DESCENT AND LANDING OF SPACECREWS AND THEIR SURVIVAL IN AN UNPOPULATED AREA

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Introduction

From a medical vantage point, the principal problems of concern in the reentry and landing phases of manned space flight are those associated with the acceleration forces experienced as the spacecraft reenters the Earth's atmosphere and at the moment of impact. Following a safe descent and landing, the primary requirement is to ensure the safety of the crew until the time of recovery. While in the vast majority of cases spacecraft and their crews have been recovered quickly, on land (USSR) or sea (USA) it is conceivable that this period could be extended by difficulties which might be encountered with the spacecraft manual landing systems, by a breach in radio communications, by inclement weather or heavy seas prevailing at the time of splashdown, or landing in inaccessible places.

The physiological effects of accelerative forces are dependent on a number of factors including the magnitude, direction, duration and other variables surrounding the exposure. With respect to the acceleration forces experienced in the final phases of manned space flight, this chapter will be confined to the specific medical and physiological experience gained in the space flight programs in the United States and the Soviet Union. ~~In the former case,~~ Mention will also be made of the application of this knowledge to certain future programs.

The topic of survival in the post-landing period will be treated in the context of the rather extensive research which has been conducted to define and solve the problems likely to be experienced during a post space flight survival sequence. Finally, a brief description will be given of the survival provisions currently made for spacecrews.

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Considerations Regarding Acceleration ~~in the U. S. Space Flight Program~~

Project Mercury, the first series of U. S. manned space flights, consisted of 25 major flight tests, six of which were manned. These six flights, the latter four of which were orbital, provided the highest G-loads in descent and landing encountered in the U. S. manned spacecraft program. The Mercury spacecraft was equipped with a contoured couch specially designed to provide maximum comfort and protection during reentry and landing. In the Gemini capsule, the support and restraint system was more conventional and the reentry forces lower than those experienced in the Mercury Program. Reentry forces experienced by the Apollo crews depended upon the mission, being more extreme following a lunar mission than following an Earth orbital mission. Lunar mission reentry accelerations approximately equalled those experienced during Gemini missions.

In these manned space flights and in the Skylab Earth orbital flights, the most recent phase of the U. S. space flight program, reentry and landing acceleration forces are directed in the transverse ($-G_x$ or eyeballs-in) direction. However, future programs incorporating reusable boosters and orbiting spacecraft may impose positive accelerations ($+G_z$ or eyeballs-down) on the crew and passengers. In the following pages, data concerning reentry and landing accelerations in the Mercury, Gemini, ~~and~~ Apollo + Soviet Programs will be reviewed. Also, results will be presented of recent studies directed toward the problems of physiological tolerance to the positive acceleration vectors expected in future programs.

The Mercury Project

While the majority of the acceleration and impact studies conducted in the 1950s were not directed specifically toward answering questions concerning manned space flight, the information derived from these studies was usefully applied to the Mercury Program. A review of acceleration physiology which summarized work up to the time of the Mercury flights was prepared by Gauer and Zuidema in 1961 (11).

Extensive studies of physiological tolerance to acceleration and impact were conducted at the Aeromedical Field Laboratory, Holloman Air Force Base, New Mexico; the Aeromedical Laboratory at Wright-Patterson Air Force Base, Ohio; and at the U. S. Navy's Aviation Medical Acceleration Laboratory, Johnsville, Pennsylvania (23,24,31,32,33). These studies identified the need for increasing human tolerance to the deceleration and impact forces that could occur in space flight, particularly in the event of an abort reentry and landing. Numerous protective methods were examined and evaluated. One device that provided the necessary G protection and also possessed the required characteristics of smallness, lightness and sturdiness was the fiber glass contoured couch developed at the Langley Aeronautical Laboratory in Virginia. In studies of the couch and of various body angles in relation to transverse acceleration loads conducted at the Aviation Medical Acceleration Laboratory, two subjects successfully tolerated 20 Gs, one for a period of six seconds (25). This G load was far higher than the expected nominal reentry for the Mercury spacecraft; however, an abort reentry using the Mercury escape system could subject the astronaut to a 20-G reentry acceleration load. The Mercury escape system consisted of a solid propellant escape rocket mounted on the top of a tower attached to the spacecraft. In an abort the escape rocket would lift the spacecraft sufficiently high to allow deployment of a parachute.

During training sessions at the Navy's Johnsville centrifuge, the Mercury astronauts completed mission acceleration profiles ranging from 8 to 18 Gs with no adverse effects. These runs included a 259 mm Hg, 100 percent oxygen atmosphere in the gondola, and simulated flights were made with and without the pressure suit inflated. During these training sessions, the astronauts learned breathing and straining techniques to increase tolerance at the higher G levels (21).

Impact problems identified early in the Mercury Program were alleviated by employing a fiber glass fabric bag which attenuated the landing impact forces by forming an air cushion between the spacecraft structure and the deployed ablation shield. Water landing impact forces were reduced from approximately 50 G to 15 G by this method.

The United States' first manned space flight was a suborbital flight by Astronaut Alan B. Shepard, Jr., on May 5, 1961. The acceleration profile for this mission is shown in Figure 1. As shown in the figure, a maximum G load of 11.0 G was reached during reentry. Landing impact forces were not measured but were estimated at 12 to 14 G (16). There were no adverse physiological effects resulting from the reentry and landing of the spacecraft. Table 1 summarizes the Mercury project missions and shows the maximum G level reached during reentry on each of the manned flights.

