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THE INTANGIBLES OF HABITABILITY DURING LONG DURATION SPACE MISSIONS

by T. M. Fraser

Prepared by
LOVELACE FOUNDATION
Albuquerque, N. Mex.

for

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PREFACE

This paper is a constructive review of human habitability in space vehicles and dwellings, in which an attempt is made, on the basis of a critical examination of appropriate publications, to present a composite picture of the nature, significance, and attributes of the habitability in this connection, and to discuss some of its less tangible requirements.

For their assistance in providing the material for the paper, my thanks are due to Mrs. J. Wilson and the staff of the Lovelace Foundation Document Library; many thanks are also due Dr. A. H. Schwichtenberg, Head of the Department of Aerospace Medicine and Bioastronautics, and to Drs. E. M. Roth and D. E. Busby for their valuable comments in reviewing the paper, and to my secretary, Mrs. J. Whalon, for her assiduous efforts in its preparation.

ABSTRACT

In this paper the nature and meaning of habitability are discussed in relation to the requirements for long duration manned space missions. Several models of habitability are examined, and it is suggested that habitability can be considered as that equilibrium state, resulting from man-machine-environment-mission interactions which permits man to maintain physiological homeostasis, adequate performance, and psycho-social integrity. The attributes of habitability are examined, and, indices of habitability are discussed. No attempt is made to examine all the requirements for optimum habitability, an exercise which would involve consideration of every aspect of the interactions occurring in the entire man-machine-environment-mission complex. Attention is focussed instead on some of the less common aspects, and a discussion ensues on requirements for free internal volume, configuration, privacy (territoriality), personal hygiene, illumination, decor, color, recreation, and the use of leisure time, during a long duration manned space mission.

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THE INTANGIBLES OF HABITABILITY DURING LONG DURATION SPACE MISSIONS

The development of any successful form of man-made transportation, whether on the land, on or under the sea, or in the air, can be shown to demonstrate three phases, always sequential, and commonly repetitive as new fields of development are opened. These phases are particularly obvious in the development of the automobile and the aircraft. The first phase lies in demonstrating the feasibility of the system as a practical transportation mode. Thus, after some form of engineering analysis and study, a suggested vehicular system is designed, built, tested, and in one modification or another, shown to be capable of achieving the function for which it was developed. Emphasis at this time is on functional capability. Concomitant with the demonstration and improvement of functional capability is the development of phase two, in which emphasis isnow directed towards improvement of the reliability and the safety of the system. When reliability and safety are reasonably assured, the third phase begins and attention is directed towards achieving standards of comfort and habitability conducive to maintenance of optimum performance, at whatever level is required, with minimum fatigue. The process, of course, is what might be called an iterative continuum, in that with each new advance in velocity, range, generation of vehicle, etc., the sequence is to some extent repeated in smaller cycles while the overall program maintains its advance.

In the initial stages, however, in which the duration of use of the system is normally very short, little consideration is commonly given to the needs of man, and reliance is placed on his capacity to withstand the stress of a new environment at least for a short time. In phase two, with increase in reliability of the system and development of a capacity for use for extended durations, or in still more hazardous environments, it becomes increasingly more necessary to consider the requirements of man as a part of the system. From this level it is a natural step to proceed to develop the levels of comfort and habitability akin to those found in a normal, non-motile, terrestrial environment. The automobile and the aircraft are currently in phase three of this development. The spacecraft, however, is still in phase two, while the feasibility of the lunar or planetary shelter, although demonstrable on paper, has not yet been validated in practice. It might be noted, however, as Hartman points out (personal communcation), that phase 3 rarely exercised to any extensive amount except where there is a commercial market. As a consequence, much of the literature tends to come from the domain of marketing, and/or marketing psychology, with the object more of promoting a point of view than of objective analysis.

At the same time, with continued increase in the reliability and safety of spacecraft, along with the realization that long duration missions are well into the planning stage, it should become obvious that spacecraft design considerations should no longer be predicated on exploiting the maximum tolerances of which man is capable, which to some extent has been true in the past, but should attempt to offer him the internal environment most suitable for his needs - not, of course, comfort for the sake of luxury, but an optimum environment for optimum habitability. Comfort per se is not a critical attribute of habitability, nor is it likely to influence crew effectiveness to any significant extent. Consequently it is not the object of this study to discuss the requirements of comfort in space vehicles. It is, however, the intention to examine some of the less tangible factors in the space vehicle environment, which, if optimum, would allow the other stresses of a mission to be more favorably met. The Space Science Board of the National Academy of Sciences, National Research Council, has recently stated: "As flights become longer and astronauts are required to play a more active role, the living and working space in the capsule, now very cramped, must be expanded and improved. Attention must be given to human engineering and its application to the design of equipment and utilization of space. Particularly important are consideration of..... 4) convenience and attractiveness of the living space [45]." The characteristics of such an optimum environment are defined in terms of its habitability.

The Significance of Habitability

Habitability, then, describes the qualities of an environment as related to the acceptability of that environment for man. In fact, in one sense it is a measure, although all too frequently a qualitative one, of the suitability of an environment for occupancy by man. Habitability, however, is not an absolute term. There is no ultimate standard of habitability. It must be considered relative to the duration of occupancy and the purpose of occupancy; and furthermore, the standards demanded will vary markedly according to the previously established customs, practices, and habitat of the occupants. This point is clearly established in the definition of the term "habitable" provided by Webster's Third New International Dictionary (unabridged), namely: "capable of being inhabitated; that may be inhabited or dwelt in: reasonably fit for occupation by a tenant of the class for which it was let or of the class ordinarily occupying such a dwelling." The dictionary also defines the term "inhabit" as: "to occupy as a place of settled residence or habitat." Thus the igloo, considered habitable by the Eskimo, would not be expected to be considered so by the penthouse dweller.

The dictionary definition, however, does not make reference to the two other points of relativity mentioned above, namely, the duration of occupancy, and the purpose of occupancy. It is apparent, however, that what is habitable for a short duration is not necessarily so for a prolonged duration, that habitability which is adequate for one purpose may be inadequate for another, and that even the most comfortable confinement would become intolerable after a time, if sufficiently restrictive.

Man, of course, is not a passive component of an environmental system, and while he can maintain adequate levels of performance, acceptable social relationships, and physiological homeostasis within a broad range of environmental variables, any adverse interaction with his environment may be reflected by changes in these parameters. These changes can provide a measure of the extent of reduced habitability. Although the foregoing is not intended to imply, for example, that disturbed social relationships need result in impaired performance. It is far from easy, however, if not impossible, to obtain a measure of enhanced habitability, or to determine, within the range of acceptable habitability, if in fact change in some environmental parameter improves well being, performance capacity, and social relations. Intuitively one realizes that ideal surroundings are conducive to best performance, but it is not always possible to demonstrate the fact. Christensen [8] remarks with wry fervor: "I hope that it doesn't require a series of experiments to convince us that the crew should be provided with a clean, well-lighted vehicle with comfortable and attractive work stations and rest areas, good food, and palatable liquids." While most of us would agree with him, it is still necessary to define as closely as possible the nature and extent of those optimum conditions in order to make the most of the limited volume, weight, and power of even the most advanced space vehicle.

While much work has been done to determine man's response to adverse environments, very little has been done to define habitability as a whole, in relation to the requirements of space missions. Noteworthy attempts have been made by Celentano and his colleagues [5, 6], and by Kubis [27], while White and Reed [56] have also looked at the overall problem.

In considering habitability, Celentano and his colleagues [5, 6] employ what Kubis [27] refers to as an "additive" approach and point out, as noted above, that habitability depends on the presence of desirable qualities to which the tenant is accustomed, and that in ensuring habitability the object should be to provide an environment as close to the natural terrestrial environment as engineering resources permit. Using the additive model they outline various requirements of a suitable environment, as discussed later, and devise a method of combining these separate factors into an overall index of habitability. Thus, by defining the acceptable limits of its components, and their relative weightings, Celentano attempts to provide an estimate of the acceptable lower bounds of habitability. These, in fact, are already defined by the critical physiological and environmental variables to which much attention has already been given.

While Celentano et al look at habitability operationally, Kubis [27] examines it deductively, and points out that it is a "global concept", involving physical, physiological, psychological, and social components. Its structure consists of several layers: "a bedrock of sheet survivability, a segment of tolerable discomfort with a possible but tolerable reduction in efficiency, and a relatively comfortable condition characterized by effective performance." The physical component describes the structure and form of the supporting environment; the physiological component relates to the homeostatic response of the individual within the environment; while the psychological and sociological components reflect his behavior, performance capacities, and social interactions. Thus, in effect, Kubis utilizes the characteristics of a man-environment interaction to define the habitability of that environment. He goes on to outline some of the characteristics of each subcomponent.

Perhaps the most comprehensive concept of habitability, however, comes out of a brief comment by White and Reed [56], who, having made the comment, did not for some unexplained reason care to pursue its potential. They examine the concept of habitability from the inductive point of view and consider it to exist as "the resultant of the interplay of all the factors relating to the man, his machine, his environment, and the mission to be accomplished." In other words, a given man-machine-environment system defines its own habitability in the light of the desired mission. Such a concept is no doubt valid, and points up the fact that habitability is determined by other factors besides the acceptability of an environment, and that it can be manipulated by altering any of the components of the total system - man, machine, environment, and mission.

Man has a dual role within such a system. He is an interactive component of the system, contributing to the habitability, and at the same time he provides the criteria by which the habitability is judged. Thus, although Webster defines habitability in terms of the class of tenant, the interactive concept above indicates that by modification of the habits, requirements, and tolerances of the tenant the needs of habitability will be changed. This type of modification, of course, is the process of selection, training, or conditioning. Man's capacity for modification, however, is limited, but by selection of those whose potential limits are beyond the normal, and training them to maintain high levels of performance while approaching their tolerance thresholds, as has been done with the astronauts, the resulting habitability may be maintained at a low but acceptable level, at least for limited duration.

The question of duration introduces the requirements of the mission. Like man, the mission also presents a dual role in the system, in that it is a component of the system, while at the same time completion of the mission is the purpose of the system. Once the mission has been defined, that component is fixed, and habitability of the system must thereafter be achieved, if feasible, by modification of the other components. Thus, the mission and its objectives have to be defined with only speculative knowledge of the resulting interactions with the remainder of the system. Since the nature of the mission is then the prime determinant of the resulting system, it is necessary to select, on the basis of informed opinion, mission objectives which will permit a resultant habitability, within the expected state of the engineering arts, that will be within the capabilities of the men involved.

Since man's adaptive capacities are limited, and are already exploited to near their maximum in handling the requirements and procedures of current manned space systems, and since the mission once defined is fixed, the major contribution towards optimum habitability in advanced space missions must come by modification of the machine component, or of the environment itself. In space systems the external environment is immutable, and the internal environment is controlled by vehicle subsystems. Consequently, unless one wishes to extend man's capacities still further if possible, habitability becomes very largely a function of vehicle design, which in turn is dependent on engineering talent and knowledge, along with the will and economic resources to implement the need.

It is axiomatic that if a manned space system is reliable, and also habitable, then the mission objectives for which it was designed can be accomplished. Reliability and design lie in the purview of the engineer. Definition of habitability, however, is a requirement for the life scientist.

In the light of the foregoing, then, how best can one define habitable? For the purposes of definition it is considered that the term habitable refers to that equilibrium state resulting from the interactions among the components of a man-machine-environment-mission complex which permit man to maintain physiological homeostasis, adequate performance, and acceptable social relationships.

On the basis of the interactive model defined above, the attributes of habitability, then, are those attributes of man, and his interactions with the other components of the system, which influence the resulting equilibrium state in a manner that renders it more, or less, acceptable to man. Thus, since man provides the reference criteria for human habitability as well as being a component of the system, only those interactions which directly involve man are significant in the creation of habitability. The attributes then can be considered in terms of factors involving man alone, factors determined by man's response to his environment, factors arising from man's interaction with the machine, vehicle, or dwelling, and those developing in relation to the requirements of the mission. Many of these factors, including most if not all of those considered critical, have already been very thoroughly examined with the object of determining acceptable standards for manned space flight. Those factors that lend themselves to quantification, and in particular the requirements for environmental control systems, have been investigated under many different circumstances, and numerous standards have been recommended to meet various levels of habitability [35, 41], although, in fact, the purpose of many of these analyses has been to define the minimum acceptable level rather than the optimum.

