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A REVIEW OF THE INFLUENCE OF PHYSICAL CONDITION PARAMETERS ON A TYPICAL AEROSPACE STRESS EFFECT: DECOMPRESSION SICKNESS

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by

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13. ABSTRACT

This study was undertaken to examine data on episodes of decompression sickness, particularly from recent Navy work in which the event occurred under multiple stress conditions, to determine the extent to which decompression sickness might be predicted on the basis of personal characteristics such as age, weight, and physical condition. Such information should ultimately be useful for establishing medical selection criteria to screen individuals prior to participation in activities involving extensive changes in ambient pressure, including those encountered in space operations. The main conclusions were as follows. There is a definite and positive relationship between increasing age and weight and the likelihood of decompression sickness. In general, any decline in physical condition also results in increased susceptibility. However, for predictive purposes, the relationship is low. To reduce the risk of bends, particularly for older individuals, strenuous exercise should be avoided immediately after ambient pressure changes. Temperatures should be kept at the low end of the comfort zone. For space activities, pressure changes of over 6-7 psi should be avoided. Prospective participants in future missions such as the Space Shuttle should not be excluded on the basis of age, certainly to age 60, if their general condition is reasonably good and they are not grossly obese.

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Foreword

This study was undertaken under the joint monitorship of Dr. Donald P. Woodward, Physiology Programs, Office of Naval Research and Dr. Walton L. Jones, NASA Deputy Director for Life Sciences, National Aeronautics and Space Administration. The purpose was to examine data concerning episodes of decompression sickness, particularly those from some recent Navy work in which the event occurred under multiple stress conditions, to determine the extent to which decompression sickness might be predicted on the basis of personal characteristics such as age, weight, and physical condition. Ultimately, such information could be used to establish medical selection criteria with which to screen individuals prior to their participation in activities involving extensive changes in ambient pressure.

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Introduction

As long as space missions involve operating pressure differentials, there is a potential risk of decompression sickness for passengers and crews. This risk is increased by the employment of a breathing atmosphere which includes an inert gas. The most straightforward solution, equalizing operational pressures, is unfortunately the most difficult to implement. In the Apollo/Soyuz Test Project (ASTP), for example, raising the operating pressure of the Apollo module in an effort to minimize the pressure differential between the Apollo and Soyuz spacecraft would create problems with windows and cabin seals, pressure release valves, and pressure avionics packages in the Command Module. As another example, mobility requirements have precluded the use of operating pressures in extravehicular suits which would match the pressure of the spacecraft.

The answer to the problem of insuring man's safety in situations that expose him sequentially to varying pressures must be sought in two areas: (1) the identification of physiological and environmental characteristics that render one susceptible to decompression sickness; and (2) establishment of optimum preoxygenation profiles. Finally, means must be available to treat episodes of decompression sickness should these occur during normal operations despite precautionary measures or as a result of accidental decompression.

Pressurized spacecraft cabins and spacesuits are designed to protect space crewmen from exposure to harmfully low barometric pressures. Nevertheless, the very nature of space operation exposes space crewmen to excursions in barometric pressure that carry with them the potential for producing decompression sickness symptoms. Launch and extravehicular activities involve atmospheric pressure transitions. The relatively remote, but nonetheless real, possibility of accidental decompression as a result of space capsule or spacesuit rupture creates a potential for severe decompression-related problems.

Future operational situations in space make the possibility of decompression sickness an even greater hazard than it has been on earlier missions. These include the addition of inert gas to the operating environment in the Skylab, ASTP and Space Shuttle atmospheres and the pressure differential in the operating environments of the U.S. Apollo and Soviet Soyuz space vehicles to be docked in the ASTP mission.

The advent of the Space Shuttle also introd a new element to the problem of protecting space crews fr compression sickness. The Space Shuttle program will, for the first time, allow persons to travel into space who are not carefully selected and conditioned to represent the best in physical preparedness. The scientists/passengers who will fly on the Space Shuttle will vary greatly in age and weight and may be a far cry in physical condition from the astronauts. The protection of these individuals from the stresses of space may pose some new and interesting challenges.