Fig. 1

Table 1

The success of the Mercury project and the early Vostok flights provided assurance that man could function in space, and could withstand the physiological stresses of reentry and landing following short periods in the weightless environments. In the six Mercury flights, astronauts were capable of normal physiological function and performance during reentry. Vibration and noise levels were well tolerated. There was no disorientation or nausea associated with reentry or landing. Heat loads, while on occasion uncomfortable, were no problem during reentry of the spacecraft. The peak heart rate during reentry occurred immediately after reaching peak reentry acceleration, or on drogue parachute deployment, and ranged from 104 to 184 beats per minute (2).

The Gemini Project

Project Gemini spacecraft systems provided for controlled reentry whereby the spacecraft was brought to a specific landing area. Table 2 briefly summarizes the 10 manned Gemini missions and lists the maximum G load experienced during each. Table 2

The original objectives for the Gemini spacecraft called for land landings; however, when problems in the development of the land landing system threatened to delay the overall program, the backup water landing system was used. This system utilized a 2.4-m diameter drogue parachute followed by a 5.5-m diameter pilot parachute and a 25.6-m diameter, ring-sail main parachute. After deployment of the main parachute and attainment of nominal velocity, the spacecraft was repositioned by rotating from a vertical position to a 35° nose-up position for landing. This attitude with respect to the water resulted in landing impact forces well below the maximum tolerated by crew and spacecraft in earlier test sessions.

The landing impact did, however, vary from a very soft landing to a heavy shock. The variance resulted primarily from the oscillation of the spacecraft and the particular point of oscillation the spacecraft was in when touchdown occurred. The wind, size of waves, and part of the waves contacted contributed to the impact; however, even the most severe landing did not affect crew performance.

The Gemini spacecraft was provided with ejection seats as an emergency escape system in the event of a launch vehicle failure, and as a backup landing system if the main parachute failed. If the spacecraft had reentered over land, the ejection seats would have been the primary landing system.

Figure 2 presents the reentry profile of Gemini 4. The reentry acceleration level reached, 7.7 G, was the highest experienced by any crew in the Gemini project. This was still, however, well below the 11.1 G of MR-4 and far lower than the G levels willingly tolerated in centrifuge training sessions. Fig. 2

A concern expressed by many was that the long periods of weightlessness prior to the deceleration stress of reentry would result in a decreased tolerance to G loading. An increased G sensitivity was noted by all three long-duration mission crews. Each crew felt that they were under a load of several Gs when, in fact, they were just beginning reentry. However, at peak G load, the sensation was the same as in centrifuge simulations.

Peak heart rates during reentry ranged from 90 to 180 beats per minute. Peak heart rates appear to be somewhat higher for longer duration missions reentry. However, no cardiovascular problems were observed during any Gemini reentry (3).

Incidentally, the Gemini project objective of providing a controlled reentry in a specific landing area was attained with an impressive degree of accuracy. Table 3 shows the landing accuracy of each Gemini mission. Table 3

The medical knowledge gained in Project Gemini and the Voskhod missions provided assurance that man could successfully live in space and accomplish those tasks necessary to attempt a lunar mission.

The Apollo Program

Reentry G levels for Apollo missions are shown in Table 4. As may be seen, acceleration levels for Earth orbital missions, Apollo 7 and 9, were about one-half those of lunar missions. Neither reentry mode results in any medically significant physiological stress. The greater reentry lift capability of the Apollo spacecraft over its predecessors accounts for the much lower acceleration forces. Acceleration levels of an Earth orbital and a lunar mission reentry are presented in Figures 3 and 4.

Table 4

Figs. 3 and 4

While nominal reentry G levels have been well tolerated by the crew and pose no severe constraints on crew performance, an Apollo launch abort could result in G_x acceleration levels as high as 16.2 G with an oscillating 1/2 Hz component ranging from $-1\ G_z$ to $+3.2\ G_z$. Such abort acceleration levels in all probability could be endured without injury by crewmembers experienced in acceleration tests and protected by the Apollo couch and restraint system. It is very doubtful, however, that spacecraft control tasks could be adequately performed under such conditions and, for this reason, crew tasks have been minimized during abort reentry. The Apollo spacecraft abort escape system is similar to that used in the Mercury Program, consisting of an escape rocket separated from the attached spacecraft by a tower. The rocket serves to lift the Command Module away from the booster and high enough for parachute deployment.

Another factor that must be considered in evaluating physiological effects of reentry is the condition of the astronaut at the time of reentry. Crewmembers are exposed to many stresses during a mission, including weightlessness, confinement, dehydration, changing illumination, a 100 percent oxygen (259 mm Hg) atmosphere (U.S. flights), vibration, and fatigue. Acceleration tolerance appears so far to be unimpaired by space flight factors. However, the cardiovascular and musculoskeletal changes associated primarily with weightlessness could conceivably influence acceleration tolerance following long duration missions.

The Apollo spacecraft landing system employs three parachutes and the repositioned command module system used in the Gemini Program. The spacecraft enters the water at a 27-1/2° angle on a nominal landing. The most severe impact experienced in an Apollo space flight to date occurred with Apollo 12. It was estimated that the Command Module entered the water at a 20 to 22° angle which produced a 15 G impact (1). This entry angle resulted when the wind caused the spacecraft to swing and meet the wave slope at the more normal angle. On impact, a camera detached from the mounting bracket and struck a crewman over the right eyebrow. The astronaut lost consciousness for approximately five seconds and received a two-centimeter laceration which was sutured following retrieval. The injury healed normally.

