change in dry-bulb temperature less than 30° F/hr with MRT constant and with period less than $\Delta T/\sqrt{15}$.
(2)	Relative Humidity	Between 25 and 60%
	Rate of Change	RH less than $45 \times \sqrt{\frac{1 + (2\pi \text{ Period}/2)^2}{2\pi \text{ Period}}}$ for light suit.
(3)	Mean Radiant Temperature	Between 85 and 70° F with higher values relating to lower dry-bulb temperatures.
	Rate of Change	Less than 3° F per hour with peak to peak variations greater than 1.5° F.
(4)	Air Velocity	Between 15 and 45 feet per minute.
(5)	Atmospheric Pressure	Less than 6,500 feet.

Rate of Change	300 feet per minute descent and 500 feet per minute ascent.
(6) Noise	Less than 80 decibels PNL with less than 90 decibels SPL in any octave band.

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