The problem to be faced by NASA in the Space Shuttle has been with the U.S. Navy over a long period. Navy divers, who also are subject to decompression sickness, range in age from the late teens to the early 50's. There also is considerable variability in the weight of these individuals. Studies have been made (Rivera, 1963; Summitt et al., 1971) on the incidence of decompression sickness in Navy divers with considerable information obtained as to the relationship between personal factors and susceptibility.

The purpose of this report is to examine the Navy data dealing with hyperbaric decompression sickness, plus similar information concerning episodes occurring inflight and in low pressure chambers, in an attempt to evaluate the potential for decompression sickness in future space missions based on the personal characteristics of crewmembers. Measures aimed at minimizing the risk of decompression sickness in space activities also are discussed.

Decompression Sickness Syndrome

When a person resides at sea level, his blood and tissues contain volumes of inert gases, principally nitrogen, in solution in proportion to the partial pressure of the gas in inspired air and the solubility of the gas in water and fat at body temperature. If the individual is transitioned to a significantly lowered barometric pressure, unless the transition proceeds slowly, inert gases come out of solution. Without protection in the form of pressurization, inert gases in the blood and tissues may begin to effervesce at pressures equivalent to altitudes as low as 18,000 feet. Above about 30,000 feet, this effervescence may lead to a complex of symptoms which cause various degrees of discomfort and/or disablement which are collectively called decompression sickness.

Decompression sickness may be defined as those signs or symptoms related to a decompression which occur at a rate such as to cause gas bubbles to develop in the body. These bubbles can produce pain, debilitation, or loss of physiological function. Pain associated with even mild decompression sickness symptoms can cause performance difficulties. The real danger, however, lies in the rare but serious instances when neurogenic peripheral circulatory failure ensues.

Decompression sickness symptoms, or dysbaric symptoms as they are also called, are generally classified in two categories, Type I and Type II. Table 1 illustrates the manifestations of decompression sickness falling into these two categories. As indicated, Type I symptoms, the less severe variety, are by far the most frequently experienced, accounting for 75 to 95 percent of all cases. The most frequent of these is referred to commonly as aviator's bends, a deep migratory pain in the extremities. The onset of Type I symptoms may be gradual or acute. Such symptoms may or may not precede more severe, Type II, symptoms.

Table 1

Manifestations Relative to Frequency of Decompression Sickness Symptoms

Type I*	
Extremities	**Systemic**
Joint pains (bends)	Mottled skin
Numbness	Rash
Paresthesia	Pruritus
Weakness	Fatigue
Edema	Fever
	Sweating

Type II**	
Cardio-Pulmonary	**Nervous System**
Chokes	Unconsciousness
Substernal distress	Headache-migraine
Paroxysmal coughing	Visual (teicopsia)
Dyspnea	Ataxia
Asphyxia	Vertigo
	Loss of hearing
Circulatory obstruction	Aphasia
Shock (pallor, dizziness, nausea)	Slurring of speech
RBC aggregation	

*Accounts for 75 to 95 percent of total cases.

**Accounts for 10 to 25 percent of total cases.

(Bohnke, 1971)

Chokes, a more severe manifestation of decompression sickness than bends which is, however, of essentially the same etiology, characteristically occurs later in the course of flight than does bends pain. It is accompanied by chest pain, cough, and difficult respiration. Chest pain and cough usually appear together, although either may occur as the sole manifestation of chokes. The cough is nonproductive. The pain is a substernal burning sensation.

A further complication of decompression sickness produces no clinical manifestations. This is the production of "silent" bubbles. If such bubbles go untreated, they can cause chronic delayed damage in the form of avascular bone necrosis. The presence of silent bubbles has been verified by use of the Doppler ultrasonic transducer; when the transducer is affixed across the body, characteristic audio signals are produced if bubbles are present.