Few serious attempts have been made, however, to develop a system for the evaluation of habitability as a whole. One of these was reported by Celentano and his colleagues [6] who describe what they call a Habitability Index. In their additive model of habitability they propose that habitability exists when the variables within each of several factors, namely, environmental control, nutrition and personal hygiene, gravitation, living space, crew fitness and work-rest cycles, are maintained within acceptable and quantifiable limits. To establish their Habitability Index they calculate an index number by a variation of the method of "weighted average of values." For each item of the systems under consideration, a "relative value" (RV) is determined which represents the percentage of the optimum value of that item existing within that particular system. To derive the relative value, the minimum (or maximum) tolerance is considered as zero and the optimal level as 100. The value for any particular system is some percentage between zero and 100. Thus, in the evaluation of the significance of CO_2 in the factor relating to environmental control systems, the maximum tolerance level of pCO_2 for a long duration mission is given as 20 mm Hg, and the optimal level less than 5. In a system allowing a level of 8 mm, the RV is the difference between 8 and 20, divided by the difference between 5 and 20, i. e., 12/15 x 100 = 80%. In general terms,

where P_a = actual measure

P_o = optimal level

P_t = tolerance level (minimum limit),

then

$$RV = \frac{(P_a - P_t) \times 100}{P_o - P_t} \qquad (1)$$

where P_t = tolerance level (maximum limit),

then

$$RV = \frac{(P_a - P_t) \times 100}{P_t - P_o} \qquad (2)$$

When individual relative values have been established, on the basis of recommended standards and actual measures, they are averaged by major groups, namely, environmental control, nutrition and personal hygiene, gravitation, living space, crew work-rest cycles and fitness. Each major group is then multiplied by a weighting factor, the derivation of which is not stated, namely, environmental control x 4, nutrition and personal hygiene by 2, gravitation x 1, living space x 2, work-rest cycles and fitness x 1. The sum of the weighted averages is then divided by 10 (weight total) to determine the Habitability Index, which in the ideal situation is 100.

Thus:

$$HI = \frac{\Sigma(R\overline{V} \times q)}{\Sigma q} \qquad (3)$$

where q = weighting factor

$\overline{V}$ = average RV by major group

This approach is good, simple, and effective, so far as it goes. Unfortunately its application is limited to a simple additive model in which the range of all the parameters is known and quantifiable, and for which exist recommendations or specifications relating to optimal levels and permissible maxima or minima.

It is very doubtful if much is to be gained by developing indices of habitability in the current state of the art. Many of the factors involved are not quantifiable, and many of those that are quantifiable cannot be expressed with the precision and accuracy necessary for the purpose. Unless a given factor can be predictably quantified with accuracy, and unless an index of habitability can take into account the influence of complex phenomena such as biological variability, along with unpredictable changes in tolerance with time, non-linear responses of man to environmental and other variables, and the effects of unpredicted catastrophic change in a given factor, the index so obtained is of very limited value, and can essentially be used only for comparing different systems viewed under the same circumstances.

In the long run, any index of habitability probably give a false sense of precision and validity, in that after various arithmetical manipulations, a single hard number is applied to what are frequently only opinions. It is probable that a more meaningful appraisal of habitability would be obtained by a skilled subjective and objective assessment of all the factors involved, followed by exercise of the best informed human judgment.

THE EFFECTS OF IMPAIRED HABITABILITY

To discuss all the effects of imapired habitability is to discuss the effects of all the interactions of the man-machine-environment-mission complex. Such a procedure would be neither feasible nor instructive in this context. Most of the knowledge that has been gained about man's physiological and psychological responses has been obtained through examination of various specific aspects of these interactions. But while much knowledge has been gained on man's reaction in the presence of various readily quantifiable phenomena, such as sustained acceleration, thermal extremes, toxic contamination, etc., there is very much more to be learned about his response to the less tangible aspects of habitability.

Since there is, as yet, little store of experience of space flight, and none of prolonged space flight, one of the problems lies in identifying habitable situations which are comparable to long duration space flight. As part of a research program concerning the social system of long-duration manned space missions, Sells (42) has compared the characteristics of an extended duration spacecraft with those of eleven other reference systems, each of which involves isolation, confinement, and stress to a high degree. Utilizing fifty-six characteristics in his comparison, he found that the submarine system had by far the closest resemblance to the extended space mission, particularly with respect to goals, values, and organization. Others, in descending order of similarity, were exploration parties, naval ships (particularly old sailing ships), bomber crews, and remote duty stations. POW situations, mental hospital wards, and prison groups were low in respect to goals, personnel factors and technology, but high in terms of physical environment and temporal characteristics.

Consequently, much of the information to provide guidelines for the requirements of habitability, and the effect of its impairment, must be derived from submarine studies, and to some extent from studies of isolated snowbound communities, neither of which is entirely comparable to the space mission situation. Submarine conditions, however, bear close analogies to spacecraft conditions, while Arctic and Antarctic settlements have a resemblance to lunar settlements. In neither the submarine nor the Arctic community, however, is the external environment quite so hostile nor the separation quite so complete as in space. The selection procedures and training standards for astronauts, however, are certainly more demanding than for inhabitants of Arctic communities.

The general reaction to the impairment of habitability under these conditions would appear to be manifested by two inter-related states, namely, reduced morale and increased fatigue, which in turn tend to lead to decrement in performance. The danger of direct application of these findings to space conditions must be emphasized. In some of the studies, at least, reduction in morale was related primarily to the fact that the persons involved considered themselves inconveniently out of reach of some recreation center, while in others actual fatigue was not specifically demonstrated but its existence was considered implicit in the complaints of the subjects. In addition, actual decrement in performance, while occurring under some conditions, was not shown to be critical.

The anonymous authors of the Navy manual on Submarine Medicine Practice [51] state in this regard, although the opinion is not entirely supported by submarine experience, "..... a considerable degree of inconvenience and discomfort can be endured by strongly motivated submariners who possess a stamina required to do reliable work under adversity. But infringement upon the fundamental organic and psychic personal needs of man cannot increase indefinitely without encountering a point of diminishing return in human performance. The relentless influx of space occupying, heat generating, and noise making equipment aboard ship can invade and usurp habitable room between unyielding bulkheads until the critical level is reached beyond which the ship's operational efficiency is jeopardized." Although written about submarines it is apparent that the comment might apply to spacecraft and space dwellings.

Morale and fatigue, of course, are two somewhat nebulous concepts, difficult to analyze and even more difficult to quantify. Webster gives one definition of morale as: "a state of individual psychological well-being based on such factors as a sense of purpose and confidence in the future."

This definition well illustrates two of the significant factors that influence morale, namely, the importance of motivation and the requirement to provide the ambiance conducive to belief in survival. The significance of leadership, identification within a group, pride in skill, and other factors have all been discussed in other contexts. Thus, although impaired habitability may give rise to reduced morale, the threshold at which impairment becomes manifest may be greatly influenced by other even less tangible phenomena. This process is of course evident in the behavior of the Gemini VII astronauts, in particular, who maintained a very high morale during their 14-day mission despite minimal habitability of their vehicle [36], and is echoed by Ebersole [13] and by Miles [34] with reference to morale in long duration submarine missions, in which many of the habitability factors are of similar type of those of spacecraft. In fact Miles states [34]: "In the earlier cruises of the American nuclear submarines there was always for the crew the strong motivation of adventure and novelty and the element of challenge. Few men would not gladly accept even months of confinement to be members of a group which made history in record dives and sub-polar voyages. What is more important is to ensure that when underwater voyages of weeks or months become routine affairs, the men are conditioned to accept it without distress."

It is difficult, if not impossible, to separate the effect of reduced morale and chronic fatigue. They no doubt have a direct interaction with each other. McFarland [31] lists the manifestations of chronic fatigue as shown in Table 1.

These manifestations are very similar to those described by Weybrew [52] in his measurements of morale, self-perceived efficiency, interpersonal attitudes, etc., during the submerged world circumnavigation of the submarine Triton. McFarland [31], in fact defines chronic fatigue as "largely a psychological and psychiatric problem characterized by boredom, loss of incentive, and progressive anxiety ", a definition which in many circumstances would apply equally to reduced morale. In either case there is a loss of will, diminished drive, loss of attention to detail, and willingness to accept less than optimum performance.

TABLE 1. CLINICAL SYMPTOMS OF FATIGUE IN AIRMEN

Early Tendency (increased vasomotor tension)	Late Tendency (withdrawal symptoms)
Subjective Symptoms	
1. Vague headaches	1. Vague disturbances of vision or hearing
2. Loss of appetite	2. Vague chest disturbances: left-sided chest pain, palpitation, difficulty in breathing
3. Diarrhea	3. Burning urination (high concentration and acidity)
4. Increased urinary output	4. Constipation and distension
5. Physical exhaustion a. Relieved by night's rest (acute) b. Not relieved even by good rest on successive nights (chronic)	5. Vague extremity aches or sensations
	6. Insomnia and restlessness
	7. Lack of ability for lengthy concentration
	8. Reduced interest in the opposite sex
	9. Immediate fainting history
Objective Symptoms	
1. Tenseness, tremor	1. Decreased startle response
2. Increased startle response	2. Confusion, depression, fearfulness
3. Increased use of alcohol and tobacco	3. Resentfulness against others
4. Increased interest in opposite sex	4. Lack of interest, drive, attention, and memory
5. Irritability, faultfinding, overcriticalness	5. Decreased personal cleanliness
6. Worried and anxious (verbally and in appearance)	6. Social withdrawal, butt for jokes of other pilots, or considered "nuts"
7. Recent preoccupation and absent-mindedness	7. Recent facial or lid spasms
8. Noncomformity as evidenced by absenteeism without cause, failure to associate with fellows at meals, taking unnecessary risks in flight, etc.	8. Recent stuttering
	9. Extrasystole

Source: McFarland (31)

Because of the difficulty in developing experimental methodologies and the limited experience of prolonged exposure in controlled or experimental fashion to conditions of impaired habitability, evidence indicating actual reduction in morale or increase in fatigue is scanty, and, as previously noted, comes largely from submarine experience.

The U. S. Navy conducted a series of studies to determine the habitability of submarines and investigate the occurrence of "operational fatigue". The first study was conducted in a snorkel-type submarine during a 14-day submerged cruise [39]. Habitability was considered to be of low quality. Quarters were extremely confined, the appearance was drab, "hot-bunking", or sequential use of bunks, was routine, and unpleasant pressure variations occurred during snorkel cruising. Increased apathy, boredom, and complaints of discomfort were very evident, although the mission was successfully completed. A second study, also aboard a snorkel submarine, but for a 30-day cruise, showed similar results, with reduced morale and manifestations suggestive of chronic fatigue [55]. The third study, conducted by Faucett and Newman [17] of Schaefer's group was labelled Operation Hideout, and was a controlled experiment involving 23 men sealed within an anchored submarine for 42 days while breathing an artificial atmosphere. The data were somewhat sketchy but no debilitating physiological effects were demonstrated, although self-rating questionnaires of the men indicated a decline in motivation, increase in tension and anxiety, disturbance of sleep patterns and reduction in overall alertness.

Development of the nuclear submarines improved the habitability over that of the snorkel submarines. Utilizing a comprehensive test and questionnaire procedure, Weybrew [54] investigated the physiological status and attitudes of the crew during a 12-day submerged mission on the USS Nautilus and found that while overt habitability had improved in comparison with the previous findings, signs of reduced morale and increased fatigue could still be observed, tending to develop after an adaptive period of 5 or 6 days.

A somewhat different test was conducted on the submarine Triton during its submerged circumnavigation of the world over a period of approximately three months [52]. A complex multivariate statistical analysis was undertaken of a daily 51 item check list questionnaire given to the crew, which investigated moods, tensions, anorexia, insomnia, irritability, motivation, etc. Preliminary analysis indicated that personal motivation and group morale in general showed a slight declining trend after 10 days of confinement. The level of morale appeared to be an inverse function of the degree of regimentation imposed, being highest on Sundays when more freedom was permitted. Tensions, interpersonal irritations, and difficulty increased to some extent, but for most of the crew not to a serious degree, and in no way to the extent of disturbing proficiency. Acute anxiety reactions developed in two or three persons.

From the above studies certain tentative generalizations can be stated. Where the quality of the habitability is known to be low, as in the conventional small submarine, symptoms and signs suggestive of reduced morale and progressive fatigue develop fairly rapidly among the confined crew, although, within the durations examined, not to the extent of interference with accomplishment of the mission objectives. When the quality of the habitability is improved, however, as in the nuclear submarines, any deterioration that occurs is less pronounced. Thus, while the interest and motivation of the crew, the demands of regimentation and duty, and the potential disruptions of strained interpersonal relations are presumably much the same in each case, the improved physical attributes of the nuclear vehicles have an ameliorating influence on morale and development of fatigue that more than offsets the increased duration of the missions, the more prolonged exposure to potentially hazardous conditions, and the unwarranted fears of radiation exposure.

In the snowbound communities, where confinement is cultural and social rather than restrictive, but where habitability overall is commonly of low quality, the same effects on morale and fatigue can be observed. From his observations of totally isolated groups in Polar communities under conditions where habitability is subjectively of low order, Rohrer has noted that a cyclic pattern can be demonstrated [40] as described below. He states that initially the period of exposure is marked by heightened anxiety, the extent of which is determined by the degree of danger or threat that the individual feels or perceives. An attempt is made to reduce this feeling by frantic and, in some circumstances, unnecessary work and bodily activity. The second phase occurs within a few days; anxiety lessens and is replaced by depression which may increase periodically and may be further supplemented with periods of anxiety. The third phase develops before the end of exposure, and is characterized by increased outward expression of feelings, and behavior in anticipation of return, to the extent that working habits are not so precise as before. A greater amount of error is evidenced, for example, in making scientific observations; housekeeping and other daily routine chores tend to be neglected, and anxieties tend to rise. It should be noted that these changes, which might be considered marginal, were not fully validated statistically.

