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16. Abstract

Second-generation general-use aerospace transportation vehicles will evolve, and aerospace medical specialists must provide timely medical criteria for (a) occupant selection, (b) vehicle design features, and (c) operational guidelines. Incorporation of this aeromedical data will result in (a) enhanced mission success and mission efficiency, and (b) minimized opportunity for mission failure, accidents, and long-range adverse consequences due to human factors deficiencies. The data include medical standards for the occupants plus standards for oxygen, nitrogen, carbon dioxide and monoxide, humidity, heat, water vapor, internal noise, radiation, and other items.

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CIVIL AEROMEDICAL STANDARDS FOR GENERAL-USE AEROSPACE TRANSPORTATION VEHICLES

The Space-Shuttle Follow-on

I. Introduction.

A follow-on to the planned first-generation space shuttle and orbital facility system will provide a means of placing distinguished scientists and other persons in earth orbital facilities for periods lasting potentially for many months. Selection criteria with respect to astronaut clearance for space flight will be, in many cases, a barrier with respect to clearance for space flight of non-astronaut personnel. Accordingly, carefully developed standards for non-astronaut personnel must be defined to assure that all of those having legitimate reason for space flight are able to participate, consistent with individual biological and physical conditions.

The second-generation aerospace transportation vehicle system is projected to involve: 1) a manned reusable booster: 2) a shuttle spacecraft which is capable of returing from orbit for an aero-dynamic non-parachute earth landing; and 3) a manned earth-orbital facility.

These second-generation vehicles will very likely become operational well before the end of this century. Considerable planning in this effort is now underway by engineering personnel. It is the purpose of this paper to delineate some of the medical parameters which can be established as tentative guidelines for use by engineers and operational personnel with respect to the safe carriage of that segment of the public having valid reasons for transport in these vehicles (over and above crew members).

Civil air transportation vehicles have been certified as airworthy for safe passenger transport by the United States since 1926.[1] The evolution of these vehicles has successively presented the licensing authorities with increasingly changing environments necessitating revised airworthiness standards and operational practices.[4] The latest example in civil aviation is the supersonic transport which operates at the fringe of space and for which tentative airworthiness standards have been issued by the U.S.[2] [3] The general-use aerospace transportation vehicles utilized for the carriage of non-astronaut members of the public will similarly be subjected to man-rated criteria and will be licensed by the responsible Federal authority in accordance with aerospaceworthiness standards. In addition, occupant physial standards must be defined which enable appropriate pre-flight screening.

The three major components of the general-use aerospace transportation system are as follows.[6] The booster prototype is projected to have a length of approximately 80 meters, an operational empty weight of 200,000 kilograms, a landing speed of approximately 150 knots, and a crew of two astronauts. Airbreathing jet engines may be used to assist in landing. The shuttle vehicle is projected to be approximately 60 meters in length and, in the empty configuration, to weigh approximately 88,000 kilograms. Its landing speed upon return to earth is projected to be approximately 160 knots. For the shuttle vehicle, a crew of four astronauts and a passenger load of about 20–22 individuals is hypothesized. For the orbital facility, within which personnel may remain for periods of three months to one year, a crew of approximately 30 and a non-crew complement of 35–40 are projected. Personnel departing as non-crew members for accommodation in the orbital facility may include astronomers, chemists, biologists, geographers, meteorologists, family members (later development) and others. (See Table One.)

II. Aerospace Medical Standards.

The following tentative aerospace medical parameters (not meant to be fully encompassing) are seen as necessary and are based in part on

Table I.—Orbital Facility: Hypothetical Crew/Other Occupant Make-Up*

Commander-Astronaut	1	
Astronauts	6	
System Specialists	6	
Atomic Specialists	3	
General Operating Technicians	4	
Surgeon-Pathologist	1	
Space Medical Officer	1	
Space Nurse-Technician	2	
Dietician/Assistant Dietician	2	
Physical Plant-Sanitation	4	
Total	30	30
Scientists	6	
Technicians	6	
Secretary-Administrative	3	
Total	15	15
Observers, short-term scientists, newsmen, historians, other**	22	
Total	22	22
TOTAL		67

*Any of these may be male or female

**For cooperative International efforts, includes interpretors

prior analyses.[8] These selected topics are presented here primarily as general take-off points with respect to later, more specific and detailed, medical parameters. These are for the purpose of initiating medical thinking within these broader areas with respect to passengers in aerospace transportation vehicles.

Sex: Representatives of both sexes are acceptable.

Skeletal System: Persons with osteoporosis could encounter difficulties in re-adapting to a one g environment following prolonged orbital flight; osteoporosis would be, therefore, disqualifying. One reason for highlighting osteoporosis is that earth orbital and lunar missions have demonstrated that a measurable degree of bone decalcification accompanies exposure for prolonged periods at zero g environment. Osteoporotics would be expected to experience additional bone loss which they could possibly ill-afford. Certain exceptions following earth-based studies may be made.