Recompression often relieves the symptoms associated with decompression sickness. In space missions, however, recompression procedures may not always be immediately implementable. Obviously, the importance of decompression sickness symptoms in astronauts is based on the type and severity of symptoms. However, even relatively minor pain can impair astronaut performance, and severe symptoms of the Type II variety could jeopardize a crewmember's life or cause a mission abort, when abort is feasible.

Spacecraft Pressure/Atmosphere Environments

While space missions to date have included activities which create the potential for decompression sickness episodes, no such episodes have occurred. The principal precautionary measure used, prebreathing pure oxygen for approximately three hours prior to launch, has successfully precluded decompression sickness despite repeated operational decompressions. Future mission profiles which involve decompression in conjunction with performance of extrevehicular activity and include inert gases in the breathing atmosphere present a greater risk from the standpoint of decompression sickness probability. To assess the hazard, one must consider environmental and operational features of a given mission in addition to physical and physiological characteristics of the participating crewmen. This section will briefly describe, for typical Apollo missions and for current and future spacecraft missions, those activities which bear on the decompression sickness picture. Table 2 summarizes spacecraft environmental data relevant to decompression sickness for the missions considered.

Apollo Mission Activities

At the conclusion of the Apollo program with the mission of Apollo 17 in December 1972, Apollo astronauts had spent a total of 7,508 hours and 3 minutes in space. Of this total, as indicated in Table 2, 3 hours and 45 minutes were spent in zero g extravehicular activity and 161 hours and 2 minutes were spent in lunar surface extravehicular activity. Because neither the Apollo Command Module nor the Lunar Module has an airlock, all extravehicular activity required depressurization of the spacecraft.

The space crew is protected from exposure to unexpected drops in pressurization by the spacecraft pressurization system and the pressure suit. Protection against evolution of inert gases in the body upon tranisitioning from higher barometric pressures to lower ones, such as experienced when donning the 3.75 psi spacesuit and exiting the space vehicle for extravehicular activity, is provided through elimination or "wash out" of inert gases from the system by means of a relatively long period of breathing 100 percent oxygen during preparation for launch (approximately 3 hours). No such period of oxygen prebreathing is required when making the transition from a 5 psi spacecraft to a 3.7 psi suit pressure

Table 2

Atmosphere/Pressure Data for Past, Current, and Future Space Flight Missions

Mission	Launch Date	Atmosphere & Pressure	Scheduled EVA	EVA Spacesuit Pressure	Preoxygenation (Denitrogenation) Time
Apollo	Missions Completed	Total: 5 psi/258.7 mmHg Launch O_2: 3 155.4 N_2: 2 105.9	Free space (zero g), 3 hr 45 min 1/6 g, 161 hr 02 min	3.7 psi, 100% O_2	3 hr preox. on launch pad; no preox. prior to EVA
Skylab (Four Missions)	14 May 1973 (First Launch)	Total: 14.7 psi/760 mmHg O_2: 3.7 201 N_2: 1.3 66	Total of 6 EVAs planned; max. duration 3 hr	3.75 psi, 100% O_2	3 hr preox. on launch pad; no preox. prior to EVA
Apollo/Soyuz* Test Project (ASTP)	July 1975				
U.S.		Total: 5 psi/258.7 mmHg O_2: 4.6 237 } (launch) N_2: 0.40 22 }	None planned	–	Not required
Soviet		Total: ≈ 9 – 10 psi/4[illegible] .5[illegible] mmHg O_2/N_2 environment with O_2 maintained above 3 psi (150 mmHg); N_2 leakage made up with O_2**			
Space Shuttle	1978	Total: 14.7 psi/760 mmHg O_2: 2.9 149.5 N_2: 11.8 610.5	As required	8 psi, single gas	Not yet specified

*Data as of 30 April 1973.

**N_2 leakage is not made up. As N_2 is lost through leakage, it is replaced by O_2.

during space flight (1) because the pressure differential is not great and (2) because there is negligible inert gas in the breathing atmosphere of the space cabin.