It might be argued that the response described above is not so much a response to poor habitability as to the fears and frustrations of isolated Polar living. To some extent this is true, although these same fears and frustrations are part of the composite of habitability. However, Pinks [37] observed in his study of Arctic Air Force Loran stations that, in general, morale and efficiency were maintained at a higher level in those situations where living conditions and habitability were better, although he also noted that morale and efficiency were higher with poor conditions and good leadership, than with good conditions and poor leadership.

The above discussion is not intended to imply that the conditions of habitability in submarines and in Polar communities are the same as those in space vehicles or space shelters. It is indeed obvious that they are not; but they are analogous, just as are to a much lesser extent the habitability problems of fallout shelters [21, 46, 47] in which the occurrence of the same listlessness and fatigue has been demonstrated in subjects after a few days of incarceration. The comparison serves to demonstrate that, even under totally different conditions of operation, if habitability is inadequate a pattern of deterioration, reduced morale, and lowered efficiency will be manifest. Furthermore, it shows that even if all the factors contributing to habitability cannot be optimized, improvement in physical living conditions alone, particularly when combined with high motivation and good leadership, will maintain morale and efficiency with minimal reduction.

SPECIFIC FACTORS RELEVANT TO HABITABILITY

While it is revealing to re-examine the concept of habitability in its entirety, as has been attempted in the foregoing, and to present an integrated picture of the scope of the overall requirements, it is not the purpose of this paper to rehash those standards that are already well established, even if they are largely oriented towards definition of acceptable minima. The intention is, rather, to examine, on a selective basis, some of those factors that do not readily lend themselves to quantification - what might be called the intangibles of habitability - but which, nevertheless, may be highly significant in determining the level of acceptability of a habitable environment, particularly for long-duration missions.

Thus, while it is probable that promotion of design strategies which utilize habitability as a unifying concept will not only maintain morale but will also assist in ensuring performance, there is little to be gained at this time in discussing the requirements of environmental control systems, as exemplified by the need for suitable atmospheric pressure and composition, thermal control, waste management, etc., or the requirements for protection against radiation and excessive force and motion. Emphasis instead will be directed on matters that have been less thoroughly investigated, are difficult of quantification, or even tend to be taken for granted or overlooked in considerations of design and development. These include the requirements for available volume per man, the configuration of that volume and the human need for privacy; the relative necessities of personal hygiene; the significance, use, and requirements for recreation and leisure; the importance of lighting, color, furnishings and decor, and the like.

Volume, Configuration and Privacy

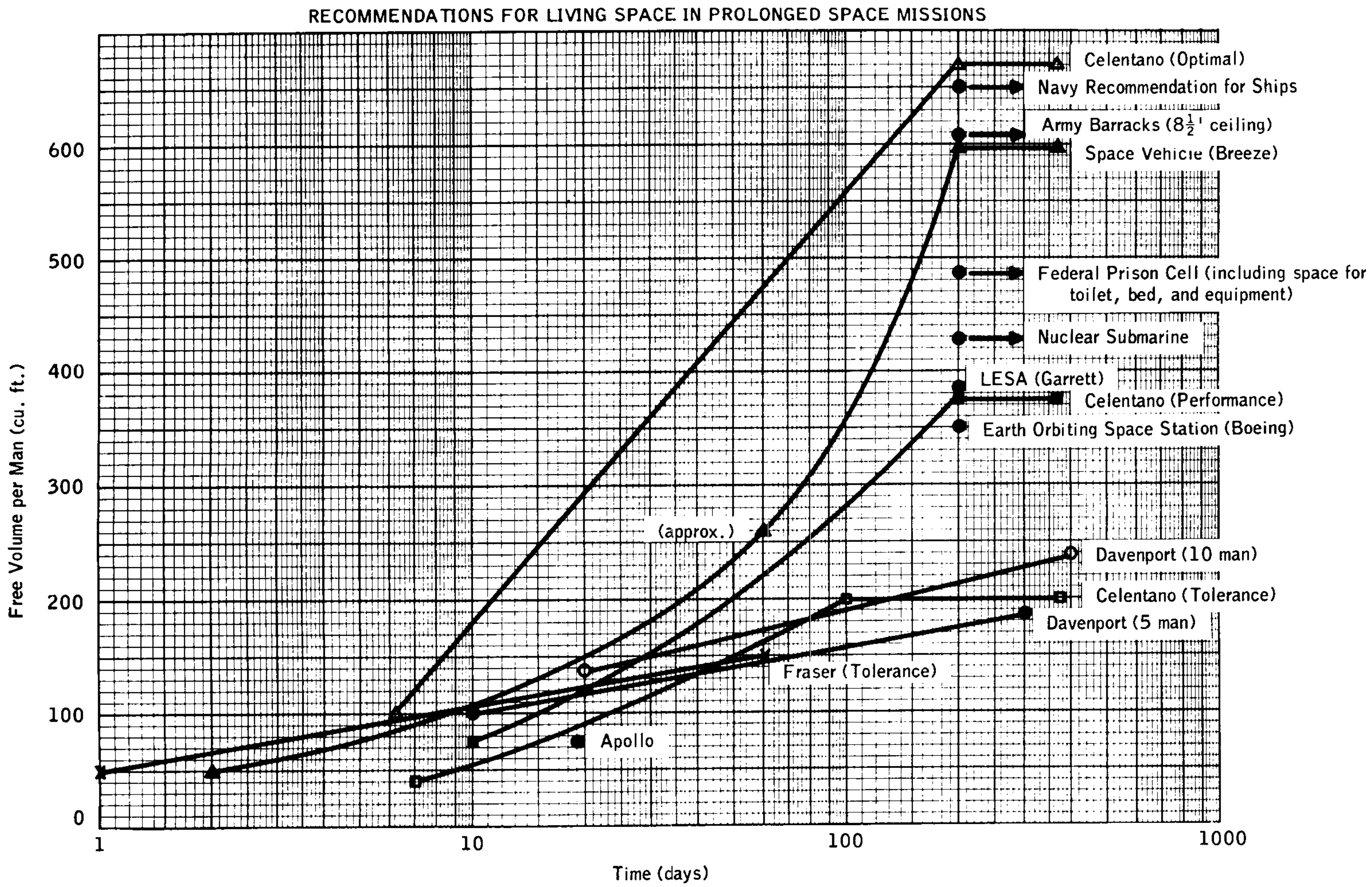
It is not yet within the state of the art to define the optimum free volume per man required for long-duration space missions, even if there were no other constraints. It can be stated, however, that if the available volume is inadequate, problems, largely physiological in nature, are likely to arise if the confinement is maintained for a long enough period [18]. Space, of course, is at a premium in any operational vehicle. The manual of Submarine Medicine [51] notes that overcrowding leads to decreased freedom of movement, absence of privacy, limited hygienic and personal facilities, and points out that deprivation of these factors gives a man a sense of frustration in commonplace activities. Paucity of space accentuates the friction that arises; he becomes overly aware of the mannerisms of others, and becomes irritated at the compulsive habits of himself and his colleagues [51]. On the other hand, as Kubis points out [27], a vehicle of adequate size makes it possible to solve or minimize many of the other problems of habitability. A suitably large vehicle provides adequate room for essential equipment, for protective and shielding materials, for supplies of food, fuel and atmospheric components, for comfortable atmospheric and thermal control, for the necessary display, communication and control systems, for the requirements of scientific or other missions, and for an enlarged living space capable of supporting the needs of eating, sleeping, social intercourse, recreation and privacy. In other words, the larger the vehicle the easier it becomes to provide the level of habitability and working conditions conducive to best performance. However, the larger the vehicle and the greater the provisions made for increased habitability, the greater are the penalties of weight, cost, and complexity.

The almost unanswerable question arises as to what then is adequate or optimal. Few attempts have been made to answer this question in quantifiable terms for long-duration missions, and indeed it is difficult if not impossible to separate the requirement of volume from the other factors contributing to habitability. Data from work that has been done in this area are plotted in figure 1 which shows elapsed time in days on the abscissa, and the suggested or actual free volume per man in cubic feet on the ordinate. A log scale on the abscissa is used for convenience. Four different approaches to the problem are illustrated. To outline the minimal requirements for free volume in relatively short-duration missions, Fraser (18) examined more than 60 studies of operational and experimentally induced restrictive confinement in which the effects of perceptual deprivation were negligible or non-existent. He graded the acceptability of the confinement in terms of the extent of resulting psychological and physiological impairment, and showed that the minimum acceptable free volume per man varied from about 50 cubic feet for one day's duration to about 150 cubic feet for at least 60 day's duration. He did not, however, define the optimal state, nor attempt to extrapolate beyond 60 days, although he discussed other factors that might influence the desired free volume.

Breeze (3) made a different approach. He used an additive model to determine volume requirements, as follows:

Volume = (Seated volume per man + work volume per man + ingress volume per man) x (Number of men)
+ Transfer volume per station
+ Intercompartmental transfer volume
+ Off-duty rest volume per crew
+ Sustenance volume per crew
+ Logistics work space per equipment station
+ Equipment volume for sustenance
+ Equal volume for waste

With anthropometric and other data he suggested a minimum volume of 50 cubic feet per man (multiman) for 2 days, 260 cubic feet per man for one



RECOMMENDATIONS FOR LIVING SPACE IN PROLONGED SPACE MISSIONS
Free Volume per Man (cu. ft.)
Time (days)
0
100
200
300
400
500
600
1
10
100
1000
Celentano (Optimal)
Navy Recommendation for Ships
Army Barracks (8½' ceiling)
Space Vehicle (Breeze)
Federal Prison Cell (including space for toilet, bed, and equipment)
Nuclear Submarine
LESA (Garrett)
Celentano (Performance)
Earth Orbiting Space Station (Boeing)
(approx.)
Davenport (10 man)
Celentano (Tolerance)
Davenport (5 man)
Fraser (Tolerance)
Apollo

Figure 1

or two months and 600 cubic feet per man for many months. His recommendations are incorporated in figure 1.

Davenport and his colleagues [11] used an adaptation of this additive approach on the basis of the hypothesis that crew volume requirements stem from the needs of crew functions and activities. They defined the individual crew activities in the light of the expected mission duration, bearing in mind that the volume required for some activities would vary little with duration while other activities would likely be volume sensitive to duration. Volumes necessary for each activity were thereafter calculated and summed, suitably adjusted for crew size, mission duration, and time sharing. In addition, a further adjustment was made on the assumption (of debatable justification) that an increased volume per man becomes necessary with increase in the number of crew. The resulting data were plotted to show minimum volume requirements per man for crew sizes of one, three, five, and ten men, and missions of one day to 400 days. Plots for the five and 10 man longer duration missions are extracted on to figure 1. It will be noted that although Davenport and his colleagues tended to regard the response of man as being mechanistic, rather than biological, the resulting curves on the figure parallel, and closely approximate, an extrapolation of Fraser's curve of operational data for minimum acceptability, suggesting that Davenport's curves might well represent the absolute minimum acceptable volume for missions up to 400 days, provided the other attributes of habitability are optimum.

Celentano and his colleagues [6] defined three curves, which are extracted on to figure 1, on the basis of work with simulators and examination of other living conditions. The hypothesis on which their work was based has a somewhat doubtful relation to the requirements of space vehicles, and, in particular, fails to take into account any deconditioning that might occur in weightlessness, but certainly does relate to some aspects of habitability. They argue that the occupants of a cabin allowing a large area, and other habitable features, would show little if any physiological differences from those in a normal life situation with a relatively sedentary occupation, such as that of an office worker. On the other hand, life in small cabins would reflect drastically reduced levels of metabolism and cardiovascular response, almost commensurate with bed rest situations. Accordingly, three cabin mock-ups were built with widely differing internal living volumes, from very small to large, (67 cubic feet, 375 cubic feet, and 800 cubic feet per man, respectively). Measures were obtained of the energy requirements per man of crews occupying these cabins for periods up to a week. Although the cabin interiors were different in available facilities, volume, and shape, and although the crews were different in number in each cabin, and occupied the cabins for different lengths of time, the investigators argue that the variations were immaterial since only energy levels were being measured. The hypothesis was validated, in that the crew of the small cabin showed energy levels commensurate with those of bed rest, while the intermediate cabin and the large cabin permitted proportionate increases equivalent to those of sedentary work and routine office work respectively. Celentano designated the resulting curves so derived as the curve of tolerability, the curve of acceptable performance, and the curve of optimal habitability, respectively. While the lowest curve falls in line with Davenport's curves and the extrapolation of Fraser's curve, and may well represent minimal acceptability, there is some doubt as to whether the other two curves actually demarcate volumes for adequate and optimal habitability with the degree of accuracy implied. At the same time, the fact that free volumes found in certain operational situations, such as Army barrack allowances, Federal Prison allowances, and nuclear submarine allotments lie within that range, (figure 1), suggests that Celentano's curves are reasonable approximations. The data for Army barracks, prison, and nuclear submarines are shown at the 200 day level for convenience. The arrows alongside indicate that the volumes designated may be occupied for longer periods. Some other recommended volumes are also found to lie in that general area, namely, the Lunar Exploration System dwelling (LESA) proposed by Garrett [19], and the Earth Orbiting Space Station proposed by Boeing [2].