Endocrine System: Initially, no diabetics requiring insulin should be considered due to the lack of support facilities in the early stages of orbital vehicular flight. Ultimately, controlled diabetics may be cleared.

Neuro-psychiatric Aspects: Epileptics, alcoholics, addicts, psychotics, and persons with personality disorders would not be cleared. The term "personality disorder" would be used in this context to indicate individuals who were incapable of serving as members of the relatively small-sized confined orbital group.

Problems in relationship to theft, uncontrollable hostility, overt uncontrollable aggressive acts and other extreme characteristics are included. It may be that certain unusual personality characteristics would be desirable for occupants. These would include tolerance to long periods of monotony and isolation and abnormally controlled emotional qualities. Also, unusually strong feeings of security in an enclosed and isolated environment may be an asset.

Cardiovascular System: All occupants should receive clearance on the basis of a stress-cardiovascular test program. Ultimately, coronary occlusion may be cleared if recovery is adequate. No untreated or advanced anemics or leucopenics could be cleared until the conditions are rectified. Hypertensives in excess of 170/96 or hypotensives below 90/60 millimeters mercury would initially be screened. No uncontrollable cardiovascular dysrhythmias would be cleared.

Renal: No advanced glomerulonephritis would be cleared and stone-formers would be screened out. In the development of bone demineralization under weightlessness conditions a certain amount of calcium is excreted in the urine above that normally discharged. Accordingly, if an individual has such conditions as pyelonephritis, ureteral strictures, and an enlarged prostrate gland, or other renal condition which may lead to stasis of urine, corrective therapy should be accomplished prior to clearance for a mission. Calcium or uric acid stones may form under the above circumstances and also inflammatory conditions can develop.

Pulmonary: No significant emphysema, no lung blebs, and no significant bronchiectasis would be allowed. If lung blebs are present, some consideration could be given to providing clearance for a mission by previous ground studies utilizing an altitude chamber as is done now with aircrew members.

Skin: No extensive contact dermatitis history and no person with an infectious dermatitis tendency would be cleared. If dandruff therapy for a given individual may be forecast, he must show prior therapeutic success with given techniques. Seborrheic dermatitis is the underlying basis for dandruff and the need for appropriate care of seborrheic dermatitis was one of the findings in the Apollo lunar flights. In prolonged space missions there is the possibility of a complicating infectious dermatitis and potential incapacitation if this condition is severe.

Gastro-intestinal: No colitis, unhealed peptic ulcers or irritable GI tract difficulties would be cleared. Dental-oral organs must be appropriately treated for space flight conditions prior to departure.

Senses: All of the sensory functions should be within the ranges considered normal for the age of the individuals. If there is a history of conjunctivitis, successful prior therapy must be established. It was found in the Apollo missions that conjunctivitis became an unanticipated annoyance. This conjunctivitis may have resulted from a number of factors which are associated with confinement for prolonged periods in sealed weightless environments. These could involve conjunctival contact with tiny particulate matter which remains suspended in the weightless state. Persons prone to conjunctivitis can experience a follow-on blepharitis and visual difficulties ultimately leading to incapacitation. Attention to these tendencies must be given prior to departure. The vestibular organ should be tested prior to departure during the medical qualification period for hyper-sensitivity to angular accelerations.

Age: Although advanced age would, of course, be a restraining factor, certain attributes of maturity have been identified as desirable for space missions, assuming that appropriate compensations are effected.[11] Weightlessness effects on growth of children and adolescents are not yet adequately assessed.

From the pre-flight standpoint, non-crew members will require careful medical evaluation, and, following clearance by certain criteria, should be fully briefed with respect to the forthcoming trip. This briefing should include the use of motion pictures, sound effects, and simulator experience. Each passenger should be provided with a personal means of exercising and light sedatives should be tried for idiosyncrasies prior to the trip. Some advance planning concerning recreation should be discussed as should arrangements concening personal finances prior to departure. In general, each accepted occupant would ultimately be termed "physically and psychiatrically oriented for space flight." Each accepted occupant will receive instruction in the space context concerning personal hygiene, dental hygiene, toilet factors (urine, feces, menstruation) and morale. For the medical aspects with respect to passengers (which may also include individuals drawn internationally), the pre-determined guidelines would involve individual assessment by an aerospace surgeon.