During lunar surface activity, pressurization is provided by the Portable Life Support System (PLSS). Both the Lunar Module cabin and the suit environment are maintained at 5 ± 0.2 psi. This equalization of pressure permits astronauts to open their face plates and remove their gloves within the LM. During lunar surface EVA, however, the operating pressure of the suit is reduced to 3.75 psi. When lunar surface activities are anticipated, the Portable Life Support System is donned, the pressure suits sealed, and the suit pressure reduced to 3.75 psi. The cabin hatch is then opened and one crewmember or both crewmembers egress. Again, since the breathing gas is 100 percent oxygen, there is no need for any preoxygenation.

Skylab Mission Activities

The Skylab program is designed to carry out a broad range of experimental investigations and to gain a better understanding of the requirements for permanent, manmade platforms in space. The Skylab orbital workshop, launched on 14 May 1973, will be manned on three separate occasions by three-man crews over an eight-month period. At least six extravehicular activities are planned. None of these will require complete depressurization of the space laboratory because the Skylab, unlike the Apollo vehicle, is equipped with an airlock. These activities will entail for the individuals involved, however, a transition from a higher operational pressure to a lower one: from the 5 psi mixed gas environment of the Skylab to the 3.75 psi pure oxygen spacesuit pressure.

Presently contemplated Skylab extravehicular activities are as follows. EVAs will be rescheduled as required by mission contingencies.

Skylab 2

Day 1: Crewmen affix sun shade prior to manning orbital workshop.

Day 26: Two crewmen exit, maneuver outside the station to the top of the Apollo Telescope Mount, and retrieve and reload film.

Skylab 3

Day 5: An extravehicular activity is performed to retrieve film from and to reload the Apollo Telescope Mount.

Day 29: An EVA is performed to retrieve film from and to reload the ATM.

Day 54: An EVA is performed to retrieve and reload ATM film and inspect degradation of film coatings.

Skylab 4

Day 3: An EVA is performed to retrieve film from and to reload the ATM.

Day 54: An EVA is performed to retrieve ATM film.

The potential for decompression sickness is present in these activities, and the risk is perhaps slightly greater than it was for Apollo crews because a diluent gas, nitrogen, is used in the spacecraft environment. The partial pressure of nitrogen is 1.3 psi. The risk is considered to be negligible, however, and no preoxygenation is to be required prior to EVA.

Apollo/Soyuz Test Project (ASTP) Activities

The Apollo/Soyuz Test Project, with a projected launch date of July 1975, is to be a joint experiment to rendezvous and dock a manned Apollo spacecraft with a manned Soyuz spacecraft. A docking module, illustrated in Figure 1, will permit the transfer of crews between the two spacecraft. The following brief description of the prospective mission is presented, recognizing that a number of mission characteristics have not been as yet definitively resolved. At the present time, the planned operational pressure