While the 15 G impact of Apollo 12 was described as very hard by the crewmen, no physical difficulties were experienced other than the cut forehead mentioned above. Apollo landing impact studies involving 288 human tests were conducted on a linear decelerating device at Holloman Air Force Base (7). These tests involved impact forces up to 30 Gs at various selected body orientations. Although significant effects to the neurological, cardio-respiratory, and musculoskeletal systems were recorded, none of the tests resulted in significant incapacitation or undue pain. An excellent review of human impact tolerance was published by Snyder in 1970 (22).

The Skylab Program

Following the Apollo lunar landing program, a space laboratory was launched and visited upon three separate occasions by three-man crews. This project, called the Skylab Program, had as a primary objective the conduct of a series of medical experiments to evaluate man's physiological responses to long duration space flight. The duration of the first mission of the Skylab Program was planned for up to 28 days; the second and third missions were planned for up to 56 days. Apollo Command Modules served as spacecraft for reaching and returning from the orbiting laboratory. Therefore, no acceleration or impact problems other than those associated directly with increasing the duration of time spent in space prior to reentry and landing were expected in this Program.

The Skylab Program extended man's time in the weightless environment significantly beyond any mission flown before. The medical evaluations made during this period provided immediate and continuing information relating to each astronaut's physical well-being. In addition to this, the greatly increased volume of the laboratory over previous spacecraft permitted greater movement and exercise capabilities and allowed for more normal daily living patterns.

The Space Shuttle Program

The Space Shuttle Program introduces a significant change in previous spacecraft reentry procedures. This spacecraft will be designed to enter the Earth's atmosphere in a reentry mode that will impose upon the pilot and passengers a $+G_z$ acceleration vector. Trajectory analyses indicate nominal reentry acceleration G levels that are within the tolerance of qualified flight personnel. It is important, however, to investigate these acceleration levels with regard to previous exposure to a weightless environment, and to identify tolerance thresholds in order to establish realistic emergency limits. A study was conducted at the Manned Spacecraft Center, Houston, Texas, in 1970 to assess the physiological effects of $+G_z$ acceleration following one and seven days of bedrest employed as a weightlessness analog. In this study nine healthy (USAF Class III Flying Physical) male subjects ranging in age from 20 to 36 were exposed to +2.5, +3.0, +3.5, +4.0 and +4.5 G_z for 370 seconds or until an established endpoint was reached. The endpoint was loss of peripheral vision, central light dimming, and a verbal request from the subject to terminate the centrifuge run. After establishing a tolerance level in baseline runs, the subjects were bedrested for 24 hours to simulate one day in space, and exposed to the same centrifuge protocol as before bedrest. After a four-day ambulatory recovery period, the subjects were bedrested for seven days and again centrifuged. All subjects were experienced participants in centrifuge tests.

The centrifuge profile consisted of a 0.03 G second ramp to the $+2.5\ G_z$ to $+4.5\ G_z$ level which was maintained for 370 seconds or until the physiological endpoint was reached. The downramp was also 0.03 G/second and included a $+2.5\ G_z$ spike occurring over a 30-second period which represents a maneuver following reentry to place the spacecraft in the normal flying position. The visual endpoint was measured using a standard light bar consisting of green peripheral lights and a red central light. The green lights were 61 cm apart, and the distance from the headrest plane to the light bar was 81.3 cm. The bedrest episodes were conducted in the Crew Reception Area of the Lunar Receiving Laboratory. Strict bedrest was observed and, insofar as possible, a subject was required to remain on his side, stomach, or back with elbows on the bed or at the sides for the entire bedrest period.

Subjects were transported from bed to the 15.2-m radius centrifuge at the MSC Flight Acceleration Facility on a stretcher, and inserted into the gondola in a horizontal position. Each subject was then adjusted to a supine seated position, with the head pointing toward the center of axis of rotation. The centrifuge gimbal was locked in place so that the subject remained in a $+1\ G_x$ environment during the entire centrifuge period. The resulting hypothetical angle of the inertial vector changed from 21.8° at +2.5 G_z to 12.5° at +4.5 G_z.

During centrifugation respiration rate was measured by an impedance penumograph and ECG was measured from sternal and biaxillary sensors. Subjects were instructed not to employ straining or breathing techniques to resist the acceleration since the runs were designed to test acceleration effects with the subject relaxed. No G-protection devices were used in this investigation.

In the baseline run all subjects completed the +2.5 G_z profile; eight, the +3.0 G_z; four, the +3.5 G_z; two, the +4.0 G_z; and two, the +4.5 G_z. After 24 hours of bedrest, all completed the +2.5 G_z profile; seven, the +3.0 G_z; four, the +3.5 G_z; one, the +4.0 G_z; and one, the +4.5 G_z. After seven days of bedrest, seven completed the +2.5 G_z profile; five, the +3.0 G_z; two, the +3.5 G_z; one, the +4.0 G_z; and none, the +4.5 G_z. Not only did the $+G_z$ tolerance level decrease following seven days of bedrest, but all subjects reported a more rapid loss of vision following the seven-day bedrest period. Tables 5, 6, and 7 show the time in seconds each subject remained at the various G-levels prior to terminating the centrifuge run. The average time for all subjects at +2.5 G_z during the baseline run, the post 24-hour bedrest run, and the post seven-day bedrest run was 370 seconds, 370 seconds, and 312 seconds, respectively. The average time for all subjects at +4.5 G_z with the same pretreatment was 103 seconds, 51 seconds, and 17 seconds, respectively.

Tables 5, 6, & 7

The results of this study indicate that bedrest has a significant effect upon tolerance to $+G_z$ acceleration. Because it is believed that bedrest is a realistic analog of weightlessness further bedrest studies, planned and on-going, are being employed to evaluate the effectiveness of various protection measures for increasing $+G_z$ tolerance following deconditioning.

