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[UNITED AIRCRAFT CORPORATION]

CHANCE VOUGHT AIRCRAFT
INCORPORATED · DALLAS, TEXAS

PHYSIOLOGICAL AND PSYCHOLOGICAL
CONSIDERATIONS FOR
MANNED SPACE FLIGHT

1 June 1959

A.B. Thompson
PREPARED
A. B. Thompson
Human Factors Project
Engineer

A.B. Thompson
CHECKED
A. B. Thompson

C O Miller
APPROVED
C. O. Miller
Chief of Operational
Factors

REVISIONS

DATE	REV BY	PAGES AFFECTED	REMARKS

FOREWORD

This data has been compiled in this format for use by engineers in the design of manned space vehicles. It represents the best available information to date on man's tolerances and requirements based on tests and analytical studies. An attempt has been made to give credit to the applicable sources of information wherever possible and numerous references are cited for those who desire further amplification of the basic data. Assisting in the collection of this information were Doctors A. H. Schwichtenberg, P. J. Clancy, R. O. Bowman, A. J. Latham, and Messrs. D. G. Starkey and J. E. Burke.

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I. INTRODUCTION

In order for the space vehicle pilot to be an effective component of the man-machine system, he must remain in an environment as near to his natural earth environment as it is possible to provide throughout the entire flight. Such an environment must not approach too closely his physiological limitations and must satisfy his needs in the fields of optimum workload, detachment, isolation, confinement, safety, and survival for the anticipated stresses and activities of an extraterrestial mission. To be able to define these needs, tolerances, and capabilities into values useful to the engineer for setting down design specifications for items of equipment for a space vehicle, an analysis of the various psychological and physiological stresses and deviations from earth environment has been programmed on a systematic basis. Definitions of specific requirements are presented in detail in the following sections in the order of their occurence on a typical orbital mission.

II. NOISE AND VIBRATION

The first major environmental change (or stress) that the pilot of a space vehicle will be subjected to on an orbital mission is the intense noise and vibration level of the large boosters as flight is initiated from the launch pad. A 1,000,000 lb. thrust rocket may generate a noise level of 200 decibels which results in approximately 155 decibels just outside the cockpit enclosure at launch and approximately 145 decibels shortly thereafter. Vibration and sound, from the physical viewpoint, consists of "compressional disturbances produced and propagated in solid or fluid media". Of interest from the human factors standpoint is the limit noise and vibration levels allowable upon the pilot of the space vehicle, both from the standpoint of work efficiency as well as permanent physiological damage. The specific effects of noise and vibration on man are:

A. Interference with communication.

B. Hearing loss, both temporary and permanent.

C. Interference with orientation and coordination.

D. Discomfort, and finally pain and damage to tissues.

E. Interference with sense of touch, vision, etc., and with the performance of skilled tasks.

F. Immediate or short-term effects such as fatigue, loss of sleep, psychosomatic or neuropsychiatric symptoms, etc.

G. Long-term cumulative impairment of brain function, circulation, etc.

The above effects depend directly upon the noise/vibration level at the specific frequencies encountered. To prevent impairment of the pilot's ability to serve as an integral link in the man-machine system as well as to reduce the possibility of actual physical damage to the man, maximum levels of noise tolerable by the human operator are defined in Figure 1. Figure 2 illustrates some general noise levels and Figure 3 shows noise reduction offered by average pressure suits. Maximum permissible levels of vibration, both low frequency and ultrasonic, as well as related charts are shown in Figures 4 through 12. Exceeding these limits (even for short periods of time at some frequencies) involves considerable risk to the man.

The direct and immediate effects of noise are easily recognized. More difficult to assess but even more important in their implications are the vague indirect effects of intense noise and vibration on human behavior and ability to work. These effects seem to be cumulative. The possibilities of direct injury to certain organs and tissues where the effects of noise may be enhanced by the resonance of particular structures cannot be predicted. The limits defined herein are based on the results of tests to date.

The following is a tabulation of the results of some significant tests on humans of interest to vehicle designers.

Frequency	Intensity	Effects
6 - 8 cps.	Approx. 3 inch	Resonance of abdominal organs, possible physical damage.

Frequency	Intensity	Effects
10 - 15 cps.	.34 inch	Intolerable precordial pain.
20 - 25 cps.	.34 inch	Abdominal discomfort, hyper-peristalsis nausea, bloody stools, extreme general prostration, rapid pulse rate.
0 - 23 cps.	.16 inch	Little deleterious effect slightly increasing toward higher frequency.
40 - 50 cps.	.16 inch	Unable to read instruments as this is at eyeball and brain nodal points.
100 - 12000 cps.	130 db	Interference with voice communication, permanent cumulative hearing loss.
100 - 12000 cps.	140 db	Auditory pain, permanent cumulative hearing loss even with best protective devices.
100 - 12000 cps.	150 db	Massive stimulation of many senses, nausea, great ear discomfort even with best protective devices.
1000 cps.	135 db	Inner ear effects - nausea, vomiting, nystagmus, shifting of visual field.
100 - 12000 cps.	150 - 160 db	Severe breakdown of psychomotor performance.
20000 cps.	160 db	Unusual fatigue, unbearable pain in palm of hand, heating.
24000 cps.	1 kw.	Hot and cold spots.
250 kc.	.5 kw.	Very painful at root of nails.
540 kc.	1.5 kw.	Nerve pains, considerable heat and unbearable pain.

Lovelace Foundation's comments on the noise limits are: "Permanent hearing loss will occur on the average to 2.5 to 5 percent of individuals chronically exposed to the desired levels, if they do not wear helmets and ear phones. Even if ear phones and helmets are worn, the same average hearing loss can be expected for those chronically exposed to the maximal levels". The levels defined in Figures 1 - 12 may be exceeded for short periods of time but noise should never exceed 140 db overall as blurring vision, nausea, vomiting, dizziness, poor time perception, etc., may occur no matter how well the ears and head are protected. Pressure suit helmet will attenuate the noise at the head by approximately 20 db at the high frequencies and 10 db at the low. The low frequency vibration limits should not be significantly exceeded even for 5 or 6 seconds as severe internal body damage may be incurred.

Insulation and vibration damping structure must be provided in the capsule to limit the noise environment on the pilot to no more than 140 db for a few seconds at launch and no more than his permissable levels for the remainder of the flight and landing. Low frequency and ultrasonic levels must also be within the defined tolerance limits.

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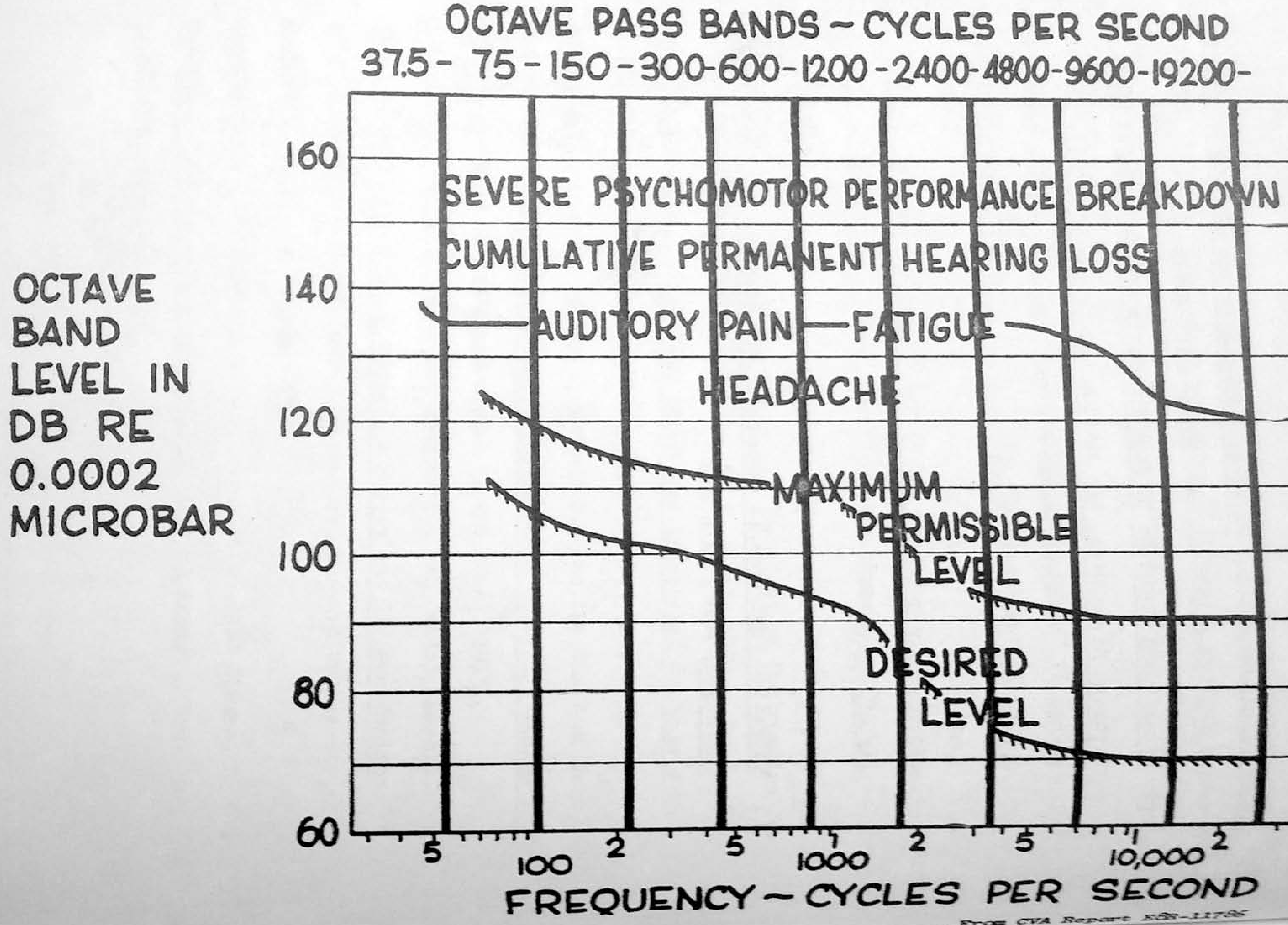
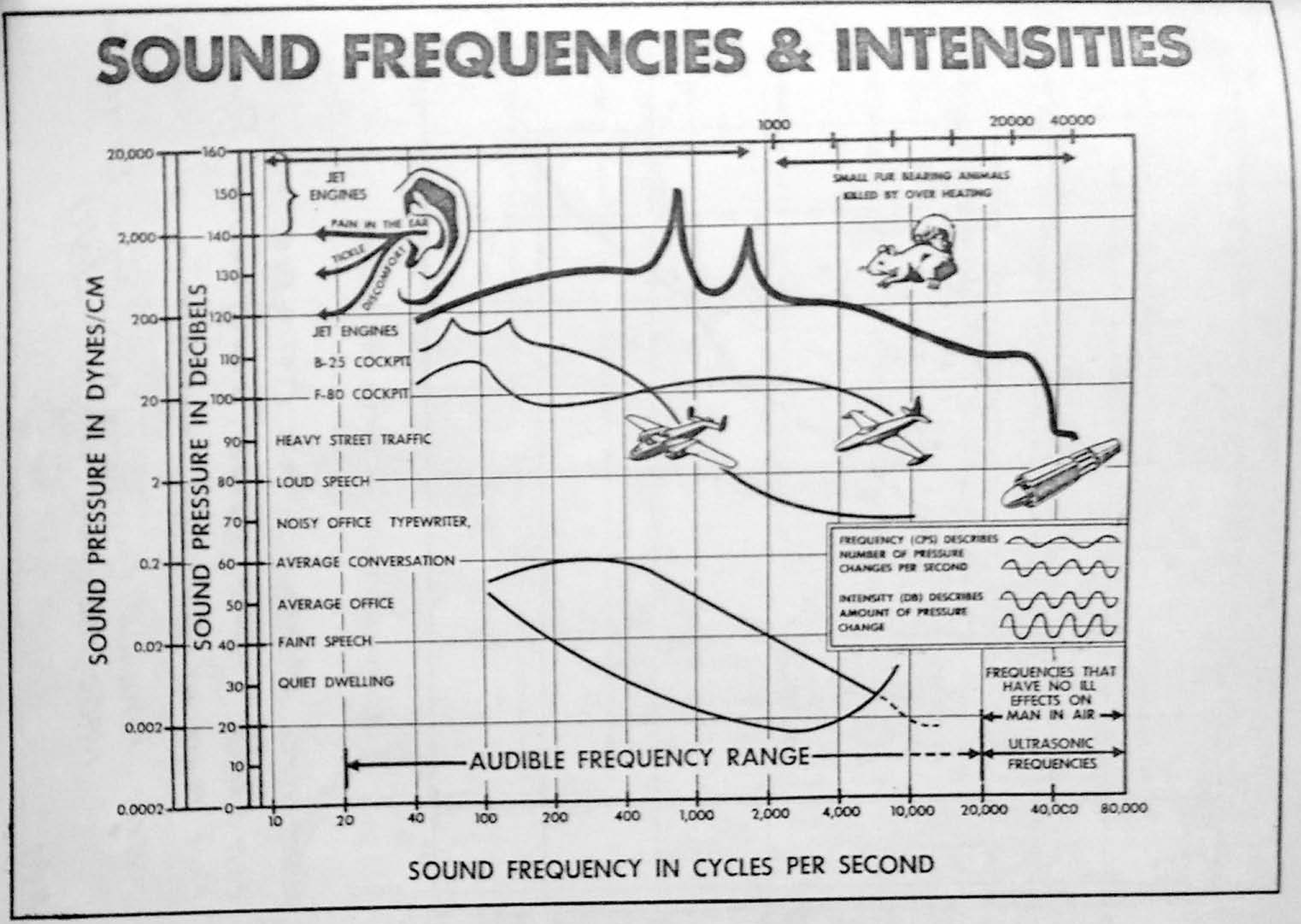
Figure 1

RECOMMENDED NOISE LIMITS ON HUMANS IN MANNED VEHICLES



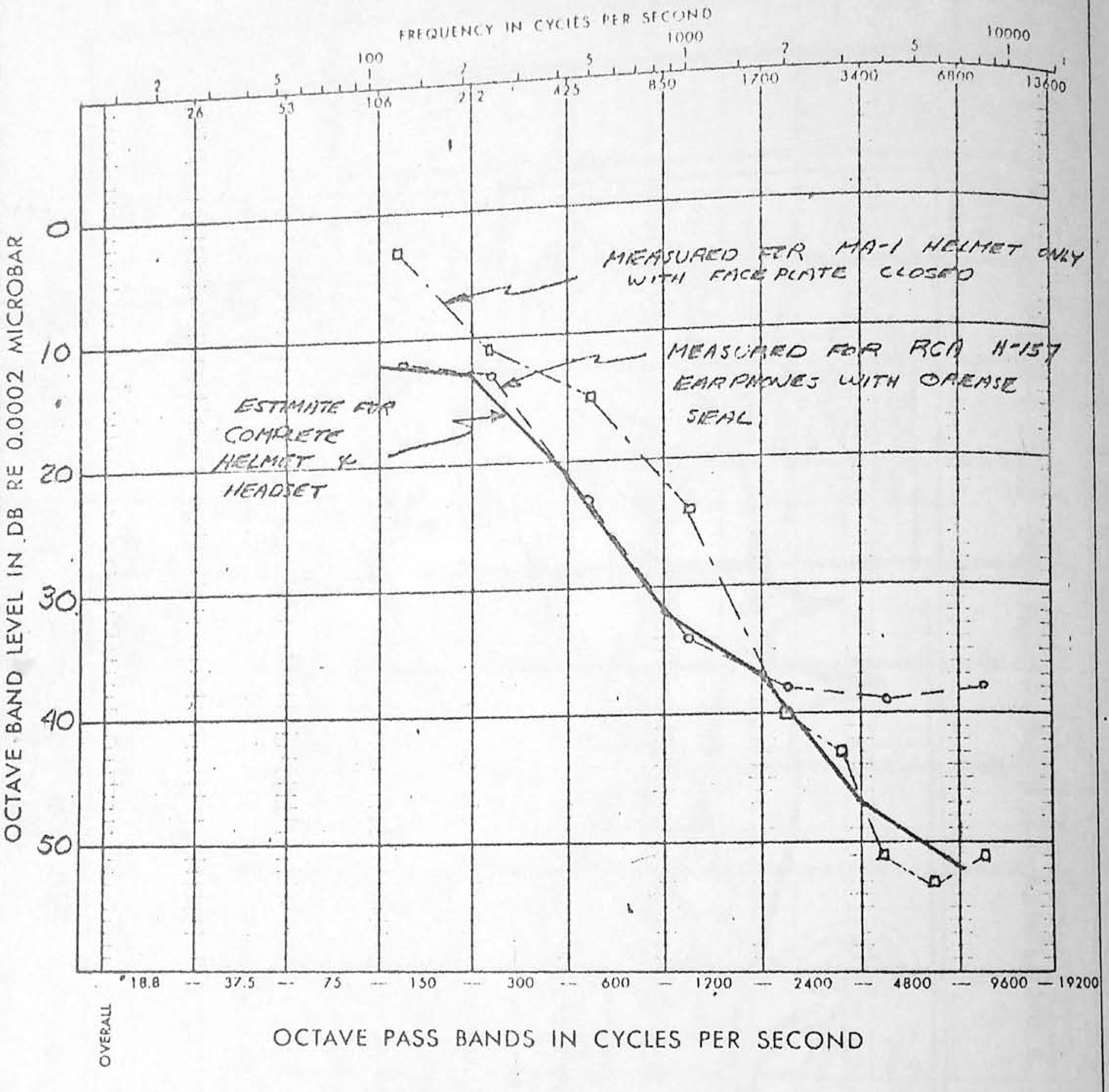
From CVA Report E9R-11785

Figure 2



From Air Force Manual 52-13 July 1953

Figure 3



ESTIMATED MAXIMUM NOISE REDUCTION OF AIR FORCE MA-3 HELMET WITH PRESSURE SEAL, FACE PLATE ON, AND RCA GREASE-FILLED AIR CUSHIONS.

REF: PERSONNAL CONVERSATION WITH MAJOR BETTSY GHE
WADC, AEROMED LAB 2/19/59

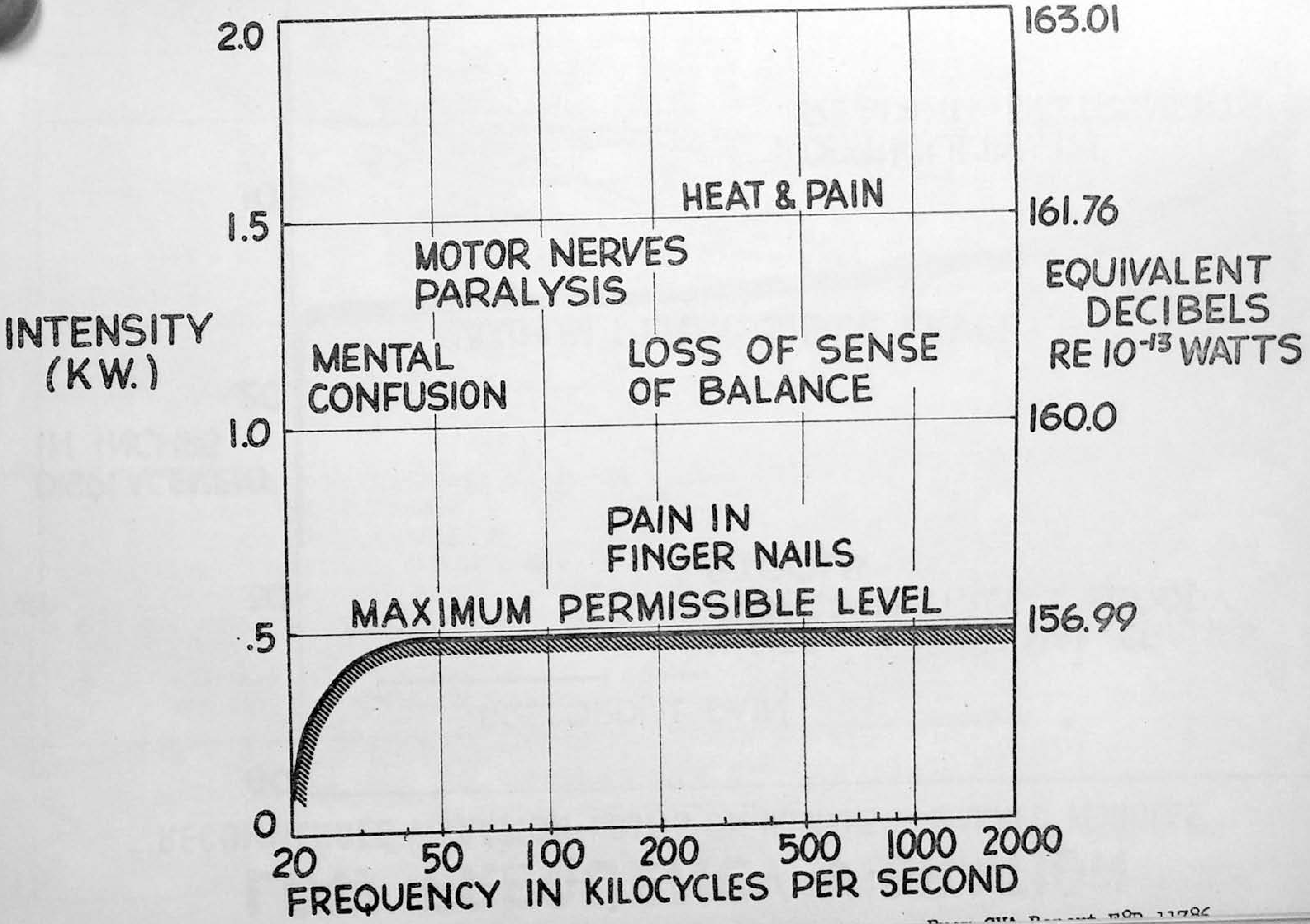
LCS 2/25/59

Courtesy Boeing Airplane Company
Seattle, Washington

Figure 4

ULTRASONIC VIBRATIONS

RECOMMENDED VIBRATION LIMITS ON HUMANS IN MANNED VEHICLES

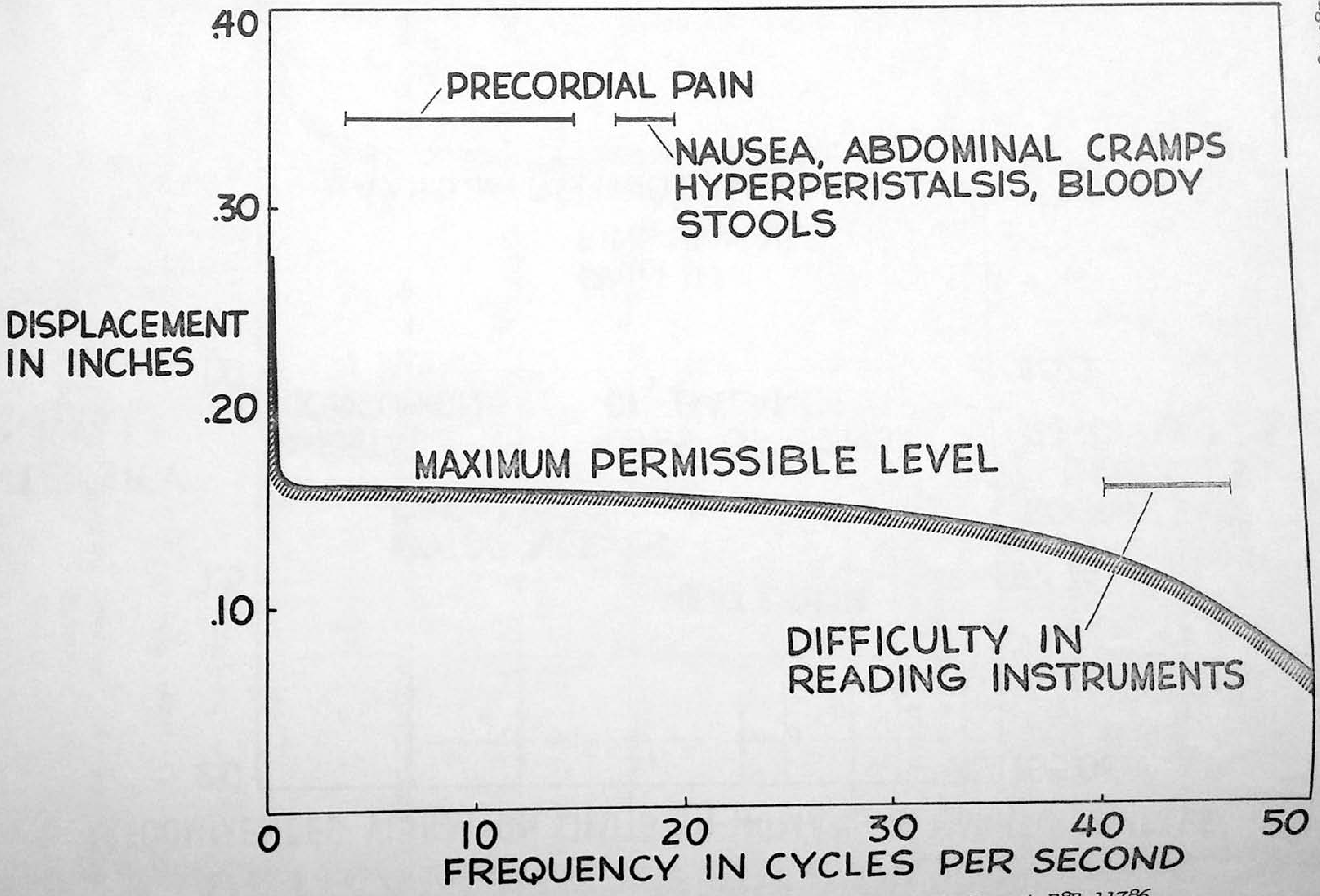


From CVA Report E9R-11786

Figure

LOW FREQUENCY VIBRATION

RECOMMENDED VIBRATION LIMITS ON HUMANS IN MANNED VEHICLES



From CVA Report E8R-11786

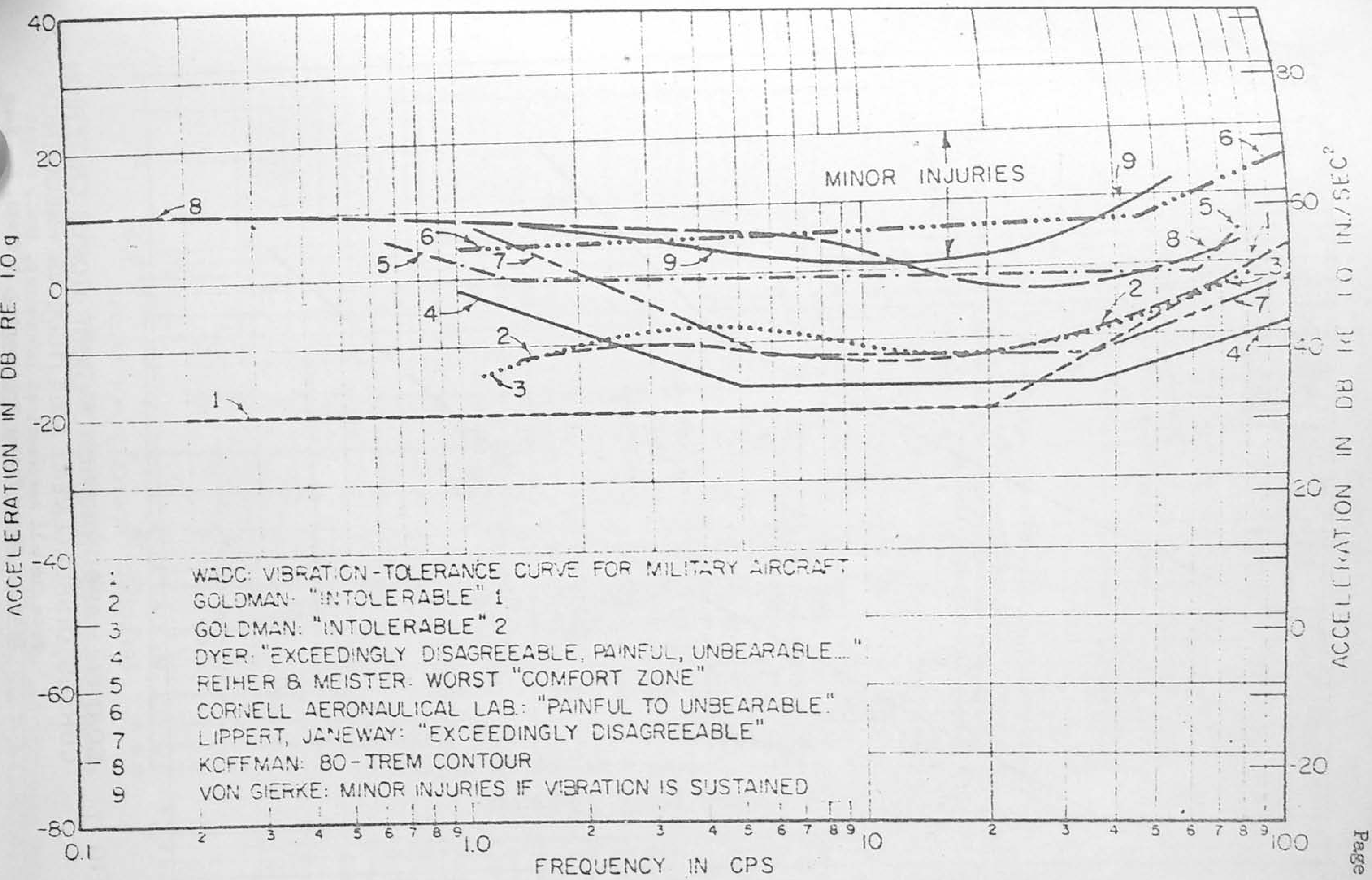


FIG. 6 NINE CURVES RELATING TO HUMAN TOLERANCE FOR VIBRATION.

Courtesy Bolt, Beranck, and Newman, Inc.
Cambridge, Mass.

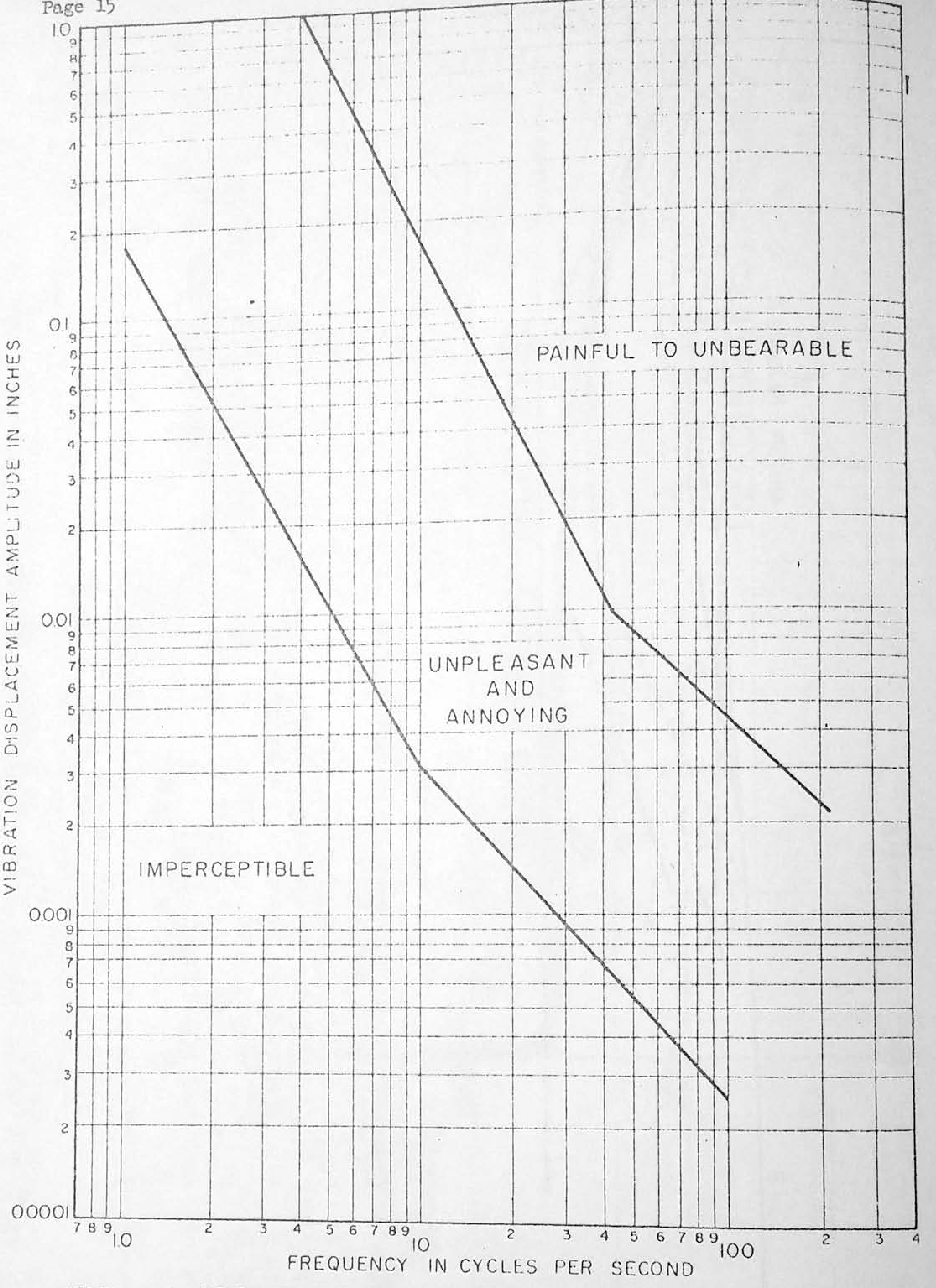
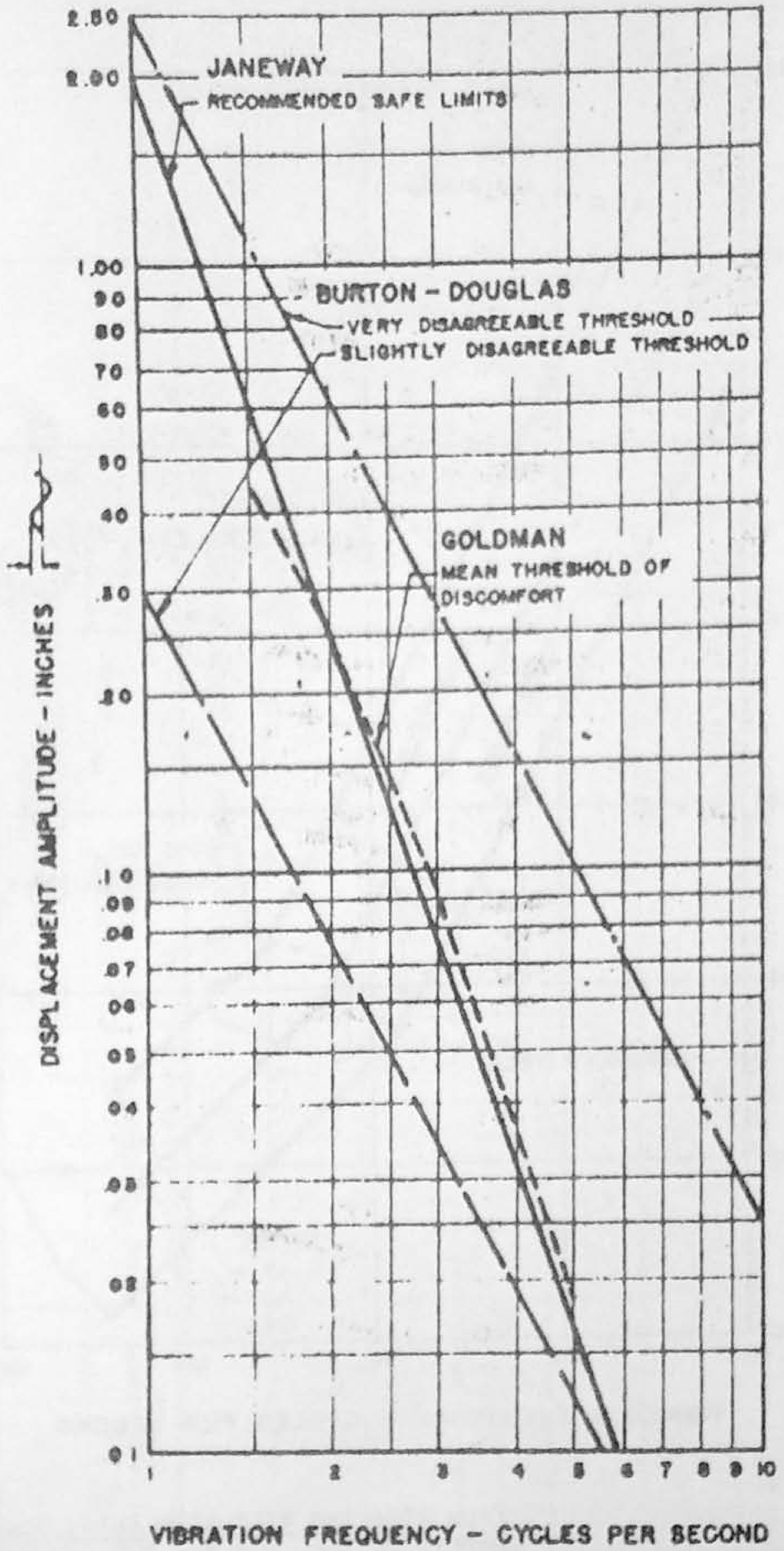


FIG. 7 CORNELL AERONAUTICAL LABORATORY'S CRITERION CURVES, DISPLACEMENT AMPLITUDE VS FREQUENCY.

From Cornell Aeronautical Laboratory, Inc., Pocket Data for Human Factor Engineering, Buffalo, New York

FIG. 8

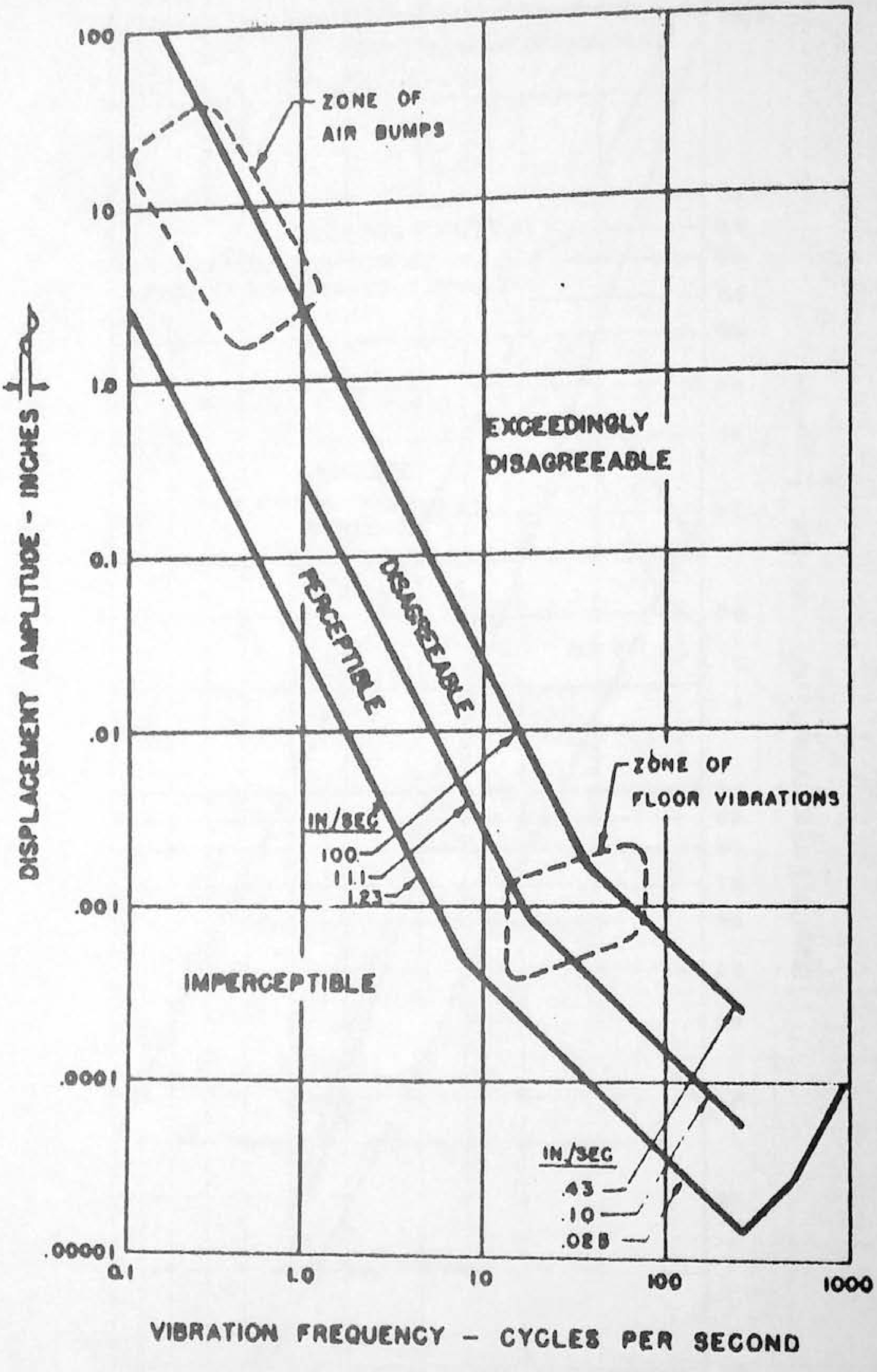
DISCOMFORT THRESHOLDS COMPARISON AT LOW FREQUENCIES



From Ride and Vibration Data, Special Publications Dept., SP154, S.A.E., n.d.