Chamberlin (7), on the other hand, is perhaps pushing the extremes of luxury when he suggests, on the basis of requirements for Arctic expeditions, a free volume of as much as 2000 cubic feet per man for multiman operations. A volume of this size appears unnecessarily large for space vehicle conditinns.

Thus, although the volume requirements per man cannot be specified with any degree of authority, it would seem that for durations of 300-400 days, or perhaps beyond, the absolute minimal acceptable volume for multiman operations would be in the region of 200-250 cubic feet per man; the acceptable would be about 350-400 cubic feet; and the optimal about 600-700 cubic feet, utilizing the volume for all purposes related to living conditions. If optimum habitability is condered the goal, design requirements for long duration missions should be based on the optimal level of 600-700 cubic feet per man.

Provision of adequate free volume does not, however, automatically guarantee habitability. Appropriate configuration of the available volume can contribute much to the overall habitability. The mode of utilization and configuration of available space can be examined from different points of view, but several ground rules can be assumed. Thus, space must be provided for conduct of tasks relating to the mission, to vehicle management, and biomedical support. Space is also required for rest and off-duty time, for dining and food management, and for hygienic provisions. Therefore it is convenient to think of configuration in terms of functional units relating to these activities, although it should be realized that functional units are not necessarily topographical units. In other words, the volume allocated to one unit need not necessarily be located in one region of a vehicle.

Except for invoking tradition, custom, and usage, it is difficult to justify logically the need for separating available volume into distinct regions, nor is it easy to determine how many such regions there should be. It is probable, however, that division of the free space of a vehicle into functional regions not only improves efficiency but contributes to overall habitability by separating work areas from rest and recreation areas, etc. There is no doubt that highly motivated individuals, such as Gemini astronauts, can work, eat, rest, and sleep for days without leaving their seats, and still maintain acceptable performance. At the same time, various studies of habitable conditions [15, 21, 24, 37, 46, 47, 53, 54] have emphasized the need for variety, change, relief of monotony, and perhaps most of all, the desire to protect some modicum of voluntary privacy and storage of personal possessions. The term "privacy", although commonly used in this connection, is perhaps not the most appropriate term. No doubt there are times when an individual seeks actual privacy, that is, the quality of voluntarily being alone and secluded from his fellowmen, and certainly for optimum habitability some provision for privacy in sleeping quarters, toilet operations, and perhaps for command prestige, is desirable. A more fundamental need in man, however, would appear to be the provision for "territoriality", or in other words, furtherance of the concept of possession of property and rights of ownership. The sailor in his bunk and the soldier in his barrack room bed have very little privacy, but the bunk, the bed, the ditty bag and the foot locker are recognized by his peers as being his property, and are only invaded with his permission. It would seem reasonable that some similar provision be made in long-term spacecraft, although no studies would appear to have been performed to support the concept, nor is it clear how much "territory" an individual might need.

To meet these various requirements, four functional units might therefore be delineated, namely:

a) Work unit: for the conduct of operational tasks, vehicle management, and biomedical support.

b) Public unit: for use in dining, food management, communal recreation, leisure, and exercise.

c) Personal unit: for sleeping, personal privacy, and personal storage.

d) Service unit: for toilet purposes, laundry, and public storage.

The actual configuration, of course, must depend on the nature of the mission, its duration, the number of crew, the tasks to be accomplished, the available volume, the shape of the vehicle, etc., but regardless of the differences, the four functional units noted above will have to be provided in one way or another. Obviously there are certain volumetric minima within these configurations that must be met. When trying to establish optimum habitability, however, one is better concerned with optima rather than minima. Using anthropometric data, and analysing the functions to be performed, it is possible to estimate the various minima for each function. This will not be attempted here, since the data are affected by factors within each mission, such as the nature of the tasks, the number of crew, etc. It is possible, however, to make a general estimate of the relative proportion of the available volume that could reasonably be applied to each functional unit. The proportions may be derived in the following manner. Examination of the tables prepared by Davenport and his colleagues [11], which outline the volumes required by various functions in the conduct of space missions, particularly the 400-day mission, shows that the ratio of volume per man required for work-related functions to volumes for non-work-related functions is approximately two to three; in other words, two-fifths of the available volume is required for work-related activities. The remainder is available for public or private use. The Garrett Company [19], working with three dimensional models and full-scale mock-ups, showed that the most effective use of space not required for work activities was to allot approximately two-thirds of it to public use and one-third of it to private use, i. e., two-thirds of the remaining three-fifths, or a total of two-fifths is then available for public use. Some of this, however, must be assigned to the Public Unit and some to the Service Unit. One approach to determining the relative assignment is to estimate the requirements of the Service Unit. On the basis that a shower and toilet combination requires approximately 40 cubic feet per man for a 6-man crew, and allowing another 40 cubic feet per man for laundry provisions, and 20 cubic feet per man for public storage, then a total of approximately 100 cubic feet per man is necessary for the Service Unit. This figure is approximately three-eighths of the available public space (i. e., 3/8 of

260 cubic feet) in the situation where the optimal volume per man is 650 cubic feet, and consequently the remaining Public Unit, for dining, food preparation and leisure, will occupy five-eighths of the available public space.

Summarizing the above, and converting the fractional proportions to percentages, the suggested relative volumes of available space which might be occupied by each functional unit are as follows:

Work unit:	40%
Public unit:	25%
Personal unit:	20%
Service unit:	15%

It is emphasized that these suggested proportions are approximate and tentative and represent merely a relative breakdown of available volume under what might be considered optimal conditions. In each case the actual proportions would be influenced by the requirements of the mission and the capacities of the vehicle and dwelling, and would need to be determined empirically by analysis of the requirements and the use of models and mock-ups.

Consideration in design should be given to separating topographically each of the four units, namely, work, public, service, and personal, in such a manner as to allow identification of each with its function and to ensure for each individual some place essentially his own. The actual configuration of each unit must, like its volume, be influenced by the requirements of the mission and the capacities of the vehicle or dwelling; the internal layout within the specifications, however, is limited only by the ingenuity of the designer in making the best possible use of such space as is available, i. e., by optimizing "furniture" design, contriving "roominess", maintaining traffic flow, and reducing clutter.

Personal Hygiene

In our contemporary culture, where success in interpersonal relationships is attributed to the use of the proper soap, cosmetic, deodorant, and dentifrice, it is not surprising that maintenance of personal cleanliness has become an almost compulsive pattern in a large proportion of the public - perhaps more so than in other western countries, as indicated by the fact that the water supply per man for U. S. military advanced bases in World War II was 25 gallons per day, whereas for other Allied forces it averaged 10 gallons [3].

Personal hygiene is distinguished in this context from sanitation. Sanitation is considered to refer to those measures designed to maintain an uncontaminated environment, while personal hygiene is concerned with the maintenance of cleanliness of the body itself and its adjacent clothing. The body and its clothing may be contaminated by the external environment, but most of the requirements of personal hygiene are directed at management of emanations and unwanted materials from the body itself.

Mattoni [32], and Mattoni and Sullivan [33], while observing that the largest consistently generated classes of human wastes are those resulting from metabolic function and eliminated as urine and feces, have noted that the remainder, of immediate concern in the management of personal hygiene, are largely of epithelial origin, with the exception of body microflora and flatus, and may be tabulated thus:

1. Skin and appendages
    a) Desquamated epithelium
    b) Hair
    c) Nails
2. Glandular secretions
    a) Sweat
    b) Sebaceous excretion (sebum)
    c) Saliva
    d) Mucus
    e) Seminal fluid

3. Microflora and microbial products
   a) Flatus
   b) Microflora
   c) Microbial products

To these might be added the possibilities of contamination with blood, pus, and vomitus.

In a comprehensive study of these considerations, Mattoni and Sullivan (33) have defined the distribution, nature, and generation rates of these components under normal conditions, and estimated the extent of contamination of the body and its immediate environment. Table 2 shows the estimated generation rate of these materials.

From the above Table it is apparent that an appreciable amount of material is consistently generated by man where it can remain in contact with his body, and in body niches, or be absorbed by his clothing. The question arises as to how desirable it is to remove this material forcibly in the process of maintaining personal cleanliness, rather than allowing it to dissipate spontaneously for elimination by a vehicular environmental control system.

The question of personal cleanliness has both social and physiological connotations. As noted earlier, our culture is cleanliness oriented, with the criteria of cleanliness being largely social in nature, namely, odor and appearance. Thus, there are strong social demands made on the individual to give, at least, the impression of cleanliness. Merely because the demands are social does not mean, however, that they can be ignored. It may be possible to train people, in concert, so that the normal social demands assume minimal significance, but the underlying social pressures might still break through to exert an unwanted influence at a time when morale is already low from the summation of other stresses. It is indeed unlikely that reduced standards of personal hygiene per se are going to affect the performance capability of the individuals concerned, or the outcome of a mission. Reduced standards of personal hygiene, however, can lower the overall habitability of the environment; and conversely, if an adequate standard of personal hygiene is maintained, the overall habitability of the

TABLE 2

Synopsis of Weight and Volume of Waste Produce Generation From All Sources in the Closed Environment of a High Performance Manned Space Vehicle.

Values are given per man per day.

	MASS/GRAMS	VOLUME/MILLILITERS
Miscellaneous Cabin Compounds	0.700	0.720
Food Spillage	0.700	0.700
Desquamated Epithelium	3.000	2.800
Hair - Depilation Loss	0.030	0.030
- Facial - Shaving Loss	0.300	0.280
Nails	0.010	0.010
Solids in Sweat	3.000	3.000
Sebaceous Excretion - Residue	4.000	4.200
Solids in Saliva	0.010	0.010
Mucus	0.400	0.400
Seminal Fluid - Residue	0.003	0.003
Urine Spillage	0.025	0.025
Fecal Particles	0.025	0.023
Flatus as Gas		2000.0
Microorganisms	0.160	0.140
Solids in Feces	20.0	19.0
Water in Feces	100.0	100.0
Solids in Urine	70.0	66.0
Water in Urine	1400.0	1400.0
Insensible Water	1200.0	1200.0
TOTAL	2802.363	2807.341
TOTAL EXCLUDING URINE, FECES, FLATUS, AND INSENSIBLE WATER	12.363	12.341
TOTAL SOLIDS	102.363	97.341
TOTAL WATER	3700.000	3700.000
TOTAL GAS		2000.000

Source: Mattoni and Sullivan (33)

environment is relatively enhanced.

The perception of personal "dirtiness" has at least two components. One is the physical attribute of contamination, grease, sweat, scurf, etc., which provides obvious sensory evidence of dirt. The other is the awareness of the passage of time during which no positive cleansing has occurred. These two, in conjunction with the highly imbued connotations of dirt, contrive an emotional set which is reflected in the desire to bathe shown by those released from environmental experiences where the possibilities of cleansing are minimal. As Mattoni [33] points out, campers who have washed regularly in streams or lakes luxuriate in the sensuality of a hot bath or shower at the earliest opportunity. The same illustration points up the psychological inadequacy of sponge baths, and the like, even though they may provide cleansing which is adequate from the point of view of dirt removal.

Thus it would seem that, influenced by one's cultural orientation, there is generally, and particularly in a large segment of U. S. society, a strong compulsion towards maintaining personal cleanliness, which if thwarted could arouse distaste; and although distaste itself will not reduce proficiency, it could contribute, in summation with other factors, to reduce morale. Where full bathing facilities are not available, there is a desire to maintain cleanliness of the facial region, hands, and mouth [29].

The physiological connotations of dirtiness, although normally minimal, are probably responsible for the social stigmata associated with it. It is very probable that dirtiness per se causes very little physiologic or pathological problems. It is only when certain attributes of dirtiness are manifest that problems arise. The attributes of concern are those associated with mechanical and chemical irritation, hypersensitivity, and provision of media which encourage microbiological growth on the skin or in body niches.

Mechanical and chemical irritation arise out of physical damage to the skin or body membranes by the contaminant materials, and are well exemplified by the inflammatory reaction that may occur in areas of excessive sweating, sites of repeated friction with dirty clothes, and regions continuously contaminated by urine or feces. Even if actual inflammation does not occur, itching and irritation of the skin, particularly of the scalp, become a problem [44], and probably arise from continuous desquamation of the surface. In addition, particles pass into the atmosphere, may be inhaled, lodge in the eye or elsewhere, and may even adhere to instrument dials.

Hypersensitivity may result in manifestation of an allergic reaction. While such a reaction is unlikely to occur by way of development of sensitivity to autogenous products, it is readily conceivable that hypersensitivity and subsequent allergic skin reactions could arise from exposure to materials from the environment lodged in the clothing, and in continuous skin contact for a prolonged period.