Potentially promising countermeasures to ~~reduce~~ increase acceleration tolerance have been previously reported by many investigators. Those receiving most serious consideration at the present time in the U. S. space program are G-suits and the application of lower body negative pressure in the final days of orbital space flight (6). ~~Continued testing in the final flight of the Apollo series and in~~ data from the Skylab Program is expected to yield important ~~data~~ information regarding the efficacy of these two methods.

~~Considerations Regarding Acceleration in~~ The ~~Soviet Space~~ Flight Programs Vostok Voskhod + Soyuz

Prior to participation in space flight missions, Soviet cosmonauts, like U. S. astronauts, are exposed to acceleration forces as great as and greater than they may experience in actual space flight. According to the statements of a majority of cosmonauts, accelerations were endured with much more difficulty during the reentry phase of space flight than accelerations of the same magnitude during centrifuge training (27). The pulse rate for some cosmonauts during these periods reached as high as 168 to 190 beats per minute. These values, too, were higher than those noted during similar accelerations in centrifuge rotation. Most cosmonauts experienced short-duration visual blackouts during the landing segment of flight. These blackouts were not observed in centrifuge training.

It was also found that accelerations were less well tolerated as Soviet space flight mission length increased. After one day of space flight exposure, heart rates were ten beats above centrifuge training levels; after three- and four-day flights, heart rates were 30 to 32 beats per minute higher; and after five days, these values reached the maximum of 62 beats per minute above those recorded during centrifuge testing in one cosmonaut. These findings gave cause for some concern regarding the effects of long-term space flight on man's ability to tolerate reentry acceleration forces. Consequently, laboratory experiments were conducted to examine the effects of simulated weightlessness on acceleration tolerance.

In one laboratory study, 21 subjects were exposed to G_x accelerations on a centrifuge before and after hypokinesia in the form of strict bed rest for up to 20 days. It was found that following 20 days of hypokinesia, tolerance for the same acceleration force (in this case, 7 Gs) was decreased from a control value of four to five minutes to four to six seconds. Systolic blood pressure was also elevated during the action of acceleration after hypokinesia; it was increased to 70 to 85 percent compared with 54 to 60 percent in control experiments. Further, a significant decrease in visual acuity was noted along with blurred vision and visual blackout after hypokinesia at lower acceleration levels than in controls.

On the basis of this experiment and similar studies*, various approaches were considered by Soviet scientists to increase the resistance of

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* The reader is referred to Chapter 2 - 3 - 2 for details concerning acceleration studies.

cosmonauts to the effects of acceleration after long periods of weightlessness. Among these are properly selected physical exercises, certain pharmacological preparations (including combinations of strychnine nitrate, caffeine, and phenamine), the application of lower body negative pressure in flight, and the use of anti-G suits (12,27).

Protecting the Lives of Spacecrews in the Landing Phase of Space Flight

The accuracy with which spacecraft landing is accomplished has already been described. But even in the most accurate of landings, the crew is not safe from the possibility of medical mishaps until the successful conclusion of the recovery sequence, which is no simple matter in water landings. The history of on-target or near-target landings not withstanding, the possibility still exists, however slight, that a failure in any one of a number of systems could require crews to make emergency escapes or landings in any region of the globe. In view of this possibility, escape and survival equipment is provided in Soviet and U. S. spacecraft.

As added insurance for the safety of spacecrews, research programs are ongoing to define physiological limits and optimum protective devices and procedures for the survival situations possible after abort landings. Again, it should be stressed that a long-term survival situation is extremely unlikely. In U. S. naval experience with the recovery of downed aviators, the longest time recorded until rescue in the last several years has been

24 hours and 45 minutes. With the highly organized, worldwide communication network monitoring the progress of the final stages of a space mission, it can be expected that rescue of spacecrews will always be accomplished at least as efficiently as is the rescue of military aviators.

The rapid rescue of spacecrews may be more difficult perhaps when spacecraft make hard, land landings. Should a space capsule land off-target and in the open sea, it will take longer to recover the crew, but it should be no more difficult to locate them. And, because of the use of modern rescue ships and aircraft and the strategic placement of these rescue vehicles, any delays would be likely to be brief. Landing off-target on land, on the other hand, could complicate the location and rescue process considerably.

Experiments have shown that men can live under the most severe conditions, but individuals who are unaccustomed to climatic extremes may be significantly less able to tolerate these extremes than acclimatized individuals. It is, therefore, important to know the limits of physiological and psychological stability for the unacclimatized individual sujected to environmental extremes so that training and equipment provided are the most effective for sustaining life in a spacecraft emergency.

The most reliable information concerning survival can be gained by studies of man under real-world conditions, equipped as he would be in a genuine survival situation. Research is ongoing to further understanding of environmental effects on the human body in the "survival" situation and the special problems posed by various survival scenarios in which spacecrews could conceivably find themselves. These situations include survival in the desert, in tropical ocean zones, and in the Arctic.

Long-Term Survival

Spacecrews can conceivably be faced with the prospect of long-term survival in arctic, tropical, or desert climates. The problems associated with each are unique. Protection from environmental extremes, principally via clothing and shelter and the maintenance of adequate water and food intake, may be crucial with the relative importance of these factors shifting with the survival scenario. For example, in a desert zone the most important actions will be protecting against injury from the sun and acquiring water; in the Arctic contending with the cold will be most important; in jungles the crew's efforts must be directed primarily to the prevention of tropical diseases (28).