From the medical standpoint, it is noteworthy that all of the manned space flight activities as of the present time have demonstrated that weightlessness has not presented the manifold medical difficulties previously predicted by early theoreticians.[9] The possibility of rotating the space facility to create an artifiical gravity is considered.[8] However, coriolis forces could stimulate vestibular vertigo under these circumstances, especially during rapid head movements contrary to the rotation. Perhaps a subunit of the station can be spun at a relatively rapid rotational velocity, with each occupant spending a small percentage of each day standing in the unit with a relatively rigid posture. This will foster maintenance of gravitational physical conditioning.

III. Life Support and Protection Standards.

The aerospace transportation booster and shuttle will primarily serve as vehicles for transporting crew, passengers, and cargo to the orbital facility. The orbital facility will constitute the habitat for the occupants and in the second generation version may remain as stated for periods up to, and in excess of, one year in earth orbit. Accordingly, in addition to the occupant standards and aeromedical briefing factors, certain environmental and design features require delineation for the guidance of design engineers and operating personnel.

The above standards include radiation standards for those sources of radiation which can be controlled (or avoided). For terrestrial individual radiation workers, the standards have been placed at 5 rems/year and for terrestrial individual general population members, 500 millirems/year. Second generation space facilities should be designed for limits consistent with the radiation worker upper limit until more information is available suggesting otherwise. This applies to self-contained nuclear auxiliary power unit shielding plans and consideration of other sources of radiation. Recently tendered radiation standards for space-mission and vehicle-design studies involving nuclear systems, are considered excessively high for passengers of general-use aerospace transportation vehicles.[5] Some of the occupants may have received pre-mission medical radiation exposures, limiting their orbital stay.

Environmentally, an interior atmosphere of 80% nitrogen, 20% oxygen, at a sea-level pressure, is an optimal design criterion. The U.S.S.R. Vostok and Voskhod spacecraft were provided with such an atmosphere.[8] A separate smoking-room with scrubbed air for those who cannot break the tobacco habit is recommended, containing a bar facility, judiciously stocked with low-congener, quality, beverage for morale purposes with respect to that segment of the occupants who may have need of such a facility. The low-congener alcohol beverages will not only minimize hangover effects and subsequent performance derogation, but also will minimize the space-cabin air-borne contaminant problems.

The atmosphere within the overall facility will require certain active controls, which, in addition to removing dust, odors, and the metabolically produced carbon dioxide, will monitor, through the use of miniaturized sensor systems, and remove, specific trace substances. These trace substances, irritating and potentially noxious, may consist of acetylene, carbon monoxide, sulphur dioxide, and various aliphatic and aromatic hydrocarbons plus certain other inorganic substances. (See Table Two.) The miniaturized sensor system may utilize a mass spectrometer and/or a type of gas-chromatograph. As can be seen, the "out-gassing" product classes yielded by materials and man relate to the categories of alkanes, alkenes, alcohols, ketones, aldehydes, alkyl and aryl halides, aliphatic nitrogens, and carboxylic acids. In addition, benzene, silicones and inorganic substances are involved. Lubricants can yieuld chlorine substituted fluoro-carbons, polyurethane yields CO_2, resins may yield ammonia, and coatings may out-gas plasticizers and solvents. The Threshold Limit Values for air-borne contaminants prepared by the American Conference of Government Industrial Hygienists (1970, 1014 Broadway, Cincinnati, Ohio) may be used as a rough guide with respect to spacecraft atmospheres, but it must be stressed that these values are developed for 8-hour work day, 40-hour work week exposures. Necessarily, space station occupants will be exposed 24 hours per day for long periods, requiring lower Threshold Limit Values in many cases.

TABLE II.—Illustrative Trace Contaminants which are of Significance to Orbital Facility Atmospheres

Derived from Man	TLV* less than:
Acetaldhyde	200 ppm
Acetic Acid	10 ppm
Acetone	1,000 ppm
Ammonia	50 ppm
Carbon Monoxide	**10 ppm
Ethyl Alcohol	1,000 ppm
Hydrogen	dangerous
Hydrogen Sulfide	10 ppm
Mercaptans	10 ppm
Methane	dangerous
Methyl Alcohol	200 ppm
Methyl Ethyl Ketone	200 ppm

Derived from Materials	TLV* less than:
Benzene	25 ppm
Butane and Derivatives	dangerous
Butyl Alcohol and Derivatives	100 ppm
Carbon Disulfide	20 ppm
Chloroform	50 ppm
Cyclohexane	300 ppm
Dichloroethane and Derivatives	50 ppm
Dichloromethane	500 ppm
Ethane	dangerous
Ethyl Acetate	400 ppm
Ethylene	dangerous
Formaldehyde	5 ppm
Fluorotrichloromethane	1,000 ppm
Methyl Iso-butyl Ketone	100 ppm
Pentane	dangerous
Propane	dangerous
Propyl Alcohol	200 ppm
Propylene imine	2 ppm
Toluene	200 ppm
Trichloroethane	350 ppm
Trichloroethylene	100 ppm
Xylene	100 ppm

*The Threshold Limit Values presently available (1970) are based upon an 8-hour day, 40-hour week, occupational exposure. TLV's for 24 hour spacecraft internal atmosphere exposure may necessarily be considerably lower (see text). TLV's are parts of vapor per million parts of contaminated air by volume at 25°C and 760mm Hg pressure.