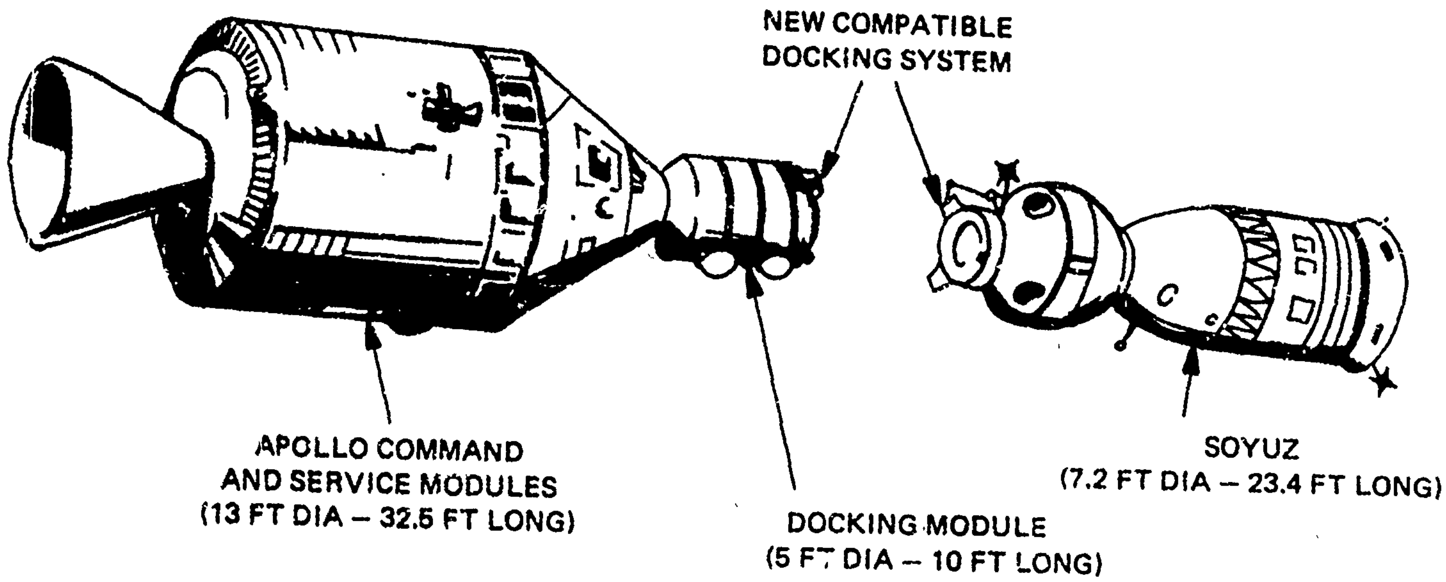

Figure 1. Spacecraft elements in ASTP mission.

of the Apollo spacecraft is 5 psia. The Soyuz spacecraft normally operates at sea level pressure. Presently, plans call for a reduction of that pressure to approximately 9 to 10 psi. Both spacecraft will use nitrogen in the breathing atmosphere (see Table 2).

Under the original plan, Soviet crewmen were scheduled to spend up to two hours in the docking module tunnel prebreathing oxygen prior to entering the Apollo spacecraft. However, further study indicated that lowering the Soyuz pressure to 10 psi would eliminate the requirement for this long prebreathing period. The operating pressure differential is, in fact, slightly smaller than it might appear to be since the Apollo Command Module pressure ranges up to 6 psi during normal operation. With a 4 psi pressure differential, the normal 25 minutes spent in the 100 percent oxygen environment of the docking module while making a normal transfer will constitute sufficient prebreathing (Fink, 1972).

Space Shuttle

Space Shuttle missions, slated to begin in 1978, will be the mode of space travel for the future. The Space Shuttle is to be a manned reusable vehicle that will be launched vertically, mounted piggy back on a large expendable propellant tank and two recoverable and reusable solid propellant rockets. The Shuttle will serve as a ferry system when transporting crews, passengers, and cargo to and from Earth orbit, and as an Earth-orbital station, when serving as a base for scientific activities. The scientific missions will be staffed by personnel with a wide range of ages and physical conditions. A number of the characteristics of the Space Shuttle environment are not fixed as yet. The atmospheric constituents and operating pressure have, however, been recently established. The atmosphere will be an oxygen/nitrogen one (20%/80%) at a total pressure of 14.7 psia. Extravehicular activity will be performed as required in connection with mission task performance. The extravehicular activity spacesuits under development are expected to operate at a pressure of 8 psi and use a single breathing gas.

The two gas environment of the Shuttle and the range of physical and physiological attributes of the passengers it will carry make the potential decompression sickness difficulties greater in these missions than in any previous ones. If the 8 psi EVA suit development program is successful, the issue of bends in transition to the EVA mode should be virtually eliminated. The problem is, of course, achievement of adequate mobility at an 8 psi operating pressure. With an 8 psi suit, the need for oxygen prebreathing would be eliminated. However, if the current 3.75 psi suit is employed, bends again become a hazard without appropriate preoxygenation schedules.