Perhaps the greatest potential problem lies in the encouragement of growth of unwanted surface microflora by provision of good growth media in sweat, organic debris, food particles, etc. Several experiments have been conducted to investigate the extent of this problem. In a recent U. S. Navy test [9] in which subjects were confined for 34 days under conditions of minimal personal hygiene, the change in skin microflora was examined. The confinement, and no doubt the results, was complicated by the fact that for 20 days the subjects were in pressure suits in an atmosphere of 100% oxygen. The results, which were reported by Gall and Reilly of the Navy group, showed that the total numbers of colonies on aerobic blood plates and in the environment increased as the experiment progressed. The build-up in the axilla, groin, glans penis, and the buccal area reached a plateau by the mid-point of the experiment, and then stayed relatively constant or decreased. These findings would seem to imply that a new equilibrium had been reached. The build-up in the throat flora, however, was more variable. The build-up on body areas was of a pattern that appeared to be the result of minimal personal hygiene. In the axilla, groin, and glans penis, it involved predominantly staphylococci, micrococci, and corynebacteria, while streptococci and to some extent staphylococci or micrococci were found in the throat and buccal area. Despite the potentially hazardous nature of some of these micro-organisms, no harmful effects were observed within the 34 day period, although as will be noted later, subjects complained of filth and discomfort.

In a related context, Levashov (29) discusses the bactericidal qualities of the skin in relation to the changes in sebum production that occur on uncleansed skin. He quotes the unreferenced work of Finogenov who showed that there is a steady accumulation of sebum on exposed uncleansed skin over a period of 5 days. Sebum formation then stabilizes at a reduced level. Meantime, on covered skin, there is little change in accumulation, which is absorbed on the clothes, until the sorption qualities of the clothing decrease. Levashov goes on to quote further the unreferenced work of Ogleznev, and Kozar, who showed that prolonged confinement of human beings in a small space reduces the bactericidal and non-specific resistive properties of the skin. Levashov suggests a relationship between the changes occurring in sebum production and the changes in skin defense mechanisms, and implies that improved skin hygiene will assist in maintaining good skin resistance.

Dental and buccal hygiene presents a more obvious problem. In the studies of Slonim (44), which will be discussed later, where subjects were confined with minimal personal hygiene procedures for six-week periods, nearly all subjects had oral problems. Maintenance of periodontal integrity was weakest, and varying degrees of halitosis occurred in all experiments in which a dentifrice was not used. Generally, the soft tissues of subjects on substandard oral hygiene suffered the most, resulting in moderate to severe gingivitis. In nine six-week experiments, two subjects developed serious dental problems that required immediate emergency care involving temporary restorations. The effects of substandard oral hygiene are shown in Table 3.

The acceptance of growth of head and facial hair, like the requirement for cleanliness, tends to be influenced by cultural patterns. With a growth rate of 0.3 mm per day for crown hair and about 0.4 to 0.5 mm per day for facial hair there comes a time when its length interferes with normal pursuits, and may cause direct irritation, as well as generalized

TABLE 3. EVALUATION OF ORAL HYGIENE PROCEDURES

PROCEDURE	EXPT	RESULTS
Toothbrush and toothpaste (No hexachlorophene)	II	Adequate oral hygiene
Gum and interdental stimulator	III	Ineffective - gingivitis in all subjects, stained teeth, halitosis
Electric brush and interdental stimulator	IV	Improvement in dental status of all subjects
Interdental stimulator only	V[a]	Ineffective - gingivitis, stained teeth, halitosis
Toothbrush and water only	VI[a], VII, X	Varying degrees of gingivitis, stained teeth, mild halitosis
Toothbrush and (USAFSAM) edible dentifrice	VIII	Adequate oral hygiene
Toothbrush and water and dental floss	IX	Improvement in dental health of all subjects

[a]Electric toothbrush used first week only; all other procedures were tested for 6 weeks.

Source: Slonim (44)

discomfort, or even interference with vision. Thus, in Slonim's studies (44) 25 per cent of his 24 subjects had to trim or wax their mustaches within 3 - 5 weeks, since they were piercing or irritating their lips. A much higher percentage had fingernail growth problems. About the fourth week of exposure, nails grew long enough in 12 subjects to cause interference with writing and manipulating equipment.

Much of the information from which the requirements of personal hygiene are derived is based on philosophic considerations, anecdotal communications, and observations. Few experiments have been conducted to determine actual effects. In the previously noted Navy study reported by Coburn (9) eight subjects were selected from forty astronaut candidates who had passed through the U. S. Navy School of Aviation Medicine. Six were utilized as experimental subjects and two as controls. The six subjects were maintained in a cylindrical low pressure chamber 22 feet long and 8-1/2 feet in diameter for a period of 34 days, 20 days of which were spent at 27,000 feet on 100% oxygen, with a total time of 21 days within full pressure suits. Suits were fully donned, except for faceplate, for about 4 hours of each of these days; for the remainder of the day helmets and gloves were removed. Opportunities for maintenance of personaly hygiene were minimal. Personal hygiene articles consisted of a washcloth and toothbrush for each subject. Unlimited hot and cold water was available, although soap and dentifrice were not used.

Body odor became noticeable after about three days, and while it was objectionable it did not become incapacitating. Constant dampness of the socks from inadequate ventilation of the feet led to the development of tinea pedis. Dampness in the groin area in one subject led to the development of irritation on the scrotum. After about 3 - 4 weeks, peeling and flaking of the superficial skin developed over the entire body in all subjects, becoming quite marked in the last few days, to the extent that a shower of these dry flakes could be produced by brushing one's body or hair. After termination of the study, a fine layer of powdery scales was found to cover the floor of the chamber. One subject developed pustules in the coccygeal area and the left chest wall; culture of the pustules, however, was negative. It was suggested that generalized skin reactions might have been more severe had the trial continued.

Daily questionnaires were conducted with respect to the feeling of cleanliness, in terms of dirty, filthy, foul, and squalid. The degree of expressed dirtiness increased as the study continued. In general, during days 1-6 dirtiness was not noticeable; during days 6-29 the subjects felt "dirty", and during days 30-34 they felt "filthy". One subject reported that he was "foul" from day 17 on.

The dirt, however, was not considered to be a problem - provided the subjects could scratch, wash their faces and brush their teeth. They would have preferred, nevertheless, to wash the axillary, genital, and perineal areas. Washcloths became dirty and malodorous after a few days of use and required regular washing and laundering.

The study reported by Slonim (44) represented conditions more limited with respect to personal hygiene, in that virtually none was permitted. In four sets of confinement experiments, part of a series of ten, four subjects at a time were maintained in a chamber facility of 1130 cubic feet capacity for four-week periods, preceded and followed by a one-week control period in a metabolic ward. Various other factors were evaluated besides personal hygiene. The minimal personal hygiene protocol permitted no bathing or sponging of the body, no shaving, no hair or nail clipping (unless necessary), no changing clothes or bed linen, substandard oral hygiene, and minimal use of wipes, which were permitted before each meal, and after defecation. Clothing consisted of long underwear, Air Force pajamas, white lightweight to heavy cotton socks, low sneakers or moccasins. Only the sneakers were removed before going to bed.

The results are summarized in Table 4. Lack of bathing or body sponging presented no major problem. Body odor reached a maximum within 7-10 days, with the sources varying in subjects among axilla, groin, and feet; the subjective response to odor subsided by the second week. The problems of hair, nails, and mouth have already been commented on. Dandruff and itchiness was a continued complaint. Inability to change clothes, particularly underwear, was troublesome, since eventually underclothes began to stick to the groin and other body fold areas, became very malodorous, and began to decompose. This problem was relieved in later experiments by the use of loose fitting garments. Even then, however, socks became soiled, damp, and odorous after the fourth week, and underclothes started to decay.

TABLE 4. EFFECTS OF MINIMAL PERSONAL HYGIENE

CONDITION	EXPT	SUBJECTS	RESULTS
AMBIENT ENVIRONMENT			
1. No bathing, 5 weeks	V-VIII	16	No major problems; body odor strongest in axilla, groin, feet.
2. No shaving, 6 weeks	V-X	24	6/24 needed to trim mustache
3. No hair & nail grooming, 6 weeks	V-X	24	12/20 needed to trim fingernails (4NB); varying degrees of dandruff.
4. No change of clothes, 5 weeks	V-VIII	16	Socks - very soiled, damp, odorous. Underclothes - signs of decay.
5. No change of bed linen, 5 weeks	V-VIII	16	No major problems.
6. Substandard oral hygiene			
--interdent. stimulator only 5 weeks	V	4	Decrease in dental status of all subjects - varying degrees of gingivitis.
--gum and interdent. stimulator, 6 weeks	III	4	
--reg. toothbrush & water, 6 weeks	VI, VII, S	12	
32°C (90°F) ENVIRONMENT			
24 hrs/day for 7 days (twice)	IX	4	Tolerated by all subjects. Clothes very damp; body odor strong; skin & scalp dry and itchy; flaking off of skin; pimples; athlete's foot.

Source: Slonim (44)

Odorous and dirty bed linen was unpleasant but tolerable. With continuous exposure under the same conditions to 32°C (90° - 91° F), the effects were exaggerated; itching was constant in the scalp and occurred also in the groin, back, neck, and feet; pimples developed; skin peeled off hands, elbows, and knees; lips became chapped and athlete's foot (tinea pedis) recurred. In general, however, under all circumstances examined, the situation was unpleasant but tolerable.

For optimal conditions, however, it is apparent that provision must be made for personal hygiene in various areas, namely:

1. Dental and oral
2. Hand and face washing
3. Body bathing
4. Hair and nail trimming
5. Shaving
6. Clothing, and laundering

Considerable work has been done in determining the thermal insulative and protective qualities of clothing. Less has been done to determine its cleansing and absorbent qualities. Russian workers report a series of studies designed to investigate the hygienic qualities of clothing under shirt-sleeve sealed cabin conditions (38). Using a heat chamber, a Vostok ground simulator, and operational flights of Vostok spacecraft, they evaluated the hygienic qualities of underwear and outer clothing made of various materials, all of which were made up as knitted fabrics with a porous mesh weave, characterized by softness, elasticity, wrinkle resistance, high degree of air permeability, and considerable capacity to absorb moisture.

Experiments were aimed at evaluating:

a) degree of skin contamination by biological products during the test period
b) capacity of underwear and outer clothing to absorb biological products
c) distribution of absorbed products between parts and layers of clothing

d) accumulation of chlorides and organic matter on skin and clothing layers

e) rate of perspiration

Chlorides were used as indices of skin and clothing contamination by perspiration, while oxidizability of washes (in mg O_2) was used as an index of contamination by organic substances. The accumulation of chlorides and organic substances on the skin and in the clothing was determined by chemical analyses of water washes from the whole body surface, and, separately, from the clothing. Materials tested included two mixtures of cotton and rayon, one rayon fabric and one pure wool. All showed a high capacity for absorption of chlorides and organic substances (80-90% of the total amount of chlorides excreted through the skin), which was retained during periods of continuous wear up to 30 days. To compare the ability of different fabrics to absorb biological products from one individual, garments were used made of two parts from different materials. The results, which are shown in Table 5, indicate that the cotton rayon fabric No. 2 (75% cotton and 25% rayon) showed the greatest capacity to absorb chlorides and organic substances, while the wool fabric showed the least. Although no incapacitating disorders of the skin of the subjects developed during the 30 day experiment, they were manifestations of hyperkeratosis and thin-flake sloughing of the skin of the feet, and a number of subjects developed sycosis, occasional furuncles, dermatitis, acne, and one allergic reaction spreading from the point of application of electrodes. These reactions, however, did not interfere with performance of the programmed tasks.

The prime requirements, then, in the maintenance of personal hygiene would seem to be the provision of an adequate supply of water, cleansing agents, facilities for their use, and capacity for changes of clothing. To allow for variations in threshold of subjective dirtiness it might also be necessary to outline a schedule of use. Of these, perhaps the most significant requirement is an adequate water supply. Ebersole (13) points out that in the long-duration submerged missions of the nuclear submarines the incidence of skin disorders was negligible in comparison with that in the conventional submarines, and attributes the fact to the abundance of

TABLE 5. DISTRIBUTION OF CHLORIDES AND ORGANIC SUBSTANCES IN CLOTHING, EACH HALF OF WHICH WAS MADE OF DIFFERENT MATERIAL, AFTER 10-15 DAYS OF WEAR.

Substances studied	Number of experiments	Set of clothing					
		No. 1		No. 2		No. 3	
		Cotton-rayon cloth No. 2	Cotton-rayon cloth No. 1	Cotton-rayon cloth No. 2	Rayon cloth	Cotton-rayon cloth No. 2	Woolen cloth
Chlorides, %	3	58.9	41.1	54.5	45.5	56.5	43.8
Organic substances, %	3	53.6	46.4	51.5	48.5	62.4	37.6

Source: Popov et al., (38)

fresh bathing water available in nuclear submarines. Adequacy, however, is a relative term. Assuming optimal conditions, and the existence of as yet undesigned facilities for the provision of showers and laundering in the weightless or reduced gravity state, guidance can be obtained from other experience.