FIG. 9

RESPONSE TO VERTICAL VIBRATIONS



From Ride and Vibration Data, Special Publications Dept., SP 154, S.A.E., n.d.

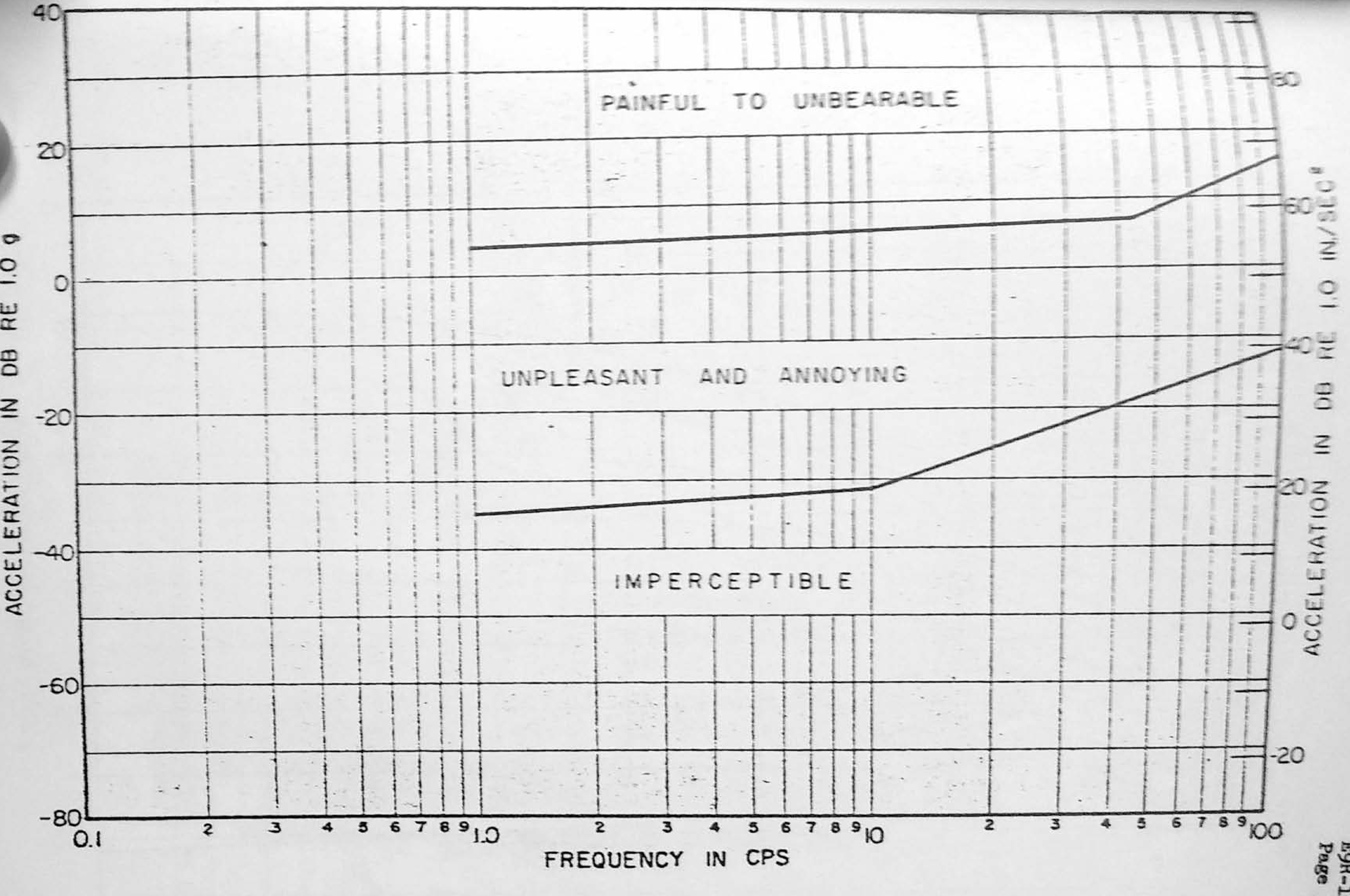


FIG. 10 CORNELL AERONAUTICAL LABORATORY'S CURVES.

From Cornell Aeronautical Laboratory, Inc., Pocket Data for Human Factor Engineering, Buffalo, New York

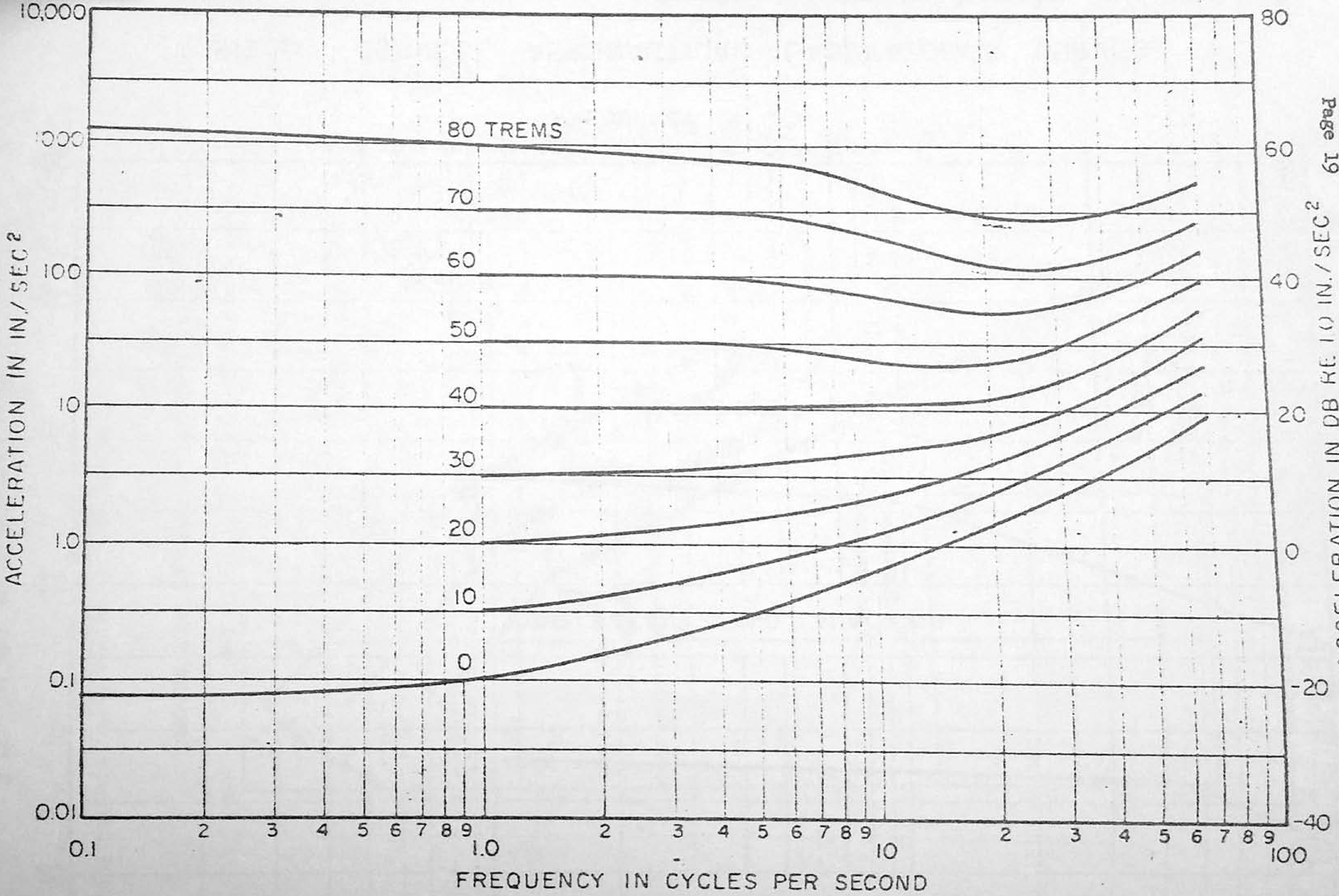
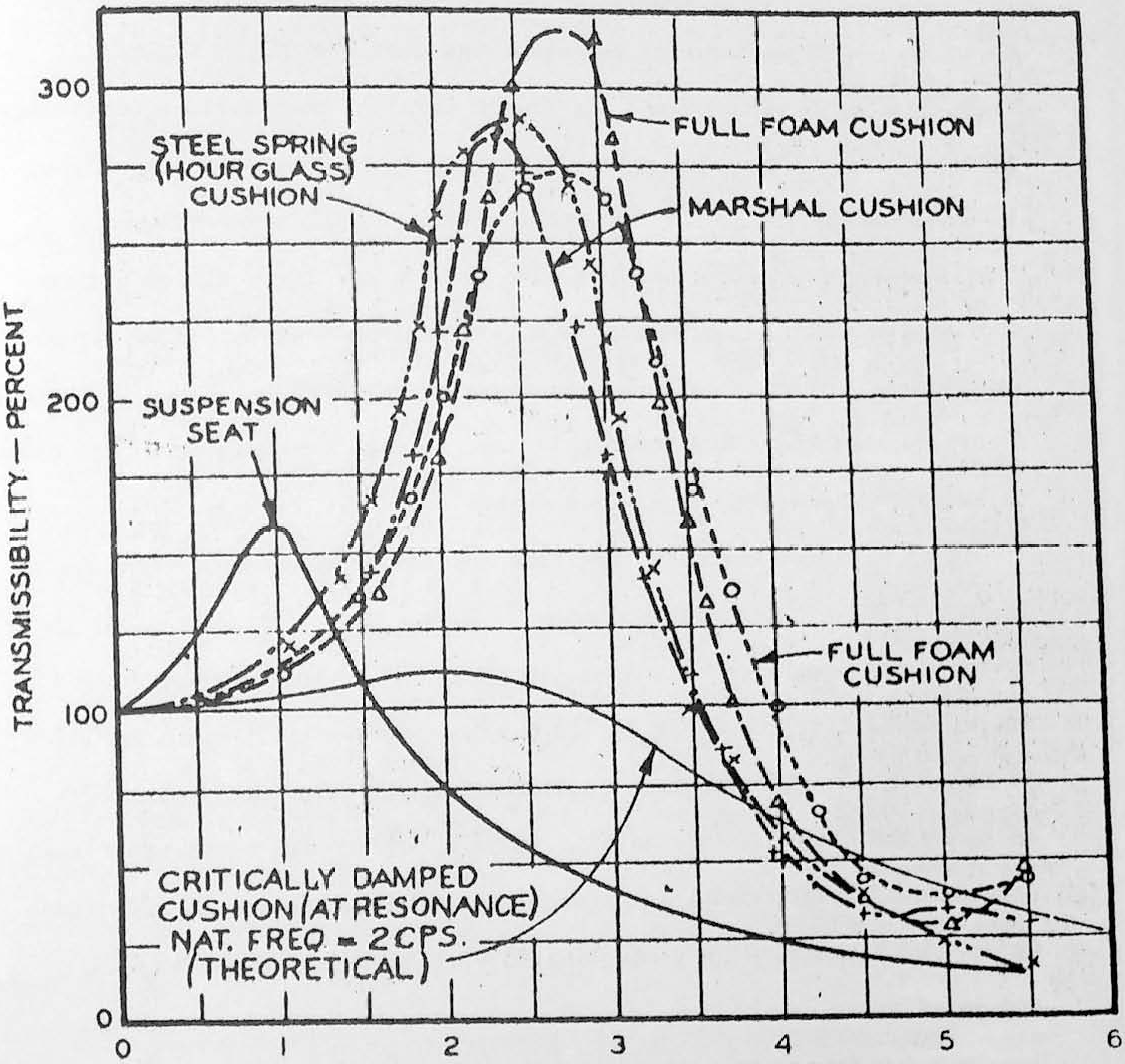


FIG. 11 CONTOURS OF EQUAL SUBJECTIVE MAGNITUDE.

From J. L. Koffman, Vibration and Noise,
"Automobile Engineer", 73-77, Feb. 1957

FIG. 512 TRANSMISSIBILITY CHART

DISPLACEMENT AMPLITUDE = $\frac{1}{2}$ TOTAL
SUBJECT WEIGHT = 185 LB (160 LB ON CUSHION)
BUCKET SEATS = NO BACK



From A Better Truck Ride for Driver and Cargo: Problems and Practical Solutions, R. N. Janeway, SP-54, S.A.E. 1958

III. ACCELERATION

The next stress of major importance to the pilot is the transverse acceleration imposed during the boost phase of the flight which will begin just at departure from the launch pad. As combinations of various stresses tend to compound rather than add, it is necessary not only to insure that any proposed boost profile is well within the tolerance limits of the human operator but also provide seating position and control manipulation requirements such that minimum degradation of his effectiveness in control and command might be realized. Figures 13 through 23 are related charts on human tolerance to acceleration and impact based on centrifuge and high speed sled tests.

It is apparent that seat position and construction is a vital factor in increasing acceleration tolerance. Humans have sustained up to 31 "g" by the water immersion technique, up to 23 "g" in the contoured rigid couch, and a little over 16 "g" in a nylon net seat. The body position is an important consideration to increasing "g" tolerance as is indicated in the charts. In addition, it is apparent that the conventional center stick/rudder pedal arrangement for vehicle control is effective up to approximately 4 "g", has limited effectiveness from 4 to 6 "g", and is of no value above 6 "g". One solution to control under high accelerative forces is a three-axis side stick controller for control in pitch, roll, and yaw as studies have indicated that wrist, hand, and finger movements are effective up to as high as 12 "g" transverse.

Specific data from tests applicable to cockpit design are:

A. Optimum pilot position for boost - optional body position for exit appears to be a seated position with 12° to 15° inclination of the trunk in the direction of acceleration with the legs fully flexed (seated, forward facing). Three-stage accelerations sufficient to reach orbital velocity with peaks of either 8, 10, or 12 "g" are tolerable in this position. The pilot must practice abdominal breathing in the above position when the "g" reaches about 6. Another variation of the seat position which is acceptable is a semi-reclining position with the trunk 8° to 12° inclined in the direction of acceleration and the knees slightly flexed (NASA contour couch).

B. Optimum seat design for boost - with the body positions outlined above the seat should be well padded or have perfect body contouring with lateral support for pilot's ribs and be designed with heel supports so that the legs can be properly flexed. The seat should be further designed to return to the normal seated position upon reaching orbit.

C. Restraint system for boost - since the force resulting from forward acceleration tends to push the pilot more firmly into the seat, a conventional aircraft restraint system is adequate. However, for backward acceleration (i.e., deceleration) above 4.5 "g" an integrated restraint suit is necessary.

D. Pilot's ability to exercise control movements during boost - arm and leg movements are not highly effective at more than 6 "g". Wrists and fingers can be moved at up to 12 "g". No limit "g" has been found for finger movement. Arm and leg movements are effective below 4 "g". Walking, crawling, and movement along a ladder against the force of acceleration is seriously restricted at 2 "g" and becomes impossible at 3 "g". Progress at right angles to the force of acceleration becomes impossible at 4 "g".

E. Effect of boost on auditory responses - auditory function has remained intact up to 14 "g".

F. Effects of boost on visual responses - depends on seat position. Is adequate as long as sufficient blood supply available to head. In transverse "g" there has been no loss of peripheral vision up to 10 to 12 "g".

G. Effects of petechiae as result of "g" forces - petechiae will not occur if adequate support (cushion) is given pilot. Any effects would be insignificant.

H. Post physiological effects which might influence pilot action upon reaching orbit, or ability to effect re-entry - conclusions are that there would be no degradation in performance.

I. To what degree can pilot tolerate transverse acceleration in the normal (10° aft trunk inclination) seated position? - Difficult labored respiration above 6 "g" with increasing pain as "g" increased; substernal pain (pain in lower breast bone); impaired performance; feeling of congestion in the head due to pooling of blood. Tolerance is limited to 8 "g" for approximately 13 seconds. Substernal pain may persist for 6 to 8 hours after acceleration.

J. Effects of labyrithine (inner ear) stimulation - is not an important factor in limiting tolerance.

K. Effects of various leg positions on tolerance - with trunk forward 20° but legs partially extended perpendicular to the direction of acceleration (semi-supine position), acceleration peak was 2 to 3 "g" less than legs flexed position.

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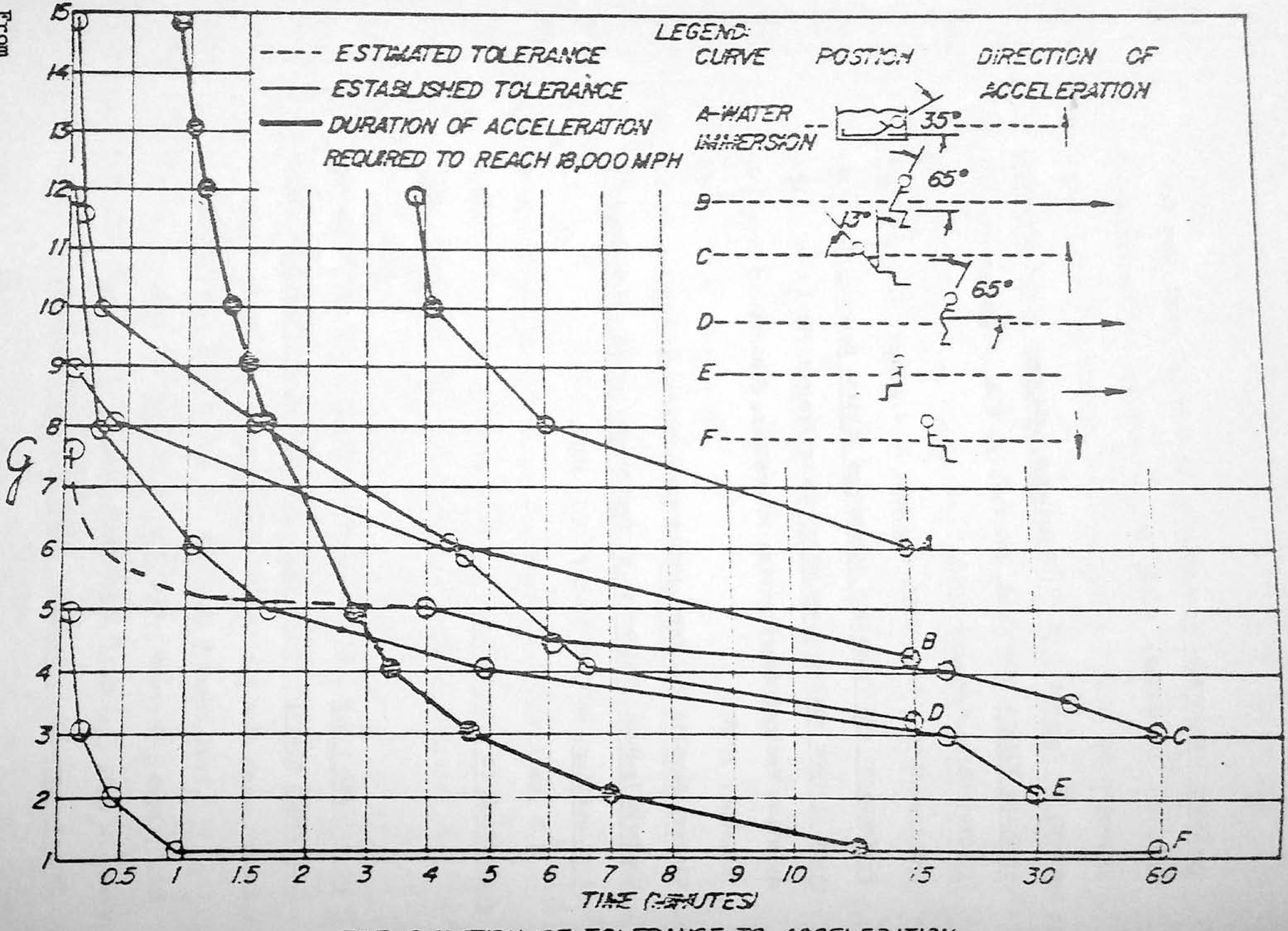
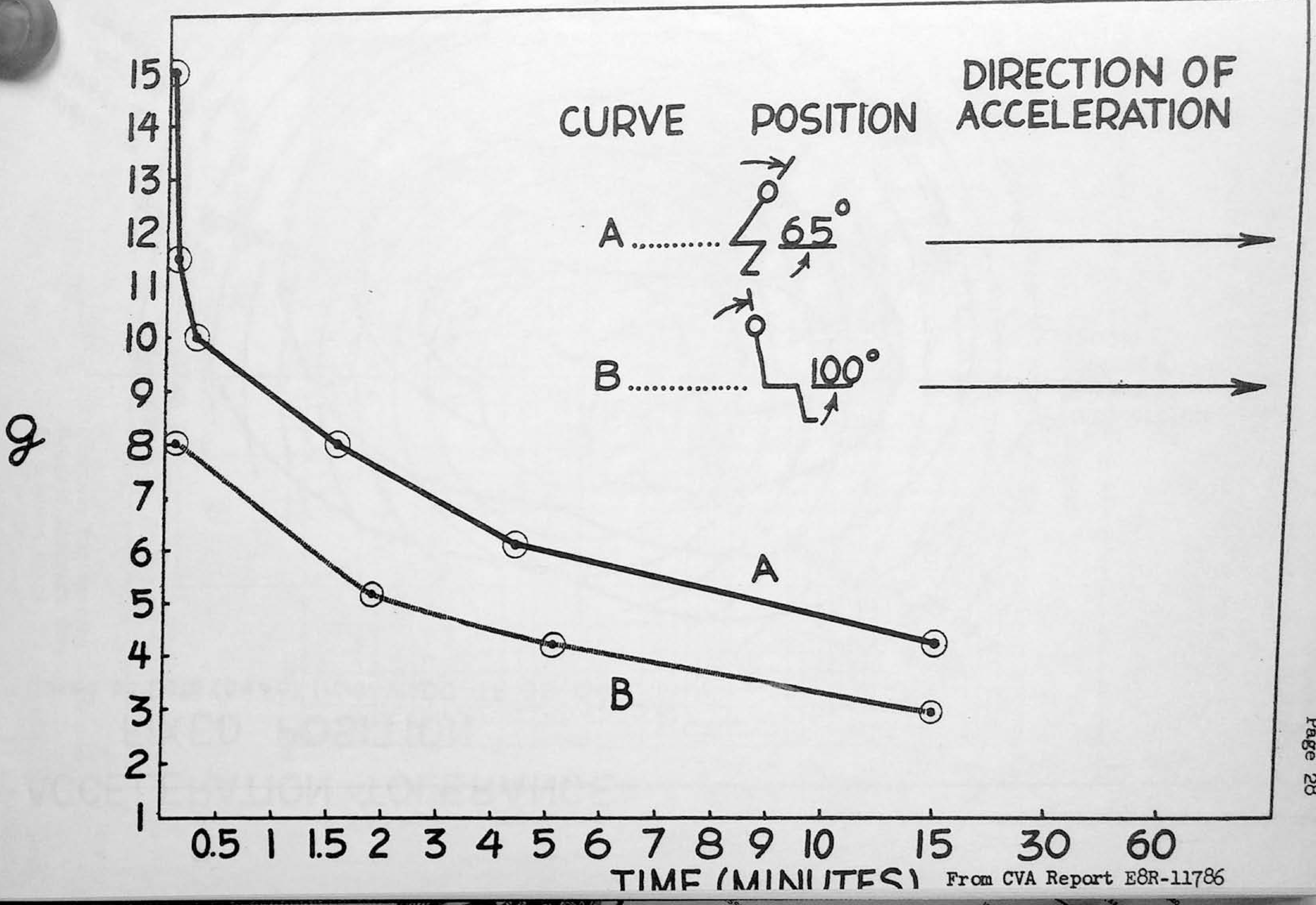
From
WADC TR 58-156

FIGURE 13



THE DURATION OF TOLERANCE TO ACCELERATION

DURATION OF TOLERANCE TO ACCELERATION



From CVA Report E8R-11786

ACCELERATION TOLERANCE
FIXED POSITION

Based on Data (o●▲□) from WADC TR 58-156

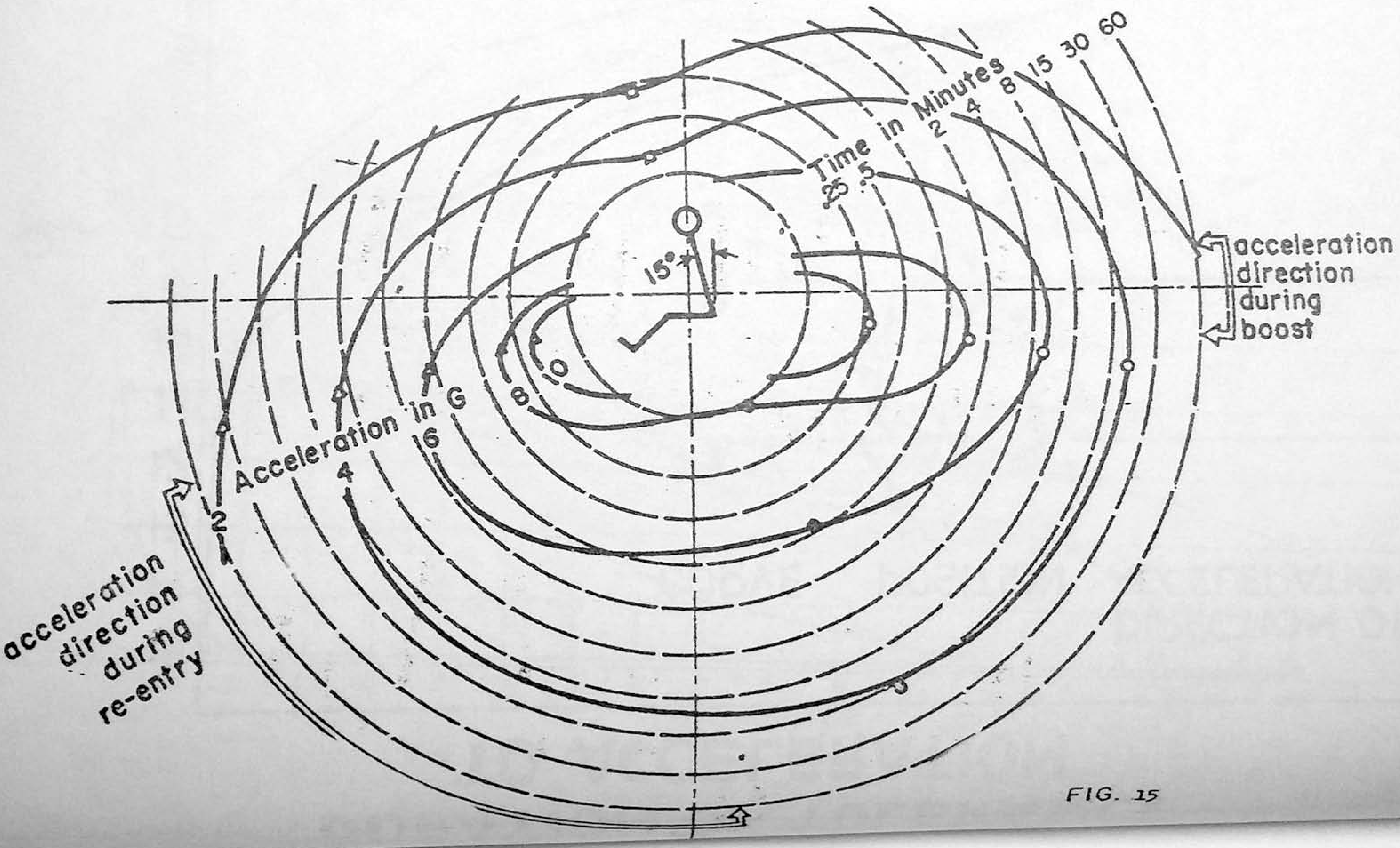
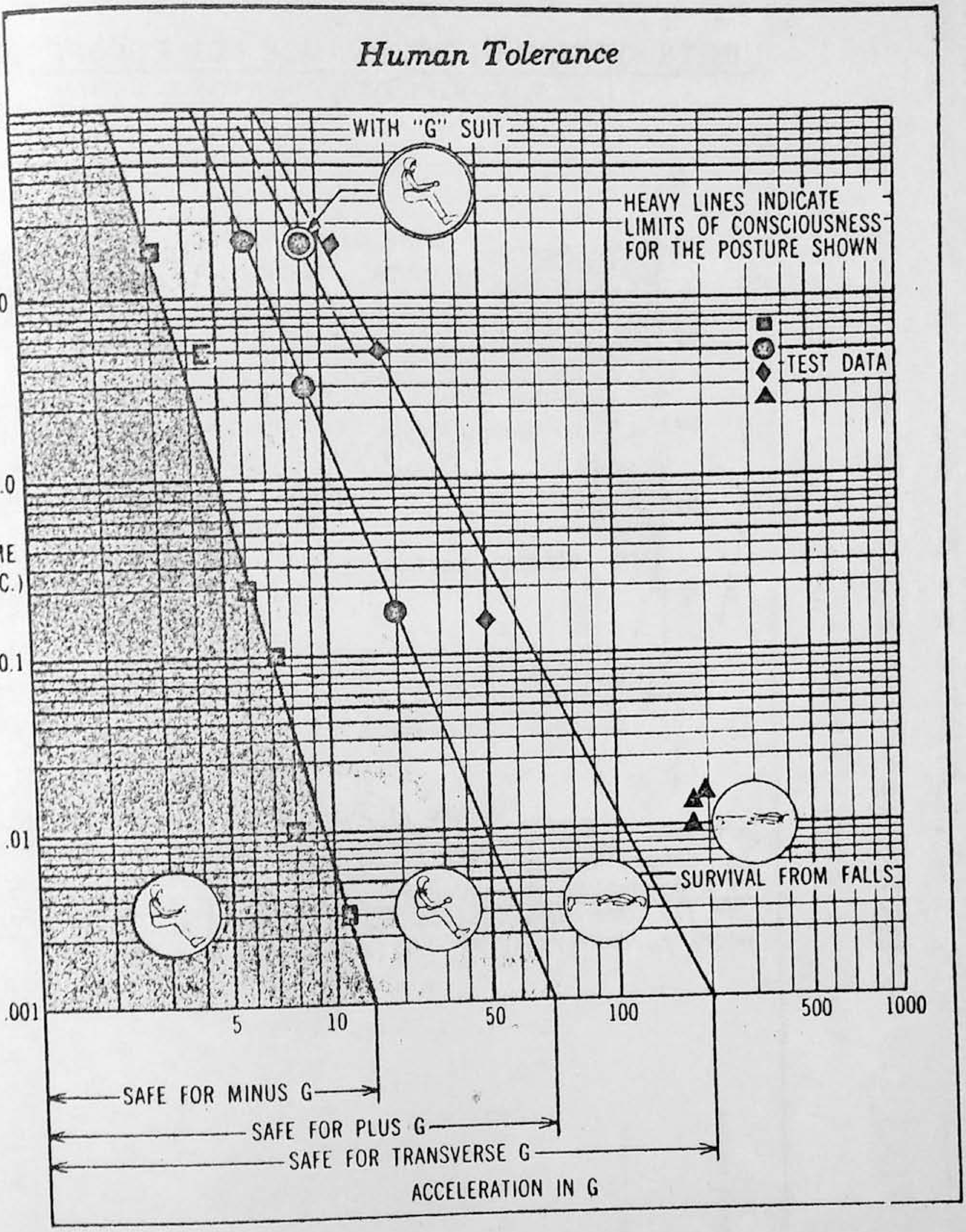


FIG. 15

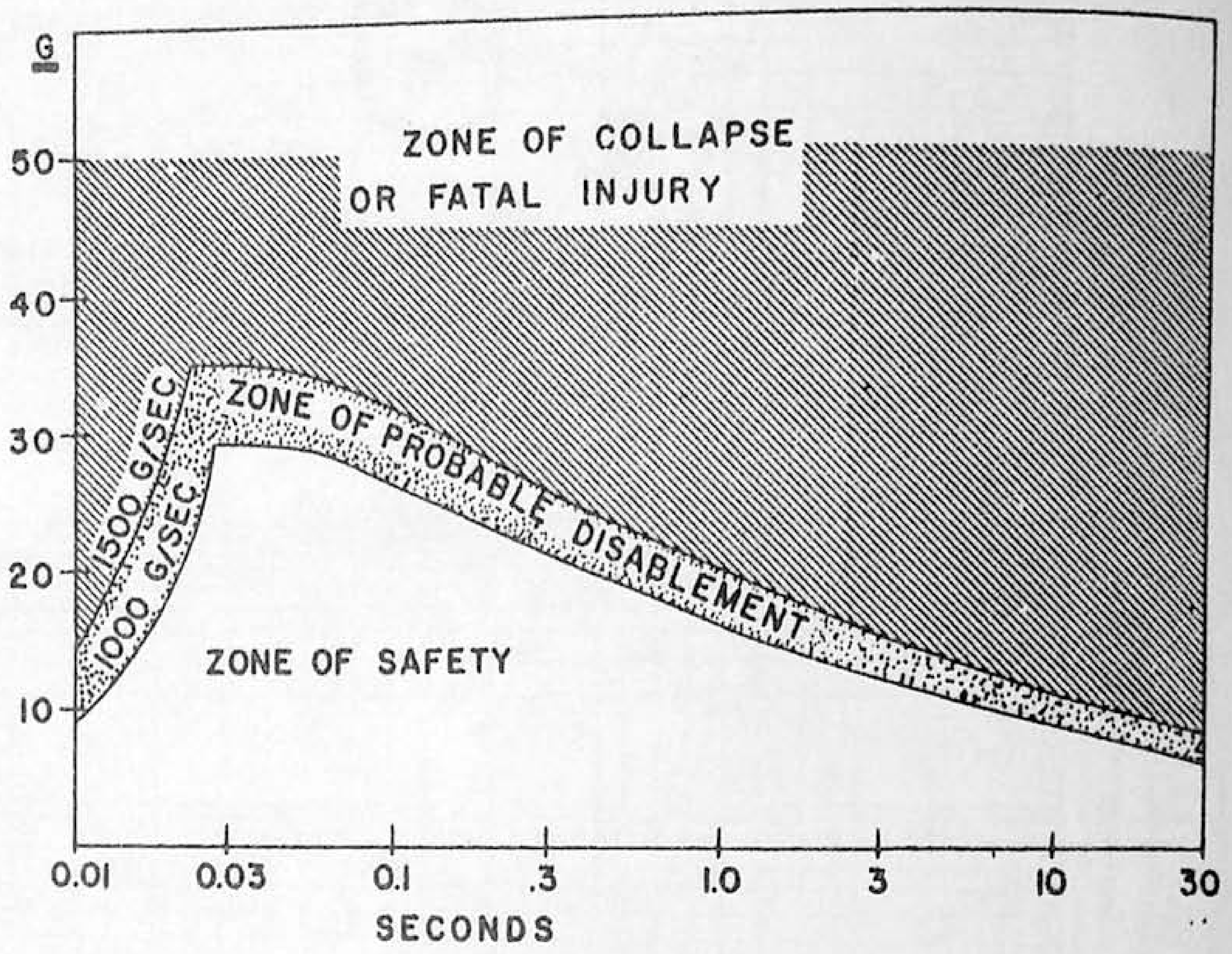
Figure 16



Courtesy Engineering Department
Douglas Aircraft Company, Inc.
El Segundo Plant, El Segundo,
California

Figure 17

LIMITS OF HUMAN TOLERANCE FOR ESCAPE SYSTEMS
(ASSUMING TRANSVERSE G IN A STABLE SYSTEM)



Limits of Human Tolerance For Abrupt Acceleration. From Savely, Harvey E.: The Physiology of Escape. In Haber, Heinz, and Slade Hulbert (editors): Proceedings of a Symposium on Escape From High Performance Aircraft, pp 35- 37. The Institute of Transportation and Traffic Engineering, University of California, Los Angeles.