Arctic Survival. As Volovich and Tumanor aptly note (28), cold is the greatest danger to which man is subjected in the Arctic. A crew which has landed in the Arctic region must create protection against exposure to low temperatures and prevent supercooling and frostbite. This first and foremost involves the construction of temporary refuges from materials at hand. In forested regions, such refuges are easily constructed from tree trunks and branches, whereas in the tundra and on drifting floes, snow is a good construction material. Burrows and caves can be excavated from large snowdrifts, and igloos can be constructed from snow blocks. Animal fat and dry moss can be used for heating a dwelling in unforested regions. Along the coast, driftwood can be used as fuel.

The essence of the danger of exposing flesh to wind under cold conditions is illustrated in the well-known "windchill chart," shown in Figure 5. This chart indicates that, under strong wind conditions, the exposed flesh of a survivor may be in danger of frostbite at temperatures in the order of 10^{O}F. Fig.5

It is particularly important to protect the extremities against the cold. Under the influence of cold, body temperature initially changes insignificantly. At the same time, the temperature of the extremities decreases by 18-20^{o}, circulation decreases appreciably, sensation is lost, and finally forstbite occurs at temperatures below the freezing point. Superficial frostbite is common on the face, hands, and feet. Frostbite is the result of crystallization of tissue water in the skin and adjacent tissues. The depth and severity of the injury is a function of the temperature, the chill factor, and the duration of exposure. Exposure of the extremities, usually the feet, to wet conditions at temperatures above freezing for hours or days can result in damage to nerves, muscles, and blood vessels, commonly known as trenchfoot or immersion foot. Immobility of the extremity aggravates and predisposes toward the condition. The onset of frostbite is signaled by a sudden blanching of the skin on the nose, ears or cheeks, which may be subjectively noted as a momentary tingling. If in severe cold, the face, hands, or feet become numb, the beginnings of frostbite have occured. Particular care should be taken not to allow hands to become wet with kerosene, gasoline, alcohol, or other fluids which freeze below 32^{o}F. These will quickly cause frostbite and freezing. Footgear must be roomy in order to permit easy movement of the toes for continuous flexion and extension to increase circulation which delays frostbite and freezing.

Clothing is of great importance at subarctic and arctic temperatures. The primary function of this protective clothing is to ensure adequate ventilation for the escape of both insensible and sensible perspiration and to provide an insulating zone of dead air space around the body. This zone must be compartmentalized in sufficiently small pockets so that currents of air will not be set up by movements of the body, dispersing heat (9).

Dry multilayered clothing has excellent heat insulating properties; but they are lost rapidly as the clothing becomes wet. Caution must be exercised to avoid profuse sweating, because during later periods of diminished activity, excessive heat loss occurs when the vaporized perspiration condenses on the cold outer cloth, thereby permitting direct heat transfer by conduction. Because retention of vaporized perspiration in clothing diminishes the effect of the sweat mechanism in cooling the skin surface, increased production of perspiration ensues and a potentially dangerous situation develops.

Man's energy expenditures at rest under arctic conditions rarely exceed the usual expenditures; that is, those observed in the middle latitudes. However, the performance of physical work in heavy clothing or in a deep snow cover, impeding movement, greatly increases energy expenditures. Therefore, an individual may find himself wearing more insulation than he needs during work and less than he needs at rest. In order to reduce sweating and, accordingly, moistening of the inner layers of clothing, some clothing may be removed and the cuffs and collar unbuttoned when physical work is performed.

Frostbite injuries should be treated immediately to prevent progression to freezing injury. Frostbite of various parts of the body may be treated by using other parts to warm the frostbitten area. Frostbite should never be treated by rubbing with or without snow or slush. When the frostbitten area begins to peel, as sunburned skin does, any bland lanolin-based ointment will allay discomfort. Though frozen tissues swell and blister, in the manner in which burned tissues do, they should not be treated with ointment as are burns. Frostbitten body parts also should not be warmed directly near fire since the injured tissue may be further damaged by the heat. The proper way to use a campfire is to melt snow or ice in a suitable container and immerse the injured part in tepid water. Quick thaw has proved clinically successful for ultimate recovery of freezing injuries. Water temperatures of 40° to $43^{\circ}C$ are required.

Other physiological problems encountered in the Arctic include snow blindness, which occurs as a result of burning of the mucous membrane of the eyes by ultraviolet light reflected from the snow. The disorder has an acute course and is accompanied by marked pain, a flow of tears, photophobia, and, with nonadherence to precautionary measures, can be repeated over and over again. It is extremely important to realize that snow blindness can occur on cloudy as well as sunny days. The most reliable protection is afforded by light-filter eyeglasses or a bandage with thin slits for the eyes.

Obtaining sufficient water in the Arctic poses no special problems since ice and snow are more than plentiful. Spacecrews are provided with rations, which will be described later, to satisfy their nutritional requirements should they be downed in a remote region. These can be supplemented if necessary, by fish.

Survival in Desert and Tropical Climates. The high temperatures and solar radiation in the desert exert an extremely unfavorable effect on the human body. Under these conditions man receives up to 300 cal or more of exogenous heat per hour. At temperatures greater than 33°C there is virtually no heat transfer by convection and radiation. The body's normal heat balance is maintained by sweating.

Water losses with perspiration at rest at an air temperature of 37.8°C are up to 300 grams per hour. They increase considerably (up to one liter or more) during physical work and when moving on sun-parched ground. As a result, during the day the body can lose from 4 to 8 to 10 liters (during heavy work) of fluid. With adequate water consumption the body can contend successfully with a thermal load without experiencing a water deficit. However, when the water supply is small and there are no natural water sources, it is impossible to compensate for water losses. Sooner or later this will result in dehydration. The rate at which this occurs may vary, but it will govern the duration of man's self-sustaining life in the desert.