Breeze (3) lists the water requirements per man prepared by various organizations, as shown in Table 6. These show a range varying from a minimum of 10 gallons per day at Allied Military Advance Base in World War II to a maximum of 150 gallons per man day at USAF permanent bases. He also points out that a study of the records of several Navy ships over a 4-year period showed an average fresh water consuption per man day of 28.3 gallons, while IGY Antarctic personnel used about 11 gallons per man day in a facility which included hot and cold showers and a washing machine. He concludes that a realistic figure, with minimization of water requirements, would be in the region of 2-4 gallons per man day.

The Boeing Company (2), in their study of requirements for earth orbiting missions of more than 45 days duration, have suggested a much lower figure, namely 8.5 lbs of water per man day, which is less than one gallon. For optimal conditions, however, this latter figure appears very low. Celentano and Amorelli (6) suggest 6 gallons per man day. It seems probable that the optimal lies somewhere between 6 and 12 gallons.

It is not the purpose of this paper to discuss engineering solutions to these problems, which are indeed great. Some approaches have been made (e.g., 30, 32, 33), and others are being made. In viewing these matters from the point of view of habitability, however, it is evident that while man can obviously tolerate squalid conditions and maintain adequate performance over the period examined, while taking no active measures to maintain cleanliness, he does so in considerable discomfort and some potential hazard. How long the conditions described could be maintained is not known, although it might well be for a very prolonged period; but for optimal habitability it is desirable to provide optimal facilities for full personal hygiene, although it must be re-emphasized

TABLE 6(a). COMPARISON OF WATER REQUIREMENTS

Organization	Gallons Per Man-Day
IGY polar expedition	11
Military advanced bases (World War II)	
Allied	10
United States	25
U. S. Air Force	
Permanent bases	150
Advanced bases	75
U. S. Navy	
Permanent bases	100
Advanced bases	25 to 50
Surface vessels	25
Submarines	20
Space System Recommendation	6

TABLE 6 (b). CONSUMPTION OF FRESH WATER ABOARD SHIP

Use	Gallons Per Man-Day
Drinking	0.5 to 1.0
Kitchen	1.5 to 4.0
Washing	5.0 to 20.0
Laundry	5.0 to 10.0

Source: Celentano and Amorelli (6)

that personal hygiene as practiced in the U. S. today is largely a cultural fetish, actively promoted by those with commercial interests; with suitable training these cultural compulsions could no doubt be reduced. As Mattoni and Sullivan (33) remark, the man who can drink his own treated waste products is not as likely to feel dirty when he knows he is hygienically clean as is the average man.

Illumination, Decor, and Color

For optimal habitability, the provision of adequate volume and suitable configuration requires of course to be supplemented with appropriate levels of illumination, and compatible schemes of color and internal decor. A plethora of literature exists on engineering and other journals on the requirements for internal lighting, and testifies to the fact that these requirements are still far from being satisfied in many instances. The problems of lighting, color, and decor, rightly belong in the conjoint realm of the illumination engineer, the psychologist, and the interior decorator, and no doubt whatever is said here will be looked on with dissatisfaction by one or another group. It is not the purpose of this paper, however, to specify criteria for lighting systems, to discuss the perception of light and color, or to establish specifications for the layout of configurations, but to examine these areas and discuss guidelines for the provision and maintenance of habitability.

Most of the work that has been done in these areas has been oriented to the needs of industry and the home. In a discussion of the requirements of lighting in industry, Gray (22) echoes the consensus when he stated that the best lighting from the standpoint of reducing eye fatigue is that which is diffused, or reflected from all directions, and notes that the controllable factors in diffusing light in an industrial situation, excluding the light source itself, are the walls, ceilings, floors, and objects in the work area, of which the reflecting value depends upon their color and texture. He goes on to advocate, as has become a common practice, the selective painting of ceilings, walls, floors, and trims in such a manner as to make the lighting more effective and seeing less difficult, to control the intensity of lighting to meet different circumstances, and the quality of light to avoid glare and unevenness of light distribution.

Overall, the same principles apply in maintaining habitability in spacecraft and space dwellings. However, in work with submarines, it was learned that the customary rules in indirect lighting, calling for high reflectance overhead and low matte finish about bulkheads, proved infeasible because of low ceilings. In particular, glare from indirect luminaires placed of neccessity at, or near, eye level proved detrimental (51). Similarly, the unique characteristics of space system stations, such as restricted internal volume, irregular compartment configurations, multipurpose regional usage, compact working consoles, and special power supplies, may make application of conventional illumination standards inappropriate (6).

Urmer and Jones (50) have emphasized the adoption of what they call a "visual subsystem concept" in the design of space vehicle illumination, utilizing the approach of systems engineering to the solution of visual problems. This approach involves analysis of the interacting elements, with the goal of optimizing man's ability to see.

The first phase consists of a task analysis, usually related to phase of flight, followed by a further analysis of the tasks outlined, to define areas where visual function might be critical. In conjunction with the task analysis, the anticipated visual parameters are determined to assure their consideration in the spacecraft design. The analysis is continued throughout system development, and serves as a subsequent basis for development of procedures and training programs. The second phase consists of experimental examination of areas that do not lend themselves to analytical procedures. Utilizing a system of this type, Urmer and Jones have developed generalized recommendations for spacecraft illumination which will be presented later.

Recommendations for illumination requirements for spacecraft owe much to work that has previously been done to define requirements for submarines. The classic work in this area is still that of Tinker (48), some of which is repeated here for those who do not have access to it. He points out that in the submarine, only artificial illumination is used, and members of the crew have normal vision. Accordingly it is necessary to consider those factors which are basic to the provision of artificial illumination which is adequate for maintaining comfortable, healthful and effective functioning of normal eyes. These factors are: 1) quality or color of light 2) intensity of light; and 3) distribution of illumination and brightnesses within the environment. These factors should be arranged to give compartments a more pleasing appearance and proportions; all three should be combined to induce in the occupants a sense of tranquility, comfort and "hominess".

The use of color, as characteristic of a reflecting medium, will be considered in more detail later. Illuminants, however, which vary in spectral characteristics, have an inherent color, which in laboratory situations, at least, affects to some extent the visual acuity. For threshold seeing, spectral yellow, or the yellow light from sodium vapor lamps, is somewhat more effective than other artificial illuminants, although the difference is not of operational significance and does not improve the acuity over that from a similar level of diffused daylight. In ordinary situations (e. g., print reading) the qualities of daylight, mercury arc light, tungsten filament light, and fluorescent lamps are all about equally effective as illuminants, although fluorescent light has been criticized because of its harsh, cold appearance [48].

The intensity of light has to be considered in relation to: 1) visual acuity; 2) size of object to be discriminated; 3) speed of vision; 4) brightness contrast; and 5) efficiency of performance. Tinker [48] reviewed the work of numerous investigators in these areas and concluded that, with respect to visual acuity, in general, with normal eyes, little is gained in acuity by increasing the illumination beyond 25 foot-candles, and there is no practical gain at all when the intensity is higher than 50 foot-candles. For large objects, subtending four minutes of arc and above, there is no practical improvement in visual discrimination with illumination above 20 foot-candles. For smaller objects, there is improved visual discrimination at higher levels up to a limit of about 40-50 foot-candles.

The data on speed of vision may be summarized as follows: a) for objects subtending thee minutes of arc or larger, and with good contrast between object and background, speed of vision is near maximum at about 15-20 foot-candles; b) for small objects on a background of low reflectance significant decreases in time for seeing occur with illumination intensities up to about 50 foot-candles.

With respect to brightness contrast, when the contrast between object and background is high, discrimination of arc sizes of three to six minutes is not significantly improved by illumination above 20 foot-candles. With an object of 1-minute size, performance improves significantly up to a practical limit of about 50-60 foot-candles. The greater the brightness contrast, the better is the visual discrimination, although, as will be noted in the examination of light distribution, the effort of seeing is more fatiguing with high contrast. Excessive illumination will not compensate for small object size or poor contrast.

To summarize the effects of intensity, as considered by Tinker (48), visual efficiency increases rapidly up to about 5 foot-candles, more slowly to 10, very slowly to 20, and by insignificant amounts thereafter, when the object to be discriminated occupies about 3-6 minutes of arc. When the object is smaller, vision improves perceptibly up to 40 to 50 foot-candles. The greater the brightness contrast, the better is the visual efficiency, and both acuity and speed of vision continue to improve slightly up to and beyond 100 foot-candles.

Brightness contrast is also of significance in consideration of distribution of illumination, and in this connection it must be distinguished from glare. Brightness contrast refers to the variation of brightness of areas within the visual field; glare describes the phenomenon of impairment of vision and visual discomfort that arises when unpleasant light enters the eye from a light source within the visual field. The effect of glare can be minimized by increasing the brightness contrast of the visual object and its immediate background, and by increasing the illumination on the visual object. Elimination of the glare source, however, by removal, or by use of diffuse or indirect lighting, is superior.

With respect to brightness contrast, it was noted earlier that a high brightness contrast increased the discrimination of small objects. It has been shown, however, that for best overall vision, with minimum fatigue, the brightness ratio between the central field and surrounds should not exceed three or five to one, and that ratios of ten to one should be avoided. The extent to which excessive brightness contrast is diminished is largely determined by the degree to which the lighting is indirect, that is, reflected from all directions. When light is properly diffused there are no shadows, no dark corners, and no areas of relatively high brightness. Light fixtures in the field of vision should have a surface brightness of not over 2 candles per square inch and preferably less [48]. Thus, in general, vision is best when the surrounds are the same brightness as the central field unless the visual object approaches the thresholds of acuity or discrimination, in which case supplementary lighting can be utilized to increase the brightness ratio, provided the latter does not exceed three or perhaps five to one [48]. Intensity and distribution, however must be coordinated. To increase intensity without distribution will only make a bad situation worse. In fact, when distribution is poor, relatively low intensities must be employed to avoid visual discomfort.

In relation to illumination, color may serve more than one purpose in the perceived environment. It determines the reflectance of colored objects in that environment, and, in addition, it may have an influence on the emotional set of individuals in that environment.

Color, as hue, has no effect on the ease of seeing. From the point of view of visual perception, the reflection factor of walls, ceilings, and furnishings of any living or working space is more important than the color used, since the reflecting surfaces become, in effect, secondary sources of illumination [48]. The reflectance of a surface is the ratio of the light flux reflected from the surface to that striking the surface. Dependent upon the surface, it may be diffuse, specular, or compound. Diffuse reflectance arises from a matte surface; specular reflection comes from a highly polished (mirror) surface and give rise to glare.

A compound surface has qualities of both. The color of an object arises out of selective reflectance and absorption of particular wavelengths of the incident light. The reflectance from the ambient environment contributes significantly to the general illumination level. For any specified level of illumination a region with highly reflecting surfaces requires a less intense light source than one with low reflecting surfaces [1]. Table 7 indicates the reflectance factors for various surface finishes.

Recommended workplace reflectances for different areas include the following: console panel 20-40%; instruments 80-100%; floors 15-30%; walls 40-60%; ceilings (i. e., above eye level) 60-95% [1]. Tinker, however, in his review [48], again draws attention to the fact that reflectances influence distribution of light, and that best vision occurs when the brightness contrast ratio is no greater than three to one. At the same time, for decorative purposes, contrast is desirable; lack of variation tends to be monotonous and undesirable. Good decorative schemes cannot readily be achieved with a one to one ratio. The blending of highlights and shadows adds attractiveness to the living space, and can be better achieved with higher ratios, while still remaining within acceptable limits.

Some of the psychological aspects of color are considered as part of a comprehensive survey of the science of color by the Committee on Colorimetry of the Optical Society of America [10]. They observe that color is perceived within the context of texture and setting. Sometimes it is identified with a surface, sometime with a volume, a film, an illumination, or an illuminant. The sensed color and its presented mode form a perceptual resultant which can be described phenomenally in terms of certain attributes (hue, brightness, saturation, etc.,). The perception is influenced by the mental set, and is more than the mere consciousness of color, or even consciousness of modes of appearance of color, but is influenced by the connotations of the color and its associations in the light of past experience.

Supplementary to the influence of mental set is the fact that distinctive color preferences exist. Studies of numerous investigators [16] show the following order of preference of six common colors among over 20,000 observers; blue, red, green, violet, orange, yellow.

TABLE 7. GENERAL REFLECTANCE FACTORS FOR VARIOUS SURFACE FINISHES

COLOR	PERCENT OF REFLECTED LIGHT	COLOR	PERCENT OF REFLECTED LIGHT
White	85		
Light		Dark	
cream	75	gray	30
gray	75	red	13
yellow	75	brown	10
buff	70	blue	8
green	65	green	7
blue	55		
Medium		Wood finish	
yellow	65	maple	42
buff	63	satinwood	34
gray	55	English Oak	17
green	52	walnut	16
blue	35	mahogany	12

Source: AFSCM 80-3 [1]

Although dominant wavelength, or hue, is significant in the determination of color preference, luminance (or reflectance), and purity, are also important. The appeal of a color increases with increasing luminance until the comfort limit is exceeded, following which there is an increasingly violent loss of appeal. Somewhat similarly, appeal increases with increase in purity up to the spectrum limit in many individuals, although a substantial minority favor weak unsaturated colors (10). It must be noted, however, that the increase in affective value noted in these circumstances is in relation to tests with very small areas of color; it is probable that when areas are large, as in compartment walls, these factors do not apply (48).