**Eight-hour day, 40-hour week occupational exposure is 50 ppm.

Carbon dioxide levels should be maintained below 3.8 mm Hg partial pressure which at sea level is 0.5% of the atmosphere, and carbon monoxide must be maintained at levels below 0.001% (10 parts per million by volume). Strategically located occupant-accessible emergency oxygen supplies and masks should be available to all occupants in the event of accidental increases in the atmosphere within any of the aerospace transportation vehicles of high levels of toxic substances or, conversely, the development of low levels of oxygen. Portable walk-around oxygen equipment should be available for safety purposes. The supply of oxygen should be commensurate with the calculated duration of pressurization emergency circumstances. In addition, "explosive" failures of various compartments within the pressure vessels of the vehicles may occur, and techniques for personnel transfer from one compartment to another must be a design feature. These circumstances would involve selective airlock facilities, light-weight body protective material (silvered polyimide), and emergency food and water rations in each compartment. These approaches would serve in the event of structural damage by meteorites or intrinsic pressure vessel tears, and would help retain occupant viability until repairs or shuttle departure are effected.

A separate, independently ventilated, compartment for the isolation of ill persons is necessary, especially with respect to those with infectious disease. For the bodies of those who may die, a suitable morgue facility with appropriate preservatives is necessary. Later detailed study of all of the tissues of any deceased will be extremely important in revealing the long-term effects of space-flight on man and of critical significance to the well-being of space travelers.

In order that the liquid and solid excremental wastes are processed in an effective manner, organic bactericides, together with inorganic viricides and fungicides, supplemented by heat, and other methods are planned.[10] In addition, inorganic agents which include the halogens and certain heavy metals, may be utilized. Jet transport aircraft and shuttle vehicles are suitable for incorporation of urine recycling systems with respect to toilet flushing.

The orbital space vehicle may incorporate special liquid sources for toilet processing. Water reclamation processing may be accompliished with respect to liquid human excrement, ultimately resulting in a potable water distillate. Means of assuring potability of this water through molecular monitoring and microbial checks may be necessary. All urine hormones, enzymes, kinins, urochromes, mucins, casts, bacteria, cells, proteins and other substances, including aromatics, must be removed. Occupants during booster operations may not have, during certain portions of flight, the freedom to proceed to and from toilet areas. Pre-flight partial dehydration and low residue intake may become an operational feature prior to booster departure. This will accommodate any periods of "holding" during the pre-blast-off phase.

Since accelerations and decelerations are not anticipated to exceed 3 g's during ascent and reentry, this aspect is of relatively little medical significance. Noise and vibration levels in the orbital facility should be damped to the extent possible, especially in sleeping quarters where these levels should not exceed 40 dB. Optional music at various stations would appear desirable. Adjustable interior temperature and humidity levels of 20–22°C and 50–60% are design objectives.[7] Since in the weightless environment there is no natural heat convection, forced air drafts are necessary, adjustable but not, in general exceeding comfortable flow velocities. Ten cubic feet per minute per individual may serve as a minimal circulation guide, adjustable downward, or upward by a factor of two, with local flow controls adjustable upward by a factor of four.

Interior colors should be selected on the basis of available psychological knowledge. The colors selected for the recreation and work areas should be compatible with area use. Interior pastoral and other scenes for decor and satisfaction may be tried and opportunities to exercise distant vision should be frequent to avoid acquired myopia. Private areas should be arranged for each occupant, free from any distractions during periods of individual study and contemplation. All areas should have controllable "white" illumination.

It is of significance to plan for a quality interior in all three vehicles of the second- generation general-use aerospace transportation system. Electrical wiring, switches, conduits, hydraulic systems, servomotors, panels, interior walls, furniture, foodware and other items must all be of the highest quality and constructed insofar as technologically feasible of highly inert, fire-resistant materials. Off-the-shelf items obtained primarily on the basis of low unit cost and ready availablility should be proscribed in all but the most carefully assessed circumstances. Polyimide, polyamide, and other advanced materials, must be considered for utilization in these vehicles.

Eight-hour duty shifts in the orbital facility are envisioned, with artificial daylight possible on each shift. It is feasible that circadian rhythms can be phased appropriately for each shift, precluding dysfunctions and performance impairments.

Incorporation of the available aerospace medical data in the design, operation and occupant selection programs for the general-use aerospace transportation vehicles will help assure certification by the responsible regulatory authority and safety of repetitive missions.

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