Accidental Decompressions and Operational Pressure Excursions

Barometric pressures are reduced at various times during space flight for operational reasons and may be reduced unexpectedly, and perhaps suddenly, in the case of accidental rupture of a spacecraft cabin or a spacesuit.

Accidental Decompressions

Space vehicle decompression may be caused by structural failures produced as a result of impact during docking or landing operations, bombardment by meteorites, collision with other spacecraft, and collision with debris in space that are the product of former space missions (von Beckh, 1970). Failure of hatch seals can, and has, resulted in catastrophic decompressions.*

*The Soyuz 11 crew was killed by a catastrophic decompression after a record 23 days in space, June 1971.

The hazard involved with a structural failure of the spacecraft depends on a number of factors. The rate of decompression will, of course, depend upon the size of the cabin wall penetration and the volume of the cabin. Decompression is a lesser hazard in space vehicles which have separate compartments; when one compartment becomes depressurized, the crew can repair to another compartment which is intact.

Micrometeoroid penetration poses some hazard but a relatively small one, provided the spacecraft is struck by only a few small meteoroids. Bombardment by a meteoroid shower is a more serious matter. It has been estimated that a 5,000 cu ft compartment takes about 1 hour to depressurize to 4 psia in the event of a one-half inch diameter micrometeoroid penetration (United Aircraft Corporation, 1970). According to these calculations, nearly two hours would be available before total pressure would be lost in the case of comparable damage to the Skylab orbital workshop structure (the habitable volume of the OSW is 9,550 cu ft. . A period of this duration would be sufficient to permit crews to effect repairs in the pressure suited mode.

Depressurization of a spacesuit can be produced by damage to the spacesuit during extravehicular activities, including space "walking" and exploration of the surfaces of celestial bodies. Like the spacecraft, spacesuits may be struck by meteoroid particles. To prevent depressurization, should such an event occur, extravehicular garments are provided with a micrometeoroid protection layer. This layer consists of an aluminum sheet, the thickness of which (0.07 inches) has been calculated to be sufficient to prevent penetration by primary meteoroid particles traveling at an anticipated rate of speed of 30 kilometers/second and secondary particles ejected at velocities of 0.2 kilometers/second (Goodman & Radnofsky, 1965). This protection minimizes the hazard associated with micrometeoroid bombardment in the spacesuited mode.

More serious problems are posed for the spacesuited astronaut by the possibility of failure of seals and punctures and lacerations of the suit by rugged terrain or pointed objects. Experiments performed to evaluate the chances of survival in an event simulating spacesuit rupture using nonhuman primates (chimpanzees) have indicated that approximately 12 seconds of useful consciousness time is available after decompression to near vacuum pressures in 0.8 second (results of Koestler, reported in von Beckh, 1970). The animals in these experiments performed complex behavioral schedules making possible the establishment of a mean value for time of useful consciousness. The total rescue time available was 3 minutes. Animals recompressed before this time was exceeded survived without permanent damage. All the animal subjects remained unconscious for 20 to 30 minutes after the decompression, but all were able to perform behavioral schedules at predecompression levels within 4 hours after decompression. von Beckh reports that these values can be extrapolated to man provided a safety margin is added. In view of the extremely hostile ambient conditions of space, it is, he suggests, a matter of conjecture as to how "useful" 12 seconds of consciousness may be. He suggests total rescue time be considered instead and sets this value at approximately 2-1/2 minutes for man under Koestler's experimental conditions. The astronaut who has become decompressed during space walking would have to be towed back into his spacecraft by his tether cord and recompressed while being supplied with adequate oxygen in this period.