Tinker (48) quotes an unreferenced study by Washburn, who measured the pleasingness of 19 saturated colors, 18 tints or pastels, and 18 shades. On the average, the tints were most pleasant, the shades next, and the saturated colors least. The size of the colored area had some influence on appeal. With saturated colors, the small areas were preferred but the large areas of tints and shades were preferred. In saturated colors, red, orange-red, and green-blue were most preferred, while yellow and yellow-green tended to be disliked. The most pleasing tints were blue, blue-violet, violet, and red-violet. Tinker himself found that with the exception of yellow-green, any color was preferred over the achromatic surfaces of black, white, and grey, while there was a suggestion that tints were more pleasant than saturated colors or shades, and that in larger areas tints were more acceptable than colors. While "pleasingness" may not be directly relatable to crew effectiveness, it does, however, contribute to overall habitability.

In addition to appeal, or affective value, colors would appear to influence emotional responses, as is evidenced by the epithetical terms applied to them, such as sober, hot, heavy, dry, juicy, voluptuous, sensual, insipid, brutal, tranquil, and discordant (10). Some colors appear cool, tranquilizing and restful; these are the blues, greens, and violets, which are appropriately used in rest and recreation areas. Red, orange, and yellow are considered warm colors, exciting, and stimulating to work, and are found appropriate for work areas, while in general lighter colors are considered cooler than dark colors [51].

With respect to color harmony, or the juxtaposition of colors, studies have shown that the affective value of a combination of colors is highly dependent on the affective value of the component colors, although the result is not strictly additive [10]. Where the composition is complex, as in a painting, the pattern of the composition exerts more weight than do the colors themselves, even if the composition is abstract.

Unsaturated complementary colors, however, would appear to provide the best harmony for complementaries. Strong and saturated complementaries in apposition tend to produce an impression of discordance, which may be aggravated by the impression of flutter resulting from after-images of each color projected on to the neighboring color as they are fixated serially. Hues tend to harmonize best that are separated by either small or large hue intervals rather than by intervals of intermediate value [10]. However, small areas (e.g., trim) of discordant or unpleasant color may be introduced for interest and to heighten by affective contrast the pleasantness of other colors, while some lightness variation will assist in reducing monotony.

Thus, in general [48], for optimum habitability, color should provide both reflecting surfaces and pleasing combinations. Saturated colors and color of low reflectance should be avoided on large areas; tints of appropriate color should be used instead. A proper proportion of reflectance should be maintained on consoles, panels, instruments, floors, ceilings, and walls. Variety in color of decoration is desirable. To maintain a pleasing environment, with appealing contrasts, different colors should be used in the same compartment, and still different combinations in other compartments. Tints and light grays possess several advantages; they make a compartment appear more spacious and ceilings appear higher. Some of the favored colored tints are buff with umber, ivory, cream, blue, coral and peach. Flat, or matte surface, paints should be used to avoid specular reflection. A light that enhances warmth and softness of colored objects is desirable, and furthermore illumination should be such that it does not markedly alter the color of natural objects, e. g., skin complexion and food.

Within these limitations, a variety of colors can be selected for the interior of spacecraft and space dwellings. Cool, work-stimulating, colors are recommended for the work area, with bright contrasting accents on trim; warm, relaxing colors are recommended for public rest and recreation areas, again with contrasting accents and trim; while subdued, "homely" colors will be appropriate for personal areas. General lightening of color values will assist in providing brighter interiors with a lower level of illumination. The latter, as much as feasible, should be indirect, diffuse and non-glaring.

In the light of the above discussion, and to provide an indication of the general requirements for industrial illumination, Table 8 (1) presents some recommendations for the lighting needed in the conduct of various representative tasks. It must be emphasized, however, that because of the unique requirements of space vehicles these recommendations cannot be directly applied to space vehicles. As will be recalled, however, Urmer and Jones (50), utilizing a systems engineering concept, undertook a task analysis of a general space mission in relation to the need for illumination. Bearing in mind the characteristics of the mission itself, the environment, the vehicle, and the limitations of man, they made some general recommendations for effective spacecraft illumination. It will be observed that these recommendations are oriented towards the provision of illumination which is primarily suitable for operation of the spacecraft and conduct of mission tasks. The requirements of living accommodations are not specifically considered. While this is no doubt a proper orientation under the circumstances, and for relatively short duration missions, consideration must be specifically given to the requirements of non-operational areas for longer missions. The recommendations of Urmer and Jones (50) are given below:

TABLE 8. GENERAL ILLUMINATION LEVELS AND TYPES OF ILLUMINATION FOR DIFFERENT TASKS, CONDITIONS AND TYPES OF TASKS.

Task Condition	Type of Task or Area	Illumination Level (ftc)	Type of Illumination
Small detail, low brightness contrast prolonged periods, high speed, extreme accuracy	Sewing, inspecting dark materials, etc	100	General plus supplementary (e.g., desk lamp)
Small detail, fair contrast, speed not essential	Machining, detail drafting, watch repairing, inspecting medium materials, etc.	50-100	General plus supplementary
Normal detail, prolonged periods	Reading, parts assembly general office work, laboratory work	20-50	General (e.g., overhead ceiling fixture)
Normal detail, no prolonged periods	Washrooms, power plants, waiting rooms, kitchens	10-20	General (e.g., random natural or artificial light)
Good contrast, fairly large objects	Recreational facilities	5-10	General
Large objects	Restaurants, stairways, bulk-supply warehouses	2-5	General

Source: AFSMC 80-3 (HIAPSD) [1]

"Effective spacecraft illumination requires that:

1. White light illumination be provided for most mission phases.
2. The intensity be variable from 0.1 m-L to about 40 m-L with the highest intensity for launch only.
3. An intensity of 10 m-L be provided as the maximum value for non-launch conditions.
4. Provisions be made to turn off all internal lights, with critical instruments being self-illuminated, particularly to allow easy maintenance of interior/exterior light balance.
5. Flexible floodlights be provided to reduce extreme contrast effects by washing out shadows.
6. Red filters (6400 Å) be provided for dark adaptation for all light sources.
7. Trans-illuminated displays be shielded to prevent their being masked by high intensity light sources.
8. Lights, indicators, and self-illuminated instruments be located to prevent reflections from windows and other instruments.
9. Filters or shutters be readily operable, using electrical switches if necessary, to aid the astronaut in programming light to achieve optimal light levels.
10. The color and intensity of caution and warning lights be considered, as they influence ambient illumination levels and dark adaptation, particularly for the dark side of the earth.
11. The reflectivity of suits, equipment, and interior paints be used to increase the evenness of illumination.
12. Inadvertent light leaks, particularly from high-intensity sources, be identified and corrected before the mission for each spacecraft, to ensure that low levels of interior illumination and dark adaptation can be maintained.
13. The color of critical markings and legends be designed such that they can be seen when red lighting is used."

For long duration missions where the demands of habitability become more pressing, the following recommendations might be added:

1. Lighting should be indirect or diffuse where possible; if not, fixtures presented to the eye should have low surface brightness and broad spread.
2. Reflectance values of walls, ceilings, floor, and furnishings should be selected to maintain the proper proportion of reflectance from surrounds, and to maximize the available illumination without producing glare.
3. An overall brightness contrast ratio should be maintained of not more than five to one with respect to both intensity of illumination and reflectance.
4. Quality of light should be such as to preserve natural colors, particularly natural complexion colors, while enhancing warmth where appropriate.
5. Illumination should be such as to provide 25-30 foot-candles at any work surface where discrimination is required, with supplementary lighting to 40 foot-candles when necessary; 20-25 foot-candles at work surface of public areas; 5-10 foot candles in personal and other areas, with supplementary illumination when required.
6. Individual, directionally adjustable, shielded light fixtures of variable intensity (to about 10-15 m-L) should be provided in the public and personal units.
7. Color should be utilized to provide both appropriate reflecting surfaces and pleasing combinations.
8. Saturated colors, and colors of low reflectance, should be avoided on large areas.
9. Variety in color of decor, and color contrast, should be encouraged, using stimulating colors in work areas, warm and restful colors in public and personal areas.

Leisure and Recreation

The concept of leisure has changed throughout the years, and even more markedly in the last few years. When most of man's time was occupied with survival, or with earning sufficient reward to ensure his place in society, leisure was the modicum of time left over from work, and was commonly occupied by sleep, rest, or inactivity. With the increasing automation of industry and the decrease in drudgery of manual work, more and more time not scheduled for work has become available to man. The possibilities of improper usage of this time by individuals, untrained in the pursuit of leisure, have been of some concern (23), and have led to increasing consideration of what might be termed the creative uses of leisure. The significance of the contemporary viewpoint has been discussed by Theobold (49), who stated: "The 19th century concept of man's life as a mere division between toil and respite from toil must disappear, along with the production-oriented factory organization which gave rise to such a curiously twisted version of the relationship between an individual and his society..... leisure will no longer simply be time not spent in toiling, but rather the full use of an individual's potential for the physical benefit of his fellows and his own recreation."

While the astronaut in the long-duration space mission is by no means comparable to the wage slave of the industrial society, he nevertheless cannot be expected to divide his day between working and sleeping. At the same time he cannot merely be allotted a portion of time with instructions to relax. Provision must be made for the constructive or creative use of leisure. Creative growth depends upon maintenance of a work-leisure cycle, but the use of leisure in this connection is not a matter of being amused, being entertained, or merely being comfortable, but exists as "an opportunity for learning, as a possible cultivator of tastes, interests, skills, and values, ...(and), as an opportunity for creative, exciting, adventuresome, and full living" (4).

Brightbill [4] points out in a discussion of the uses of leisure that the crux of the matter lies not in providing people solely with passive forms of recreation, participant or otherwise, but in assisting them to acquire the values, desire, skills, and opportunities to use their free time in ways which will contribute to their own full personality development, their satisfaction and stability, either with or without organized resources. What is required are people who see leisure as an opportunity, who will be challenged rather than bored by free time.

Translated to the needs of long-term mission astronauts, application of this concept entails the initial selection of individuals with these capacities already in being, and provision of training to develop their talents still further, as well as provision of opportunities to harness the potential so developed.

The selection system already in effect, of course, is oriented largely to that end, in that by its means are selected trained and educated individuals with qualities of self-reliance, objective judgment, and self-sufficiency, which lend themselves to creative use of leisure time. Perhaps even more potential will be found in the trained scientist who is selected for astronaut duties. Those characteristics which caused him to select a scientific career, amplified by his training, are such that his leisure time and his work time tend to overlap diffusely, or that in his leisure time he continues to pursue activities which will develop other areas of compelling interest.

The question of training for leisure time activities is difficult. Obviously, the training given to all astronauts assists in developing self-sufficiency and those other qualities which assist in the constructive use of leisure. It is also relatively simple to encourage and develop a useful talent that is already in existence. The essence of a leisure time activity however, is spontaneity- the activity must be the free choice of the individual. Thus, among those individuals who have shown no particular bent towards a particular type of activity, or whose leisure activities cannot reasonably be pursued within a spacecraft, training could be oriented towards some useful ancillary field, along with, if requested, indoctrination in particular areas desired by the participants.

Provision of opportunities for furtherance of creative leisure activities within a vehicle must of necessity be limited by the constraints of the vehicle and the mission. It is neither reasonable nor feasible to provide the resources of a terrestrial laboratory for a scientist, or the materials for a hi-fi enthusiast, but some provision can be made to meet appropriate requirements - particularly if these are known and accounted for in advance - and furthermore, the well oriented individual will seek and find his opportunities within the limits that are available to him.

This creative use of leisure, however, although vital for man's long-term well-being, is not the only desirable use of leisure. Just as one cannot expect man to divide his time between sleeping and working, one cannot expect him to devote all his leisure to self-development. Part of that time is reasonably spent in relatively passive amusement.

Several studies have been made to determine how leisure time is actually spent in different population groups, and while the results are not relevant to the needs of spacecraft, they indicate the type of activities that might bear consideration. One such study is an urban population group involved a random sample of 1660 individuals representing a cross section of the community with all population elements in the sample in the same proportion as they existed in the community [23]. The results are extracted in the Table below,(Table 9), which indicates the proportion of the sample, as a percentage, who claimed to occupy their leisure in the ways mentioned. It will be apparent that some, if not all, subjects recorded their activities in more than one category.

The above study, of course, pertains to an entire urban population and is not necessarily applicable to the habits of a highly specific group of astronauts and astronaut scientists, and it is obvious that data should be collected from astronauts themselves. Eddowes [14], however, undertook a study in which the subjects were somewhat more closely related to the population group from which astronauts and astronauts-scientists are selected. He investigated the leisure time activity of some

TABLE 9. LEISURE ACTIVITY - URBAN POPULATION SAMPLE

Activity	% of Sample
1. Radio, TV, movies	62
2. Reading	48
3. Other unspecified	42
4. Outdoor activities (participant)	35
5. Arts or handicrafts	25
6. Music (active and passive)	24
7. Specified hobbies	15
8. Spectator sports	13
9. Social work	9
10. Self-improvement	9
11. Nothing	3

eighty male professional personnel of an industrial aerospace organization, ranging in age from nineteen to thirty-six, with a modal academic degree of Bachelor, and professional specialties including various branches of engineering, human factors, physics, mathematics, etc. Some of the results are shown in Table 10. The data were analyzed by counting the number of times a given activity was indicated by the subjects, and dividing the result by the number of subjects. The resulting number is termed the Relative Frequency of an activity.