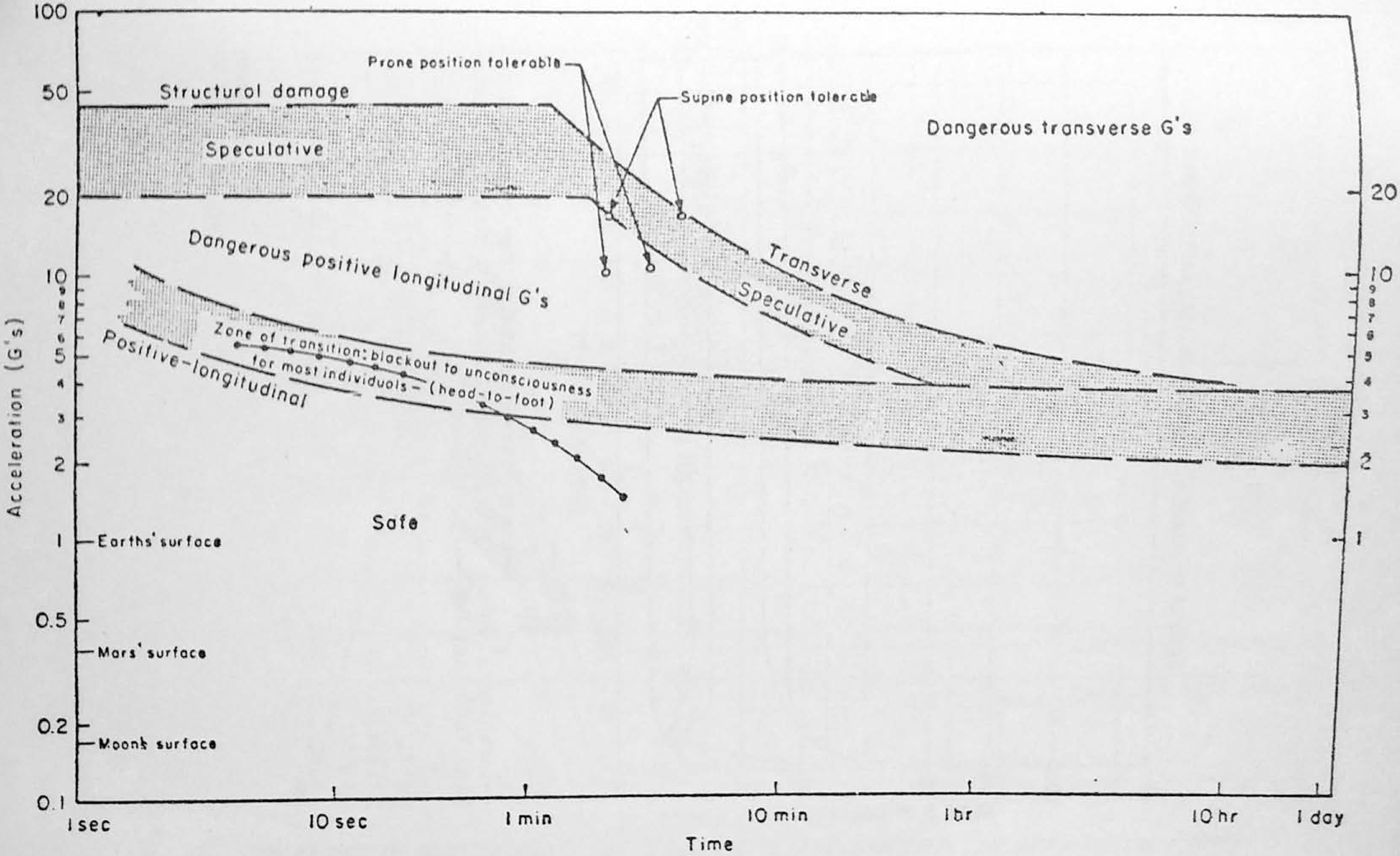
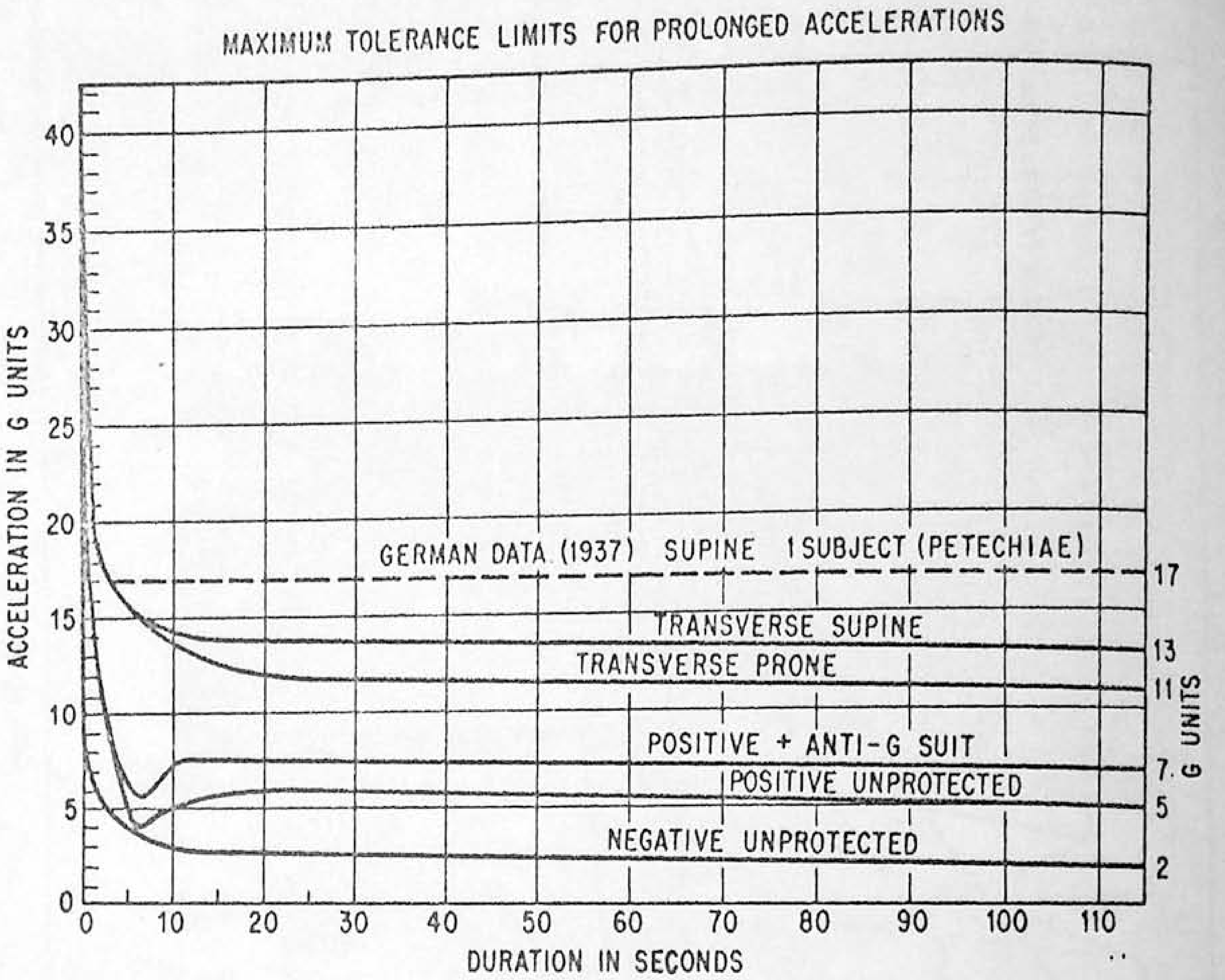


Fig. 18 —— Human time-tolerance: acceleration

From Space Handbook: Astronautics and its Applications, Staff Report of the Select Committee on Astronautics and Space Exploration, Washington, D. C.

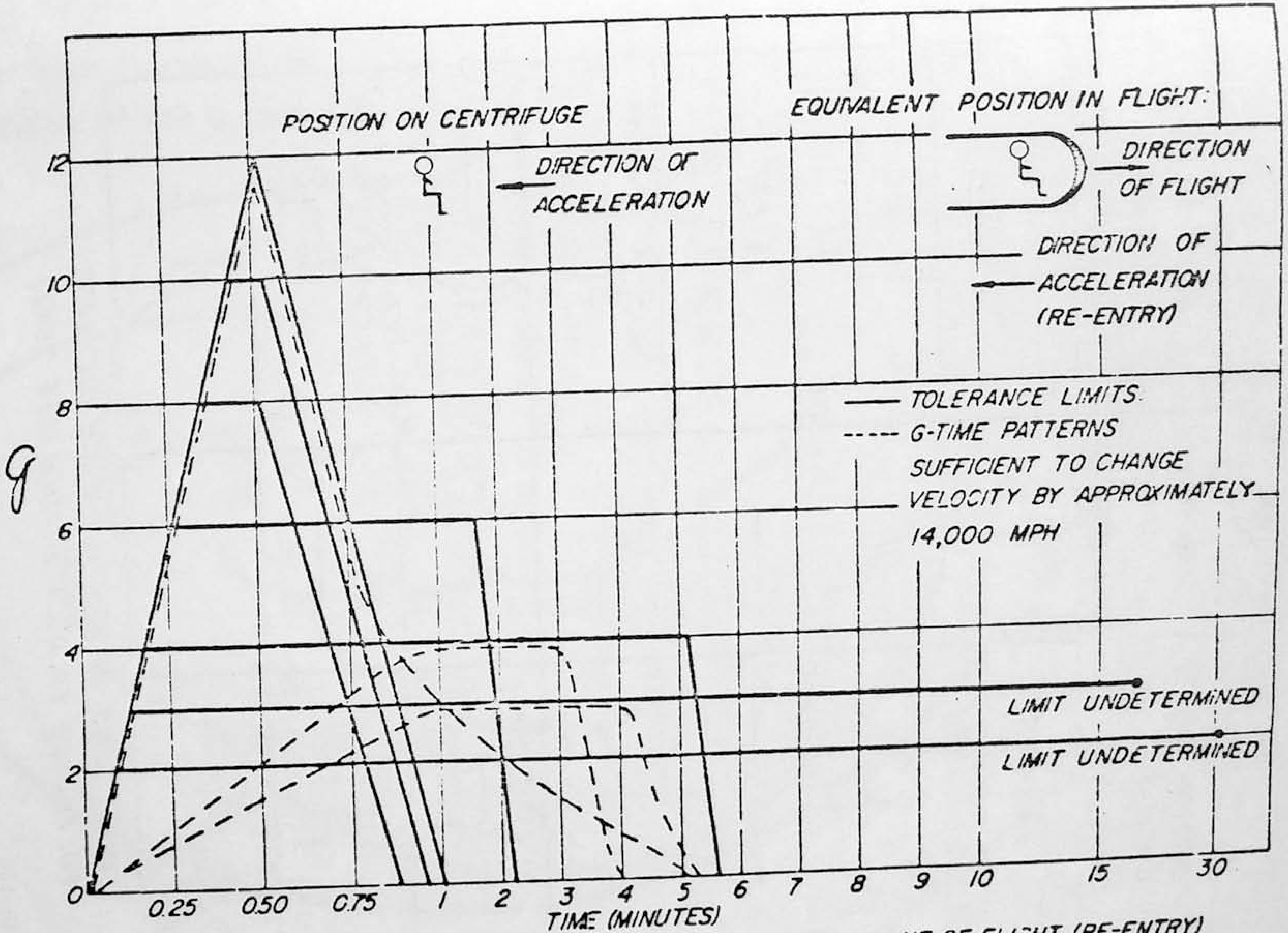
Figure 19



Maximum Tolerance Limits for Prolonged Accelerations. Drawn by Dr. Richard Bancroft, School of Aviation Medicine, February, 1958.

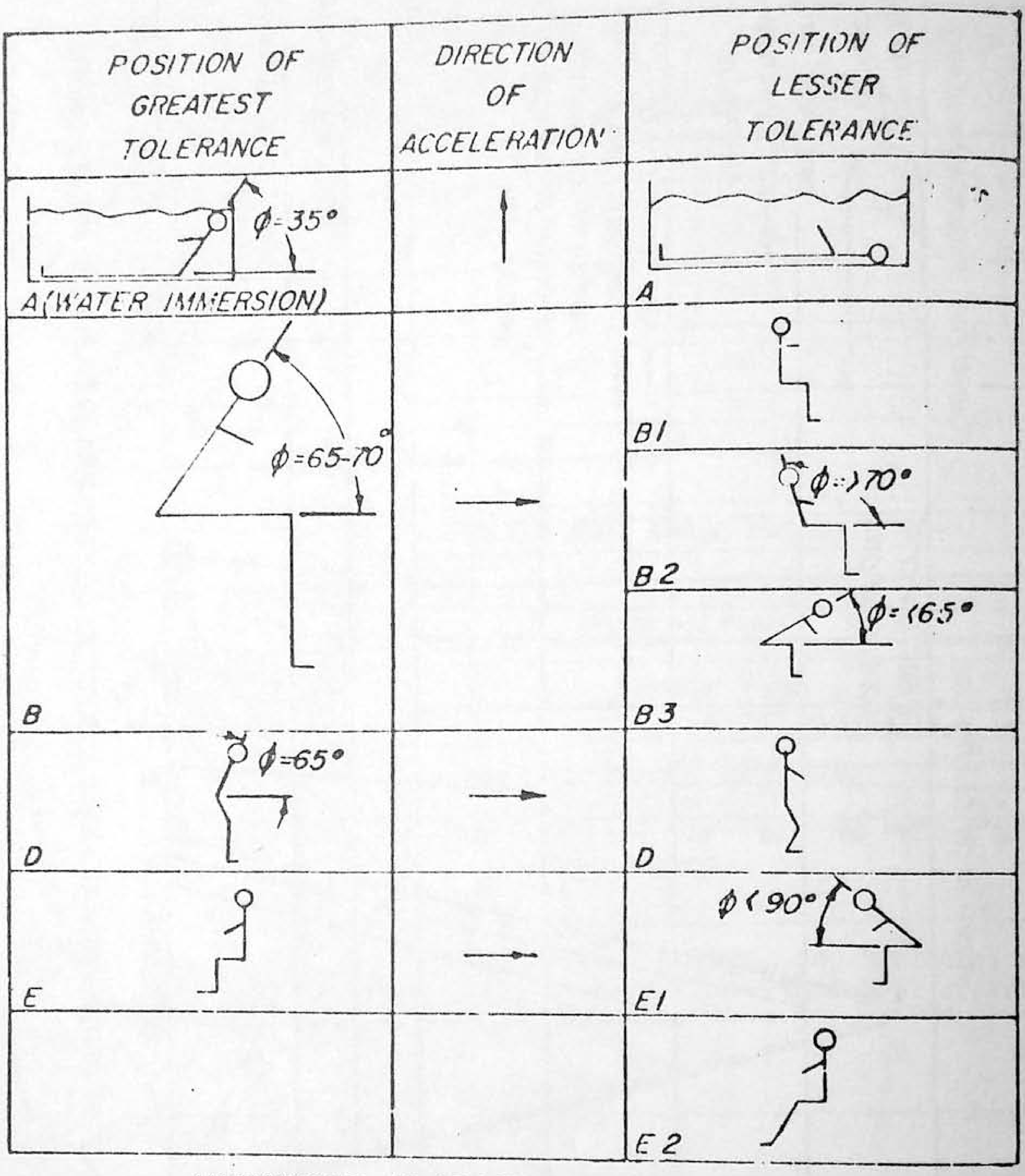
From
WADC TR 58-156

FIGURE 20



TOLERANCE OF SEATED, FORWARD FACING SUBJECT TO DECELERATION IN LINE OF FLIGHT (RE-ENTRY)

FIGURE 21



VARIATIONS IN POSITION WHICH DECREASE TOLERANCE TO ACCELERATION (SEE TEXT)

From
WADC TR 58-156

IMPACT TOLERANCE
FIXED POSITION

Based on Data from Lombard in Physics & Medicine of the Upper Atmosphere

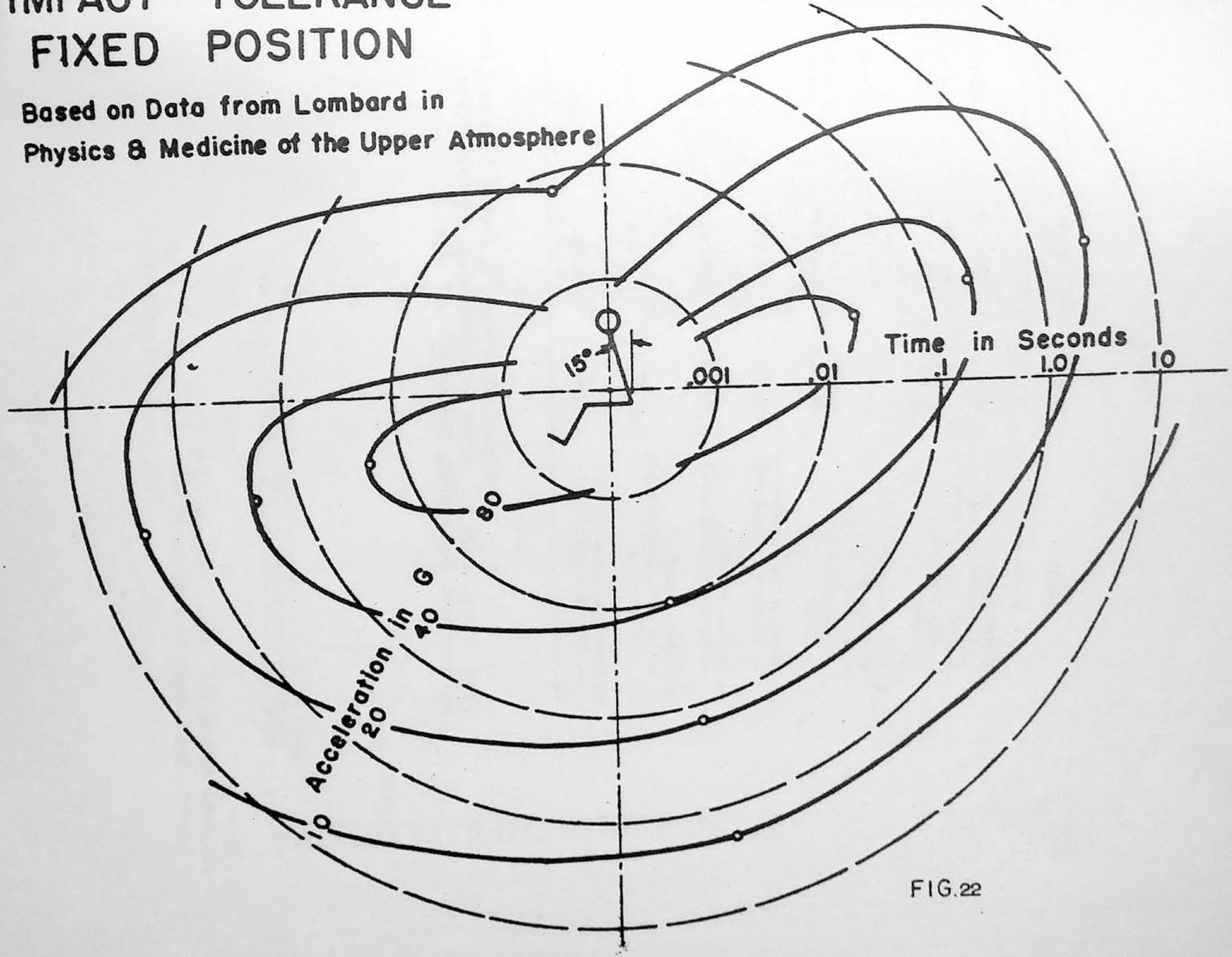


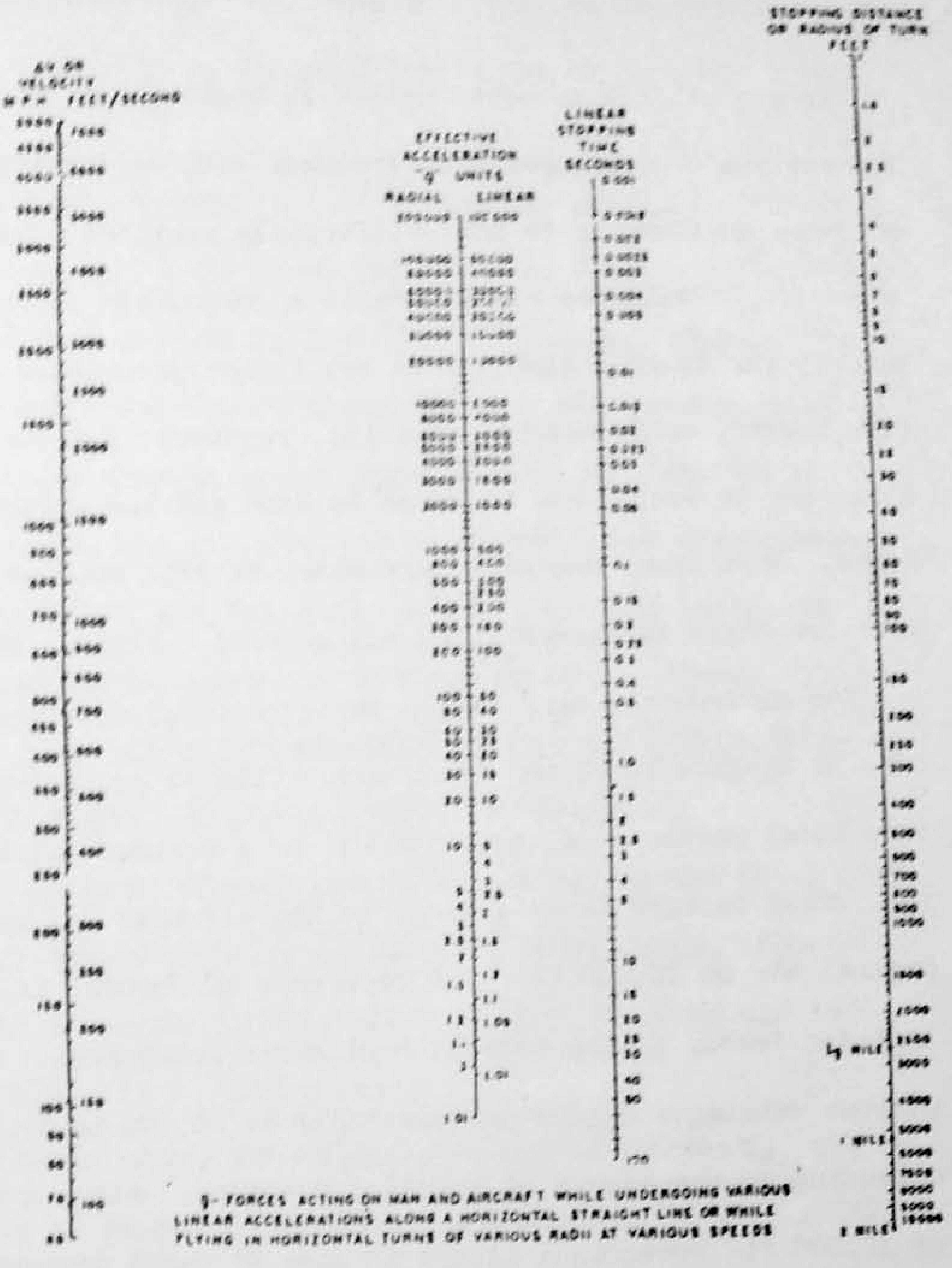
FIG.22

Table I

POSITION	PEAK "G"	RATE OF CHANGE g/sec	TOTAL DURATION SECONDS
1. Seated forward facing			
a. Tolerance (human)	10-46.6	280-1370	.15-.37
b. Survival, uninjured			
(Chimpanzee)	9-100.0	210-3400	.10-.20
(Hog)	30-125.0	1500-15000	.04-.08
2. Seated backward facing			
a. Tolerance (human)	10-35.0	500-1200	.15-.42
b. Survival, uninjured			
(Chimpanzee)	20-100.0	870-3350	.10-.16
(Hog)	20-100.0	1500-15000	.04-.08
3. Seated facing sidewise			
a. Tolerance (Chimpanzee)	20-47.0	900-1200	.12-.17
4. Supine, feet first			
a. Tolerance (Chimpanzee)	28-51.0	700-1000	.13-.20
5. Supine, head first			
a. Survival, minimal injury (Chimpanzee)	11-150.0	550-1450	.08-.35
6. Seated, buttocks to head			
a. Tolerance (human)	5-33.0	50-400	.004-.03

Biological Tolerance of Abrupt Acceleration. From Stapp, John P.: Crash protection in air transports. Aeronautical Engineering Review 12: 17 (April), 1953.

Figure 23



Nomogram for Lineal and Radial Acceleration. Courtesy of the Department of Physiology, School of Aviation Medicine, 1958.

IV. INTERNAL ATMOSPHERIC ENVIRONMENT

As the vehicle proceeds upward in boost phase of flight, the human limitations of atmospheric environment will be quickly exceeded if an adequate environment is not artificially provided (Figure 24). The selection of suitable atmosphere is a compromise which appears to best satisfy the diverse limitations set by the occurrence of bends, hypoxia, fire hazard, cabin weight, toxicity, pressure, and temperature. It is necessary to decide how this can be done and the equipment required to do it. When these decisions are made, it will then be possible to provide for their instrumentation and control. Figures 26 through 33 apply.

The minimum alveolar oxygen pressure (P_{O_2}) that precludes any symptons of hypoxia is 61 mm of mercury. This is equivalent to 100% oxygen at a total pressure of 144 mm of Hg, or a pressure altitude of 39,500 ft., which in turn is equivalent to the alveolar P_{O_2} when breathing natural air at 10,000 ft. The occurence of "bends" is, however, a limiting factor in the selection of cabin atmosphere. It may occur without extensive oxygen pre-breathing at 20,000 to 25,000 ft. altitude, depending on the amount of physical exertion. Also, a cabin pressure of 18,000 ft. presents a hazard in case of rapid decompression. An emergency pressure suit will provide approximately 180 mm Hg pressure (equivalent to 35,000 ft.). Submarine practice establishes a maximum pressure change ratio of 2:1 without danger of bends. This criterion permits cabin pressurization to a maximum of 360 mm Hg (approximately 18,000 ft.) since the 360 to 180 mm pressure change does not exceed 2:1.

Another dominant consideration is to provide adequate conditions for gas exchange in the lungs where the blood is charged up with oxygen and excess carbon dioxide is given off. Since gas exchange is accomplished by diffusion, it is dependent upon the partial pressure of oxygen and carbon dioxide in the inhaled gas. On entering the respiratory passages, the inspired gas is warmed up to approximately body temperature (98°F) and fully saturated with water vapor, the latter exerting a partial pressure of 47 mm Hg at all times. This has to be taken into account in consideration of the effective partial pressure of oxygen and carbon dioxide at altitude.

The partial pressure of each gas is determined by the total pressure and the dry volume fraction (F) of each constituent. Thus, the partial pressure of oxygen in the warm saturated inspired air is:

$$P_{O_2} = (760-47) \times .2093 = 149 \text{ mm}$$

At 5000 ft. altitude with a barometric pressure of 632 mm Hg, the partial pressure of oxygen on entering the lungs is

$$P_{O_2} = (632-47) \times .2094 = 122 \text{ mm}$$

In view of the fatiguing effects of hypoxia in extended operation adequate partial pressure of oxygen of at least 122 mm Hg should be required, (Figure 25). Thus, if a total cabin pressure corresponding to 18,000 ft. (7.35 psi or 379 mm Hg) is contemplated a dry volume fraction of oxygen of 37% is necessary:

$$P_{O_2} = (379-47) \times .37 = 122 \text{ mm Hg}$$

For a cabin pressure equivalent to 22,000 ft. (6.2 psi or 3216 mm Hg) a volume fraction of 45% oxygen would be appropriate:

$$P_{O_2} = (321-47) \times .45 = 122 \text{ mm Hg.}$$

The lower the partial pressure of carbon dioxide the better. Under no circumstances should it exceed 15 mm Hg which corresponds to a volume fraction of 2% at sea level or 4 1/2% at 18,000 ft.

It is estimated that the average oxygen consumption per man for 24 hours will be 600 liters (sea level temperature and pressure) and the corresponding carbon dioxide elimination is 500 liters. However, it should be taken into account that this turnover rate may be exceeded by a factor of two or more during periods of increased physical activity or stress.

For the inert gas of the cabin air it is probably better to use nitrogen than any other inert gas. It has been found that voice pitch changes appreciably if the enrichment of the atmosphere with helium gets as high as 50%.

As far as toxic substances are concerned, there are factors in orbital extra-atmospheric flight which must be kept in mind since they modify the earth-based notions of toxicity.

A. Physical removal from the harmful region is not possible.

B. Data for industrial plants do not apply because exposures are not 40 hours a week or 8 hours a day, but 168 and 24, respectively.

C. Ventilation for air removal and dilution with safe air is not possible, except to a severely limited extent.

D. Pressure of 1/3 atmosphere increases evaporation of volatile substances.

E. Rare and unexpected events such as overheating, fire or explosion convert harmless material to harmful.

Toxicity is considered here for materials which might be deleterious to health and normal longevity and reproduction, even through signs or symptoms may not be evident after successful completion of the orbital flight. Many persons have made the point that toxic (derived from the Greek word for poison) can be applied to normally nontoxic materials in large doses, or in unusual circumstances; e.g. NaCl in sea water as the only liquid source, aspirin in certain persons, foods in allergy cases. It is possible then that substances may be neglected which would in these special circumstances cause unforeseen trouble.

A. Acids. Methyl chloride used in refrigeration systems yields the irritant hydrochloric acid in a fire. Methyl bromide used in fire extinguishers yields hydrobromic acid with a fire. Nitrogen oxides can be produced in small amounts from atmosphere N_2 at spark gaps.

Some of these are irritant and anaesthetic gases forming acids by dissolving in water. Sulfuric acid in storage batteries might get out of the container in the zero gravity state.

B. Alkalis. NaOH and KOH used as CO_2 absorbers are deliquescent and with enough uptake of water become a corrosive soup likely to get out of control without gravity. This is not likely in a 24 hour trip. LiOH is a preferable absorber. If tertiary amine is used as a CO_2 scrubber, its fumes must be controlled and the liquid retained in its vessel.

C. Carbon monoxide. Smoking should be prohibited, because it uses O_2 and produces CO_2 and CO. Fire in the cabin which burns carbon containing material would also be deleterious. A probably insignificant production of CO comes from growing algae. Efficient removal of CO from cabin air can be done with Houdry's Oxy-catalyst or a hot-wire device. Hemoglobin has 2-300 times the affinity for CO as for O_2 and even 0.04% of CO can be toxic.

D. Carbon dioxide. This in 3-5% of the atmosphere speeds the breathing rate and acidifies the person breathing it. Increase of CO_2 is at the expense of O_2 so that asphyxiation results with 7-25% concentrations. Efficient removal is a must for a closed atmosphere with an animal such as man present to produce it. As stated above, smoking and fires are contributors. Obvious no CO_2 fire extinguisher should be aboard.

E. Carbon tetrachloride. Another fire extinguisher filling to be omitted, halogenated hydrocarbons in any form (solvents, cleaning agents, degreasers, refrigerants fire extinguishers) if they could contaminate the cabin environment or be destroyed by heat or fire, should be avoided. Some of them produce phosgene when burned.

F. Freon. This is CCl_2F_2. The above applies to this common refrigeration and pressure bomb expellant. Pressurized cans of shaving cream or other similarly activated toilet articles, should be kept out of the cabin.

G. Fats. Fatty substances heated to 300°C or more give off an irritant and poison called acrolein or acrylic aldehyde.

H. Hydrocarbons. Gasoline, kerosene, naphtha, and other volatile solvents or fuels should be hermetically sealed if they are present. Compressed or liquefied petroleum gases (methane, ethane, propane) are preferable since they are less toxic than the longer chain types. The aromatics such as benzene have special toxic action on the bone marrow with delayed effects from exposure, in some people.

I. Metals. Mercury should not be present in instruments or exposed to the atmosphere. Even mercury in clinical thermometers is forbidden aboard submarines because of possible atmosphere contamination. This danger is greater at the lowered pressures in an orbital space vehicle. Cadmium and Zinc platings should be eliminated to avoid metal fume fever caused by them at high temperatures. Lead is less volatile but is a potential hazard in the presence of fire. Solder used for electronic equipment would melt in case of fire and liberate fumes of lead, tin and sometimes antimony. While elimination of all solder is impractical for electronic equipment, this possibility of danger is a calculated risk.

J. Metal organic compounds such as lead tetraethyl or similar tin compounds should not be used or taken into the cabin.

K. Nitrogen. This gas is considered inert, but where one has a low-loss space containing an O_2-user, with CO_2 being absorbed, and with replacement by a high percentage O_2 mixture, N_2 will not be used and its addition to the atmosphere leads to a diminution of O_2. N_2 could become asphyxiating by its inertness.

L. Oxygen. At the pressures normally contemplated for cabin and pO_2, no toxicity is possible from too much (pO_2 of 300 mm or more for 4 hrs.). Lack of O_2 could arise from the above N_2 effect, from equipment failure, from fire in the cabin, or from accidental loss of cabin atmosphere (skin rupture, leaking vent valves).

M. Ozone. Generation of traces of this gas are possible at switch contacts, spark gaps and ultraviolet generators. The amounts should be less than the toxic range and the rapid destruction of ozone in the presence of organic matter, aerosols, wood and plastic is an added safety factor.

N. Paints. The U. S. Navy submarine base has pointed out that rubber-based paints take 30 days to polymerize to non-toxic materials. Solvents such as naphtha, turpentine and petroleum distillates evaporate rapidly and if cabin is flushed out after painting, no residues are to be expected.

O. Plastics. Teflon, Kel-F and other fluorine plastics should probably be eliminated. These give rise to halogen-hydrogen, free halogen and phosgene when heated to 600°F or higher. As with solder, the toxic potential in case of fire is to be considered as a calculated risk, or a danger which can be eliminated by design.

P. Phosgene. This highly poisonous gas ($CO\ Cl_2$) is formed by heating chlorinated hydrocarbons, some of which are $C\ Cl_4$, Freon, Teflon, halogenated plastics and ethylene dichloride. For maximum safety, they are best eliminated.

Q. Propellants. Hydrocarbons have been considered. While these are not ordinarily in the cabin space, storage tanks may be in the vicinity. Structural failure could lead to contamination of the cabin. Hydrazine, fluorine, boron compounds, chlorine, LOX, are dangerous but unlikely to get into the cabin.

R. Radiation. Potential radiation toxicity has yet to be fully evaluated. Radiation in the Van Allen belt is high enough to give dangerous dosage in a 4-hour exposure. What protection the filtering of surrounding structures give is unknown. There is a possibility of secondary radiation from such structural materials activated by the primary radiation. Strontium 90, a 28 year half-life B-emitter is a possible lighting material for cabin switches, side-stick controller, etc. The B-rays can be readily filtered by a layer of plastic or glass over the radio-isotope. Other such devices may be used. Their radiation danger must be carefully evaluated.

S. Overall. All materials used in construction, decoration, finish, wearing apparel, equipment and living functions of the pilot should be considered for potential hazard under heating and low pressure conditions. It is recommended that the air conditioning system and its moving parts--other than the fan--be carefully separated from the atmosphere of the cockpit, so that in cases of over-heating, with breakdown of oil, the toxic fumes which are made up of sulphur compounds, aldehydes and ketone products, do not get into the atmosphere. These fumes are not only toxic to the human, but also irritants to the eyes and lungs.

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1. American Society of Heating and Air Conditioning Engineer's Guide, 1958.
2. Brant, A., Industrial Health Engineering
3. dal Laval, Micromeritics
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5. Strughold, H., Living Room in Space, ATC Instructors Journal, Winter 1954.

6. Fenno, Richard M., Maj., USAF (MC), Man's Milieu in Space, Journal of Av. Med., Vol. 25, December 1954.

7. Clamann, H. G., Problems of Respiratory Metabolism in Sealed Cabins, Journal of the Interplanitary Society.

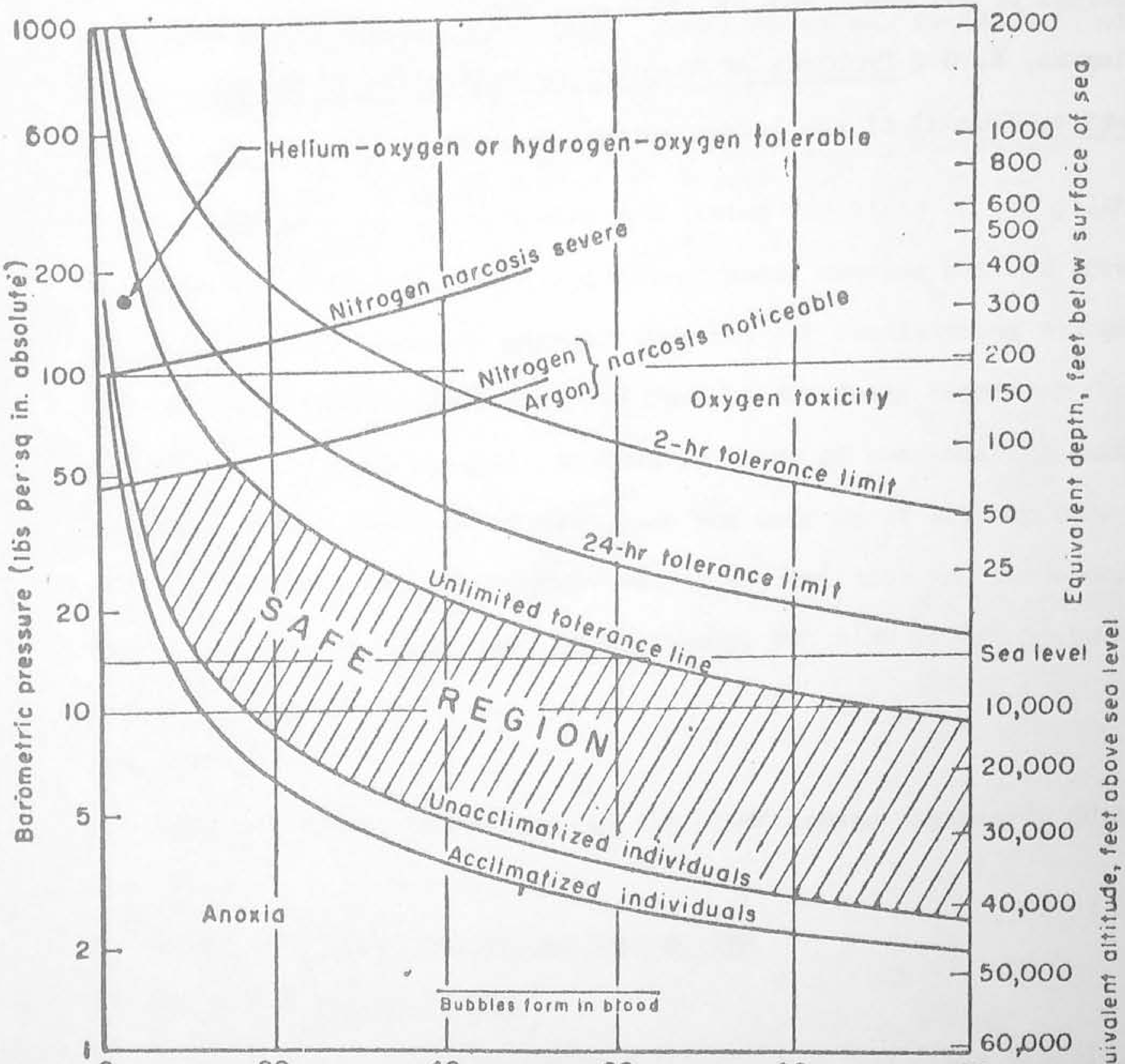


Fig. 24 —Human tolerances—atmospheric composition and pressure

From Space Handbook: Astronautics and Its Applications, Staff Report of the Select Committee on Astronautics and