The process of dehydration creates thirst, which first manifests itself as a conscious stress and, later, as an overwhelming one. After prolonged water deprivation the urge to drink may not be sufficient to maintain hydration in hot climates. Unabated water loss soon leads to physical and mental deterioration. Death ensues in a matter of hours in a highly unfavorable environment. Under ideal conditions, man can survive for as long as 14 days without water (19). Figure 6 illustrates the symptoms which accompany dehydration. Fig. 6

Since the energies of a spacecrewman downed in the desert must be directed, on the one hand, to creating protection against exposure to exogenous heat (erecting improvised tents, wearing clothing), if he is to survive, and, on the other hand, to reducing body heat production, the drinking schedule will play an extremely important role.

In investigating this matter, Kenney (14) established that with a single intake of one liter of water a considerable part of it (371 $\pm$ 207 ml) is eliminated by the kidneys. However, when drinking this same quantity of water in 83 ml portions the renal losses will be only 82 $\pm$ 29 ml; that is, when drinking small quantities, the body uses almost all the ingested water in perspiration.

In another study conducted in the Soviet Union in 1969, the effects of hot, dry desertlike conditions were observed. Subjects were exposed to temperatures of 46° to 48°C (114.8° to 118.4°F) in the shade and provided with low calorie (900 kcal) diets. The daily water needs of these subjects ranged from 1 to 2.5 liters per day (30).

In the desert, the best way to conserve water is to control sweating. Figure 7 shows sweating rates for various activities performed in the desert at an air temperature of 100°F dry bulb (20). Fig.7
The advantages of sitting quietly in the shade in the daytime and doing any neccessary walking at night are clear from these data.

When water supplies are limited, they should be rationed and drunk in small sips four to eight times a day. Since eating hastens dehydration (digestion requires water which forms urine to remove waste products), a normal amount of food should not be eaten unless the water ration is 1.8926 to 2.8390 liters daily. If there is a choice in food selection, preference should probably be given to carbohydrate. Water should be purified before drinking by boiling or by the use of water purification tablets or a small amount of an iodine solution, available in survival kits.

In the tropics, in addition to the problems of obtaining sufficient food and water, conserving energy and minimizing water loss (a less severe problem with tropical humidity), the additional problem of protection from insects and predators must be dealt with.

For maximum protection against insects and pests, many of which carry disease, clothing which covers the entire body should be worn at all times, especially at night.

Even the smallest scratch can cause serious infection within hours. Immediate first aid should be applied to all scratches. Skin exposure should be minimized by tucking trouser cuffs into the tops of boots. Sleeves should be rolled down. Clothing should be removed in the morning and it and the skin should be inspected for evidence of ticks, chiggers, insects, leeches, or other vermin. Clothing loosely worn will help keep the body cool; trapped air makes good insulation. In open country or in high grass, a neck cloth should be worn or a head covering improvised for protection from the sun and/or dust. In the desert, clothing protects against sunburn, heat, sand, and insects. It also conserves sweat and delays dehydration.

Survival in the Tropical Zone of the Ocean. The tropical zone of the ocean is characterized by high air temperatures in combination with a considerable moisture content. These cause functional shifts in a number of body systems and especially in the heat regulating system. Intensive sweating leads to the body's loss of a great quantity of fluid which carries the threat of exhaustion by dehydration.

Dehydration can occur rapidly while awaiting rescue on the open sea. The rapid rolling motion of the sea can produce severe seasickness. Accidental ingestion of petroleum products on the water surface or of seawater itself will aggravate vomiting. The resulting water losses can be great. Should this condition be accompanied by diarrhea, the resulting dehydration could become a matter of grave concern in a very short period of time.

Ewing and Millington ([10]) suggest procedures which can be followed to minimize the loss of body water through sweat production and insensible water diffusion through the skin. Since such loss is directly related to skin temperature, the skin must be kept cool if the loss is to be minimized.

These procedures include:

1. Erecting a barrier between the sun and the body such as a parachute cloth parasol or awning.
2. Avoiding unnecessary exercise and, thus, increased skin blood flow and sweat production.
3. Directing whatever breezes exist onto the skin.
4. Keeping clothes dampened with sea water on the skin to allow evaporative cooling from other than body water.
5. Occasionally completely immersing the body in the sea. Caution should be observed here, however, since a weakened man might not be able to reboard the liferaft.

The effectiveness of moistening clothes and remaining in the shade as a means of minimizing water loss has been demonstrated in a number of studies(29,30). In one study, when nude subjects were exposed to the sun at temperatures of 45° to $50^{\circ}C$ (113° to $122^{\circ}F$) water losses of 350 to 600 grams per hour were noted. Moistening the clothes reduced this to 100 to 150 grams per hour and remaining under an improvised tent reduced the loss to 200 to 300 grams per hour.

Since survival at sea may depend on the conservation of body water, great care must be exercised in developing the appropriate "water management program." Drinking seawater can produce fatal results. Seawater can be recommended only in small quantities after it has been diluted with three to six parts of fresh water, and then only for the replacement of salts lost through sea sickness and induced vomiting (18). Seawater introduces a hypertonic solution into the circulation, causes intracellular water to move into the extracellular space, and thus throws a load on the kidneys to remove the excessive water. While the increased electrolyte is partially removed by renal filtration, the body experiences a net gain in electrolytes which causes a constant cellular space dehydration which must eventually cause death (10). In addition to its basic dehydrating effect, drinking seawater also is likely to lead to intestinal discomfort followed by diarrhea. If large amounts are drunk, mental disturbances can follow.