In comparing these two studies it is interesting to observe that despite the fact that two widely different population groups are involged, the activity preference is much the same in each group. Even if the observed similarity arises from the fact that only a limited number of leisure activities are available, it nevertheless suggests the existence of a cultural pattern. Excluding outdoor activities, the major interest would appear to be with reading, radio, TV, movies, music (active and passive), arts, handicraft, card playing, and the like. These

TABLE 10. RANK ORDER OF LEISURE TIME ACTIVITIES

Rank	Activity	Relative Frequency (F/N)
1	Reading	.725
2	Television	.300
3	Musical activities	.275
4	Manual activities	.213
5	Playing bridge	.163
6	Educational activities	.150
—	Miscellaneous work	.125
—	Social activities	.125
9	Travel and driving	.100
—	Family activities	.100
—	Photography	.100
12	Sports	.088
—	Hunting and fishing	.088
14	Gardening	.075
15	Chess	.063
16	Art activities	.050
17	Playing golf	.038
—	Sailing	.038
—	Solving crossword puzzles	.038
—	Walking	.038
21	Making models	.025
—	Attending movies and plays	.025
23	All others	.025

Source: Eddowes (14)

preferences, of course, may well reflect the fact that such activities are easily pursued, since the requirements for all of them are an integral part of our contemporary culture and little initiative is needed to pursue them. Eddowes also invited his subjects to indicate what recreational equipment they would wish for a hypothetical space mission. The results are tabulated below:

TABLE 11. RANK ORDER OF EQUIPMENT DESIRED FOR HYPOTHETICAL SPACE JOURNEY

Rank	Equipment	Relative Frequency (F/N)
1	Books	.925
2	Playing cards	.613
3	Chess	.525
4	Musical instruments	.425
5	Record equipment	.413
6	Handicraft equipment	.313
7	Art supplies	.288
8	Writing supplies	.275
9	Athletic equipment	.263
10	Puzzles and games	.250
11	Photographic supplies	.225
12	Flowers and pets	.063
—	Sex responses	.063
—	Food and drug responses	.003

Source: Eddowes (14)

It will be observed that the equipment chosen, in order of relative frequency, tends to match the order of relative frequency of activities, with the exception of chess, which ranks considerably higher on the equipment list than on the activity list.

The desire to pursue certain activities within a confined situation is not necessarily implemented, however, in practice. Rohrer (40) points out from his experience in the Antarctic that almost everyone prior to becoming isolated, had made plans to utilize leisure in a constructive manner, such as studying for promotion, reading worthy novels or technical books, studying languages, listening to technical and scientific lectures, etc., but with time these good intentions began to dwindle and were replaced with simpler, more fundamental types of activities, such as reminiscing, telling tall stories and so forth. This finding is contrast with that of Ebersole (13) who, in a discussion of leisure activities aboard a nuclear submarine, reported an increasing desire for complexity of reading material with prolonged submergence. In the early phase of the patrol, mystery and western novels were selected, but, as time went by, books of greater complexity, requiring greater concentration were chosen. Kinsey (26) also observes upon the drive towards higher rating or qualification among the men on the submerged cruise of the submarine 'Nautilus' under the North Pole. The difference in attitudes between the Antarctic groups and the submarine groups is difficult to reconcile, but may simply reflect the high morale found aboard nuclear submarines. In other words, creative use of leisure may be both a function of morale and a factor in maintaining high morale.

Aside from the self-development aspects of the use of leisure activity, it would seem that two general classes of recreational activity require to be considered, namely, the active and the passive. The active include those pursuits into which the individual puts some participant input, such as craftwork, communal game playing, and musical instrument playing. Craftwork has been one of the most popular leisure activities on submarines, where complex hobby kits have been in great demand (26). Not all craftwork, unfortunately, is suitable for even the most advanced spacecraft foreseeable, but, particularly if a gravitational field be provided, and storage space is available, many different types of craft would be feasible. Possibilities would be open for model building, electronic tinkering, jewellery making, leatherwork, painting, and even photography, although subject matter for the latter might be limited.

Communal games, especially card games, and to a lesser extent chess are very well established leisure activities, while in nuclear submarines games such as Monopoly have proven very popular, if only because they consume a lot of time (13).

The participant playing of music, as opposed to the passive enjoyment of music is open to only a few, but provides immense satisfaction to the player (although perhaps less so to his listeners, particularly in a confined spacecraft). Should the company, however, be suitably talented, the rewards accruing from the creation of a space ensemble would probably be greater than from any other form of leisure activity, while even the lone musical instrument would be a great satisfaction to its owner.

Passive entertainment, such as is provided by radio, TV, movies, and reading, is the major leisure time activity of the majority of persons. According to a random sample of 7000 interviews, during one week in the U.S., approximately 72% of the population over the age of 12 spent nearly 2 billion hours watching television, about 60% spent over 1 billion hours listening to radio, over 80% spent more than 400 million hours reading newspapers, and nearly 30% spent about 150 million hours attending movies (23).

Casual listening to radio or recorded music is particularly pervasive since it can be combined with many work activities, in addition to being a favored leisure activity. It has been found of particular value in reducing the boredom associated with routine and monotonous activities, and in fact the first objective study of the use of music in industry goes back to the days before commercial radio was established (20). Several studies have been conducted, all of which show either that production in monotonous work increases measurably during periods in which music is provided, or that employee attitudes become highly favorable towards it. One such study by Humes [25] investigated the effects of music on scrappage of radio tubes in a tube-making industry. Unknown to the employees, he followed production during five periods, one with mixed music, one with fast music, one with slow, one with especially selected music, and one with no music. He found that scrappage was greatest in the no-music period, less so in the mixed period, still less in the slow and fast periods; during the non-music period a petition was presented to management by the employees asking for resumption of the music.

The duties of astronauts and astronaut scientists are not comparable to the monotonous piece-work of the industries examined, but music might be found beneficial as an adjunct to some other forms of leisure activity. Steps, however, must be taken to account for preferences in taste and the times when music is available. Kinsey [26] reports on a "juke-box" system in the 'Nautilus' with three selector stations in different parts of the ship, none of which had priority over the others. This system was apparently played virtually night and day over public loud speakers and could be supplemented by high-fidelity tape decks. While such a system may be suitable for the large and widely varying crew of a nuclear submarine it is believed that for a relatively small-crew spacecraft individually controllable outlets would be preferable, with a public system available for special situations.

Radio is also available for other things besides music, notably news, information and personal communication. The importance of the latter has been well attested to, and in fact personal communication between astronauts and their families has been a feature even of the short-duration missions to date.

Apart from the use of TV as a news and information medium, TV and movies present much the same characteristics, notably that they each require conscious observation, as opposed to radio and recorded music which can be utilized as a background. Thus, TV and movies can be reserved for specific timed entertainment; and, in fact, to enhance their value (and incidentally reduce the requirements for bulk storage) it might be wise to restrict their presentation as entertainment to once, twice, or thrice weekly occasions only. In nuclear submarines, with large crews, movies have been presented twice nightly with great success [26], but for small crews of spacecraft this is not only unnecessary but logistically infeasible. In this connection, Kinsey [26] makes the interesting, but dubiously validated suggestion, that the selection of a few poor quality movies is desirable, not only to make the good quality appear better by contrast, but to mobilize, activate, and release anxiety, particularly that occurring from a more or less repressed feeling of hostility.

Reading probably provides the greatest potential diversion, and of course can be varied from light escapist reading material, through significant literature, to advanced technical. Again, however, the logistics involved for a long-duration mission present great problems. No doubt pre-selected reading material could be reduced to microfilm, but prolonged microfilm reading is very unsatisfactory for the reader, and the current display apparatus is bulky. Perhaps it might be more feasible to prepare specially printed small lightweight texts, or to utilize a high-resolution TV type display, or even to convert reading material to audio and present it through earphones.

One form of leisure activity that has not been discussed is that of exercise. There is little doubt that exercise in some form or other is not only desirable for subjective well-being, but perhaps also essential for maintenance of physiological integrity, particularly if no provision is made for the production of artificial gravity [28]. The opportunities for obtaining adequate exercise within the confines of a spacecraft are considerably limited, but it would seem necessary to set aside some portion of the public area to double as a gymnasium. Recent studies of requirements for relatively long-term orbital missions have included the provision of exercise areas and equipment within the configurations delineated [12, 19]. Equipment might include isometric exercise devices, bungee cords, and specially fabricated exercycles, while if artificial gravity were available, Swedish-type exercises would be of value.

In summary of the above discussion, the most significant factor is that leisure activity should not be considered merely a way of filling in time. By selection of suitably inclined individuals, and provision of an appropriate climate and opportunity, encouragement should be given towards the creative use of leisure for the self-development of the persons involved. Provision should also be made for some recreation, both active as in hobbies, communal games, and music-making, and passive as in listening to recorded music and radio, watching TV and movies, and reading. Provision for exercise programs is also required. Particular care should be taken in searching out the needs of the individuals concerned and providing for them where feasible. At the same time it will be remembered that persons selected for this type of duty will tend to be those persons who will seek and make the most of such leisure activities that are available within the limitations of their surroundings.

The foregoing discussion has focussed attention on certain aspects and some of the intangible features of habitability. It must not be construed, however, that these are the only features of habitability, or even the most important. This is certainly not so. But when the major requirements of the primary factors have been attended to - the provision of protective shelter, breathable atmosphere, thermal neutrality, toxic and waste management, food and water supply - the less tangible factors become relatively more significant.

There are subtler aspects, however, even of these primary factors, which as yet are not open to a clear answer. It is obvious that an environmental control system should provide an environment that is not hazardous and also subjectively acceptable. However, should it perhaps vary its qualities from time to time - vary in pressure, temperature, and even relative toxicity - or is environmental neutrality an ideal state?

Similarly, with respect to problems of force and motion, it is obvious that occupants of a spacecraft should be protected from hazardous acceleration and vibration, but the significance of weightlessness, particularly for very prolonged periods, and the requirement for artificial gravitation is still far from clear. Intuitively, ideal habitability would approximate the best found on earth, and consequently artificial gravitation would seem desirable for long-term space missions, but the evidence on which to make such a recommendation is not yet available.

Similarly, with respect to noise, the damage risk criteria are established for 8-hour day industrial situations, but little is known about long-term continuous exposure, not only from the point of view of possible hearing loss, but from the point of view of performance. Yuganov and his associates (57) point out that the basic acoustic noise of a spacecraft cabin during the course of a mission is created by the continuously operating units of the environmental control system. The noise is characterized by stability both in amplitude and spectral composition, and acquires the nature of monotonous and unpleasant stimulus which, under conditions of prolonged space flight, may give rise to "inhibited processes in the central nervous system". Thus, it may be necessary to control not only the maximum level of permissible noise in a spacecraft cabin, but to provide for random variation in amplitude and spectral composition of the noise that is continuously generated.

In another area, one of the factors of primary importance is that of nutrition. Again it is obvious that provision of food and liquid of high nutritive quality and adequate quantity is mandatory, and that individual preference is influential in determining what is acceptable. From the point of view of long-term habitability, however, presentation of food will no doubt assume considerable significance. In contemporary civilized cultures eating is more than supplying fuel to meet the needs of body metabolism. To many, the eating of meals is a divertive entertainment, and to most the meal occupies the position of a threshold dividing one portion of the day from another, and has connotations of ease, comfort, and stability. Consequently, the provision of characteristically recognizable foodstuffs, the formalization of meals, and presentation in familiar modes can provide a stabilizing influence and create an atmosphere readily identifiable with terrestrial conditions.

One of the major factors indirectly influencing the habitability of a spacecraft for a long-duration mission is that of man himself, and his inter-relations with his fellowman. Since the subject of small group interpersonal relationships is vast in itself and somewhat peripheral to the immediate discussion, it will not be considered at this time, except to point to the excellent bibliography prepared by Sells [42], and his work on developing a model for the social system for a multiman extended duration spaceship [43], along with the discussions on social relationships in spacecraft by Kubis [27], and in submarines by Weybrew [53], among many others.

In conclusion, the purpose of this study was to draw attention to some of the less tangible factors involved in the creation and maintenance of a habitable spacecraft environment, and not necessarily to solve the problems arising therefrom. The intangibles will tend to remain intangible, and in fact the problems they create may never be really defined, but progressively succumb to the evolutionary development of long-range spacecraft. At the same time, care must be taken not to create mystery where none exists. As Lieutenant Commander Ebersole remarked aboard the nuclear submarine 'Seawolf': "If there had been a psychologist on the Santa Maria they wouldn't have made it!"

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