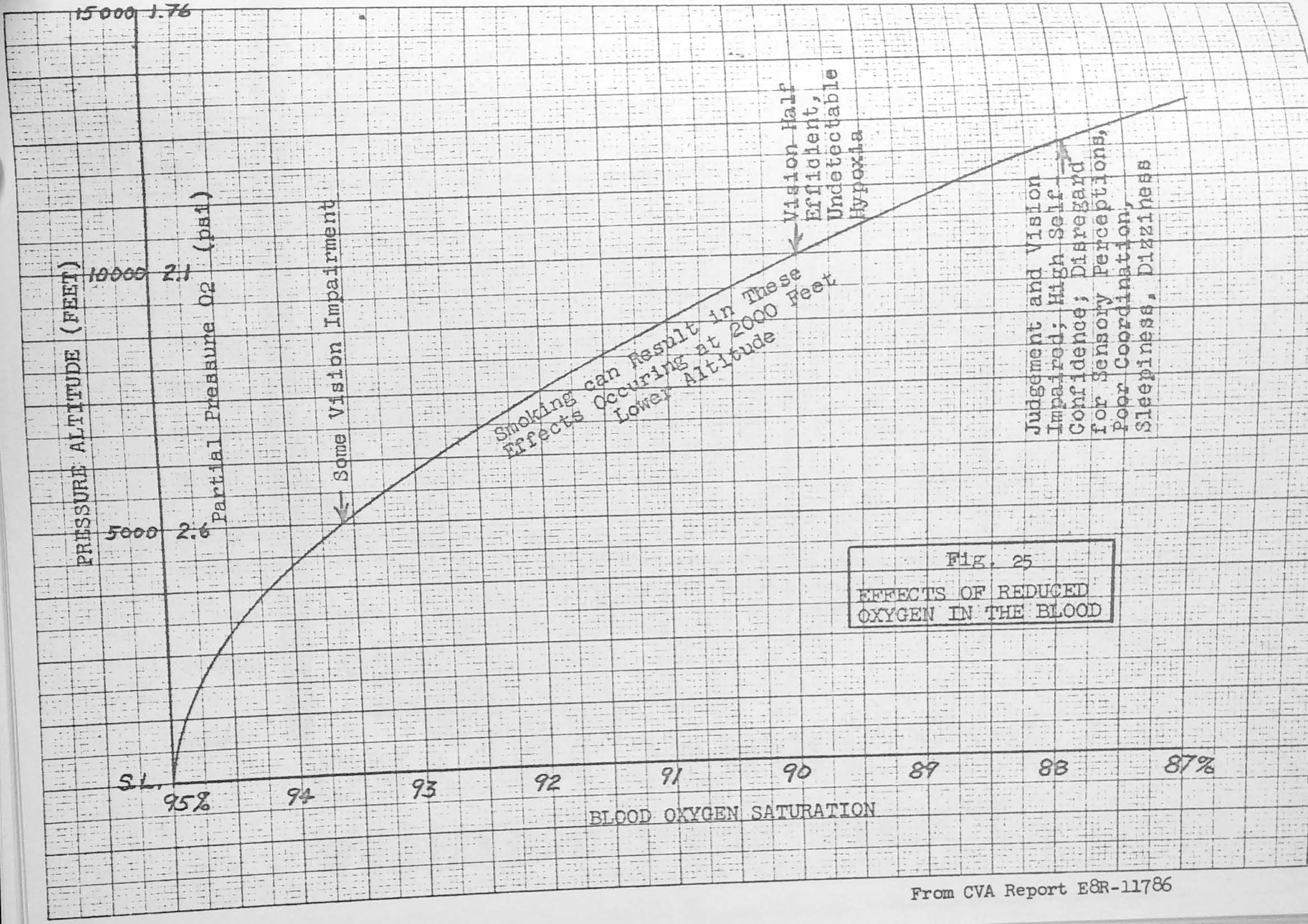


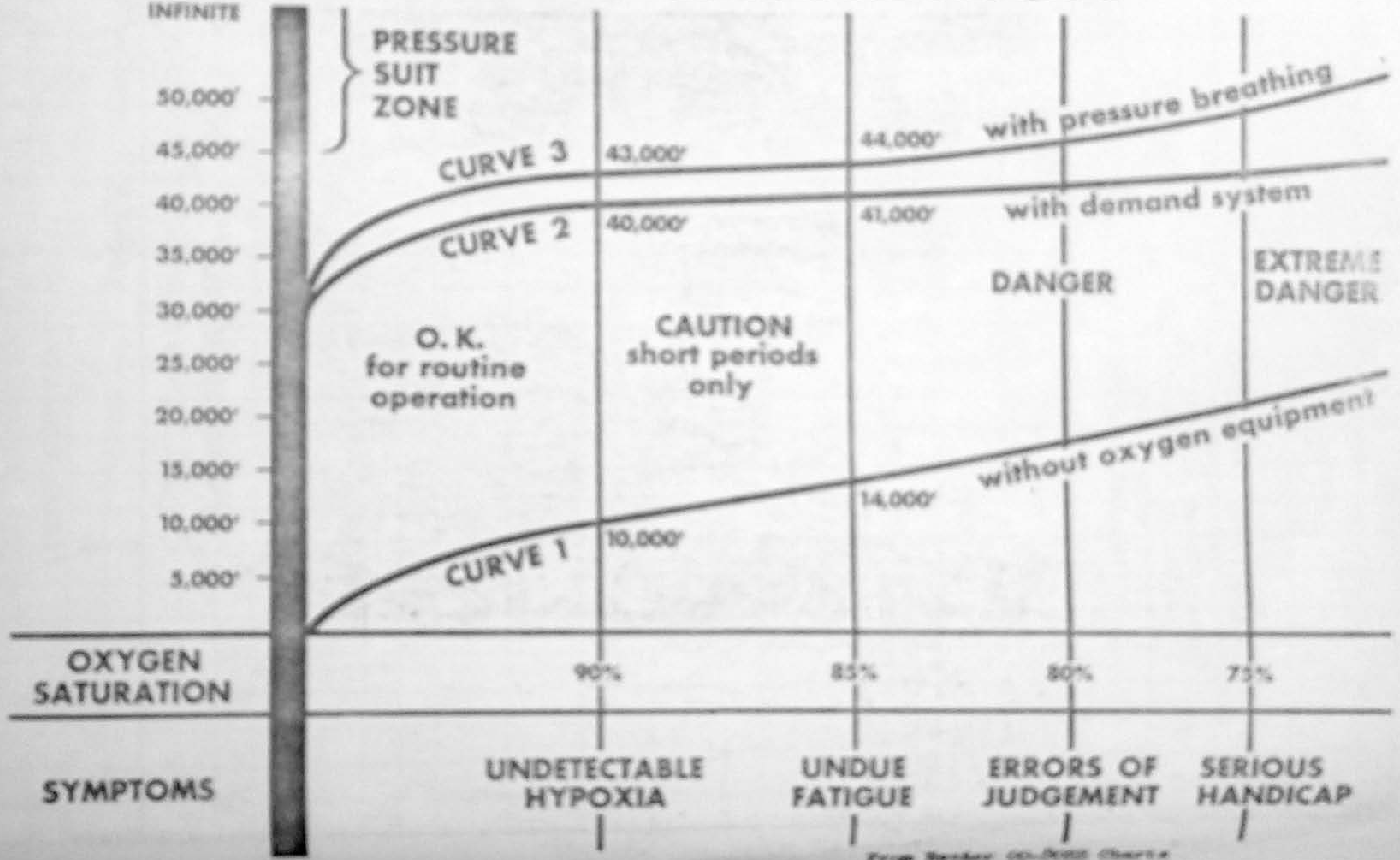
Fig. 25

EFFECTS OF REDUCED OXYGEN IN THE BLOOD

From CVA Report E8R-11786

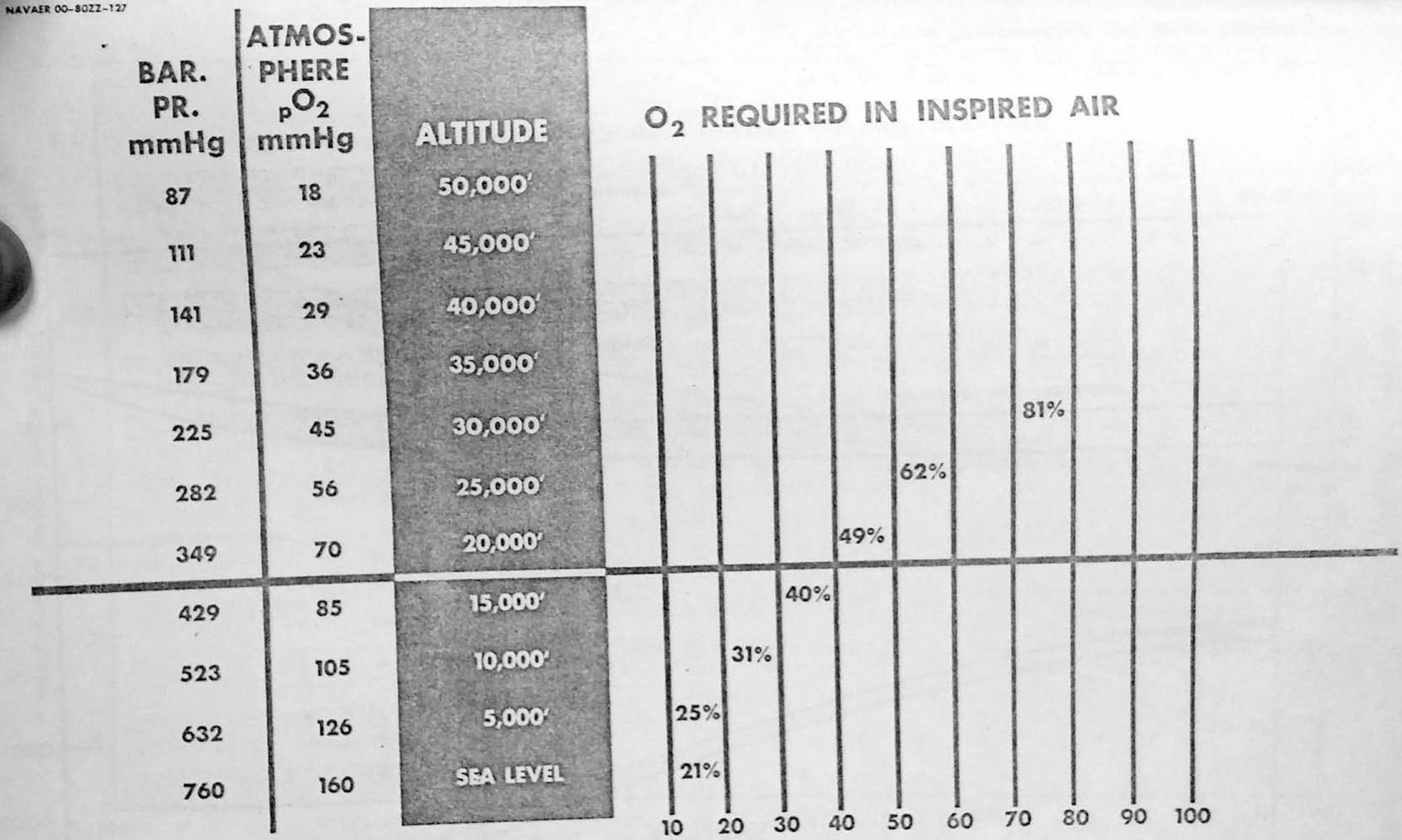
Figure 26

ALTITUDE AND BLOOD OXYGEN SATURATION



From Bendix [illegible] Charts

Figure 27



OXYGEN REQUIREMENTS

From NavAer 00-80ZZ Charts

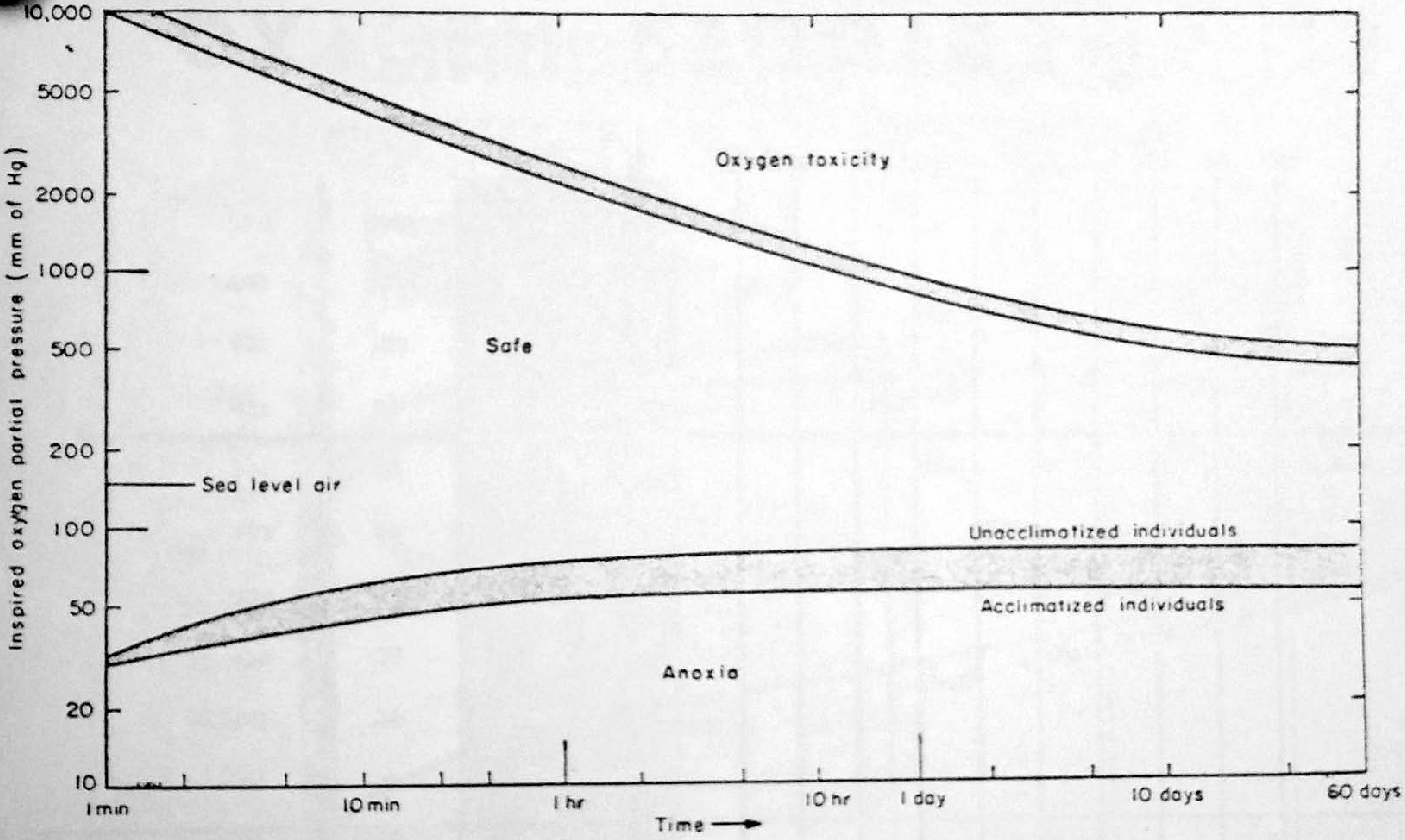
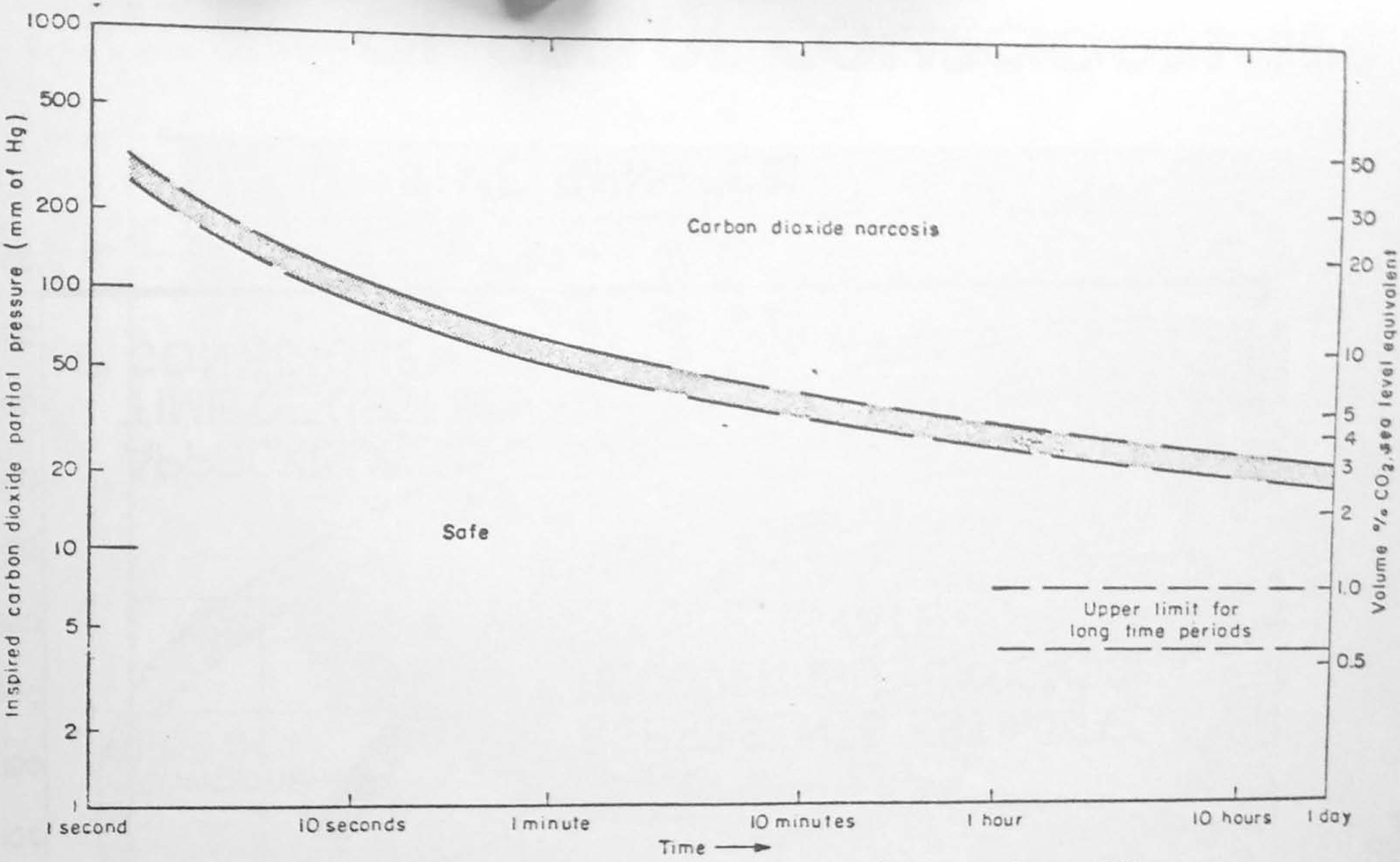


Fig. 28 — Human time-tolerances - oxygen partial pressure

From Space Handbook: Astronautics and its Applications, Staff Report of the Select Committee on Astronautics and Space Exploration



Note: Normal sea level partial pressure of CO_2 (inspired) = 0.21 mm of Hg ≈ 0.03%

Fig. 29 — Human time-tolerance – carbon dioxide partial pressure

From Space Handbook: Astronautics and its Applications, Staff Report of the Select Committee on Astronautics and Space Exploration

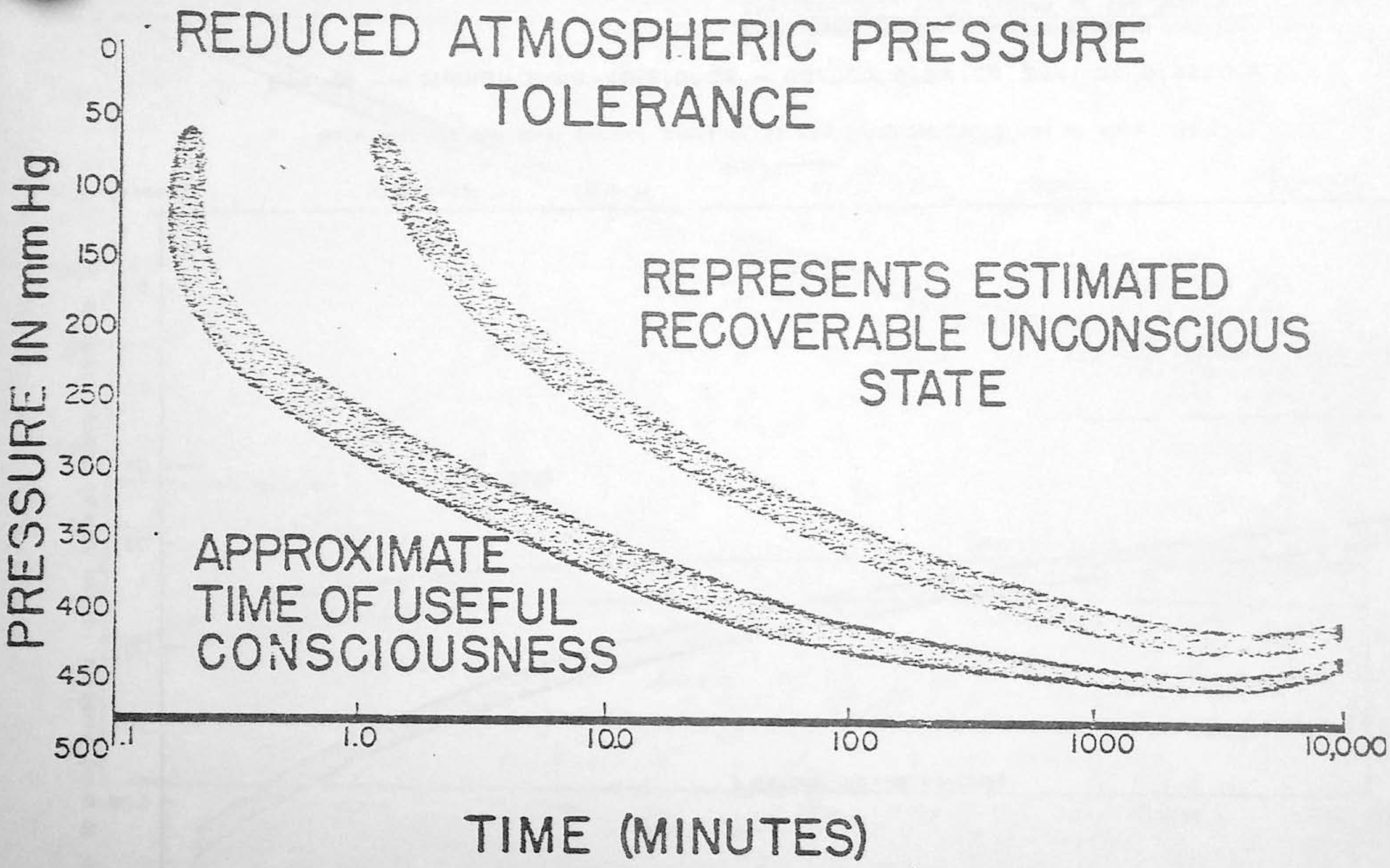
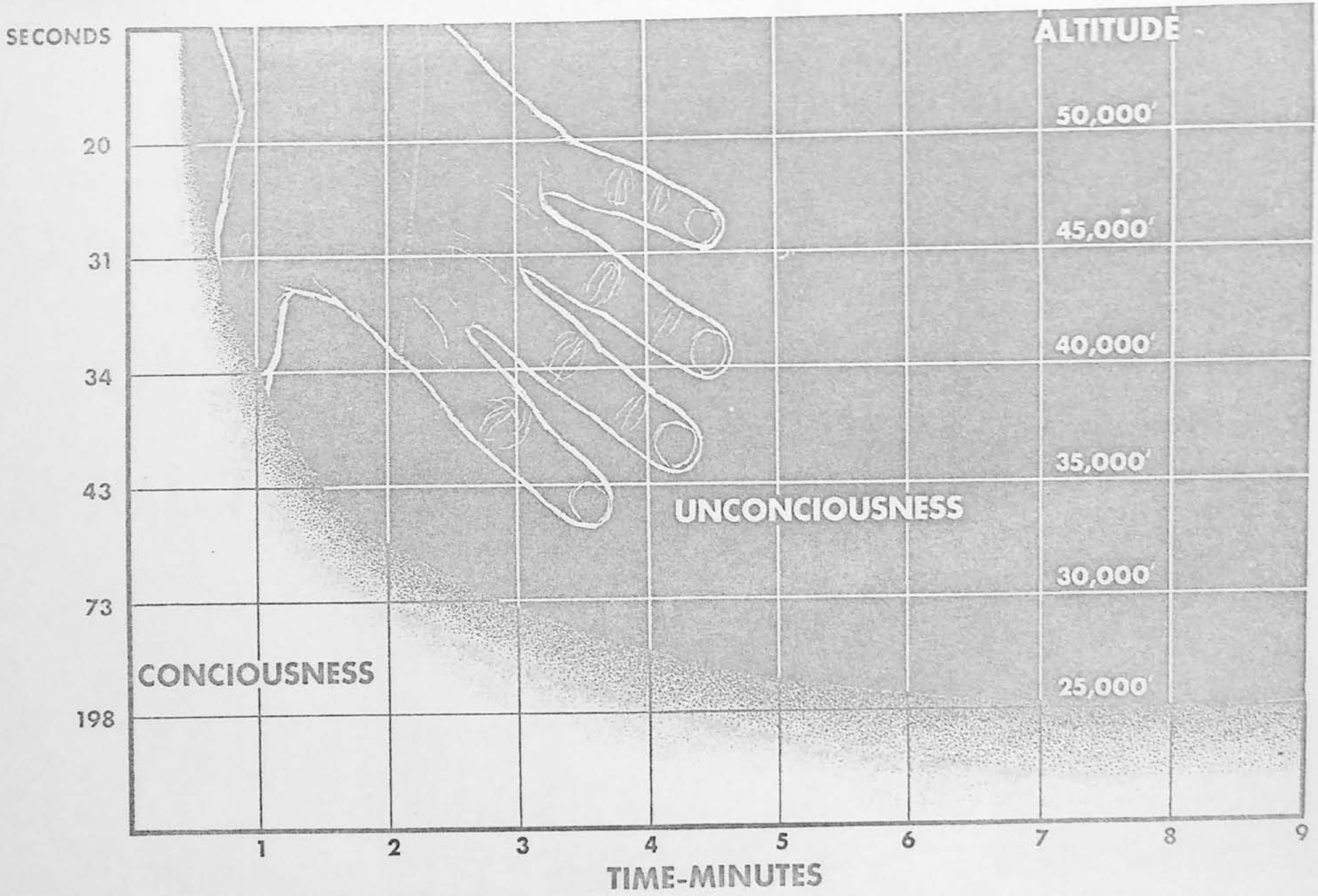


Figure 30

From <u>Survival In Space, the Vehicle - Combined Requirements</u>, A. M. Mayo, Douglas

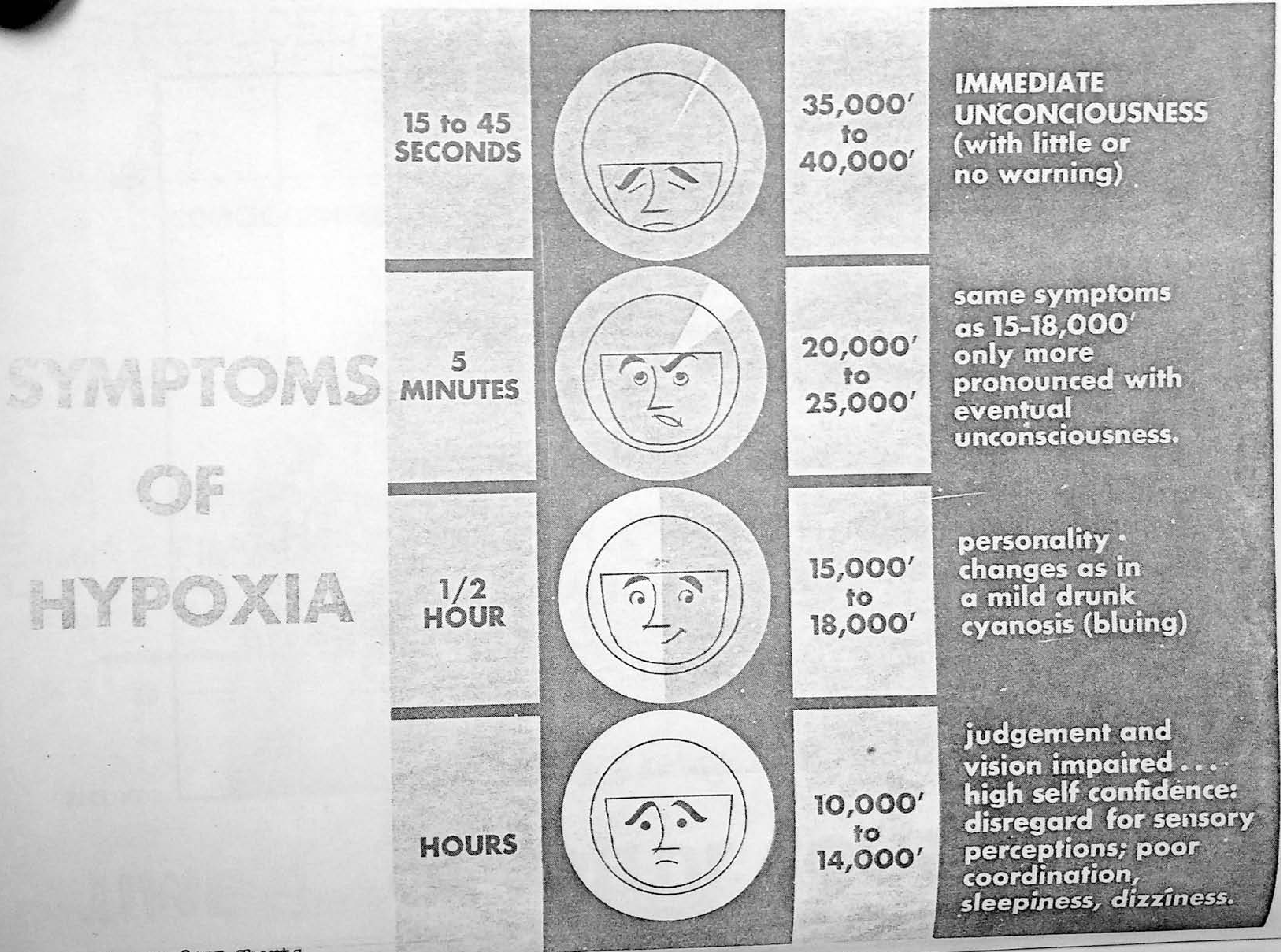
Figure 31

TIME OF USEFUL CONSCIOUSNESS



From NavAer 00-80ZZ Charts

Figure 52

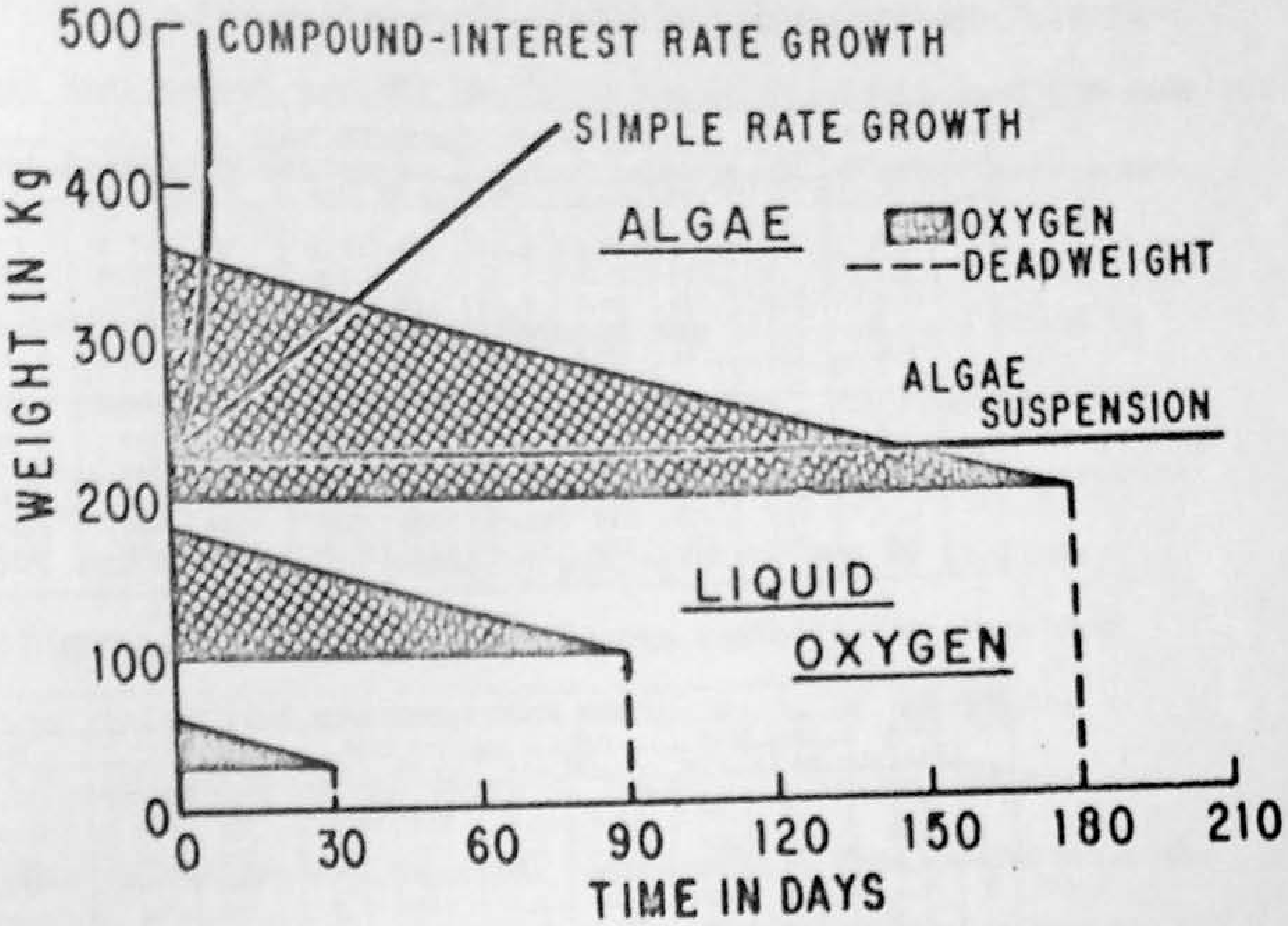


SYMPTOMS OF HYPOXIA

15 to 45 SECONDS	35,000′ to 40,000′	IMMEDIATE UNCONCIOUSNESS (with little or no warning)
5 MINUTES	20,000′ to 25,000′	same symptoms as 15-18,000′ only more pronounced with eventual unconsciousness.
1/2 HOUR	15,000′ to 18,000′	personality changes as in a mild drunk cyanosis (bluing)
HOURS	10,000′ to 14,000′	judgement and vision impaired . . . high self confidence: disregard for sensory perceptions; poor coordination, sleepiness, dizziness.

From NavAer 00-80ZZ Charts

Figure 33



Comparison of Liquid Oxygen System to an Ecologically Balanced Algae Oxygen Regeneration System. The cross-hatched areas represent weight of oxygen and its utilization; dead weight is shown by height of triangle base above zero line. If weight of algae system remains constant, at some point it becomes a lighter system than liquid O_2 for the same period of time. If growth is allowed, liquid O_2 may remain lighter for all durations. From Clamann, Hans-G.: To be published in J. Brit. Interplanetary Soc..

Table II

OXYGEN CONSUMPTION AND CARBON DIOXIDE PRODUCTION RATES

PART A

CREW No.	O_2 RATE Man/hr	OXYGEN CONSUMPTION RATES									
		per hour		per day		per week		per month		per year	
		cu ft	lbs	cu ft	lbs	cu ft	lbs	cu ft	lbs	cu ft	lbs
1	0.8	.8	.066	19.2	1.59	134	11.2	576	47.8	7008	582
	0.9	.9	.075	21.6	1.79	151	12.5	648	53.8	7884	654
	1.0	1.0	.083	24.0	1.99	168	13.9	720	59.8	8760	727
	1.2	1.2	.100	28.8	2.39	202	16.7	864	71.7	10512	872
	1.4	1.4	.116	33.6	2.79	235	19.5	1008	83.7	12264	1018
5	0.8	4.0	.332	96.0	7.97	672	55.8	2880	239	35040	2908
	0.9	4.5	.375	108	8.99	756	62.9	3240	269	39420	3280
	1.0	5.0	.415	120	9.96	840	69.7	3600	299	43800	3635
	1.2	6.0	.498	144	11.95	1008	83.7	4320	359	52560	4362
	1.4	7.0	.581	168	13.94	1176	97.6	5040	418	61320	5090

PART B

CREW No.	CO_2 RATE Man/hr	CARBON DIOXIDE PRODUCTION RATES									
		per hour		per day		per week		per month		per year	
		cu ft	lbs	cu ft	lbs	cu ft	lbs	cu ft	lbs	cu ft	lbs
1	0.7	.7	.08	16.8	1.9	118	13.5	504	58	6132	702
	0.8	.8	.09	19.2	2.2	134	15.4	576	66	7008	802
	0.9	.9	.10	21.6	2.5	151	17.3	648	74	7884	903
	1.1	1.1	.126	26.4	3.0	185	21.2	792	91	9636	1103
	1.3	1.3	.149	31.2	3.6	218	25	936	107	11388	1304
5	0.7	3.5	.40	84	9.6	588	67	2520	288	30660	3510
	0.8	4.0	.458	96	11.0	672	77	2880	330	35040	4012
	0.9	4.5	.52	108	12.4	756	87	3240	371	39420	4514
	1.1	5.5	.63	132	15.1	926	106	3960	453	48180	5517
	1.3	6.5	.74	156	17.9	1092	125	4680	536	56940	6520

Oxygen Consumption and Carbon Dioxide Production Rates. Courtesy of Douglas Aircraft Co., Tulsa, Oklahoma, 1958.

V. TEMPERATURE

Optimal mental and physical efficiency can be maintained only when the thermal environment permits the normal heat dissipation of the body without unduly taxing the physiological mechanisms of body temperature control.

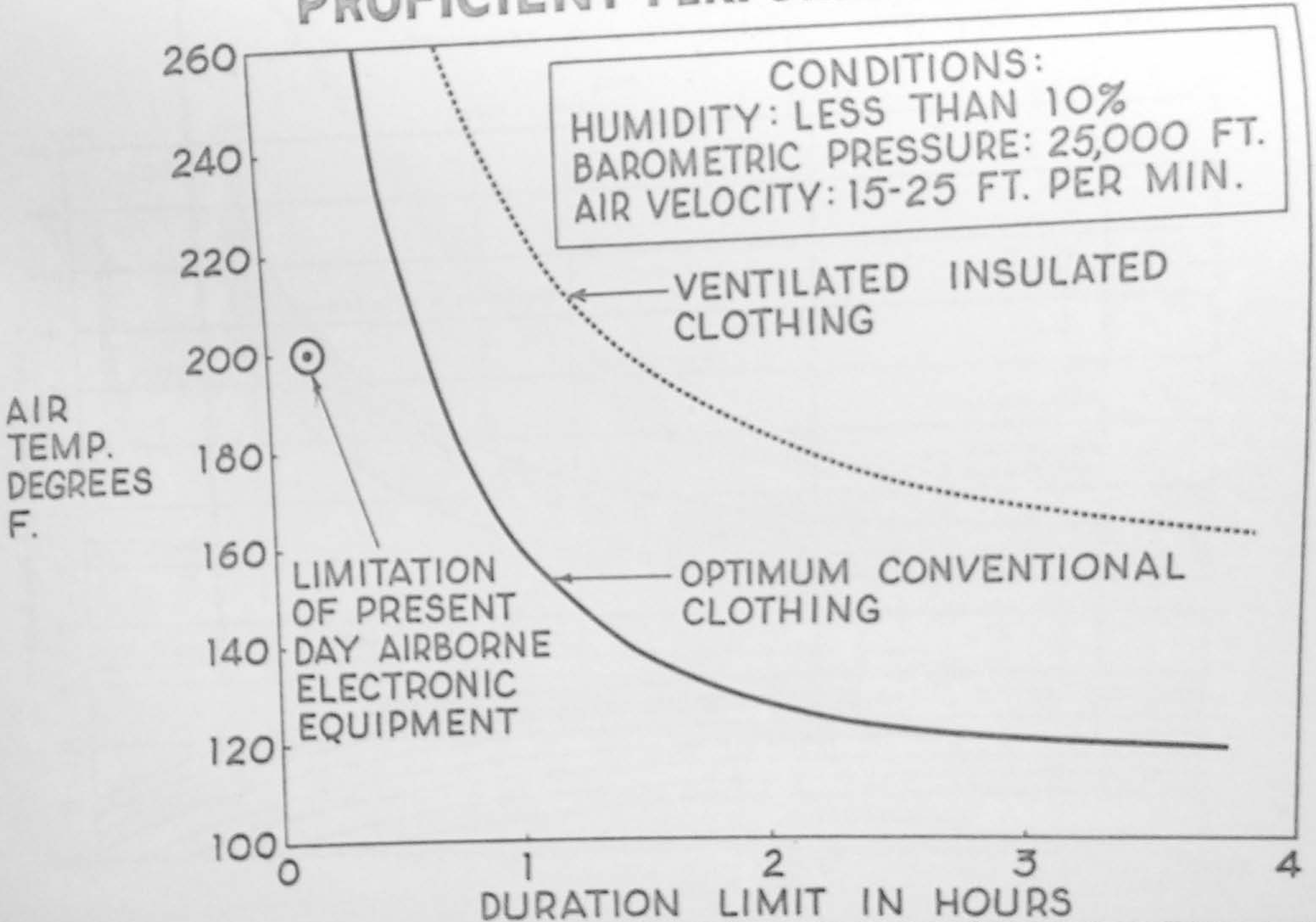
Since heat transfer at the surface of the body can take place by conduction, convection, evaporation and radiation, the operative temperature of the environment is determined not alone by the temperature of the air, but also by its humidity and velocity and by the temperature, configuration and distance of objects radiating or absorbing heat in the vicinity of the body such as the walls of the cabin.