Operational Decompression and Pressure Excursions

The potential for decompression sickness arises as a result of requirements for operational decompressions during various phases of space flight missions. Decompression to capsule pressure during orbital flight is the first of these events. A further decompression from the 5 psi operating pressure to a

3.75 psi pressure occurs prior to extravehicular operations. Spacesuits are currently maintained at a pressure of 3.75 psi rather than the 5 psi pressure of the space capsule to provide the necessary mobility for the pressure-suited individual.

The normal pressurization level maintained in the Lunar Excursion Module is 5 ±0.2 psi. Astronauts engaged in lunar surface activity wear spacesuits while inside the LM. These are maintained at the same pressure as the cabin itself. When the cabin is depressurized to permit entrance or exit, the pressure suit must be sealed and the suit pressure reduced to the emergency pressure level of approximately 3.75 psi. The normal internal operating environment of the Extravehicular Mobility Unit (as the lunar surface spacesuit is called) is 3.75 psi. Decompressions are undergone also during docking of the Lunar Module and the Command Module after lunar surface activity. Measures designed to preclude decompression sickness in crews of the docked Apollo-Soyuz spacecraft were described in conjunction with the earlier description of this mission.

Controlled decompressions may take place during spacecraft operations in case of emergencies. For example, it would become necessary to decompress the spacecraft cabin by opening the valves in the docking hatches should there be a fire inside the spacecraft or accidental contamination of the life compartment by noxious agents. The necessary steps would be carried out relatively simply in a spacecraft configuration which had more than one compartment. The ASTP (Apollo/Soyuz Test Project) typifies the situation. The configuration is schematically illustrated in Figure 2. In case of an emergency such as a fire, crewmen would assemble in the cabin not affected. After closing both lock hatches, the docking hatch valve would be opened by remote control and the contaminated cabin would be decompressed. After decompression was completed, crewmembers wearing pressure suits