However desperate the circumstances, urine should not be drunk. Drinking urine accelerates intracellular dehydration by introducing excessive electrolytes into the body water which simply accelerates the dehydration process.

Finally, the survivor in the open sea must not be overzealous in conserving water supplies. The longer an individual remains reasonably fit, the better are his chances of survival. Simply put, it is better to drink a cupful of water for ten days and be relatively fit when the water is gone, than it is to ration it to a couple of teaspoons per day and die of dehydration at the end of one week, with some water supplies still remaining.

Water supplies can be supplemented by precipitation (rain,dew), fluid squeezed from the flesh of fish which have been caught, and by employing special chemical and solar distillation apparatus for freshening seawater.

The food supplies in the survival kit can be supplemented with fish. But, again, great caution must be exercised because in the tropical zone there are many poisonous fish. One must avoid eating flesh of fish with a bright color, unusual spherical configuration, or with spines or growths on the skin. Regardless of the external appearance of the fish, it is recommended that the milk, eggs and liver not be consumed.

Sharks constitute another serious danger for persons in a lifeboat or on a raft in the tropical zone. During one U.S. Project Gemini mission, sharks were seen swimming in the vicinity of the space capsule, and the shark repellant used in this instance was not particularly effective. No truly reliable means have been developed for protection against sea predators with great aggressiveness and voracity. Although sharks usually do not attack boats, it is nevertheless recommended that no actions be taken which could incite their attack. For example, when sharks appear near a boat, fishing should stop at once. Wastes must not be thrown into the water, etc.

Survival Rations and Survival Kits

While considerable amount of study has been concerned with optimum food rations for survival situations, again it should be stressed that the type of food carried is probably of little importance since man can easily survive for a day or two without food until he is rescued, and it is unlikely that the time needed to rescue a spacecrew will exceed this period. Still, since long-term survival is theoretically possible, a short discussion of the rationale on which emergency rations have been developed is included here.

While food is rarely the most critical factor in survival, it can play a key part. Food must provide calories sufficient for basal metabolism and for the increased metabolic load associated with physical exertion and exposure to a cold survival situation. The precise caloric requirement depends chiefly on the amount of muscular work performed and the temperature at which the work is done. It may range from 1000 calories per day in a sedentary individual to as much as 7000 calories per day in a man in northern latitudes doing extremely hard work. Figure 8 illustrates the effect of ambient temperatures on caloric intake. Fig. 8

Only in very long-term survival is maintenance of adequate dietary protein critical. As a rule, the emergency food ration is made of high-calorie products which can be used either after cooking or in the dry form. However, the shortage of space in the survival kit container makes it necessary to use preserved products which have the maximum caloric content with minimum weight and volume. Some investigators feel that the emergency food ration must strictly maintain the ratio between the basic nutrient substances (8), but this point of view is not generally accepted. Others proceed on the basis that a stay under independent living conditions is relatively short, and therefore an increase in the caloric content of the ration is more important than strict observation of the ratios between the food components: fats, proteins and carbohydrates. This view concerning the principles of the makeup of the emergency food ration was supported by the successful testing of a ration which was intended for regions with a cold climate. In this ration, in comparison with the regular one, by reducing the carbohydrates from 711.4 to 627.7 grams, the amount of protein was increased from 141.1 to 184.5 grams and the fats from 179.8 to 279.8 grams. This made it possible to increase the caloric content of the ration from 4654.0 to 5930.0 kcal. In a test performed under laboratory conditions, one group of individuals was fed the experimental ration and the others received a regular ration for seven days. As a result of the experiment, the average weight loss among the subjects fed the experimental ration was 1.2-2.9 kilograms, while the subjects in the second group lost 1.9-3.5 kilograms. Despite the increased content of fat and protein in the ration, none of the subjects showed any indications of disturbances of fat and protein metabolism, as indicated by the data from laboratory studies of the urine and blood. In addition, those who had eaten the experimental ration showed a decrease in the amount of total nitrogen excreted with the urine (26).

The designers of other emergency rations have given preference to carbohydrate products. It is known that the energy consumption of the organism during subcaloric nutrition is made up through the deposits of fat. The use of endogenic fat is accompanied by the formation of unoxidized products (acetone, beta-oxyoleic adid). To have a more complete utilization of endogenic fat, it is necessary to have an additional amount of readily assimilated carbohydrates, no less that 60-70 grams per day (17). This was used as the basis for the development of a diet proposed by a group of authors--Komarevtsev, L.N., Pobol', Ye. P. and Kumanichkin, S.D., (15).

This diet, intended for survival at sea, was composed of sugar and vitaminized candy drops. To test the ration, 16 sailors spent four days in inflated rafts at air temperatures of 14-19^{o}C with a water temperature of 15^{o}C. On the first day, the subjects did not receive any food. Beginning the second day, the crew of the first raft was given the experimental ration, consisting of 50 grams of sugar and 100 grams of candy containing 225 mg of vitamin C, 5 mg of vitamin B_1, 5 mg of vitamin B_2, 2.5 mg of vitamin B_6, 10 mg of vitamin PP, 25 mg of folic acid, 25 mg of pantothenic acid and 10 mg of paraaminobenzoic acid. The caloric content of the ration was 600 kcal. The sailors aboard the second raft received 150 grams of candy made from maltose. The subjects aboard the third raft were fed concentrates, bread, butter, and received 1700 kcal per day. The water ration for all three groups was limited to 0.5 liter per day. Medical examination of the subjects involved checking the cardiovascular and respiratory systems, in conjunction with a number of analyses aimed at determining the urinary content of total nitrogen, vitamins, amino acids, oxygen, chlorides, creatinine, and acetone.