If the temperature of the walls is comparable to that of the air in the cabin, a man dressed in light clothing will feel comfortable at a rate of air movement between 30-50 ft/min, with a relative humidity of 30-40% at temperatures between 65°-90°F. Figures 34 through 41 show the comfort zone and tolerance limits with regard to temperature and humidity of the environment. Human tolerance studies by Bledele and Taylor indicate that a low humidity, dry bulb temperatures up to 240°F (116°C) can be tolerated for short periods of time. Under these conditions, heat dissipation is limited to evaporative heat loss. Functional heating of the cabin wall may lead to excessive radiant heat loading of the body which cannot be compensated for by evaporative or convective cooling. Outer garments of reflective metallic material combined with wetting and precooling of the skin and underclothing would appear to offer the best protections against intense thermal radiation.

References:

1. American Society of Heating and Air Conditioning Engineer's Guide, 1958.
2. Blockley, V., Designing for the Human Factor in Space Flight, Dec. 1957.
3. Mayo, A. M., Survival In Space, the Vehicle - Combined Requirements, Douglas Aircraft Co., El Segundo, Calif.

THERMAL LIMITS FOR MAN'S PROFICIENT PERFORMANCE



From Designing for the Human Factor in Space Flight, V. Blockley
Dec. 1957

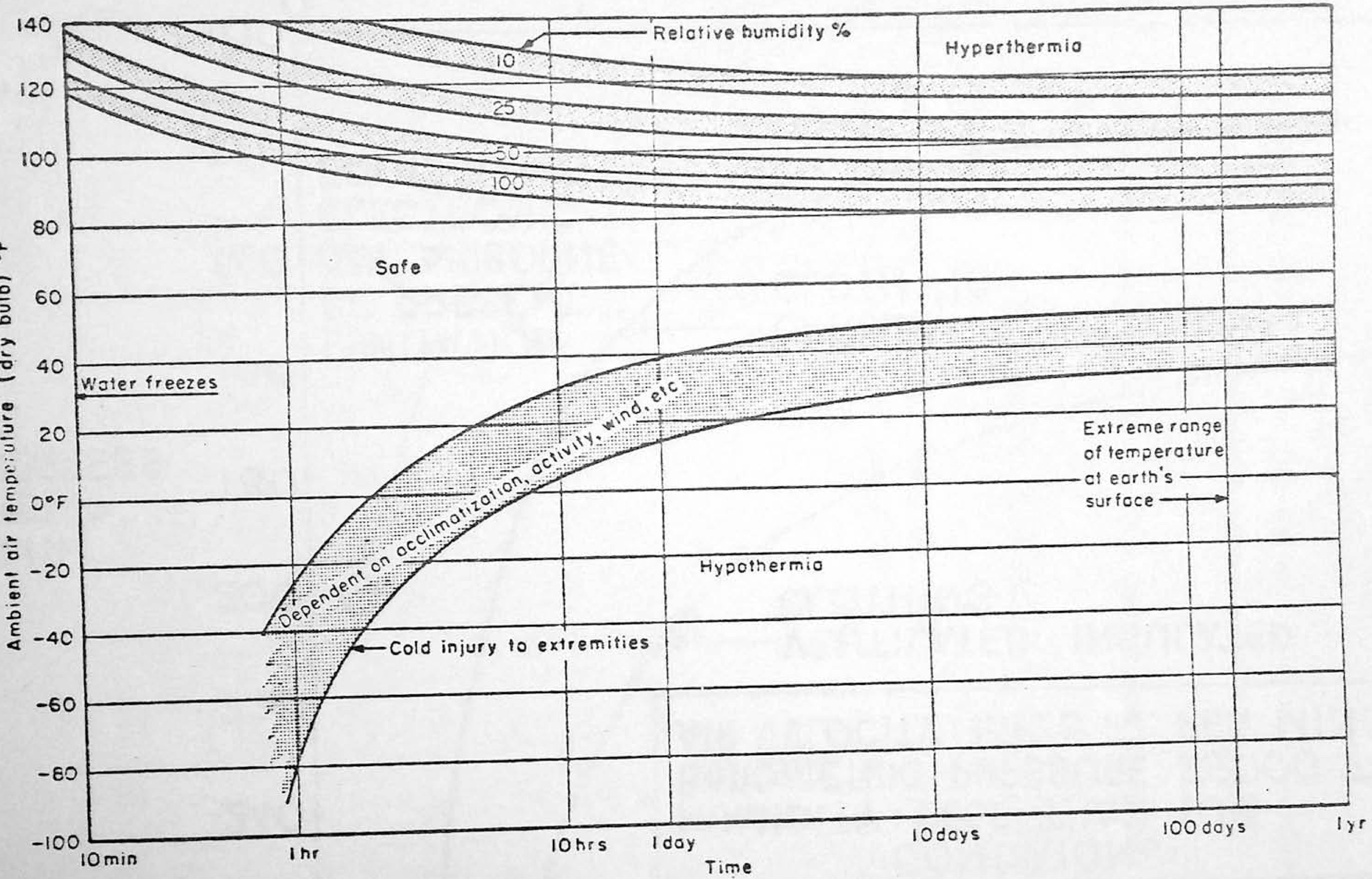


Fig. 35 —Approximate human time-tolerances: temperature

Optimum clothing

From Space Handbook: Astronautics and its Applications, Staff Report of the Select Committee on Astronautics and Space Exploration

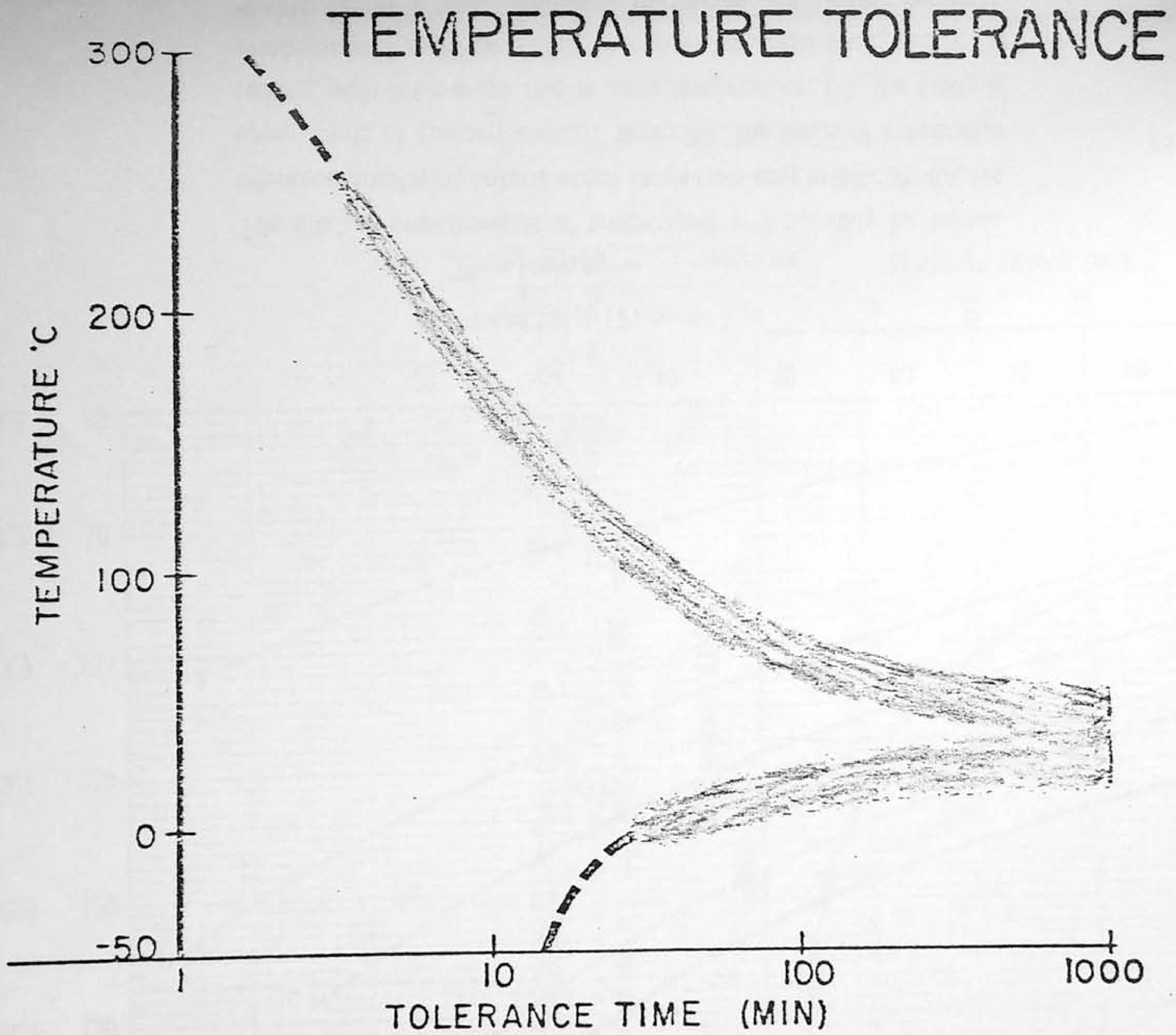
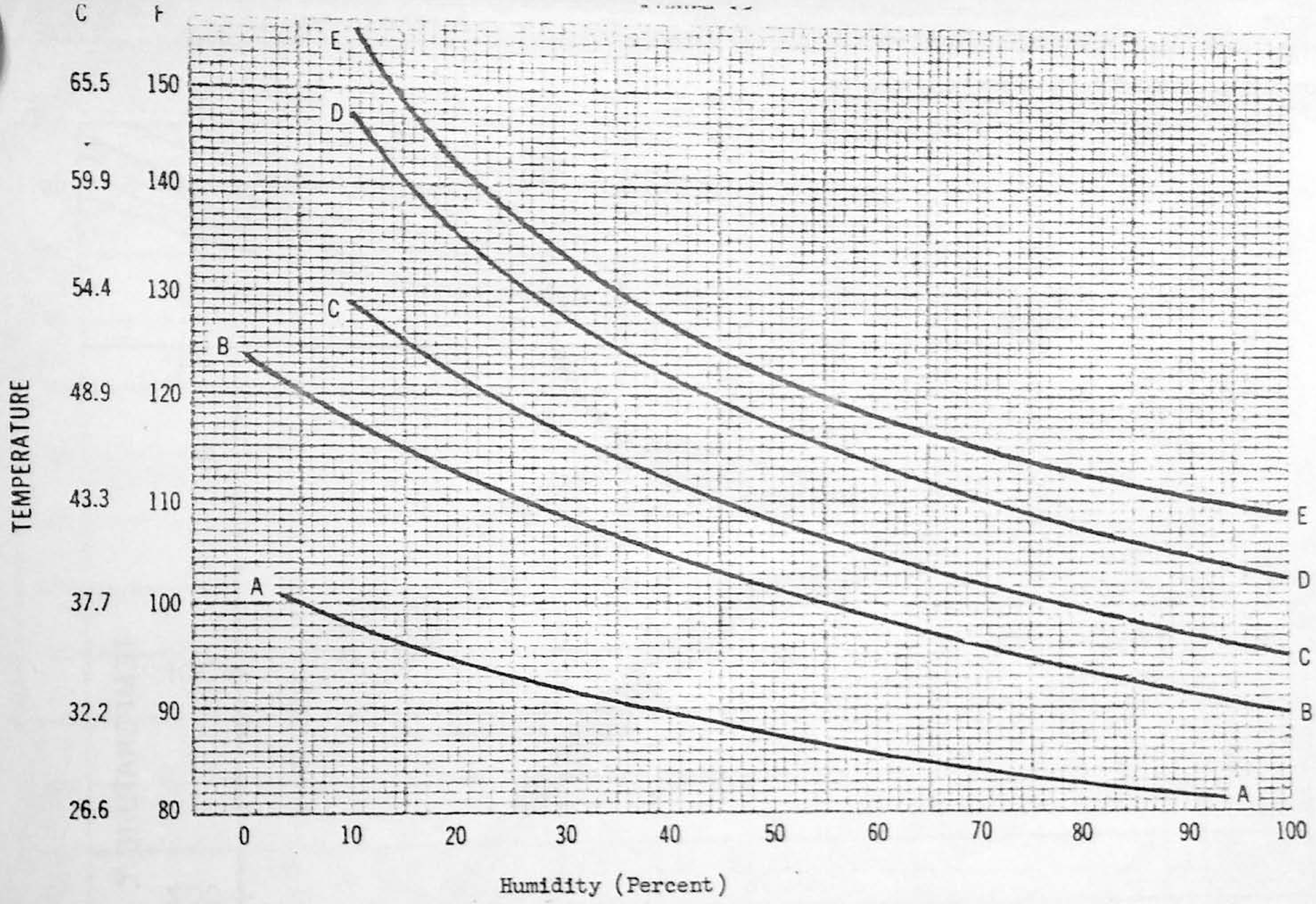


Figure 36

From Survival In Space, The Vehicle - Combined Requirements, A. M. Mayo, Douglas Aircraft Company, El Segundo, California

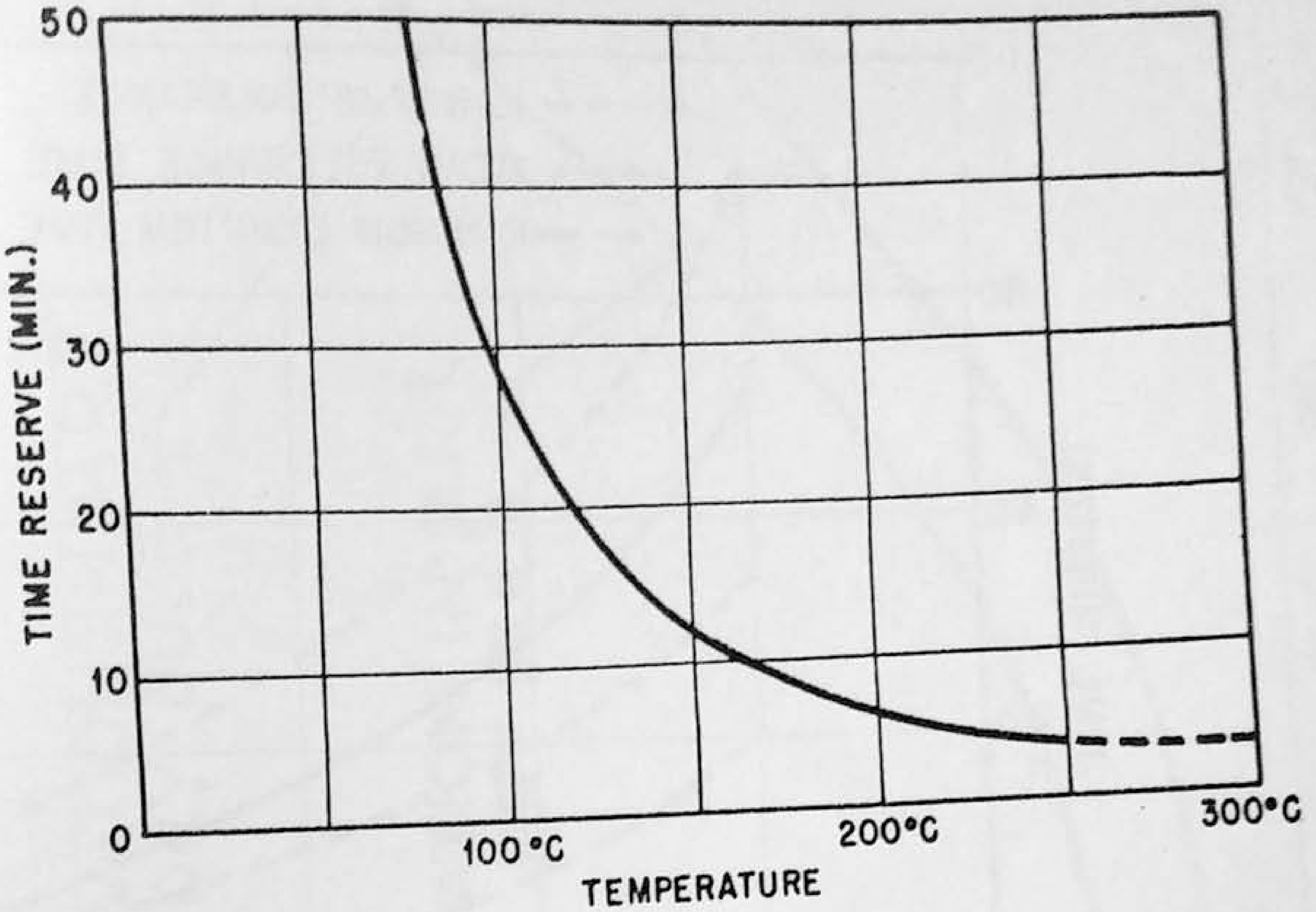


Temperature Tolerance

The limiting environments of temperature and humidity for human tolerance, employing criteria which range from easy to difficult: AA, the upper limits of summer comfort zone: BB, the limits of evaporative cooling, with little or no rise in body temperature; CC, the limits of compensated hyperthemia; DD, 60 minute tolerance, limit; and EE, 30 minute tolerance limit. (Winslow, Herrington and Gagge; Robinson, Turrell and Gerking).

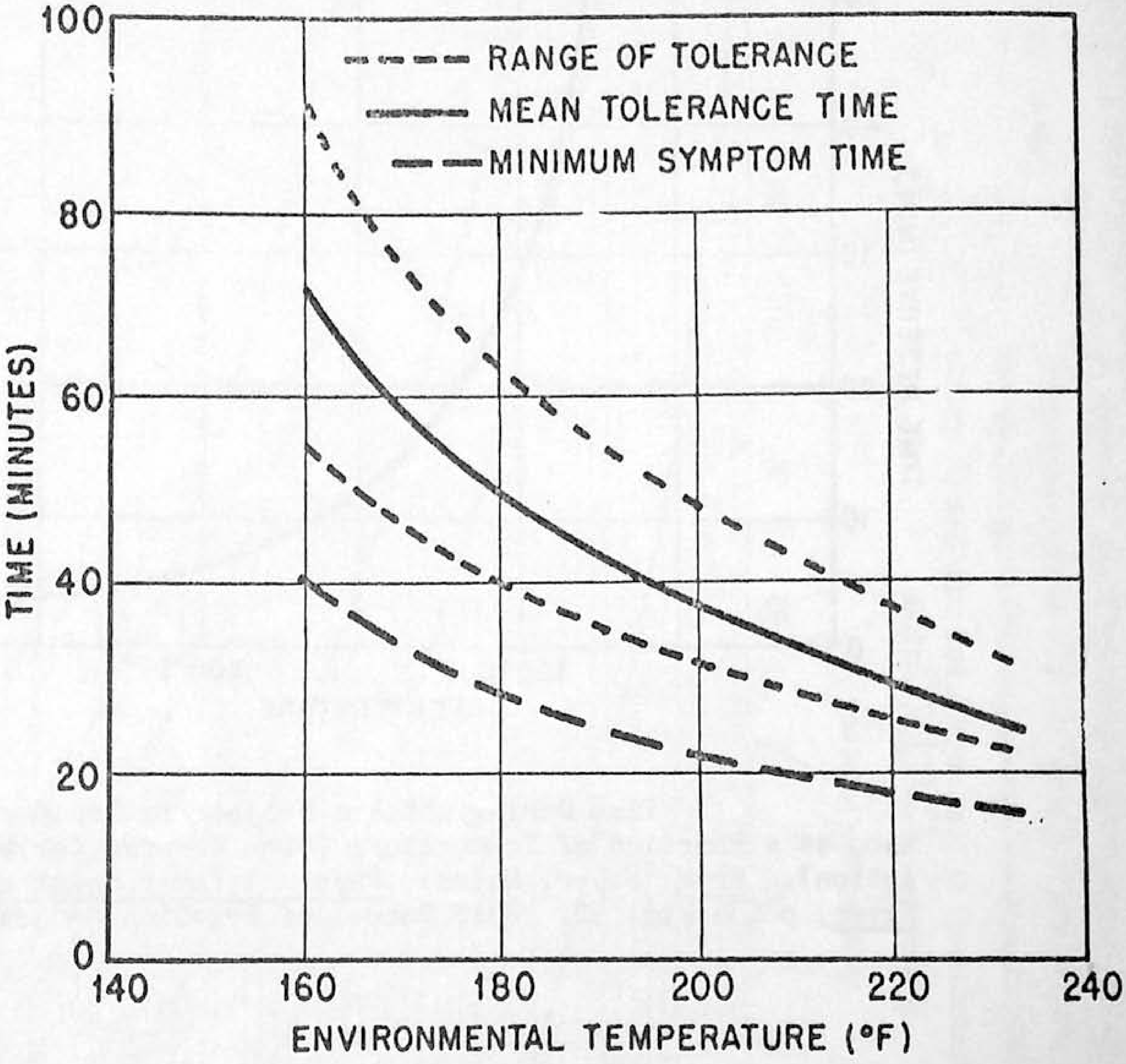
Figure 37

Figure 38



Time During Which a Subject is Capable of Action as a Function of Temperature (Time Reserve for Useful Action). From Haber, Heinz: Physical Environment of the Flyer, p 134 Fig. 52. USAF School of Aviation Medicine, 1954.

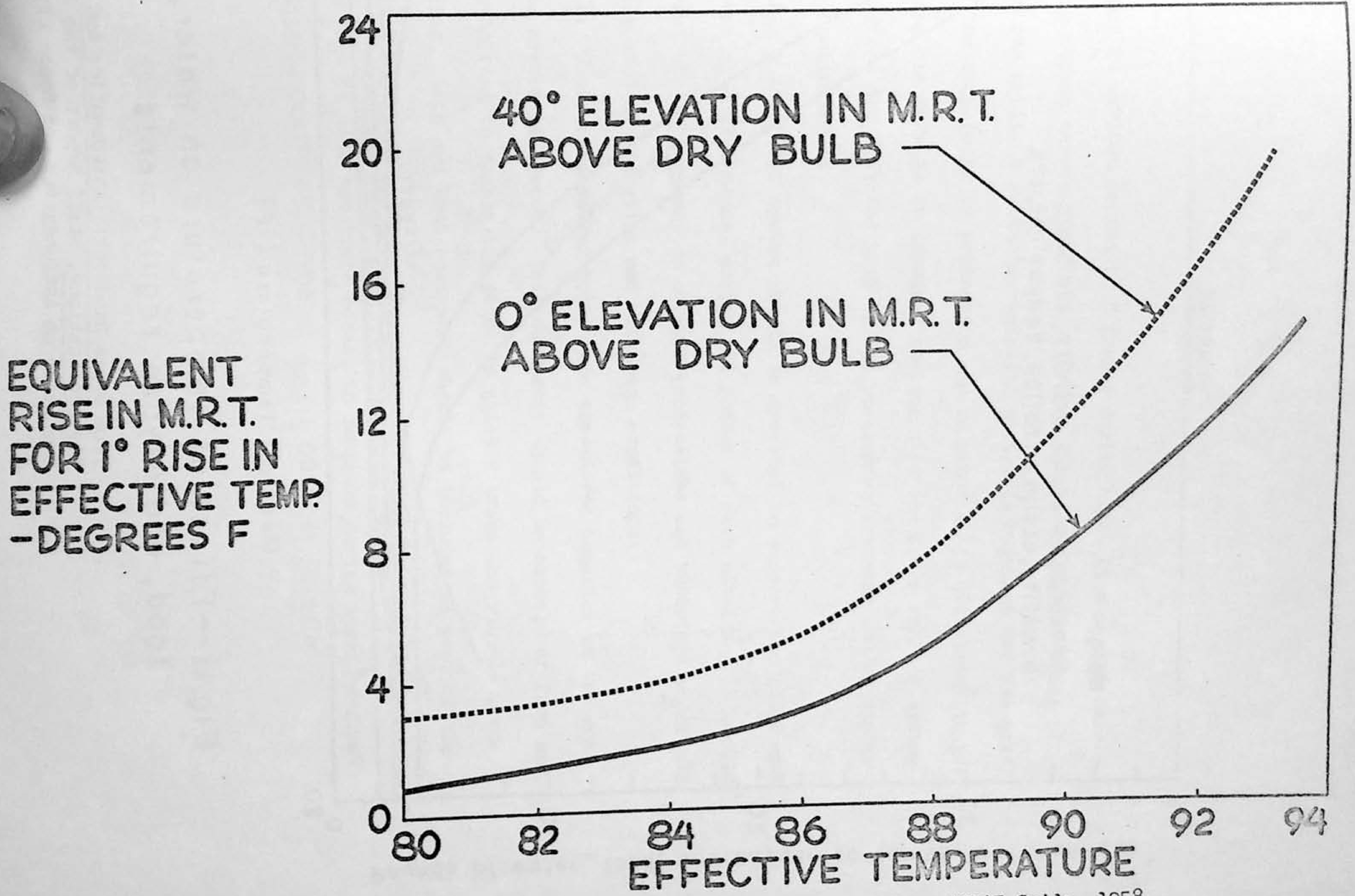
Figure 39



Mean and Range of Tolerance time, and Minimum Symptom Time, for Temperatures From 140° to 240°F. From Blockley, W. V.: Personal communication to Fred A. Hitchcock 6 August 1953. Cited By Dryden, Charles E., Lit-Sien Han, Fred A. Hitchcock and Richard Zimmerman: Artificial Cabin Atmosphere Systems For High Altitude Aircraft, p 26 Fig. II-8. WADC Technical Report 55-353, November, 1956.

Figure 40

EFFECT OF MRT ELEVATION IN TERMS OF EFFECTIVE TEMPERATURE



From ASHAE Guide, 1958

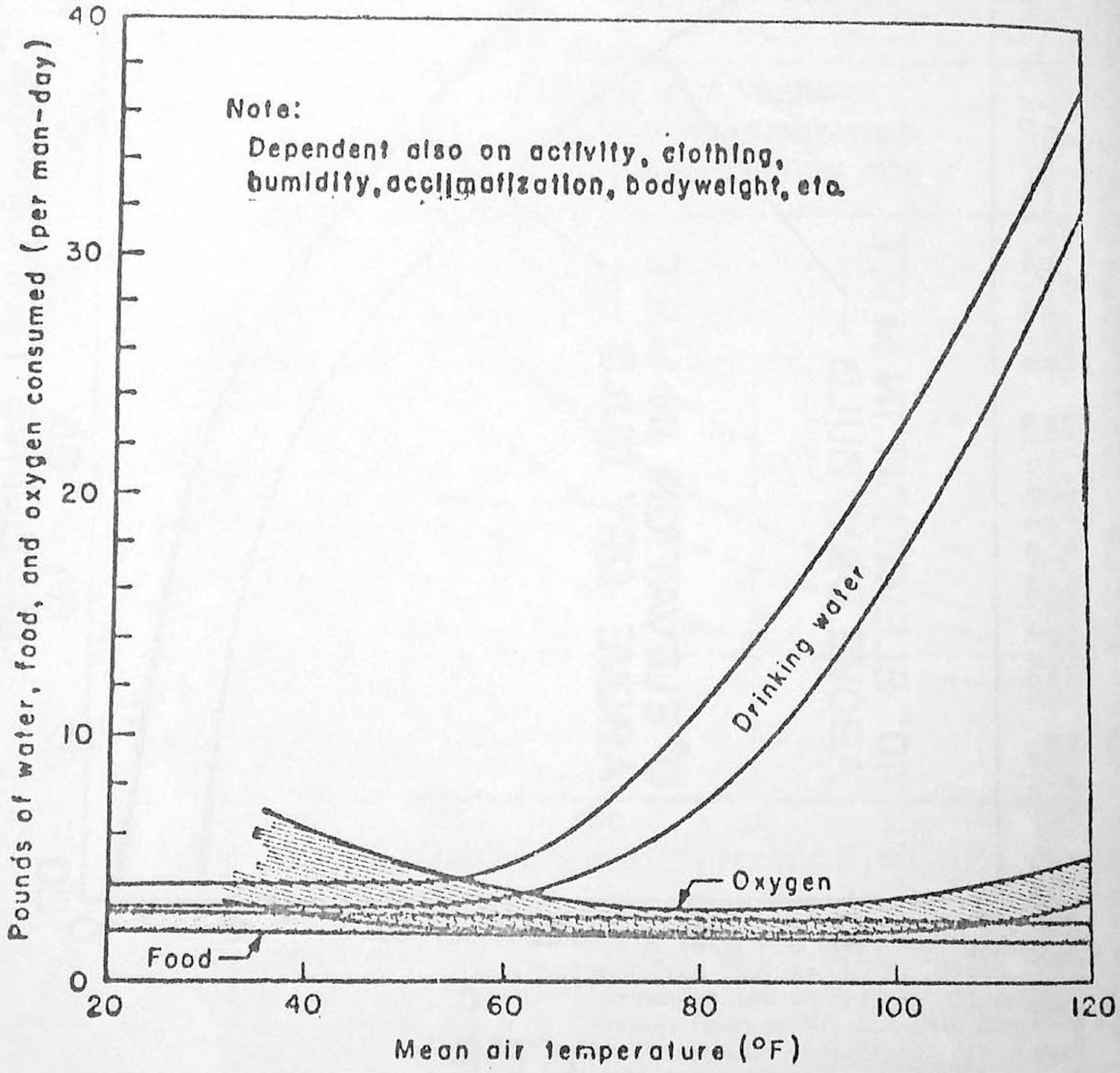


Fig. 41—Effect of temperature on water, food, and oxygen requirements

From Space Handbook: Astronautics and its Applications, Staff Report of the Select Committee on Astronautics and Space Exploration

VI. RESTRAINT

Due to various transient G forces during boost (i.e., wind shear, uneven thrust termination, etc.) as well as the weightless state of coast and orbit, a suitable restraint system is required for the pilot from the standpoint of protection and to promote his efficiency in performing his role as an integral component of the space vehicle system. Provisions are dictated both by the working environment and by emergency contingencies.

A. A restraint system should be provided to support the pilot and prevent his displacement during all phases of each mission. It should prevent his impingement on cockpit protrusions and structure under all anticipated acceleration and vibration conditions.

B. Seat, harness and helmet are considered together as the complete restraint system. This equipment should be capable of fast and easy doffing to enable the pilot to quickly leave the vehicle upon landing. Limb and head restraint should be included as part of the overall restraint system. The restraint system should be designed such that it does not limit access to controls during normal flight conditions.

VII. CREW SPACE COLOR AND LIGHTING

Internal instrument display and control vision must not be compromised by external vision provisions. The cabin lighting and reflecting surface environment must be selected to make outside and internal vision compatible. Provision to control extremes in external radiation and heat transfer must be provided.

Detail requirements are:

a. Provisions must be made to shield out direct sunlight,

b. It must be possible to make required visual observations at orbital altitude, during re-entry, and during low level flight including landing during both daylight and night conditions.

c. The sun erythemal flux (sun-burning energy) at altitude must be filtered by a factor of 40.

d. Visual acuity controls the minimum acceptable level for background illumination. A minimum of .2 lumen/ft^2 of background brightness should exist inside the cockpit.

e. All instrument panel letters should have a minimum height of 0.1". Stroke width should be approximately 1/5 of total height.

f. Preliminary analysis indicates that instruments should have black letters on a light background to increase internal illumination level. The background reflectance for black letters on a white background should be 50% or greater.

g. Console illumination sufficient to provide 100 foot-lumens of incident light from the console is required to prevent excessive glare from high level outside illumination.

h. White light incident illumination is required if color vision is required.

i. Glare must be reduced to an extent which will guarantee that visual fatigue will not limit the functioning of the pilot. Painting the inside portion of the cabin outside of the pilot's vision a flat white as was done in Manhigh balloon flights is desirable to minimize glare.

j. The periodic shift from intense light to darkness and back again makes the use of dark glasses type shading highly desirable on demand by the pilot. Shade hinged on pressure suit helmet would be satisfactory.

VIII. WEIGHTLESSNESS

D. G. Starkey

During the coast period and then again during orbit, the pilot will for the first time be subjected to prolonged weightlessness. It has not been possible to evaluate this condition adequately for significant lengths of time. Parabolic flight paths which provided 42 to 85 seconds of near weightlessness have revealed no insurmountable problems as far as it affects eating, drinking, breathing, blood circulation, etc. There has appeared a decrement of one to one-half "G" in ability to withstand normal "G" after a short period of weightlessness, however, there is no data as to its effect on transverse "G" tolerance such as will be encountered upon re-entering the Earth's atmosphere. Other senses, most notably the optical sense, apparently substitute satisfactorily for the loss of the otoliths during the short periods of zero gravity so far evaluated. The only prolonged weightlessness experiment to date, the dog carried into orbit in the second Russian Sputnik satellite, indicated that it required three times as long for circulation to return to normal after boost acceleration as compared to the same acceleration profile on the centrifuge. It is possible that other physiological adjustments will be similarly retarded.

Experience in the weightless state was first encountered by a group of German fighter pilots during World War II. This new phenomenon occurred when attacking German fighters penetrated the allied bomber and fighter defense from high altitudes, made their pass at the bombers from below after a violent pullup, and then evaded by another dive. During such a maneuver the pilot first produced high positive "g" as he pulled up from his dive and then negative "g" and weightlessness during the pushover into the second dive. These maneuvers frequently caused disturbances in vision, weakening in the legs and insecure control movements during the weightless state. However, after becoming accustomed to these gyrations, some pilots stated that the maneuver was a pleasant flying experience. The occurrence of this phenomenon lead to speculations about the effects of weightlessness on the human body by several German doctors and this interest spread to the United States. Subsequently, many experiments and studies have been performed.

The most practical means of producing the weightless state has been with the T-33 and the F-94C aircraft. The situation obtained in flight is more realistic than that obtained in any other way and can be employed for training or research purposes. The flight maneuver to produce zero "g" requires that all accelerations be eliminated except the one caused by gravitation, which constantly acts downward at a magnitude of approximately 1 g. Several prominent test pilots and researchers first flew this parabolic flight pattern (also known as the Keplerian trajectory) in 1951. Scott Crossfield made some thirty flights in an F-84 in which he experienced the weightlessness state from 15 to 40 seconds. He reported a feeling of "befuddlement" during the transition into weightlessness, but this feeling disappeared after the fifth flight. He had no sensation of falling and no loss of muscle coordination other than a tendency to over-reach with his arm. He did experience some vertigo occasionally on the pullout after a run. Dr. E. R. Ballinger of WADC also experimented with several subjects at the same time and his observations coincided with Mr. Crossfield's. His subjects expressed the opinion that, if they had not been restrained in the seat and had been blindfolded "disorientation might be extreme". At the same time, Major Charles E. Yeager who also participated in such flights stated that he experienced a sensation of spinning around in no particularly defined direction and became lost in space at the end of 15 seconds of weightlessness. With returning weight, his orientation was restored.

In another experiment, subjects were required to draw crosses in seven small squares arranged diagonally across a sheet of paper while riding the zero "g" trajectory and to hit a bull's eye with a stylus under conditions of 1g, 3g and 0g (Figures 42 through 44). In the first experiment, the tests were made with the eyes open and then they were closed. It will be noted that extreme difficulty was exhibited by the subjects in drawing the crosses under zero gravity conditions, and when the eyes were closed, they lost all sense of orientation. However, Dr. Von Beckh, the experimenter, states that after a considerable number of flights their accuracy improved. It will also be noted that the hit accuracy in the latter experiment shows steady improvement with succeeding trials during the weightless state. The results of these studies indicate that learning and adjustment under the state of zero gravity was showing steady improvement.

According to Dr. Siegfried J. Gerathewohl, almost one hundred individual subjects have participated in experiments on the effects of weightlessness through mid-1958. In general, the results of these studies show that minimal disturbances of coordination and orientation is experienced as long as the subject retains tactile (touch) and visual references. Responses were highly individualistic, however, particularly in regards to tolerance to weightlessness. At the school of Aviation Medicine, Randolph A.F.B., one group of 47 subjects were carefully screened before and after such flights regarding their physical condition, tolerance to air sickness, personal reactions during the flight, etc. All were physically qualified for jet flying and were highly motivated for the experiment. Seventeen were either Air Force pilots or had at least some flying experience; only nine had no jet experience prior to the study, and all had flown in conventional aircraft. Practically all subjects reported sensations of floating or slowly drifting and about half of these felt very comfortable and reported no unusual sensations other than slight elation associated with the feeling of pleasantness. Several others described sensations of falling, tumbling, rolling over, or being suspended in mid-air in an inverted position. About one third of the group reported feeling of discomfort, nausea, and severe motion sickness.

Other studies have investigated the effects of sub and zero gravity on the human body, its nervous system and the various sense organs. While information is by no means complete, many of these effects are known. Table III summarizes some of these findings in relation to the sense organs and their manner of reacting to the weightless state. It is apparent that the greatest detrimental effect is on the inner ear orientation organ (the Otoliths), whereby the human loses the sense of gravitational vertical through this sense modality. However, this loss can be compensated for by means of visual cues since the eye does not appear to be affected. Other effects on the autonomic nervous system such as those automatically controlling digestion, respiration, heartbeat, bladder and bowel function, and to some extent those affecting sight, are not entirely known. However, experiments on both animals and humans to date do not indicate any serious impairment of these processes. It is interesting to note that the release of information by the Russians regarding the dog experiment in Sputnik II stated that there were no significant changes in its physiological functions during the six days of weightlessness.

While research to date has produced results indicating some of the effects of the weightless state on the individual, by and large, it has not given the reasons for these reactions, i.e., the degree to which they are physiological or psychological in origin. For example there is evidence to believe that those individuals who have little or no fear of the weightless state and who maintain their frame of reference and concentrate on the task at hand (rather than in terms of what is happening to them and the physiological stimulations resulting therefrom) will experience little or no motion sickness and vertigo. Furthermore, it appears that experienced jet pilots have a higher tolerance to the zerogravity state than most other flying or non-flying personnel. It is also known that highly motivated personnel show a higher tolerance. Other evidence indicates that visual acuity will be unaffected, although visual orientation (under all circumstances and for prolonged periods) may be disturbed.

The above indicates:

A. The serious functional disturbances observed in subjects during weightless experiments occurred mainly in persons having a relatively low resistance to motion sickness.

B. The majority of subjects participating in weightlessness experiments to date have enjoyed the experience.

C. It is concluded that selected crews, properly trained, will be able to perform efficiently under sub and zero-gravity conditions.

D. Since visual reference is the most valuable means of orientation in zerogravity, its functioning must be ensured under all circumstances. The overall cockpit configuration with its properly designed and adequately lighted instruments, will afford the pilot the necessary "up" and "down" - "right" and "left" orientation.

E. To maintain his proper position in relation to controls and instruments during the weightless state, the pilot of a space vehicle must be supplied with a minimum restraint device of lap belt and shoulder harness.

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TABLE III

STIMULATION AND RESPONSE OF SENSE ORGANS (AND THEIR MANNER OF OPERATION) TO SUBGRAVITY

	Nerve Endings or Organs Responding to Differences in Pressure (e.g., those of touch or hearing)				Receptor Organ Sensitive to Light
	Those Responding Specifically to Gravitational Stimuli	Those not responding solely to gravitational stimuli but provide similar information to the brain			
	Motion and Position Sense	Muscle Sense giving body position and movement	Posture Sense	Pressure Sense	Optical Sense
Sense Organ	Otoliths (inner ear orientation organ)	Muscle Nerves	Sense Corpuscles along the course of nerves	Sense Corpuscles of touch	Eyes
Normal Stimulus	Acceleration and weight	Tension and weight	Tension	Pressure and weight	Light
Effect of Subgravity	Decreased Wt. & displacement of Otoliths	Decreased Wt. & muscle tension	No Effect	Decreased Pressure at contact points of body with support	No Effect
Effects of Og	Lack of Wt. & displacement of Otoliths	Lack of Physical Stress	No Effect	No feeling of pressure at body contact points	No Effect
Sensory Inputs during Og	None or Og Signal	No signal	No Effect	No Signal	No Effect
Sensory Output during Og	None or Og Signal	No signal	No Effect	No Signal	No Effect
Sensation during Og	No Gravitational Vertical	Stress-Free Sensation	No Effect	Stress-Free Sensation	No Effect
Psychological & Physiological Results	Loss of Vertical orientation without visual reference	Disturbance of muscular coordination	No Effect	Loss of touch sensation	No Effect when visual cues available

From Weightlessness, Dr. S. J. Gerathewohl, Air University Quarterly Review

TABLE IV

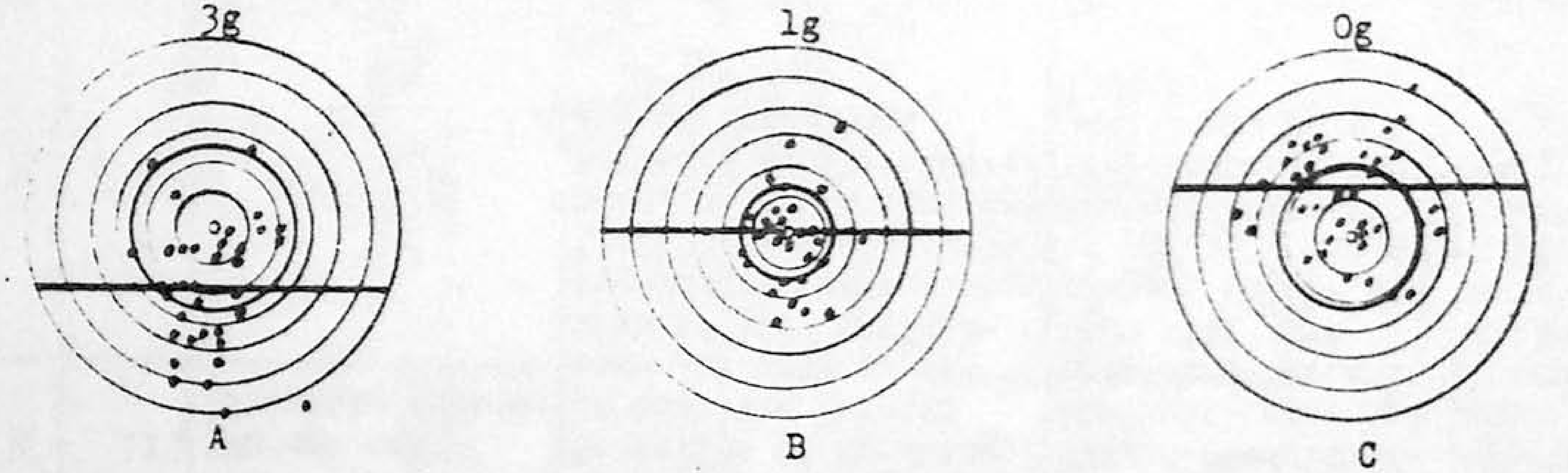
RESPONSES OF 47 HUMAN SUBJECTS TO SHORT PERIODS (10-30 SECONDS) OF WEIGHTLESSNESS

Group	No. of Subjects	Attitude Prior to Flight	Psychological Reactions	Physiological Reactions	Involuntary (Nerve) Reactions
1	22	Normal or Slightly Anxious	Sensation of Resting, slow floating, well-being, comfort, pleasure, enjoyment, enthusiastic responses; same experience during repeated exposure	Tingling sensation in abdomen, slight disorientation with eyes closed, some giddiness, slightly overactive knee reflex (jerk)	None
2	11	Normal or Slightly Anxious	Sensation of floating or tumbling forward and backward; sensation of lift or falling during transition; feeling of standing on head, mild elation; experience neither pleasant or unpleasant	Slight disorientation with eyes open greater disorientation with eyes closed; mildly dizzy and slightly nauseated; increased perspiration; tired and sleepy after flight.	None to moderate degree of vertigo and nausia caused by changes in acceleration and weight
3	14	Normal or slightly anxious with occasional fear and acute anxiety	Same as Group 2 above with "light" or "heavy" feelings in head and stomach with latter seeming to move upward; elated in the beginning with progressive discomfort	Motion sickness symptoms; sweating, dry mouth; feelings of cold and hot	Vertigo and nausia; vomiting during flight.

From Weightlessness, Dr. S. J. Gerathewohl, Air University Quarterly Review, Summer 1958

EFFECTS OF WEIGHT AND WEIGHTLESSNESS
EYE-HAND COORDINATION TESTS

Figure 42

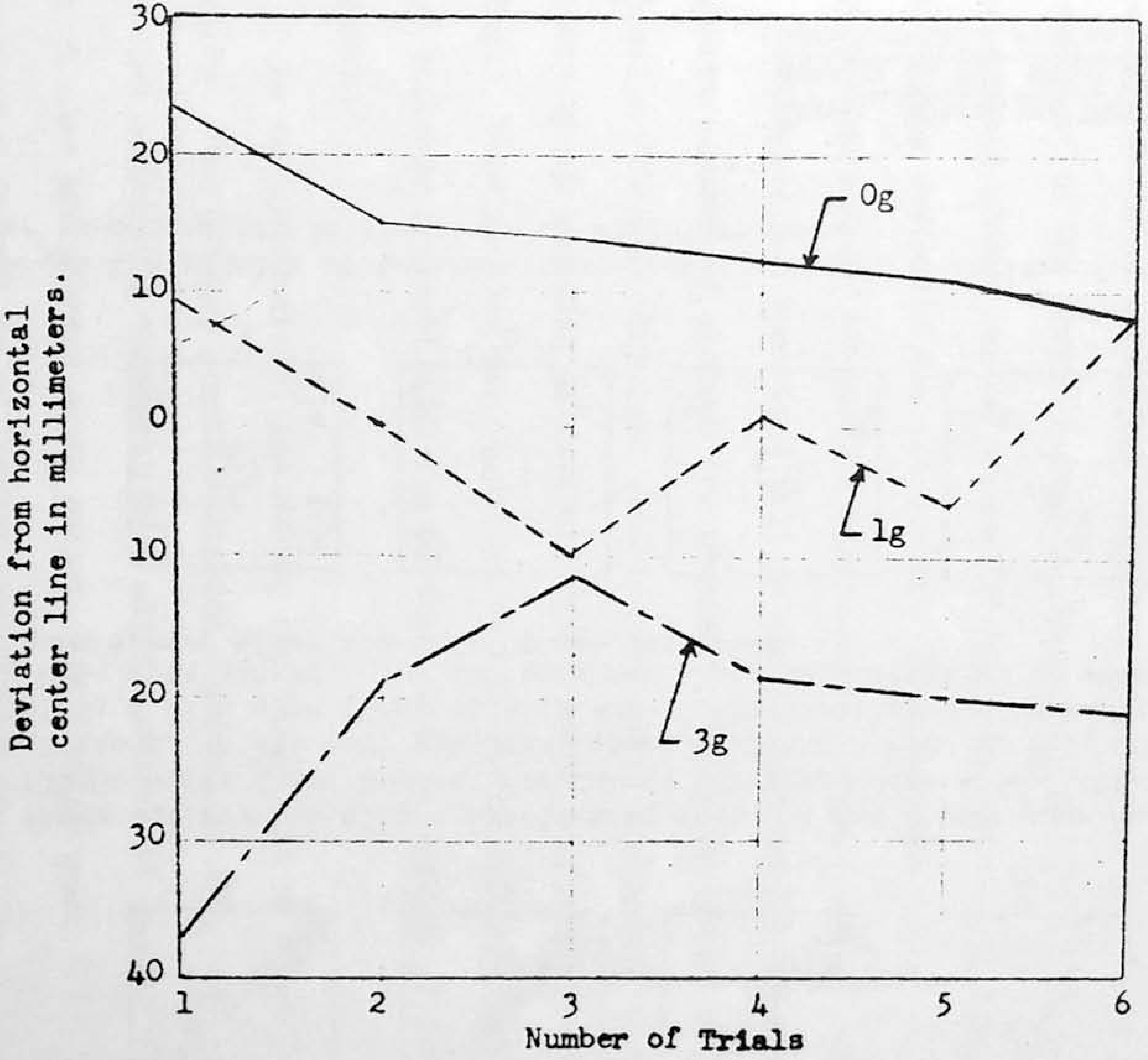


Hand-eye coordination tests were administered to each subject, first on the ground (B) in the cockpit of a T-33A aircraft. Subject was instructed to try to hit a bull's-eye located 3 feet away, using a stylus. The same test was then repeated under 3g acceleration and during 0g while flying parabolic maneuvers. Above, the results of a group of subjects show the trend to hit too low during increased g forces (A), and too high during the weightless condition (C). (The heavy horizontal lines and circles show the mean for each test condition.)

From Sensomotor Performance During Weightlessness: Eye-Hand Coordination, S.J. Gerathewohl, Journal of Avia. Med., Feb. 1957

EFFECTS OF WEIGHTLESSNESS
(LEARNING CURVE FOR EYE-HAND COORDINATION TESTS)

Figure 43

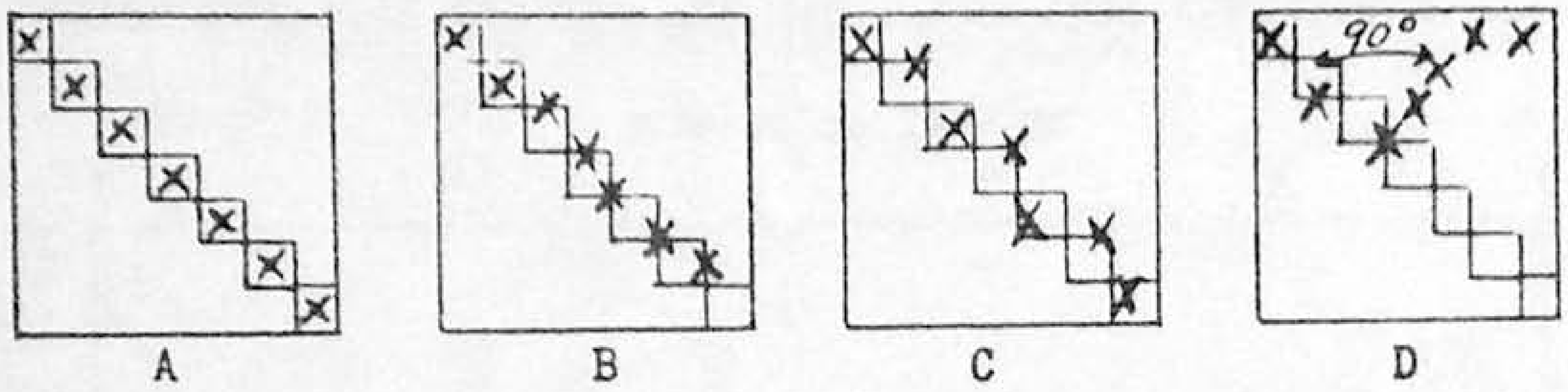


The above graph shows the test results for the three test conditions given in Figure 42. The hit accuracy for the weightlessness curve shows steady improvement during the six trial attempts.

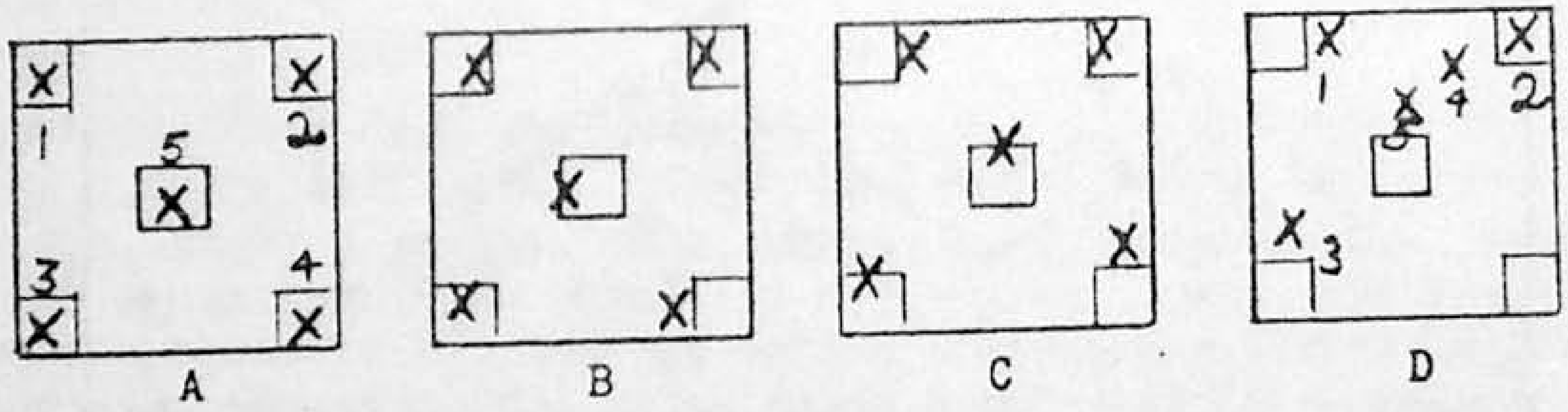
From Sensomotor Performance during Weightlessness: Eye-Hand Coordination, S. J. Gerathewahl, Journal of Av. Med., Feb. 1957

EFFECTS OF WEIGHTLESSNESS
Muscular Coordination Tests

Figure 44



The above shows the results of a cross-drawing test. A and B were made during straight and level flight while C and D were made during the dive under sub-gravity and zero-gravity conditions. A was made with eyes open; B with the eyes closed, showing some irregularities; C with eyes open, showing some irregularities due to sub and zero-gravity, and D with eyes closed. The latter shows a typical deviation of about 90° toward the right hand corner after the third cross was drawn.



The above shows the results of another cross-drawing test in a series of experiments on muscular co-ordination in the state of weightlessness.

From <u>Comparative Studies on Animals and Humans in the Gravity-free State</u>, S. J. Gerathewohl, Journal of Av. Med., August 1954

IX. RADIATION

The radiation problems in connection with an orbital space vehicle can be considered under four headings. There is the problem of visible and ultra-violet light, the radiation hazard from the "lightly-ionizing" component of the cosmic radiation, that from the very densely ionizing components (heavy nuclei tracks) of the cosmic radiation, and the high intensity radiation Van Allen belt. Infra-red and larger wavelength radiation present no problem due to normal vehicle cockpit construction.

Ultra-violet radiation will be easily absorbed by the glass of transparent windows if windows are provided. (Ordinary glass is a very effective filter). Sunlight entering the cabin may result in an extremely contrasting lighting situation, because of lack of atmospheric scattering. This problem can be solved by the use of suitable diffusers and by suitable internal lighting in the cabin, especially of the instrument panel.

As indicated above, the cosmic ray hazard can be considered in two parts. The primary cosmic radiation consists of very high energy atomic nuclei bombarding the earth from all directions in space. Most of these particles are protons or He nuclei, but a significant fraction of the radiation is made up of heavier nuclei such as carbon, oxygen, calcium, iron or even heavier particles. As these primary particles reach the earth's atmosphere (or the shell of a satellite) they interact with it in many ways producing a heterogeneous mixture of gamma-rays, electrons, mesons, neutrons and other ionizing radiations. The total ionization due to this heterogeneous mixture of radiations has been measured as a function of altitude and the results obtained show that the hazard is not serious if the radiation is made up of "lightly-ionizing" components (gamma-rays, electrons, and even protons or alpha-particles), whose biological effects are at least not very different for a given amount of ionization, from those of X- or gamma-rays studied in the laboratory. For instance, at a geomagnetic latitude of 60°, the total ionization reaches a maximum of about 15 mrad/24 hr. at about 75000 ft. and then decreases slowly. This is much smaller than the maximum permissible dose rate of 300 mrad/week. (Figures 45 through 47). It is possible, because of transition effects within the vehicle, that the actual ionization in a man in a space vehicle may be higher, perhaps by a factor of two, than the ionization chamber movements indicate, but even so the hazard is not serious.

Up to about 60 or 70,000 ft., practically all the cosmic radiation is of this "lightly-ionizing" type. At the higher altitudes at which a space vehicle may orbit, appreciable numbers of the heavy primary cosmic ray particles survive and must be given special consideration. This is because although averaged over large volumes their contribution to the ionization is small, they can transfer to an absorber large amounts of energy in a very small volume. This occurs particularly in what are known as "thin-down" hits. When these heavier nuclei reach the end of their tracks, they produce very intense ionization along cylindrical volumes several millimeters in length and with widths of cellular dimensions. In this "thin-down" region, the absorbed dose, averaged over the volume of single cells, may be hundreds or even thousands of rads. It has been suggested that, because of their ability to destroy small cylinders of cells, they could produce irreparable damage of appreciable importance if they occur in certain times. For instance, heavy nuclei can damage the hair follicles in black mice, so as to cause the growth of single or small groups of white hairs. This particular biological effect is not specially deleterious, but it has been suggested that more serious damage to the whole animal might result from such events occuring in important structures, particularly in regions where damage to a few cells may affect large parts of the body (e.g., the hypothalamus), or in regions where cells affected do not have the ability to regenerate (e.g., various parts of the central nervous system), or in structures where a single hit may inactivate a group of cells necessary for a biological function (e.g., the pigment cells referred to above). However, this is all highly speculative, and, in any case, it is clear that at the moment nothing in the way of shielding is practicable. Considerable thicknesses of absorber would be needed and inadequate thicknesses of shield may actually increase the "thin-down hit" frequency. This is because such thicknesses may slow down some nuclei which would otherwise have passed completely through the body, to such an extent that they reach "thin-down" within the body.

Shielding from 'ordinary' hits (not 'thin-down' hits) of heavy nuclei can be achieved by large thicknesses of low atomic number material, but the thicknesses required are impracticable. For instance, shielding by a factor of 4 for C, N and O nuclei can only be achieved by a 27 g per cm^2 shield of hydrocarbon plastic (22.5 cm. thickness of plastic of density 1.2 g/cc.).

It may be concluded that shielding against the heavy particle component of the cosmic rays is completely impracticable at present, and that, although there is some uncertainty about the effects of these particles, the hazard in flights as contemplated in typical orbital vehicles is very small.

The Van Allen belt of intense radiation is found only above about 1100 km. (Figures 48 through 51). It undoubtedly presents a definite radiation hazard but to a certain extent may be circumvented by exit into very high orbits through the polar regions. Low altitude orbits can remain below it. Modification of Figure 48 has been indicated by data gathered by Pioneer IV on March 3, 1959. The outer radiation belt begins at an altitude of approximately 8000 mi., extends to approximately 52,250 mi., and is about 20,000 miles wide from north to south. The inner radiation belt begins at about 1300 mi., extends to 3000 mi., and is approximately 4000 mi. wide north to south. The inner belt contains highly penetrating radiation while the outer belt's radiation was almost completely absorbed by 0.16 inch thick lead shielding.

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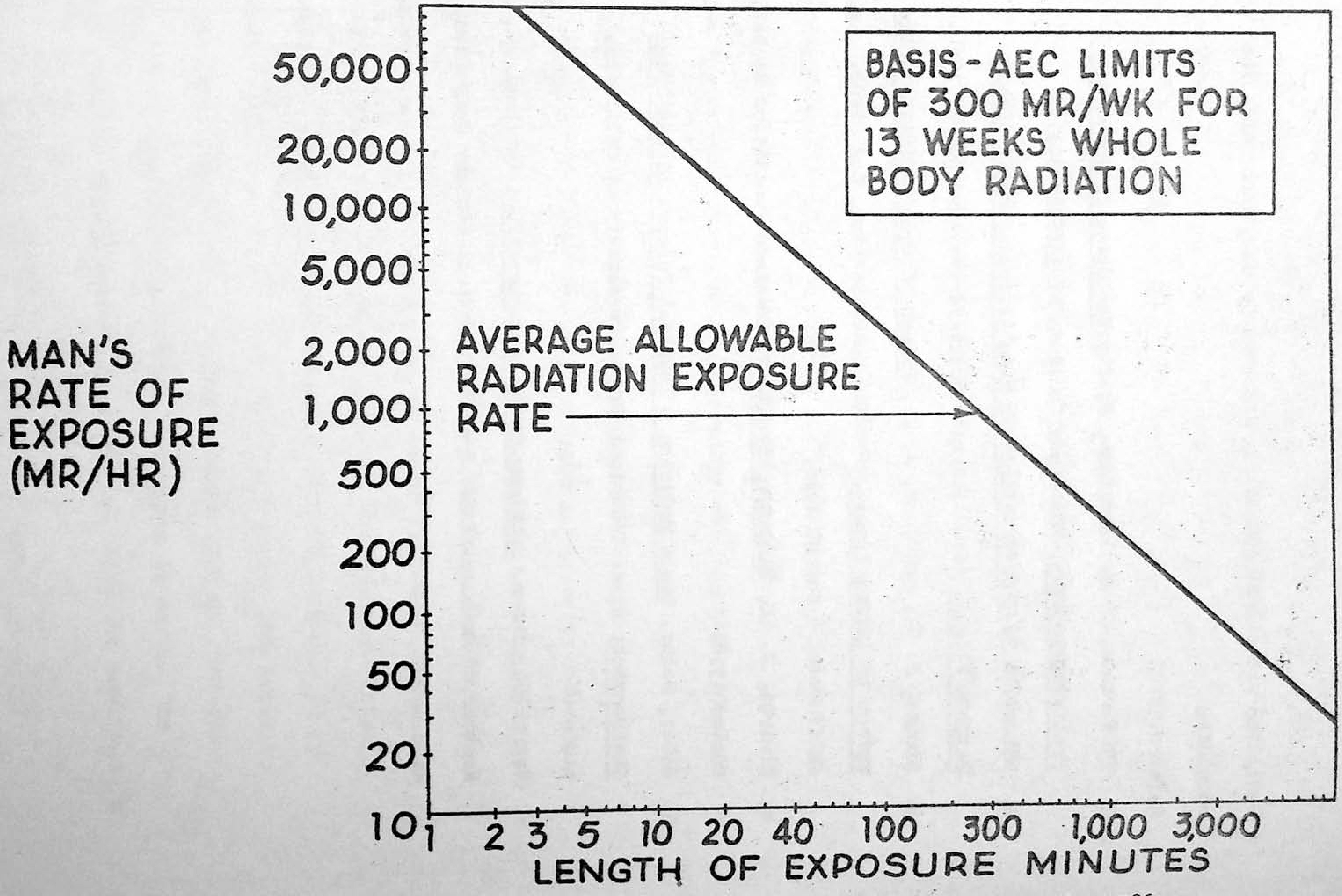
Figure 45

MAN'S ALLOWABLE RADIATION EXPOSURE RATE



From CVA Report E8R-11786

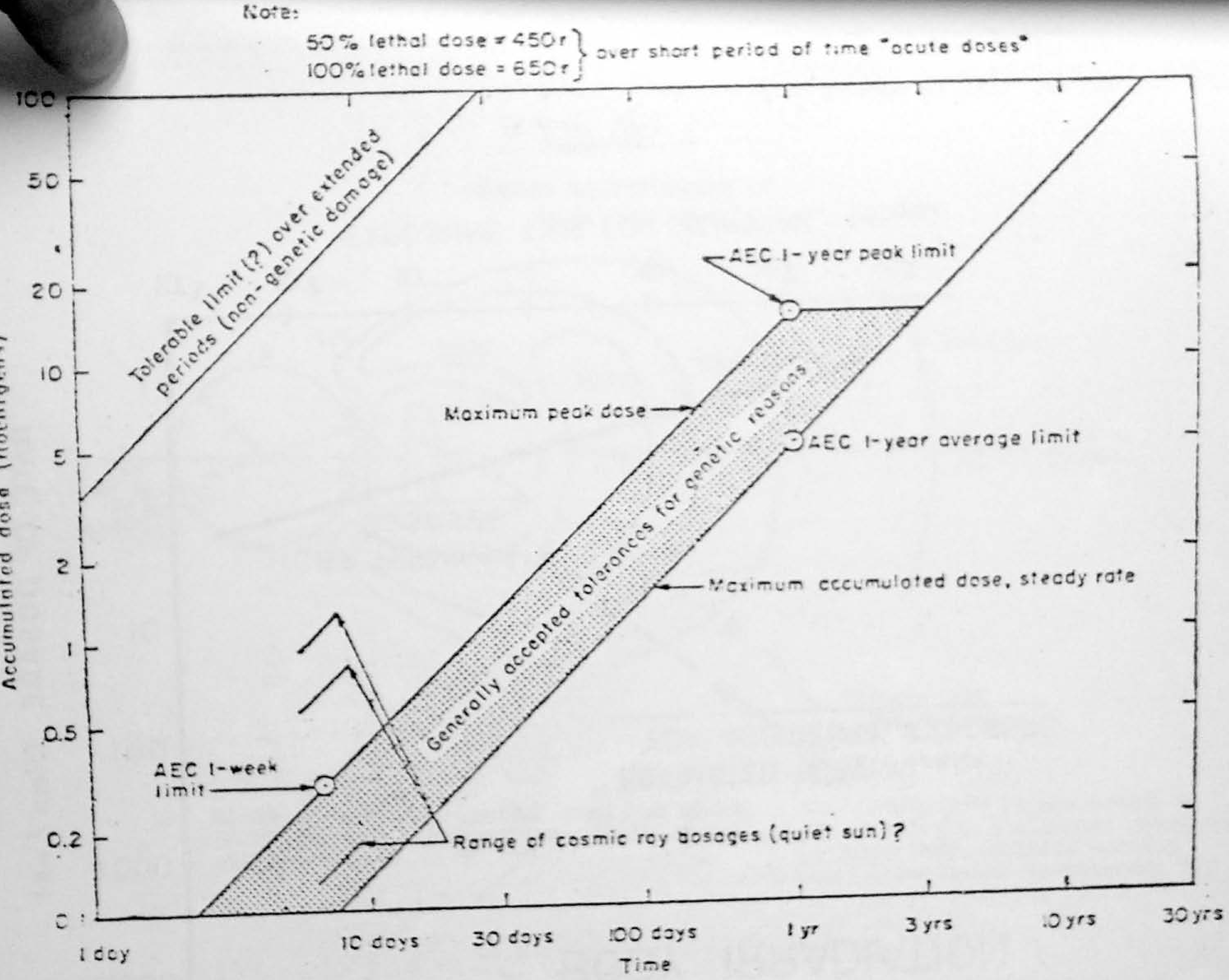


Fig. 46 — Human tolerances to radiation

From Space Handbook: Astronautics and its Applications, Staff Report of the Select Committee on Astronautics and Space Exploration

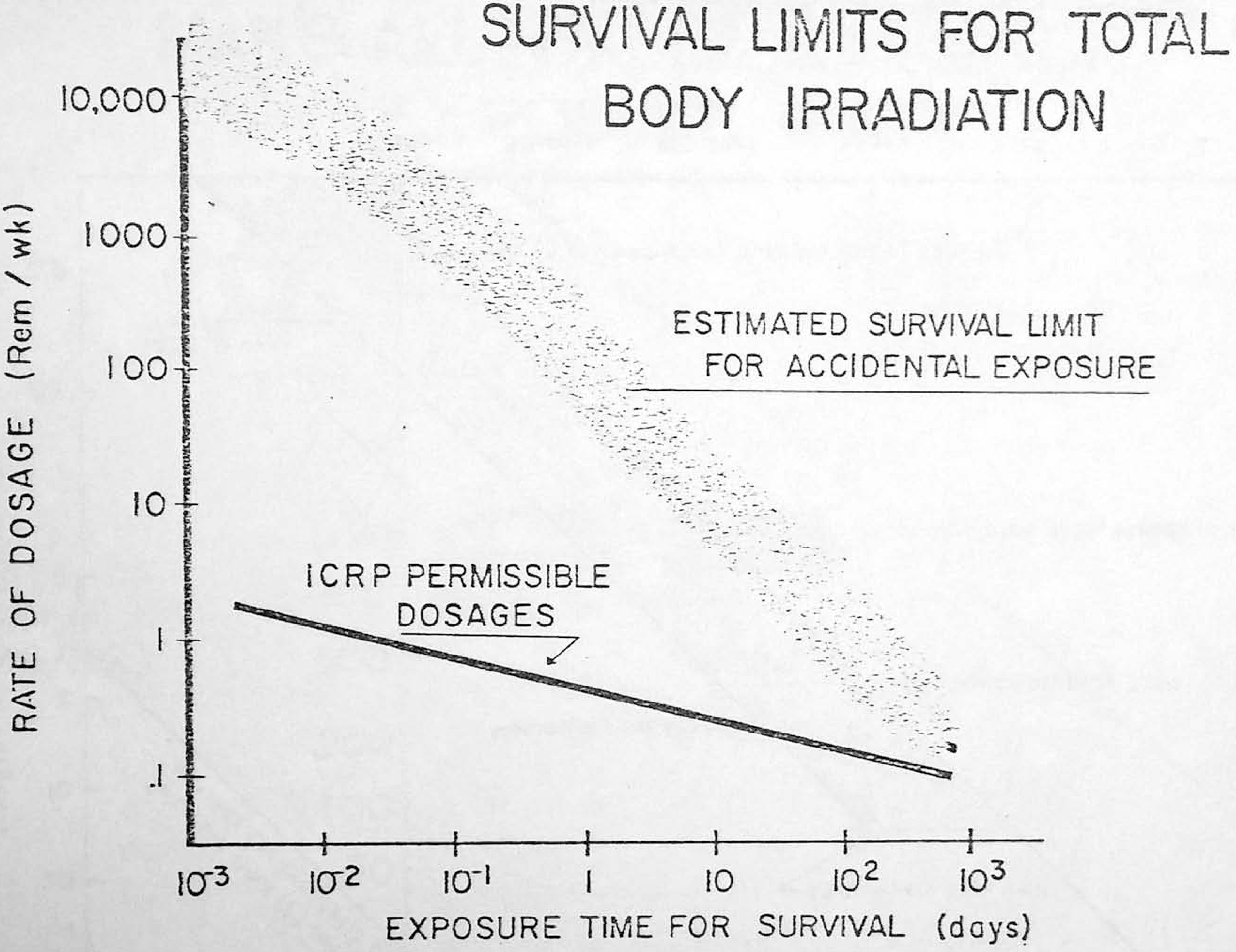
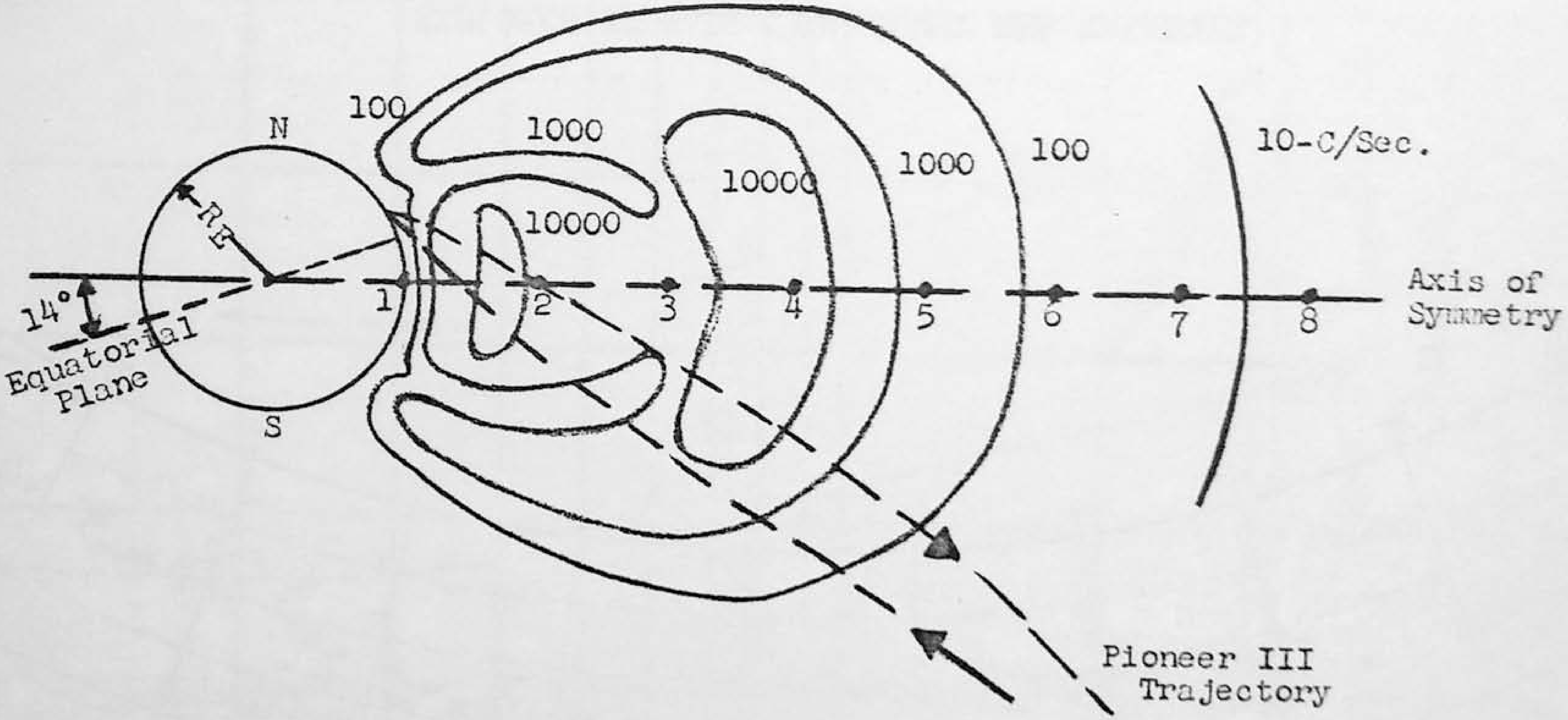


Figure 47

From Survival in Space, the Vehicle - Combined Requirements, A. M. Mayo, Douglas Aircraft Company, El Segundo, California

Figure 48

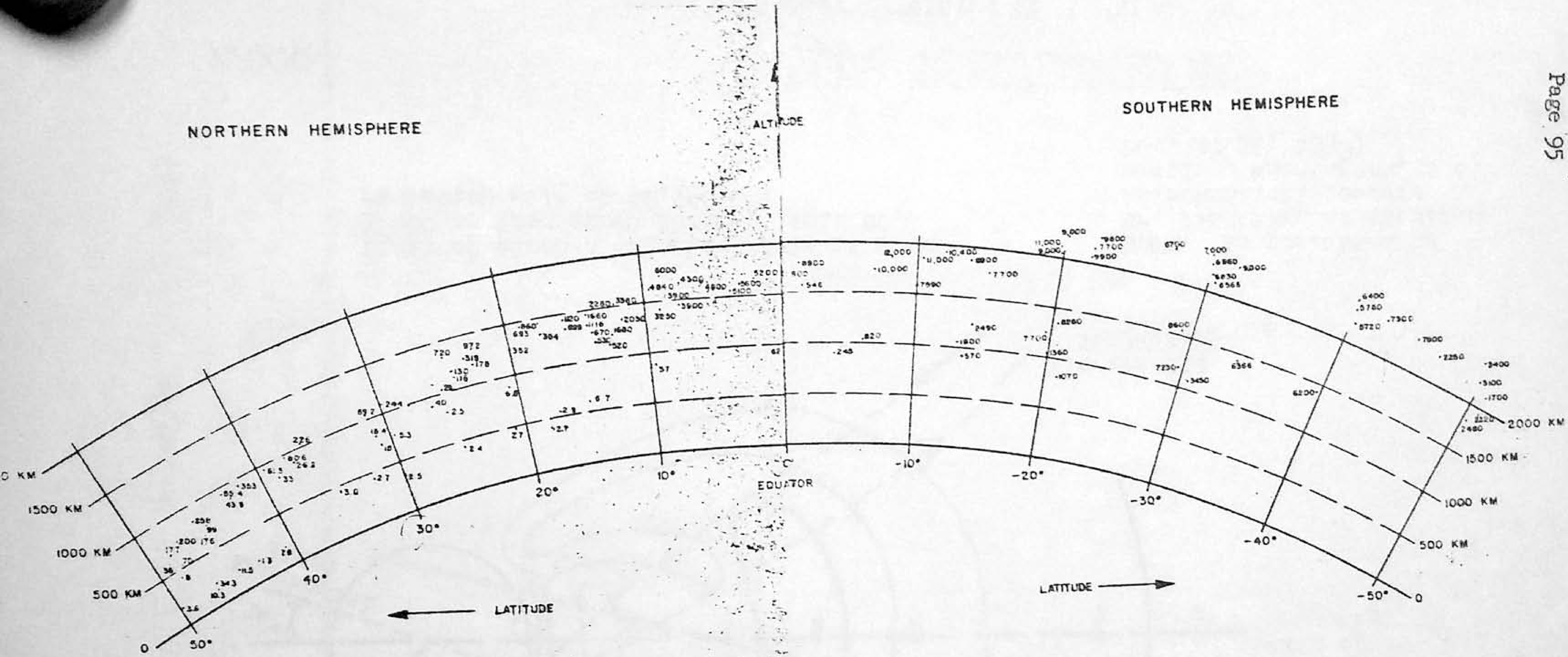
GENERAL DISTRIBUTION OF
RADIATION BELT



Limit of earth's magnetic field at about 36000 km from earth center; limit of radiation belt at 60,000 km.