The results of the examinations performed after the end of the experiment showed that the most significant weight losses occurred among the sailors on the first raft, i.e., those who had been fed the experimental ration; the average weight loss was 4.5 kg. The sailors on the second raft lost an average of 3.7 kg. The subjects who had been fed a ration with a relatively high caloric content lost an average of 0.5 kg. In addition, those who had been on the experimental diet showed a more pronounced decrease in the amount of nitrogen, aminoacids and total urinary nitrogen, indicating a better retention of proteins by the organism. All showed an improved vitamin supply situation, as a result of active administration of vitamins. Hence, this ration was found to be the best for conditions of independent existence aboard liferafts at sea.

Survival kits provided Soviet cosmonauts were typified by the Vostok survival kits which included the following items: a radio with a range of several thousand kilometers; day/night signals for alerting recovery helicopters; a portable stove with solid fuel; wind/water proof watches; a specially designed navigation sensor and small-scale map; water for several days and chemical purifiers; rubber, one-man rafts with automatic inflation capability; medicines, slings, etc., for first aid; lightweight, high calorie food.

U.S. Apollo astronauts carried the following items for survival: survival lights; desalter kit; sunglasses, radio beacon; spare radio beacon battery and spacecraft connector cable; survival knife; a water container; sun lotion; utility knife; survival blankets and utility netting; a three-man survival raft with carbon dioxide inflators; a sea anchor; sea dye markers; sun bonnets; a mooring lanyard; mainlines and attachment brackets. This survival kit is designed to provide a 48-hour post landing (water or land) survival capability for three men between 40° North and South latitude. Food was also provided for emergency use.

In conclusion, it should be stressed that the provisions made to help the astronaut or cosmonaut through a survival situation will only be effective if they are appropriately used. Survival training is therefore an important phase of astronaut/cosmonaut preparation. A part of this training should be devoted toward indoctrination in "survival mentality." Perhaps the key ingredient in the survival scenario is the survivor's mental attitude. Depression, monotony, physical and mental fatigue are all to be expected and must be coped with. An attitude of "never-give-in" optimism may be crucial to the successful conclusion of a long-term survival situation.

<u>Recovery Techniques</u>

Since, in all likelihood, the downed astronaut or cosmonaut will be rescued very quickly, his knowledge of rescue techniques may be even more important than his knowledge of the use of survival kit items.

Egress from space capsules in heavy seas is not a simple task, particularly for an astronaut who may be in a weakened condition from exposure to weightlessness. This procedure becomes further complicated if seasickness supervenes. Like all other aspects of space flight missions, capsule egress is practiced prior to flight by spacecrews, in the open sea. During such training, astronauts are instructed, among other things, in the proper way to inflate individual flotation gear. Flotation gear is provided since a space suit may tear during capsule egress, fill with water, and cause the wearer to sink rapidly.

An additional problem during capsule egress is the possibility of entanglement in the shroudlines of the capsule parachutes. Ideally, shroudlines are automatically guillotined, and parachutes sink rapidly to pose no threat to the crew leaving the capsule. If the guillotine mechanism is ineffective, care must be taken by both rescue personnel and spacecrews to avoid entanglement. Survival knives are provided in the survival kit, and these may be used by the astronaut to cut shroudlines if the spacecraft lands out of range of recovery vehicles and personnel.

Once capsule egress has been accomplished in normal operations where swimmers are present to assist the crew, transfer of the individual from the capsule to the liferaft is the next operation. Here again, great care must be exercised because the astronaut may be in a deconditioned, weakened state. It is imperative and standard practice in transfer in the U.S. program for a swimmer to be on either side of the astronaut to assist him into the liferaft. The same caution must be exercised when transferring the individual from the liferaft to the helicopter rescue device, the Billy Pugh net.

The Billy Pugh net is the latest of a number of devices to be used in spacecraft recovery operations. Early in the U.S. space program, rescue seats and rescue slings (commonly known as horse collars) were used. The Billy Pugh net, pictured in Figure 9, is superior to either of these rescue devices for spacecrew recovery operations for several reasons. It is sufficiently large to permit two men to be lifted simultaneously out of the water if desired. Its principal advantage is that it eliminates the danger of a rescuee's falling during the recovery operation. Unlike many other helicopter rescue devices, the Billy Pugh net is a nonconductor of static electricity, eliminating one further potential problem.

Fig. 9

Summary

The American projects Mercury, Gemini, Apollo, and Skylab, and the Soviet Vostok, Voskhod, Soyuz, and Salyut programs have demonstrated that reentry and landing of spacecraft, both on land and sea, pose no significant medical problems for crews. The absence of specific difficulties during these operations is attributable to the design of spacecraft systems and to the training of both spacecrews and recovery teams. It is believed, on the basis of ground-based testing, that the probability of injury during an abort reentry and landing is low. Nevertheless, the problems which might be encountered after such a landing continue to be assessed by both the U.S. and the U.S.S.R. so that optimum equipment and training can be provided for all future missions, and survival of crews insured.

When future programs extend the duration of space missions, attendant stresses, particularly weightlessness exposure, could conceivably influence the physiological and medical aspects of reentry and landing. In relation to future missions, as was the case for earlier space flights, these stresses are being carefully assessed and the necessary countermeasures evaluated and designed.

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