(NOTE: As presented by Dr. Van Allen at American Astronautical Society meeting, Washington, D.C. Dec. 27-31, 1958)

Figure 49



EXPLORER IV RADIATION COUNT MEASUREMENTS

From CVA Report E8R-11786

VARIATION OF RADIATION LEVEL WITH ALTITUDE

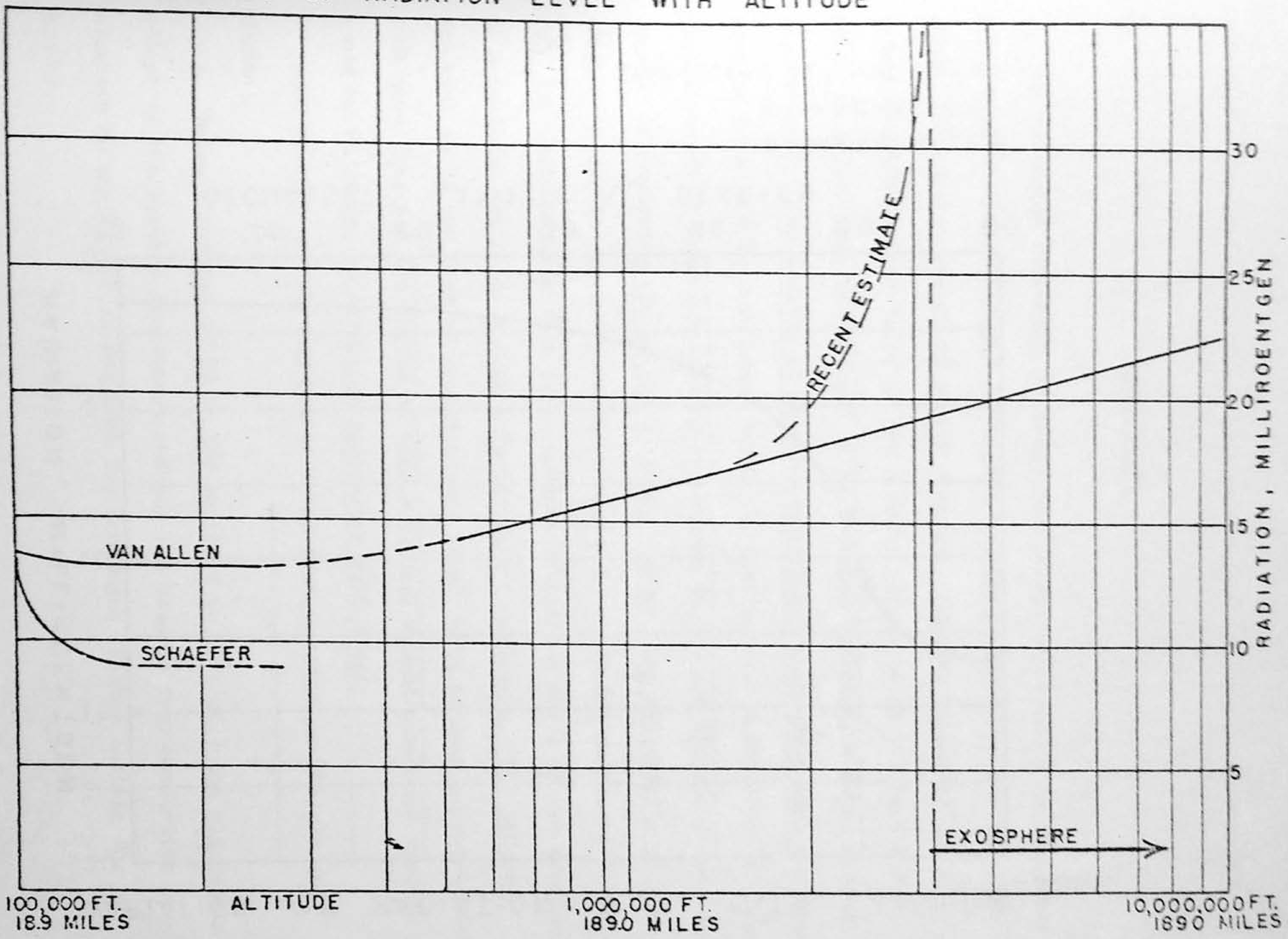


FIG. 50

Courtesy McClelland and Brown Mfg. Co.
Portland, Oregon

VARIATION OF RADIATION LEVEL WITH LATITUDE

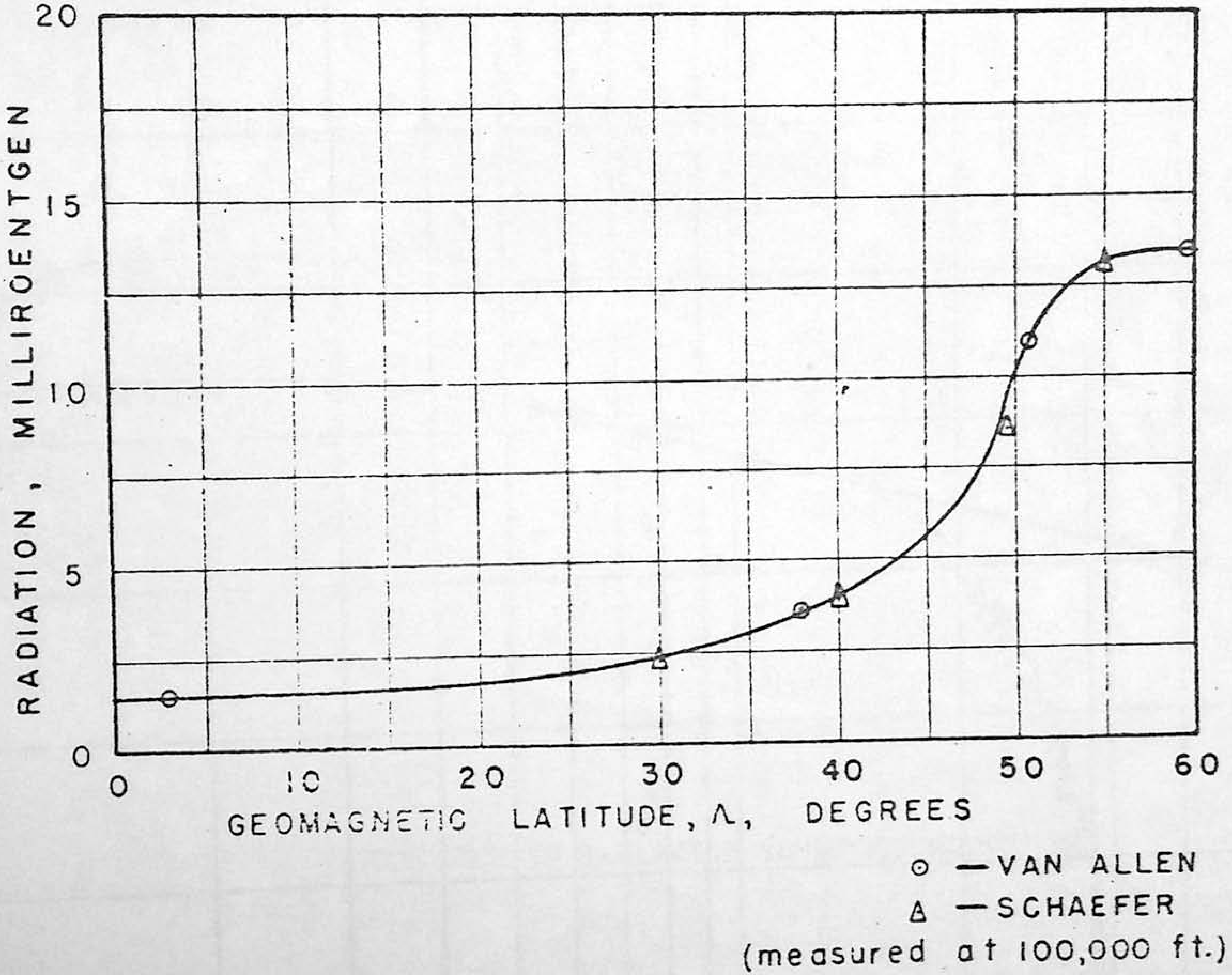


FIG. 51

Courtesy McClelland and Brown Mfg. Co.
Portland, Oregon

X. METEOROIDS

The estimated frequency of occurrence of micrometeorites is presently being revised from satellite data; however, large particles are known to occur infrequently except in meteor showers. Present estimates for the visual magnitudes from 10 to 30 are a daily influx of 13,000 tons (per Dubin of AFCRC, GRD, and Whipple of Smithsonian Institution Astrophysical Observatory). The density of meteoroids is still unresolved with estimates ranging from 8.00 to 0.05 grams per cubic centimeter. A meteoroid of 1/10 inch diameter or larger traveling at between 36,000 and 230,000 ft/sec. is capable of rupturing the pressure cabin, however, the probability of encountering one is extremely remote. Micrometeorites are much more plentiful, but their major effect is to produce sputtering which is the erosion of a metal by impact of a high velocity atom or molecule. The eroded material is in the form of single atoms. Experience to date on satellites indicates that for the period of time a typical manned satellite vehicle would be in orbit, no effective sputtering will occur.

Some general conclusions may be drawn from the work of Whipple and Dubin:

A. Below altitudes of 80 to 100 km (49.7 to 62.1 mi.) the blanketing effect of the earth's atmosphere reduces the hazards from meteoritic penetration to negligible values even for prolonged flights lasting for months.

B. At altitudes above 100 - 120 km (62.1 to 74.6 mi.) the probability of penetration for a spherical vehicle of 3 meters diameter and aluminum skin-thickness of 0.32 cm is only one part in 2000 per day. Recent satellite data indicates this probability may be too high by a factor of at least 10. It is safe to conclude that for short (less than 24 hours) excursions above these altitudes the danger from meteoritic penetration is minor to negligible in comparison to the other hazards of such flights.

C. Only for prolonged excursions of months at altitudes greater than 100 - 120 km does the danger from meteoritic penetration become serious. In other words the hazard may be a serious one for a satellite vehicle or for general space travel.

D. Even in the more serious case of a satellite vehicle or in general space travel for periods up to the order of a year, the safety factor would be greatly increased by navigating so as to avoid the orbits of comets, known meteor streams, and the fundamental plane of the solar system, particularly between Mars and Jupiter.

E. Various engineering precautions can reduce the hazard to personnel from meteoritic penetration to negligible values in the case of the satellite vehicle or in general space travel. The precaution of a secondary thinner skin, or meteor bumper, outside of the primary skin of the vehicle and the use of suitable warning devices or more complex devices render the hazards rather negligible.

F. For high-velocity (1 km/sec or 3281 ft/sec) travel at all altitudes over appreciable periods of time (days), all optical surfaces exposed to space should be covered when not in use to protect against the sand-blasting action of micro-meteorites or atmospheric dust.

G. Although the probability is very small it is clear that if the space vehicle is struck by a meteor of any large size at the velocities they generally move, the results will probably be instantaneously catastrophic.

Figures 52 and 53 are pertinent charts.

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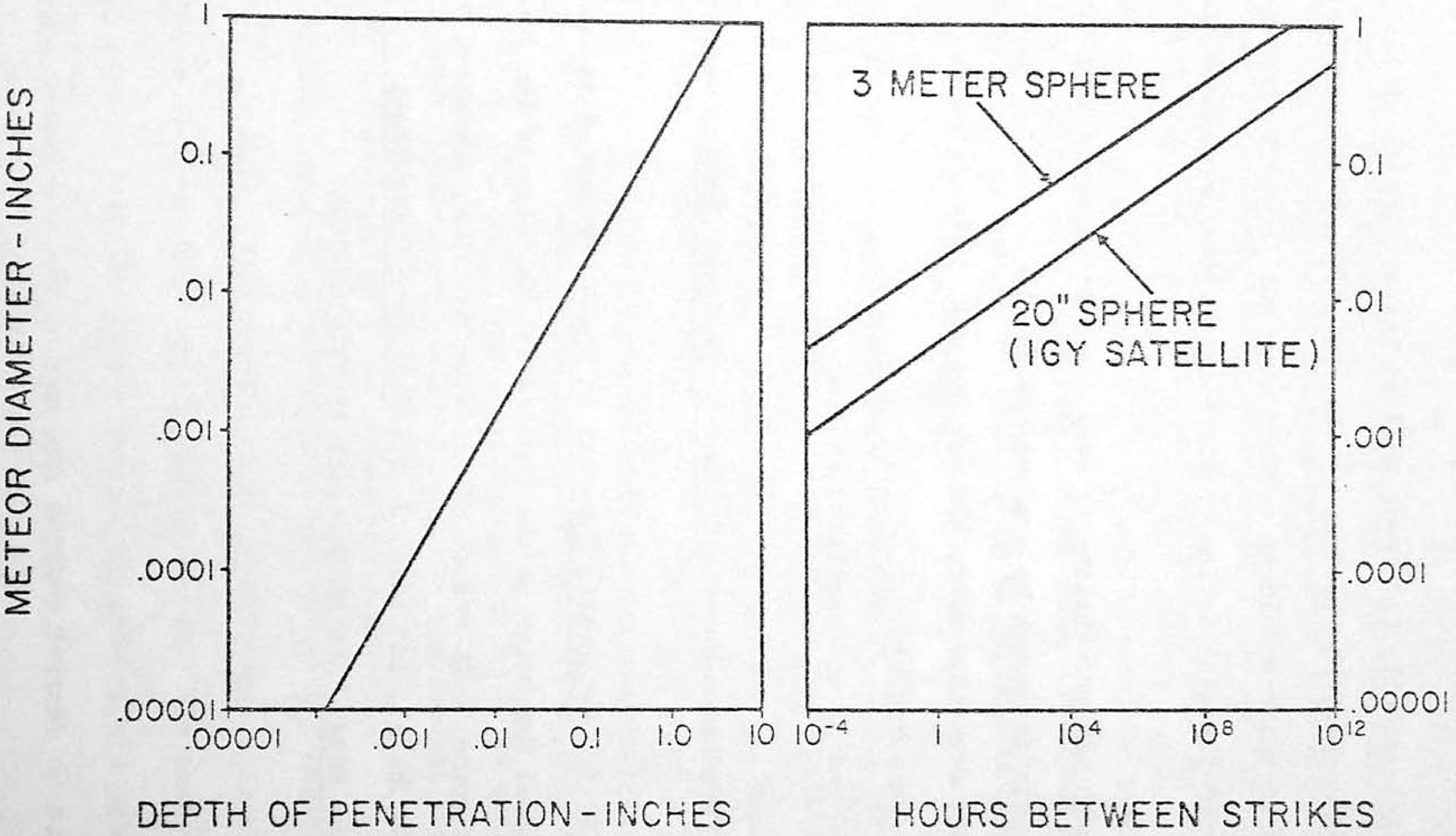
1. Lovelace Foundation Report, Optimum Environment System, Summer 1958.
2. Whipple, F. L., Meteoritic Material in Space, Presented at Second International Symposium on the Physics and Medicine of the Atmosphere and Space, USAF School of Aviation Medicine, November, 1958.
3. di Taranto, R. A., and Lamb, J. J., The Space Environment - A Preliminary Study, RCA AF Contract AF 33(616)-3915.

Figure 52

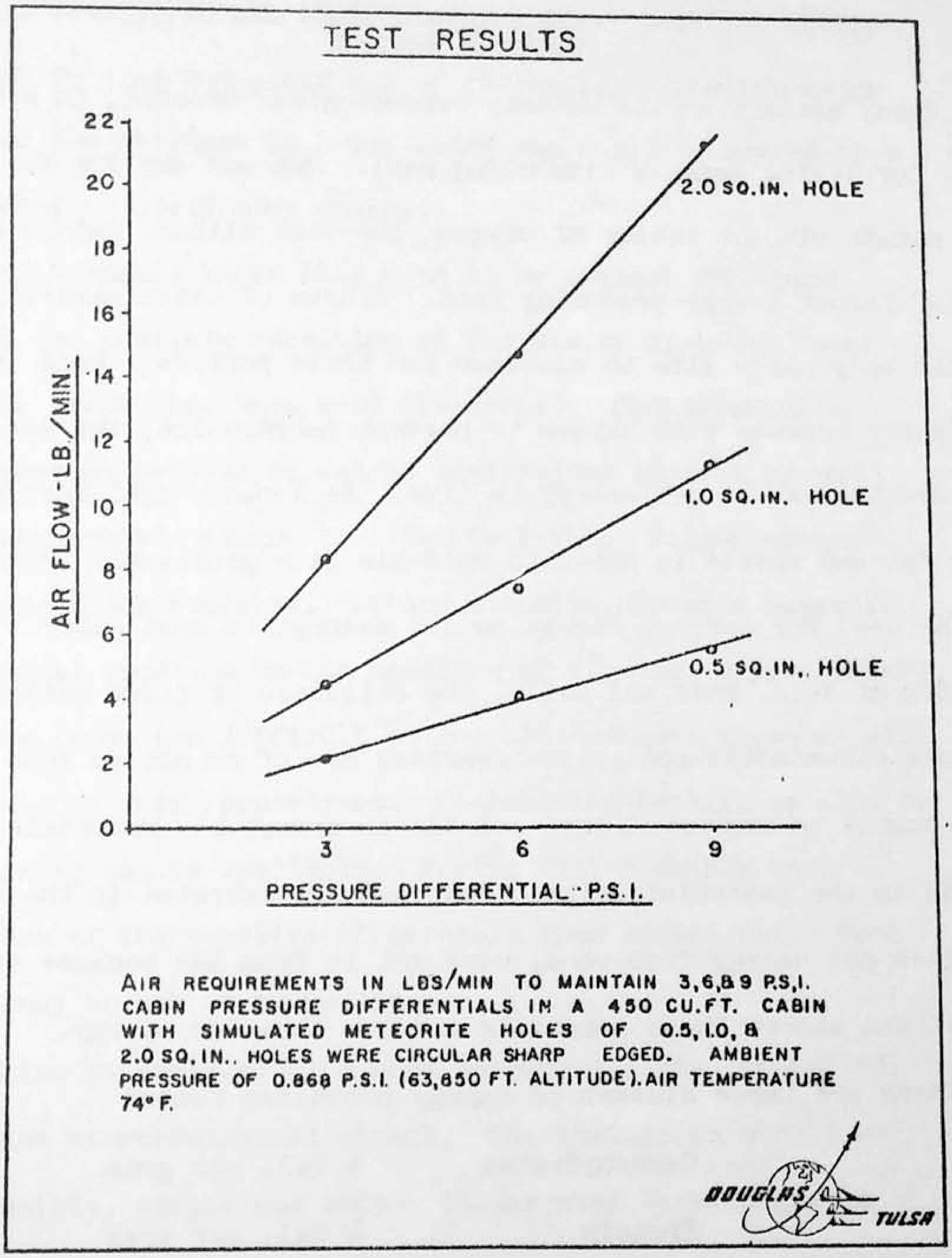
PENETRATION OF ALUMINUM PLATE BY METEORITES AND PROBABILITY OF A METEORITE HIT



BASED ON NUMBER OF METEORS OF A GIVEN SIZE PLUS ALL THOSE OF LARGER SIZE

From Human Activity in Space, Cabin Design, Personal Equipment, A. M. Mayo, Douglas Aircraft Company, El Segundo, California

Figure 53



AIR REQUIREMENTS IN LBS/MIN TO MAINTAIN 3,6,& 9 P.S.I. CABIN PRESSURE DIFFERENTIALS IN A 450 CU.FT. CABIN WITH SIMULATED METEORITE HOLES OF 0.5, 1.0, & 2.0 SQ.IN.. HOLES WERE CIRCULAR SHARP EDGED. AMBIENT PRESSURE OF 0.868 P.S.I. (63,850 FT. ALTITUDE). AIR TEMPERATURE 74° F.

Air Requirements in Lbs/Min to Maintain Various Cabin Pressure Differentials in a 450 Cubic Foot Cabin With Simulated Meteorite Holes of 0.5, 1.0 and 2.0 sq. In.. Holes assumed to be circular and sharp edged. Ambient pressure of 45 mm Hg, air temperature constant at 74°F. Courtesy of Douglas Aircraft Co., Tulsa, Oklahoma, 1958.

XI. NUTRITION

Dr. R. O. Bowman

Food, aside from its satiety psychological benefit, is a necessity for living animals (including man). Man can survive for about one minute without intake of oxygen, one week without water, and one month without energy-producing food. Stores of these materials within the body allow life to continue for these periods. Food is least necessary because with oxygen to prevent dehydration, the man burns his own tissues to get energy to live. He loses weight mostly from body fat and muscle in order to maintain life processes. Before food can be used for energy, digestion and absorption must occur. The keratin of skin, hair and nails, the cellulose of plant materials and various albuminoids and polysaccharides are of no use as food because they cannot be converted into soluble or absorbable materials. They remain in the gastrointestinal tract and are excreted in the feces. Termites get energy from wood, cows get it from hay because they can digest and absorb these materials and use them for energy.

There are three classes of energy producing foods:

Carbohydrates	4 Cal. per gram
Protein	4 Cal. per gram
Fats	9 Cal. per gram

Food also contains water (average 70% by weight), minerals, vitamins and the indigestible "fibre" mentioned above, none of which contributes any energy, but all are necessary dietary factors. Digestible carbohydrates and fats yield all their energy and are oxidized to H_2O and CO_2. Protein does not yield all of its energy since the major end product of the nitrogen is urea, which can still be burned in a bomb calorimeter to yield some energy.

Food as is commonly known will need to be changed for space feeding, with the possible exception of flights of up to 48 hours where the "box lunch" has been used (balloons). The duration of flight is important because of weight limitations imposed by the present payload-vehicle ratios of 1:200 to 1:700. Weightlessness introduces unfamiliar concepts. Eating utensils become a hazard; there are special problems in the handling of liquids; dry, powdered or small piece foods are difficult to contain and use; clean-up will have to be done by "dry" procedures. Preparation facilities will be minimum. Warming can be available. Frying will probably be prohibited because of the toxicity of acrolein from heated fat. Food will be as ready to use as is possible.

It must also be packaged with good keeping quality, protected from enzyme and microbiological attack. The containers should be light, collapsible, simple and soft. It has even been suggested that they be made of edible material to decrease the disposal problem. Waste and rejection must be kept at as close to zero as possible. This latter means meeting the individual's acceptability.

Experience with such diets on earth pre-flight can spot food types and flavors not to be sent along.

In spite of the minimum concept, there must be a reserve of food for contingency, appetite variations and psychological therapy. With the exception of "roughage" noted later, all food should be highly digestible to save on waste and decrease fecal excretion. Even so, the diet must meet all needs and be adequate in all respects, in amount, in flavor, etc.

The essentials of an adequate diet are eight in number:

A. Calories - A measure of the energy available. An average value of 5 Cal. per gram of dry weight means one must have 500 grams of dry food to get the 2,500 Cal. needed for sedentary life. Caloric requirement varies with body size, age, sex, activity, climatic conditions, body temperature, thyroid activity and nature of diet. The Food and Nutrition Board of the National Research Council recommends 3,200 Cal. for a 65 Kg (143 lb.) man in a temperate climate, normally healthy and vigorous. This is excessive for a sedentary occupation, and physical effort in the weightless state requires less than usual use of energy. The usual estimate of 3,000 Cal. per man per day for a 175 lb. man is generous enough to allow for contingency and other factors. This means 600 grams of dry food (1-1/4 lbs.) per man day. Food as we eat it is 30% dry material and 70% water. Partially dehydrated paste food should average 30% water. When its fat content is increased the water is lowered and the caloric value increased. Useful approximations of 30% water content, 4.2 Cal. per gram for average tube feeding preparations would mean 715 grams per man per day of which 215 ml. (grams) is water. Two men for 15 days would need 21,450 grams (48 lbs.). Assuming mylar or other collapsible containers weighing 1/10 of the contents this adds to a load of 23,600 grams (53 lbs.).

B. Water - Except during growth water intake is balanced day by day against output. Output per 24 hours in design figures for the 175 lb. man in comfortable ambient temperature, humidity and convection is made up of

Urine	- Range 500-4,000 ml.	Mean 1,200 ml.
Insensible perspiration	- Range 600-1,200 ml.	Mean 800 ml.
Exhaled H_2O from lungs	- Range 200-800 ml.	Mean 350 ml.
Feces	- Range 25-400 ml.	Mean 150 ml.
Total	- Range 1,400-6,500	Mean 2,500 ml.

Negligible losses occur in hair and nail clippings, desquamation of surface skin, nose blowing, spitting and tears. The ranges above vary chiefly with water intake, with activity, and with bowel habit. Similarly the intake and production of water by oxidation is made up of

Liquids ingested	- Range 400-4,000	Mean 1,000 ml.
Water of solid foods	- Range 200-2,000	Mean 1,000 ml.
Water of oxidation	- Range 200-700	Mean 500 ml.
Total	- Range 800-6,700	Mean 2,500 ml.

Taste, habit and activity cause variation in these ranges. If intake varies markedly from day to day there may be a day of inbalance with make up in the next 24 hours. Decreased or increased intake is balanced mainly by variation in urine volume, other losses being maintained.

Since the water in solid food has been reduced to a low value by selecting partially dehydrated pastes, more than the liter of water must be allowed for liquids. The suggested amount is 1,800 ml. per man per day, this to include fruit juices or concentrates, beverages such as coffee, carbonated beverages and plain water. The fruit juices, coffee if it has sugar and cream, and the beverages have caloric value. Approximately 2,000 ml. of water would be available per man per day for recovery and reuse by freeze-distillation. Except as an experiment this would not likely be done in the proposed vehicle. It becomes more important and even necessary for longer voyages. Packaging of water and other fluids should be in impermeable Mylar or similar film squeeze bottles with suitable hermetic seals and valves. Two men for 15 days would need 54,000 ml. of water (120 lbs.). With a 10% allowance for containers, the load would be 50,000 gm. or 132 lbs.

C. Protein - This material is used for repair and replacement of cells, for enzyme and hormone production, as well as for energy. Requirements for an adequate diet include proper amounts of eight essential amino acids, which are present in the 1 gm. per Kg. body weight recommended allowance unless the protein happens to be cereal type. Meat, fish, eggs, liver, and cheese proteins are excellent. Proteins are expensive, and carbohydrates are used for the caloric needs. The 175 lb. man needs 80 grams of good protein per day. This is about one ninth of man's diet allotment weight, and near 30% of the calories. If diet tubes average out to 40% fat, 30% each for protein and carbohydrate, if the proteins used are of several kinds (suggest fish, cheese, beef and pork), the needs will be met by the former weights of paste tubes.

D. Vitamins - These trace materials are present in foods. Some are water soluble, others fat soluble. Some are destroyed by heating, others stable. Adult man needs no added vitamins if varied foods are selected, if cooking does not destroy those present, and if vegetables, fruits and animal products are eaten. Seeds and nuts are rich sources of vitamins which can easily be incorporated in the paste formulas. If testing proves that the vitamin C content of such pastes are below 25 mg. per day per man or per 3,000 Cal., then ascorbic acid can readily be added. Hermetically sealed containers of orange or tomato juice concentrates, included with liquid supplies would supplement even a zero content of vitamin C. A vitamin-free diet could be eaten for 15 days without harm to a healty adult.

E. Minerals - Small amounts of inorganic elements in the form of ions are an essential of an adequate diet. Again no harm would result from no intake of minerals or ash for 2 weeks to a healthy individual. All foods contain them, iron particularly in meats, liver and prunes, iodine in sea food, phosphorus in cheese and animal products, calcium in eggs and cheese, potassium in plant or animal cells, trace elements in animal foods. No allotment is needed for minerals. They are present in our food pastes and juices.

F. Unsaturated fatty acids - These are needed in milligram per day quantities, but will always be present in excess in a mixed diet containing plant and animal fats. No allotment is needed.

G. Roughage - Some fibre is needed in the diet for health. Indigestible material prevents constipation. Other than this discomfort, no fibre in the diet for two weeks would not harm the well-being of the crew. Once more, the use of various foods in making the food pastes, will mean that adequate fibre will be present.

H. Pleasant appearance and acceptability - Kitchen foods (edible portions only) could be homogenized to various degrees and partly dehydrated, sterilized and tubed. These could be an adequate diet, but if they were rejected for appearance, taste, flavor or for other prejudice, they would not be an adequate diet, because they would not be eaten. An indoctrination program; an elimination of personally disliked tastes, flavors or ingredients; the use of encouraging word and picture labelling; an optimistic approach and understanding will all help in acceptance and enjoyment of such foods. Monotony of type can be varied with colored containers, contrasting labels, flavor additives such as monosodium glutamate, essential oils retored when they are removed by processing, by variation in size and shape of containers (hexagon, square or circular cross section; eighth, quarter and half pound sizes). Such earth-bound foods as chocolate sundaes, charcoal broiled steak, shish kebab and old-fashioneds will not be supplied, but simulated turkey dinners, fruit pies, lamb with mint jelly, lima beans and baked potato can be.

Details of types of foods desired can be spelled out better by the crew members acting as a taste panel. WADC has quite an experience in the preparation and packaging of such paste foods. Their experience and experiments gives valuable clues to acceptability, texture, preferences, etc.

The processes of comminution and mixing, dehydration, and sterilization before packing in sterile leak-safe containers has been outlined above. Neutron or gamma ray sterilization is a relatively new technique. Some texture should be preserved consistant with flow through the orifice. Chewing and sensation of texture should not be eliminated, to relieve monotony. Seeds and chopped nuts can be used in some mixtures for this and their vitamin content. Entree or main course formulations should be in the larger size, dessert in intermediate and appetizer or antipasto in the smallest size containers.

In general the preparatory processes should insure keeping quality at room temperature for six weeks or more. No equipment need be carried for preservation. From experience with the American taste, some type of cooler for the water supply will be helpful. This should be large enough to cool one container of water for each member of the crew, probably in the quart size. Such a device could well be a part of the heat exchanger for air conditioning, or the cool side of the ship if orientation to keep warm and cool sides is arranged. It need add little weight, would require some power. Similarly the hot side could be used for warming foods and drink as needed.

Weight-space breakdown to supply two men for fifteen days is as follows:

	Type	Size/Day	Weight
Food	Main course	Three-quarter-pound	22.5 lbs.
	Breakfast	One-quarter-pound	7.5 lbs.
	Dessert	Two-eighth-pound	3.8 lbs.
	Appetizer	One-eighth-pound	2.0 lbs.
	Condiment	1 candy bar	2.0 lbs.
	Gum	2 Chiclets	0.2 lbs.
		Total	43.5 lbs. 1 ft.^{3}

Allowing 1/10 of content weight for container and equal volume for stacking space, this becomes 48 lbs. and 2 cubic feet.

	Type	Size/Day		Weight
	Plain	1 qt.		60 lbs.
Liquid	Coffee	1 pt.		30 lbs.
	Juices	Two 1/2 pt.		30 lbs.
			Total	120 lbs.

Again container and volume allowances make this 132 lbs. and 7 cubic feet.

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XII. ISOLATION

D. G. Starkey

Review of existing data on the psychological effects of isolation indicate that without proper diversionary interests, isolation or detachment can be a problem on long space flights.

Some of the effects of confirnment, detachment and sensory deprivation on individual behavior and suggestions for mitigating these deleterous effects on the crew of an orbital vehicle are discussed below. Confinement is defined as being "shut in" or restricted to certain physical boundaries within which the human must function (i.e., work, sleep, relax, eat, exercise, etc.) for a given period of time.

Detachment concerns that particular state of isolation in which man is separate from his accustomed behavioral environment by physical or psychological distances of inordinate extent, while sensory deprivation is that condition imposed upon the individual as a result of confinement and detachment. To determine how reliably the human can function under these conditions, many additional extensive and systematic tests will have to be conducted. Work is presently being conducted in this area at various research centers such as WADC, the School of Aviation Medicine at Randolph Air Force Base, the U. S. Naval Medical Research Laboratory at New London, Connecticut, where studies are being conducted pertaining to submarine internal environments, and at other research centers.

To date, results of isolation effects on the human have come to use from four primary sources, namely, autobiographical accounts of isolated living, either forced or voluntary; from solitary confinement studies of inmates of penal institutions and Prisoner-of-War Captives; from analysis of survival experiences of such personnel as downed airmen, shipwrecked parties, etc.; and from controlled experiments such as those conducted in the space cabin simulators at Randolph Air Force Base and WADC, those conducted by psychologists and psychiatrists at various university research centers throughout the country and others by the U. S. Naval Medical Research Laboratory. Below are the major findings from each of these sources in the order given, together with some typical examples of individual responses to isolation and detachment where such behavior appears to be common and universal to such conditions.

A. Results Taken from Autobiographical Accounts - -

Admiral Byrd volunteered to spend six months alone in the Arctic to "taste the peace...quiet and solitude long enough to find out how good they really are." Dr. Alain Bombard wished to prove that shipwrecked people could survive at sea for an indefinite length of time and voluntarily sailed alone across the Atlantic Ocean for 65 days on a life raft, subsisting solely on what food he could get from the sea. Both of these dedicated scientists reacted to their isolation and loneliness in almost identical fashion. Due to the monotony and lack of change in their environment, both felt oppressed and drew deeply within themselves for emotional sustenance. Both stated that while their lives were threatened daily by the hazards of their environment, it was constancy of these surroundings which seemed like a force which would destroy them. In essence, both men further stated that:

(1) They felt an overpowering need for outside world stimuli and yearned for sounds, smells, voices and touch.

(2) They wanted someone with which to confirm or debate their impressions to maintain their mental balance and to confirm right and wrong opinions and behavior.

(3) They constantly had to fight overpowering feelings of depression and anxiety and felt that they could only control themselves and their environment by thoroughly organizing their days, assigning themselves to a strict routine of work, and spending no more than one hour at a time doing a task.

(4) They learned to fight off depression by concentrating on pleasant past experiences and associations and refused to allow themselves to think about anxiety-producing aspects of their situation. Nevertheless, there were moments of severe anxiety, fear and irrationality. On several occasions Dr. Bombard experienced both visual and auditory hallucinations. Keeping the mind on an even keel proved to be a trying experience for both men throughout the duration of their respective detachment periods.

Hallucinations and delusions as well as depression and anxiety play a prominent part in the accounts of other individuals under severe stress and isolation. Christine Ritter, who volunteered to accompany an exploratory force to the Arctic, reported that a various times she saw a monster and heard ski strokes on the snow where no one was evident. At one time during the long Arctic night, she experienced depersonalization to the extent that she thought she and her companions were "dissolving in moonlight" and wandered out into the snow only to be rescued by the natives. She stated in her book that those who successfully survive such experiences must create for themselves a sphere of activity and thus a realm of reality to hold on to when no stimuli comes from the outside environment.

General Dean, an unwilling subject for perceptual and sensory deprivation in a Communist Chinese prison camp, had great difficulty in preserving his judgment and at one time became so depressed that he attempted suicide. Being a physical fitness enthusiast he did calisthenics and algebraic problems in his head (as did Dr. Bombard). By such activity, he felt that he was maintaining his physical and intellectual integrity.

Gibbons, a British soldier in the British Indian Army whose ship was torpedoed in the Indian Ocean by the Japanese in World War II, was forced to survive initially with 134 persons, only four of which were living one month later. He reports that as conditions became more extreme and as social control dissolved, murder, suicide and cannabilism followed. Lacking food and water and trustworthy companionship, all survivors had vivid dreams and hallucinations of food, drink and family gatherings during the first week. He reports that some four weeks later after landing on an island, faces of dead companions appeared around him from rocks and stones on the beach.

B. Results from Prisoners of War and Prison Inmate Studies - -

It has been stated that the Chinese Communist, by numerous techniques, divided the allied prisoners into groups of isolation which prevented each prisoner from validating any of his beliefs, attitudes and values by meaningful interaction with other men. Thus, many prisoners, losing their capacities for discrimination, were in a highly suggestible state ready for Communist indoctrination. Psychologists and psychiatrists term this process the replacing of the individual's internal (mental environment) by the external environment whereby he now begins to believe this external milieu. Rigid controls causing extreme fatigue, cold, sleep loss, hunger and thirst and physical discomforts and pain were practiced to lower the overall efficiency of the prisoners to its lowest ebb.

Stypulowski, in an autobiographical account of interrogation for several months by the Russians in Lubiank Prison, Moscow, confirms the techniques used by the Chinese Communists on Allied prisoners, i.e., the use of the "social isolation"---pressure technique.

Studies of prisoner behavior in solitary confinement from many of our institutions, while not entirely comparable to the situation when men are alone facing the unknown, nevertheless continue to show how the inmate withdraws into himself, hallucinates, and shows a decreasing capability to deal with reality.

C. Results from Analysis of Survival Experiences - -

An analysis of the survival experiences of downed airmen shows that the tendency to consider suicide was greatest in the cases of men in solitary isolation, next highest in large groups of survivors, and smallest in survival parties of two to four. Men who were misfits in large groups were generally the ones who considered suicide. The men who were actively concerned with the welfare of the group by scouting or navigation action, foraging or cooking, etc., were too busy to contemplate self-destruction as a way out of their predicament. Most men stated that physical condition and mental spirit were of utmost importance. Noises, or the lack of noise, shadows, dripping water and even the "ticking of a cheap watch" all became major problems for some men. It was concluded that whether a man returns from an isolated survival experience depends largely upon the individual concerned. No amount of survival equipment will help some men, while others through sheer ingenuity, planning, and determination will survive the experience and return regardless of whether they possessed such equipment or not. It has been concluded that great courage was characteristic of most

Arctic survivors. In a group of three or more, a leader was necessary. Every individual had to dicipline himself (or be disciplined) and carry out a schedule of activities.

D. Results of Experimental Isolation Studies - -

Since most of the isolation studies to date have concerned the detachment and confinement of the single individual, obviously the many complex effects of human interrelationships resulting from confining a crew of several men are yet to be determined. Some work has been done in this area by the Navy prior to the commissioning of the Nautilus. In one such study, the crew remained "submerged" for 43 days. The results of this study were reflected in human engineering refinements and habitability improvements to the vessel. Whereas many of these findings may be extrapolated to space travel confinement and isolation, by and large, the findings presented in this section are those resulting from single individual confinement studies.

In studies at the School of Aviation Medicine, USAF, subjects have been confined within the SAM space cabin simulator for seven days. The results of these experiments have shown that:

(1) The subject's increasing hostility during the latter stages of the flight became a matter of great concern to the investigators.

(2) The subjects became highly fatigued and bored and the highly efficient system of work, housekeeping, toiletry, sleep, etc., developed

during the first two days, was gradually reduced to the minimal essentials for such activity.

(3) The cumulative effects of boredom and fatigue upon operators' proficiency were equally severe.

(4) No phobias developed.

(5) Time began to weigh quite heavily for each subject early in the flight and increased in a ratio directly proportional to the duration of the flight. For example, the onset of oppressive feelings occurred sooner for subjects of flights of shorter duration (32 to 48 hours) than it did for subjects of the seven day flights. (All subjects knew the duration of their flight plan prior to starting the experiment.)

(6) Cool, fresh tasting water and a variety of appetizing foods (all of which must be non-gas forming) contributed to higher morale and efficiency. So did adequate provisions for shaving, bathing and the changing of underwear.

(7) A shirt sleeve environment was highly desirable.

(8) Facilities and adequate space for exercising is highly desirable to relieve atrophy of the muscles.

(9) All subjects strongly felt the need for their usual number of uninterrupted hours of sleep to restore them to maximum efficiency.

At the McGill University in Canada, experimental isolation studies were conducted with the aim of reducing the PATTERING OF STIMULI to the lowest level, while at the Bethesda Mental Health Institute, investigations were made to determine the effects of reducing the ABSOLUTE

INTENSITY of all physical stimuli to their lowest ebb. In the former experiments, healthy college students (paid $20 per day) were placed on a comfortable bed in an air conditioned sound-proof cubicle. The subjects' arms and hands were enclosed in cardboard cuffings to minimize tactile stimuli and their eyes were covered with translucent glasses which permitted entry of light but abolished all pattern and form vision. Observation of these subjects revealed the following: After several hours, directed and organized thinking became progressively more difficult; suggestibility was greatly increased; the need for extrinsic sensory stimuli and bodily motion became intense; most subjects could not tolerate the experiment for more than 72 hours; those who remained more than 72 hours developed overt hallucinations and delusions.

The Bethesda experiments were conducted by suspending the subject, wearing only a blacked out mask for breathing, in a tank of water maintained at 34.5 degrees centigrade. With this technique, visual, auditory and tactile stimuli were reduced to a minimum. The longest period of time any subject remained in the tank was 3 hours.

A variety of results occurred some involving highly personalized fantasy material and projection of visual imagry. After emersion the day apparently started over and this effect persisted throughout the experiment. Subjects also had to re-adjust to social intercourse.

Of the nine patients observed in one study, it was shown that the mental abnormality which began after the patient had been in the tank for 24-48 hours or longer, was characterized by well-organized visual and auditory hallucinations and delusions. It was concluded that these abnormalities were related to perceptual isolation or restriction (sensory deprivation) imposed by the unique conditions. In all patients these symptoms were worse at night and better during periods of feeding, visiting and physiotheraphy. These symptoms lasted 10-15 days and recovery was independent of recovery of motor function or of continued existence in the respirator. Most patients were able to recall their experiences with great vividness and detail even many weeks after the symptoms ceased. They could not be attributed to physical disease because the authors reported none of the accompanying symptoms of toxic, anoxic, or metalolic derangement.

In another experiment highly motivated volunteer subjects were committed to 30 consecutive hours of work at a complex perceptual motor task. The essential nature of the task was to monitor an instrument panel and to appropriate control of discrete events. With the exception of 20-minute breaks for food and relief, which were given at regular meal times, the subjects remained confined to their cockpits and were not permitted to sleep. Following 12 to 15 hours of work and continuing up to the end of the 30-hour period, all subjects reported having experienced disturbances of illusions and hallucinations.

These ranged from simple, poorly defined phenomena to highly structured, well organized aberrations. For example, one subject reported having to "brush away the little men that kept swinging on the airspeed indicator", while another reported the "instrument panel kept melting and dripping to the floor". One subject stated that "on several occasions the bank indicator showed a hippopotamus smiling at me". The authors conclude that these disturbances were caused by the high degree of concentrated attention required of the subject in performing the task and the deprivation of other and varied sensory events which would otherwise serve to stimulate him. In addition, the tasks required of the subjects were highly repetitious in nature. In fact, as time continued, repetition became so dominantly oppressive that many of the subjects became highly irritated at their inability to think of some undetectable method of jamming the whole system thus relieving their irritation.

E. Observations on Mechanics of Isolation - -

Dr. John Lilly asserts that experiments such as these demonstrate results similar to these given for solitary polar living, sailing alone or solitary confinement studies: if one is alone long enough and at levels of human and physical stimulation low enough, the human mind turns inward and projects outward its own contents and processes. He further states that not only does the brain stay active despite the lowered levels of inputs and outputs, but accumulates surplus energy to extreme degrees. Apparently, as evidenced by the findings in this report, even healthy minds react this way in isolation. Dr. Philip Soloman et al has further summarized the general findings of sensory deprivation by stating it is clear that the stability of man's mental state is dependent on adequate perceptual contact with the outside world and that isolation produces an intense desire for extrinsic sensory stimuli and bodily motion, increased suggestibility, impairment of organized thinking, oppression and depression, and, in extreme cases, hallucinations, delusions, and confusion.

Whether or not there exists some optimal time-volume relationship as a function of crew number will have to be discovered before flights of prolonged periods can take place. Constant and minute observation of each other's characteristics seem certain to produce severe tensions among crew members, particularly where duties are routine and monotonous, extending over a relatively long period of time. Ross has suggested that if the internal environmental conditions conform to the crew's physiological and psychological needs, many of these crew tensions and stresses can be eliminated. He suggests that we not try to adopt the human to a new and radically different environment, but rather, design the system such that it will be fully compatible with the human and his desire for comfort.

From the findings above, it should be evident that additional experimental studies will have to be conducted before possible dangerous effects of crew isolation and confinement are fully recognized and counteracted by appropriate measures. However, some present-day findings, as follows, should prove directly applicable to proper utilization and protection of the crew of space vehicles:

(1) Rest and duty cycles for the crew should be scheduled so that each member will have eight hours of uninterrupted sleep and a 16-hour period of duty or relaxation. The sleep cycle for each member should be consistant, i.e., 8 hours of sleep, 16 hours of duty, then 8 hours of sleep, etc.

(2) Some method of cooling and aerating the drinking water should be provided; this is a definite morale booster.

(3) Methods of continuous communication with the outside world should be established. This helps to eliminate some of the effects of detachment and confinement and, in addition, can be utilized to convey knowledge from the ground to the vehicle occupants of the results of their labor. This will serve as a stimulating and motivating factor. Music and/or entertainment programs from either internal or external (Earthly) sources would be highly desirable. Variety should be stressed.

(4) In addition to meeting nutrition requirements, the diet supplied the crew must be acceptable to them.

(5) The internal environment of the space craft must be designed so that the operator is constantly occupied with meaningful stimuli and significant tasks. This prevents the brain from accumulating surplus energy from within and projecting it outward in the form of illusions, hallucinations, etc.

(6) The sleep and/or recreation area should be large enough to permit the crew members to exercise. A consistent result from confinement studies shows the need for exercising (i.e., stretching, flexing the muscles, etc.) the human body. It has been indicated that under the weightless state, this need may be even greater.

(7) The responsibilities of each crew member must be clearly defined and a pre-designated work-rest-sleep schedule should be carefully followed.

(8) The personalities of a multi-man crew should be discriminately matched.

(9) Habitation tests under simulated space flight conditions must be considered as part of the selection program as well as of necessary crew conditioning.

(10) Evidence to date indicates that it will probably be necessary to create an artificial day-night cycle for the crew, particularly in the sleeping area.

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16. Hauty, George T., Modifiability of Day-Night Cycling, American Rocket Society, No. 680-58, dated November, 1958.

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XIII. WORK-REST CYCLE

The success of any long-term space operation will depend a great deal upon the crew's physiological day-night cycle and fatigue. The first of these considerations is due to a phenomenon common to all higher forms of biologic life, the physiological day-night cycle, which is manifested by alternating phases of sleep and wakefulness. Earth's periodic variations in illumination, temperature, etc., as well as man's productive activity necessary to sustain life, tend to synchronize the physiologic day-night cycle with man's daily schedules of work, rest, and sleep. It appears that man is committed to this diurnal rhythm, i.e., it can be shifted, reversed, lengthened, and shortened to some extent, but never broken or eliminated. As the space vehicle will completely disrupt the natural sequence of day and night, an artificial cycle must be simulated within the portion of the space vehicle housing the crew. If this is not synchronized with the crew's work-sleep schedules, fatigue is engendered. Fatigue is a cumulative effect which results in drastic deterioration of operator efficiency.

Man's normal work cycle is 8 hours of work and 16 hours of rest, recreation, and sleep. Variations of this cycle which cause sleep deprivation or prolonged commitment to a skilled or semi-skilled task result in a type of fatigue which manifests itself in the form of impaired judgment, slower decision time, decline in alertness, increased variability of proficiency, degradation of attitudes and feelings, and various metabolic changes. Work has been done in space environment simulators at School of Aviation Medicine, Randolph AFB, Texas, and at Wright Air Development Center, Dayton, Ohio, where the work-rest cycles were varied from normal to determine effect on task efficiency. One seven day test of alternating 4 hours work and 4 hours rest indicated that performance declined during that portion of a 24 hour day that would normally be devoted to sleep. In addition there was an overall decrease in proficiency on succeeding days from that expected with a normal work-rest cycle. It was apparent that the subject did not make satisfactory adjustment to the schedule of work and rest to which he was committed. As a result, the engendered fatigue was never completely dissipated.

Based on the above, it appears highly desirable to maintain the crew on a work-rest schedule as near to that of their earth environment as possible, particularly on very long or extended flights. Too great a variation will result in drastic deterioration of proficiency with resulting inadequate performance in carrying out the skilled tasks of the space mission.

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XIV. WARNING DEVICES STIMULUS - RESPONSE

At any time during the mission, certain warning and caution information must be supplied the pilot for proper evaluation of critical component/vehicle operation. An analysis was made to determine the optimum methods of attracting the attention of the pilot from his normal task concentration for these emergency inputs.

Of the five senses available to the human operator to receive warning stimuli it is recommended that visual stimulus be the primary method for caution and danger warnings due to its wide stimuli-response band and its high response definition in the low and medium stimulus range. The sense having the next widest range is audition which should be utilized as a secondary method as it surpasses the vision stimulus/response sensibility when the stimulus is very large but is quite poor when the stimulus is of a low or moderate magnitude. In addition, the condition of weightlessness can be expected to degrade the effectiveness of man's vestibular apparatus or at least confuse it. The other methods of stimulus--cutaneous, smell, and taste--are of limited value and should not be assigned any primary warning functions. Detail analysis indicates the stimuli that man can receive and that could be useful as warning input channels are the following:

(1) Vision

(2) Audition

(3) Cutaneous

(4) Smell

(5) Taste

Considerable investigation in the simulus-response field has been made in the past under 1G conditions but relatively little has been done under high G conditions, and still less under conditions of weightlessness. Figure 54 is a chart of modified Weber-Fechner functions representing these five different sense modalities as evaluated under the 1G condition. Numerous investigators have shown that the assumption of a constant fraction of the stimulus magnitude in each barely noticeable difference of perception is merely an approximate statement of a special case, and that Fechner's formulation does not represent the true relationship between the intensity of the stimulus and the magnitude of sensation over the whole range of perception, however, for the purposes of this requirement it does show the relative effectiveness of the various sense organs. Vision is a good receptor at the low and moderate stimulus level and has a very broad band width. Audition is quite poor at the low and moderate stimulus level but is superior to vision in the high stimulus level although its bandwidth is less. Smell and taste are sensitive enough at low stimulus levels but their time response and the engineering problems involved to effectively utilize them as warning sensor make their use as primary input channels undesirable. The final stimulus sensor--cutaneous (pain, temperature, and pressure)--has a lower stimulus-response sensitivity and narrower bandwidth than any of the other sensors and its use would tend to reduce the operator's performance from a psychological standpoint.

A. Vision - In view of the above it is recommended that vision be the human operator's prime method of keeping himself orientated and receiving warning stimuli as it appears to be unaffected by weightlessness and only moderately affected by accelerations of the boost phase. It is recommended that the stimulus, the function of which is to attract attention, be a flashing light while legend lights should be steady. The present standard color coding of lights appears to be satisfactory for space vehicles. The rapidity of flickering is one acceptable method of indicating urgency, but it should not exceed 1/2 cycle per second. In order to facilitate keeping track of a multitude of instruments and equipment it is desirable to group warning lights and danger lights on central boards within the pilot's normal field of view.

B. Audition - Man's auditory system is relatively good and he can distinguish presence or absence of sounds above background. His hearing is very sensitive to pitch although his ability to distinguish tones using only memory as a reference is very low. He also can usually distinguish whether sound enters his right or left ear if he has normal hearing. Certain vital emergency warnings can be initiated through the pilot's headset as back-up warnings or in some cases primary warnings, i.e., gear not down for landing, fire, dangerous atmospheric concentrations, etc. In such cases the pilot must have the capability of turning off the warning once he is aware of the condition or in the event of warning system malfunction. It is expected that positive, negative, and absence of G forces will reduce the usefulness of his vestibular apparatus or more likely confuse it. He will need to have a strong reference point in his other senses (especially visual) to keep himself orientated with respect to his surroundings, immediate and worldwide.

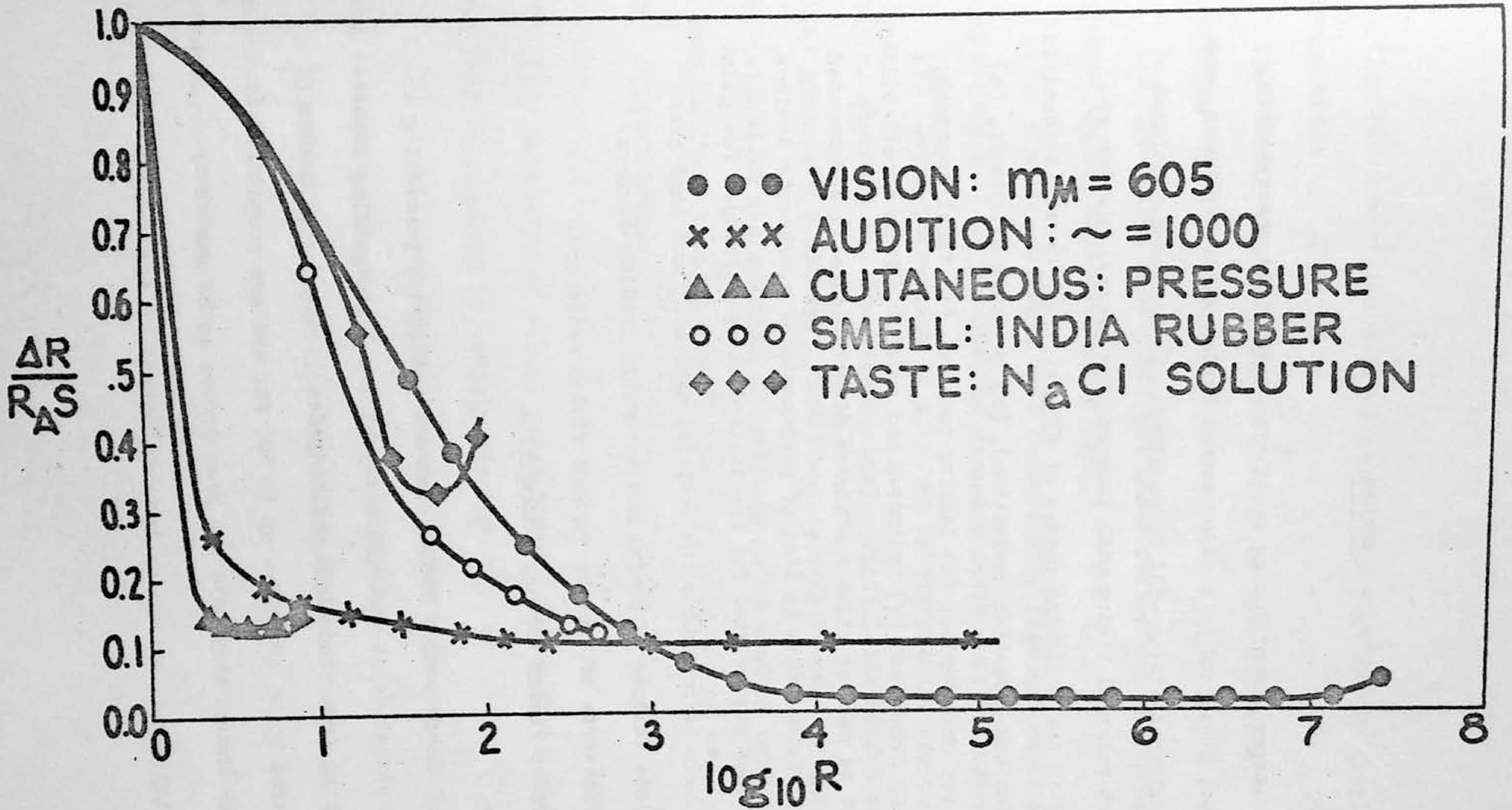
C. Cutaneous - Pain, temperature, and pressure are discernible all over the body, while the other senses are located in special sense organs. It appears that pain, temperature, and light touch sensations or deep sensibility are not good receptive facilities for direct use in warning systems. The sensation of pain, if it is received promptly, is generally caused by a rather severe prickling of the skin, and the inborn response to it is the alarm reaction which promptly initiates an escape response. This is a relatively rapid response following receipt of sensation and such a response is considered undesirable under the circumstances. People react to increases and decreases in tempertture and can do so over relatively small portions of the body. The response is rather slow since the heat or cold input has to continue for at least three seconds (sometimes considerably longer if it is applied slowly) before an action is initiated. The normal action would be to pull the affected portion of the body away from the warm or cold region. Humans are also responsive to a light touch or pressure. Here stimulus may or may not be felt depending upon the preoccupation of the individual with his particular task. In addition to this, a relatively large area would have to be stimulated.

D. Smell - The human has probably the least well developed olfactory organ of all mammals and although it can detect an almost infinite number of variations in odor, the olfactory organ rather rapidly raises or increases its threshold of smell. For example, a person routinely working in an area where there is a relatively high concentration of hydrogen sulfide gas will rather rapidly lose his ability to smell the gas. In addition to this, it is difficult to present a sharp clear odor for a short period of time and have it dissipated. Apparently the olfactory organ in the human receives its sensations from eddy currents in the nose rather than currents of air passing directly in the nasal passages. It is only while these eddy currents are in motion that man is able to smell, that is during inspiration and expiration.

E. Taste - Man generally differentiates four taste sensations -- sweet, sour, bitter, and salty. Time of onset is rather slow and will linger for quite some period of time. This is because a solution must be formed. There is no apparent need to use this sensor as a warning device in a space vehicle.

Figure 54

INTENSITY OF STIMULUS AND MAGNITUDE OF SENSATION



MODIFIED WEBER-FECHNER FUNCTIONS REPRESENTING FIVE DIFFERENT SENSE MODALITIES. R= a MEASURE OF THE STIMULUS (USUALLY c.g.s. UNITS); ΔR IS A NECESSARY CHANGE OF STIMULUS TO PRODUCE A JUST NOTICABLE DIFFERENCE ΔS IN SENSATION.

From Comparative Studies on Animals and Human Subjects in the Gravity-Free State, S. J. Gerathewohl, Journal of Av. Med., August 1954

XV. VISION

To a lesser extent during orbit (for scientific observations, navigation, etc.) and to a major extent during glide, approach, and landing external vision will be required. It has been concluded that pilot external vision will increase the overall mission reliability in the following phases of flight: (a) Orbit (scientific observation and celestial navigation), (b) re-entry alignment, (c) landing area orientation, (d) landing pattern, (e) final approach, (f) landing flare, and (g) touchdown and rollout. From a reliability standpoint as well as pilot confidence direct vision is recommended as primary vision media in lieu of periscopic or electronic devices (although they may be used for specialized observations). The pilot should be able to orientate the vehicle, approach, and land even with complete failure of homing and automatic landing devices.

The trade-offs offered by various vision media are:

A. Direct Vision through Windshields

Advantages

(1) Stereoscopic vision cues are available, permitting a maximum in visual depth perception capability (disregarding impairment resulting from windshield deficiencies). Stereoscopic cues are considered to be effective up to 500 ft. and are considered to be desirable though they have not been proven to be mandatory.

(2) Pilot confidence level relatively high due to simplicity of viewing media.

(3) Highly reliable due to lack of mechanical parts.

Disadvantages

(1) Shielding from glare and other radiations will probably be required during high altitude flight.

(2) Viewing surfaces must be optically flat and multi-pane configurations must be parallel to minimize deviations in vision fields.

(3) Depth perception is affected by windshields rotated in the horizontal plane (i.e., Vee windshields). Windshields tilted in the vertical plane are preferred. Small angles with respect to the horizontal (tilted in the vertical plane), are to be avoided because of the high loss in light transmission.

B. Optical Devices

Advantages

(1) Extension of visual range through telescopic devices should this be required by vehicle mission.

(2) Permits use of collimated reticles as an assist in locating distant objects in an empty visual field.

(3) Scanning capability can be provided to increase size of area viewed.

Disadvantages

(1) Basic field of vision limited by optical configurations.

(2) Stereoscopic capability limited or eliminated dependent on configuration.

(3) Optical system distorts subjective judgement of apparent size and distance.

(4) Optical loss in light transmission dependent on configuration.

(5) Glare problem dependent on configuration, resulting in excessive fatigue when alternating view from optical device to other cockpit displays.

(6) Hypnotic effect.

(7) Problem of maintaining proper head position for viewing.

(8) Loss of horizon reference during certain flight maneuvers due to restricted field of view. This could result in cases of vertigo.

C. Electrical Devices

Advantages

(1) Extension of visual range (radar and infra-red).

(2) Ability to brighten viewed image under poor lighting conditions.

(3) Greater field of view possible through the use of multiple viewing points, possibly approaching the ideal.

Disadvantages

(1) Poor image quality, as compared to a direct view, reduces ability to perceive small details.

(2) Stereoscopic capability usually eliminated in two-dimensional screen display.

(3) Reduction in visual detection due to lack of color definition.

(4) Pilot confidence level low because of relative complexity and current low reliability as compared to other vision media.

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XVI. CREW INCAPACITATION INDICATION

Investigation has been made of literature and of professional opinions regarding means of determining remotely the ability of an operator to make judgments and perform work. The need for such an indication is apparent in both the safety requirement and the job performance requirement of a man alone many miles above the earth's surface.

The difficulties of such remote observations of physical and mental condition are enormous chiefly because the physiological changes that would betray incapacitation are subject to change for other reasons. Respiration, pulse rate, blood pressure, galvanic skin response, and others vary with temperature, emotion, fatigue and other conditions.

One potential source of information on useful consciousness is the electroencephalogram. The pattern of brain waves is different and characteristic for conditions as eyes open, eyes closed and asleep. According to verbal report from Dr. Vail, Physiological Section, WADC, the incapacitation of subjects can be predicted one minute or more before the event by the EEG pattern. Pratt and Noell report that the most reliable indicator of hypoxia is the occurrence of two or more consecutive bursts of 5-7 cps brain waves.

A less complicated method would be to request performance by the pilot of sequential tasks; for instance to close and then open a designated panel switch two times, followed by some third activity, all of which would reach the ground observer by telemetering communication channels. The ground observer must know (1) what action was requested, (2) what action the operator took and (3) whether the action was correct. Ability to do as requested indicates judgment and work capability. Inability to do so would warn of beginning or real incapacitation. This has the advantage of use of existing cabin equipment and does not add to the already large list of such. It avoids any extra mechanical or electronic devices and involves no extra weight. This method is recommended as currently available and highly reliable.

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XVII. HUMAN PARAMETERS AFFECTING ESCAPE INITIATION

There are multiple factors which may affect escape initiation by the crew of an orbital vehicle. A partial listing (order of importance will vary with the stage of flight and development of emergency situations) includes:

a. G-forces, acceleration, deceleration, weightlessness.

b. Noise and vibration.

c. Temperature extremes, high and low.

d. Radiation effects, UV, visible, alpha, beta, gamma, x-ray, light and heavy charged particles (cosmic).

e. Micro-and macrometeorites.

f. Lowered barometric pressures, decompression and the "bends".

g. Humidity excesses.

h. CO_2 accumulation.

i. O_2 lack.

j. Toxic materials such as CO, ozone, metal and plastic fumes, others.

Initial training, indoctrination and selection of crew must be as intensive and accurate as possible. This phase would be used to eliminate persons with susceptibilities to hypoxia, the "bends", aerotitis media, deafness produced by noise, disorientation by weightlessness, intolerance for discomfort, pain or hardship. Closer to launch are the precautions with regard to gas-forming diet items, denitrogenation by high-O_2 breathing, sufficient rest, freedom from worry, and positive assurance of the high probability of safe return. A point of importance for a first flight is the glamor and personal adulation of a "first", which will be lessened for subsequent flights.

During launch the G-forces (transverse front to back) will vary up to 8 to 10 and have been shown by centrifuge tests to have no effect on the pilot's ability to initiate escape. Propulsion failure may, however, give rise to wild gyrations, vibrations or tumbling with variable high G-forces. These are unlikely to exceed human tolerance limits for transverse G but in the event of foot-to-head forces, the tolerance limits are much lower.

Vibrations in the 15-25 (greater than 1/3 inch intensity) and 40-50 cps (greater than 1/6 inch intensity) can cause intolerable pain and loss of vision, either of which could incapacitate the pilot. Noise and other frequencies must be within the limits of human tolerance and not of an intensity to adversely affect hearing.

Man can exist and carry out simple tasks in environmental temperatures from -40° to 140°F if suitable clothing is worn for the low, and if humidity is kept at 30-50% for the high. Time of exposure to high temperatures should be well below man's tolerance limits. Up to 160°F can be withstood for 20 minutes. Such temperature highs are possible at re-entry into atmosphere. Insulation, double walls, cabin temperature and atmosphere cooling should limit the heating of cabin to less than 140°F even when skin temperature of the vehicle is much higher.

Skin friction at escape velocity is a potential source of cabin heating but experience with the satellites shows again that cabin temperatures are in the tolerance range.

Failure of dehumidification would lead to discomfort at temperatures above 95° and decrease the tolerance limit by 20-30°F and the time before heat pain to half or less than that for "dry" atmospheres. Discomfort should not interfere with escape initiation. Severe pain could.

None of the listed forms of irradiation would have immediate and incapacitating effects. Even roentgen and cosmic rays would not prevent action to initiate escape.

Micrometeorites ($<$10 micra diameter) are unimportant. Larger particles at speeds of 11+km./sec. could penetrate the vehicle skin and cause decompression of an already low cabin pressure. Relatively rapid decompression requires a hit by a large (1 gm. or more) particle. Even then, an emergency supply of 100% O_2 in pressure suit could allow escape initiation. Even though in pain, the task of starting the escape could be carried out with the "bends".

CO_2 accumulation to 3 or even 5% will stimulate respiration, cause acidosis but not interfere with activity of a minor sort, or with decision. CO_2 can be removed and kept below 3% by means of solid absorbers such as CaO or Li_2O. Both of these have a water-removal action also.

Hypoxia is incipient and incapacitating while the subject thinks he is still rational and able. Decrease in arterial O_2 saturation of 80% or less (45 mm p O_2) will lead to incapacitation of the pilot in 1 to 2 minutes. In twice this time, he will be unconscious.

Toxicity is usually gradual in its effect. Since the cabin must be designed to eliminate toxic materials, only emergencies like equipment fires should ever give rise to poisonous materials. None of these seem to be made in quantity sufficient to incapacitate a pilot for escape initiation.

XVIII. PHYSIOLOGICAL MEASUREMENTS

To determine the extent of man's ability to adapt to and function effectively in space flight requires an accurate knowledge of his basic physiological parameters before, during, and after his exposure to the space environment. Upon the early manned flights of the space vehicle, the pilot's body functions should be monitored by flight surgeons through telemetry and inflight recording to further knowledge of the physiological stresses imposed by space flight.

For the telemetered data, the keynote should be simplicity. Monitor, but record only when abnormal signal is received, i.e., why transmit complete EKG (wide band) when only heart rate is required? If waveform is desired, extract vital information in vehicle and transmit computed value. Normally detailed records should be recorded in vehicle and recovered for analysis after landing.

In order to adequately evaluate the human component of this man-machine system the following physiological measurements should be considered essential:

a. Heart rate - microphone

b. Blood pressure - both systolic and diastolic

c. Respiratory - rate and depth

The following measurements are highly desirable but need not necessarily be taken on every flight:

a. Galvanic skin resistance - emotional effects

b. Partial pressure CO_2 - exhalation* and inhalation*

c. Partial pressure O_2 - exhalation* and inhalation*

d. Radiation - skin plate samples*

e. Body temperature - skin and air*

f. Acoustics - at pilot's ears*

g. Vibration - body vibration (pressure suit neck ring measurement)*

h. Acceleration - on body (angular and linear dimensions)

i. Blood oxygenation - ear lobe measurements

j. EEG - for brain activity

k. Optic response - photographic recording of pilot's torso and head (16mm camera)*

l. EKG - more complete data on heart (recommend torso leads)

m. Humidity - surrounding pilot*

Items marked by * may be taken external to pilot's skin.

XIX. EMERGENCY SURVIVAL ON EARTH'S SURFACE

To achieve a system which imposes minimum risks to the crew member requires the capability of return to earth and survival from the mission profile. In addition to successful return to earth, the terminal landing and survival requirements must be adequate for anticipated possible environment. These additional requirements are:

A. A capsule capable of floating and sheltering the pilot for a minimum period while search and rescue operations are in progress.

B. A flotation garment, preferably a vest type such as the B-5 "Mae West".

C. All necessary items of equipment to provide survival capability under all environmental conditions.

D. A highly reliable means of pinpointing the exact location of a downed capsule or space vehicle is an absolute necessity. Analysis indicates that it should be equipped with a rescue beacon of considerable range. In addition, it is deemed highly desirable that it be equipped with a blinking light as an aid to locating it at night. Other standard light weight and compact visual and electronic signaling devices presently found in standard survival kits such as the URC-11 radio, sea marker, mirrors, flares, smoke signal devices, flashlight, as well as a whistle should be included.

An analysis of survival experiences which occurred during World War II and the Korean Conflict proved conclusively that the two most essential items to surviving on the sea were the life raft and some type of flotation garment, generally the "Mae West". The latter proved to be an indispensable aid in keeping men afloat, in helping them escape from sinking chutes, tangled harnesses, and sinking aircraft, and brought them to the surface from depths as low as 40 feet. It was also frequently used as a means of staying afloat while catching fish, while retrieving a lost article from the raft, or for remaining aloat while arighting the raft.

Figures 55 and 56 are presented as additional information to this analysis. Figure 55 shows that under given temperature conditions, with even a minimum water supply, man can survive on the sea for several days. Other factors being equal, increasing the water supply increases his survival capability. Figure 56 shows recovery periods of 607 incidents in relation to time in days. It will be noted that of those who were recovered, 70% were recovered on the first day of search, 8% during the second day and 5 1/2% during the third day. The normal search period generally covers six full days while maximum effort extends the period to eight days. A life raft or floating capsule are essential items.

As might be expected, results of numerous investigations of the rescue of downed airmen from both sea and land have proved conclusively that locating the survivor(s) was the major problem. One Air-Sea Rescue unit operating in the Central Pacific during World War II estimated that when the position was known and the search begun immediately, the chance of recovery was about 90%, while random searches starting one day after the aircraft was reported missing produced only some 10% success. "Darkness was the greatest single cause for losing contact....and night rescues succeeded only when the position was given accurately and when survivors had means of night signaling". Such findings leave little doubt as to the necessity for a highly reliable night signaling device (such as a blinking light) for the space capsule. Other results from survival and rescue experiences involving approximately 1,000 cases have shown that:

A. The duration of individual survival episodes averaged less than 48 hours before contact was made with rescuers or natives; the longest recorded period of individual isolation was 23 days. Some fliers spent as much as 8 weeks awaiting rescue or traveling back to their bases; but these men were aided by friendly natives.

B. Mirrors, flares, dyes, parachutes and signal panels were successful in the order given in leading to rescue. (88% were first contacted by visual means; 12% by electronic aids.)

C. The Mark 3 signaling mirror was used effectively in rescue at sea to a maximum distance of twenty miles. (It may be used as long as the sun is a few degrees above the horizon.)

D. Injuries were incurred by 90% of the survivors before they were rescued, 60% of which was due to injuries sustained upon crash landing, ditching or upon surface impact during parachute descent.

E. Under normal weather conditions, aircraft at 1,000 feet frequently spotted sea-marker die at 5 miles; under optimum conditions it was spotted 7 miles away at 2,000 feet. It may be dispersed by rough seas in 20 minutes.

F. A smoke grenade fired from a .45 caliber pistol could be seen from 10 miles.

G. In most cases, flashlights were first seen between 100 and 200 yards. (Due to battery corrosion--even in the case of waterproofed batteries and flashlights--and its short range, this item has proved to be very unreliable as a signaling device.)

H. The most valuable single item of over-water equipment issued to fliers was the pneumatic life jacket called the "Mae West". Even though this item might conceivably never be used by the crew of a floatable capsule at sea, the psychological advantage of its presence in alleviating fears would be tremendous.

I. Without the aid of sea-marker die, a man in a life jacket is practically impossible to spot in a moderate sea.

J. It was difficult to forecast a lost raft's position without reliable data on winds and prevailing ocean currents. (Obviously these factors must be taken into account in searching for a lost floatable capsule.)

K. The best altitude for visual sighting of liferafts is 800 to 1,000 feet.

L. Thoughts of suicide were more common to solitary individuals than to large groups. Mental, physical and factual preparation for survival was reflected by high morale; fliers were conspicuously more optimistic and energetic than passengers. The will to survive was declared the deciding factor.

The pilot of any orbital space vehicle should be thoroughly trained in the art of escape and survival in all areas of the world including survival at sea, in the tropics, in the polar regions, and in the desert and jungle. An increasingly large number of flying personnel are undergoing such instruction and experience at a number of survival training centers. The crew members should be taught how to use the equipment (and how to improvise when necessary), they should be supplied with information regarding habits and customs of the people of numerous countries, and they should know about climatic and geographical conditions of the world, and any other pertinent information which may enhance their survival probability. Above all, the crew should be taught that they must consider themselves active members of the rescue party.

It may be concluded that any survival incident can be divided into three phases: the first is saving one's life, the second is signaling for help, and the third is the maintenance of shelter and subsistence until rescued or return to home base. All lifesaving equipment must be *immediately* available to the survivor(s) and signaling devices must be *readily* available when needed and carried in such a manner that it cannot be lost. Equipment used for shelter and subsistence need not be as readily available as the former.

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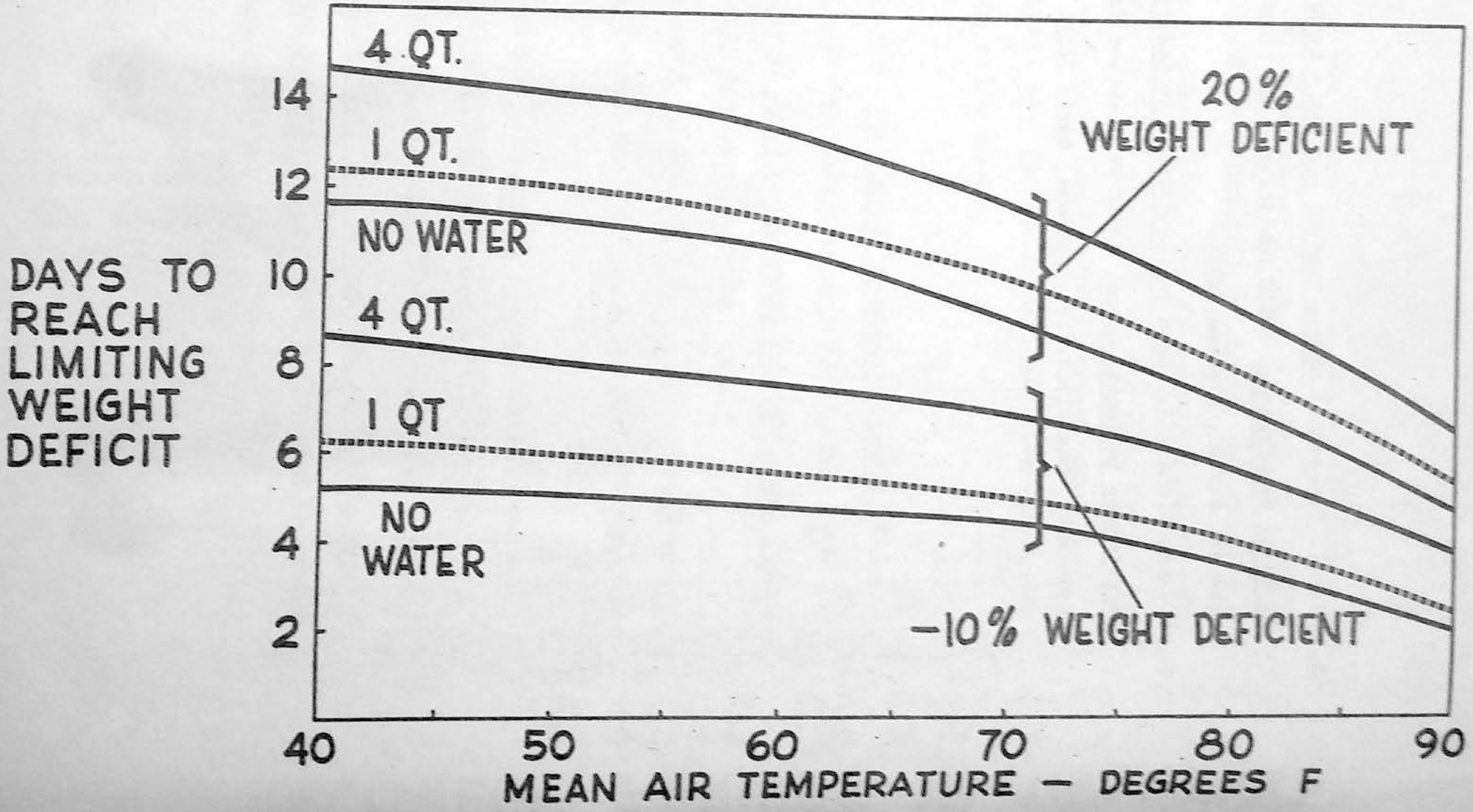
Figure 55

HUMAN SURVIVAL AT SEA WITH WATER RATION OF ZERO, I QUART AND 4 QUARTS

THE CURVES ARE CALCULATED ON THE BASIS OF TIME REQUIRED TO BECOME DEHYDRATED BY 10% OF BODY WEIGHT, WHICH IS INCAPACITATING, AND BY 20%, WHICH IS THE LIMIT OF BARE SURVIVAL.

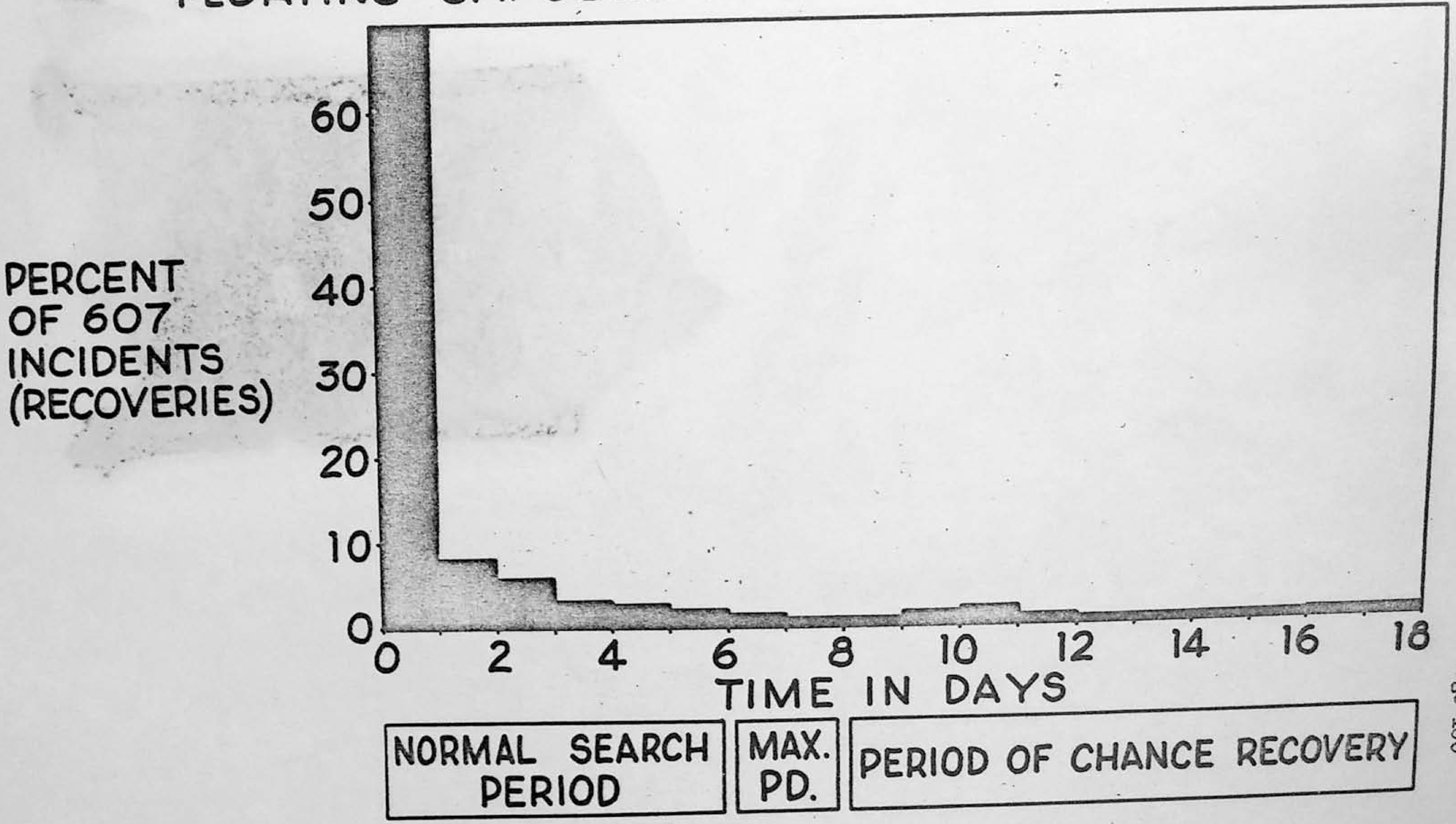


From CVA Report E9R-11786

From CVA Report E8R-11786

RECOVERY PERIODS IN RELATION TO TIME IN DAYS

THIS CHART SHOWS RECOVERY PERIODS IN RELATION TO TIME IN DAYS. LIFE RAFT OR FLOATING CAPSULE IS ESSENTIAL ITEM.



From CVA Report E8R-11786