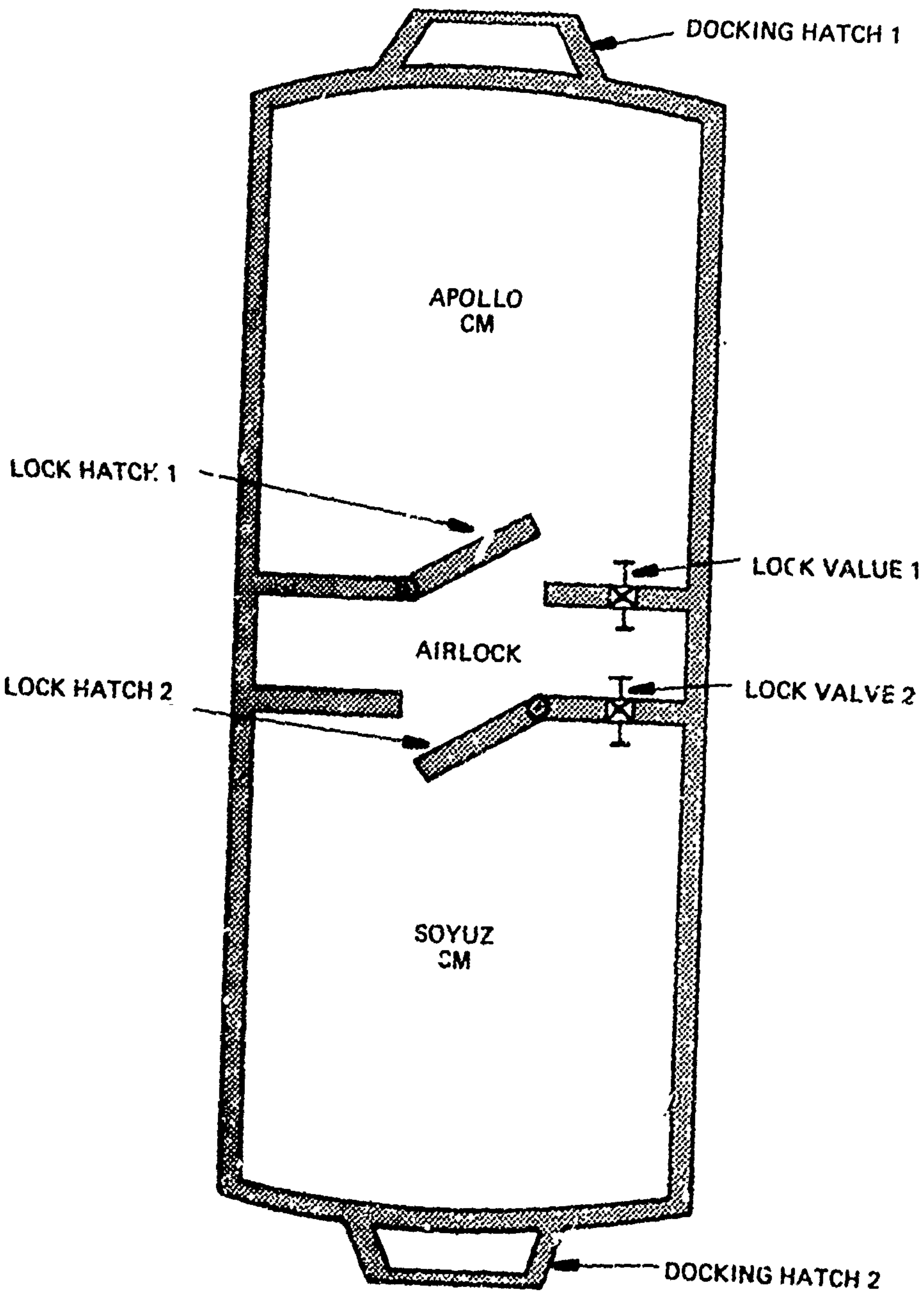

Figure 2. The application of the compartmentalization/airlock concept to an orbital twin station.

would transfer through the lock to the decompressed cabin. The docking hatch valve could then be closed and the station repressurized.

Under ordinary operating situations, automatic repressurization systems prevent the hazards which might be associated with slow, undetected depressurization from, for example, cabin gas leakage.

Flight and Underwater Events

The concern in this report is basically with the decompression sickness hazard experienced in normal spacecraft operations. While the hazard is far greater during rapid decompressions, such as would occur in an emergency, these events are relatively unlikely. The principal issues of this review are: how likely an event is decompression sickness in space operations, and what individual factors increase susceptibility to decompression sickness? (These factors will be treated in some detail under the heading Predisposing Physiological Factors.)

Because the number of individuals who have participated in space missions has been too small for drawing of statistical implications, we must turn to other data to examine how likely or unlikely an event is decompression sickness in space flight. Where correlations between decompression sickness and other factors - environmental and physiological - can be demonstrated, these will be noted.

Examination of the incidence of decompression sickness in operational flight, in altitude chamber use, and in deep diving, because these situations involve transitions from one barometric pressure to another, may be instructive for those considering the potential for decompression sickness difficulties in space operations. The following section briefly reviews information concerning the incidence of decompression sickness in U.S. Air Force operational flying, in altitude chamber training in both the U.S. Air Force and the U.S. Navy, and in Navy deep helium dives.

Operational Flying and Decompression Sickness

Lewis (1972) reported the incidence of decompression sickness in Air Force operational flying for the period 1 January 1968 through 31 December 1971. His data were obtained from reports for all aircraft accidents and the incidents in which decompression sickness was implicated, as reported to the Air Force Inspection and Safety Center, Norton Air Force Base. His statistics are conservative in that only those cases are included in which there was no doubt as to the diagnosis of decompression sickness.

During the 3-year reporting period, there were 14 cases of decompression sickness, 13 of which contained sufficient information to permit analysis. The severity of symptoms ranged from bends to severe neurological decompression sickness. Simple bends occurred in seven cases; bends with more severe manifestations occurred in two cases. Table 3 shows the location of bends pain. In these nine cases, there were 15 occurrences of bends, some with multiple joint involvement. Knees were involved more than any other joint, with six occurrences; the shoulder ranked next, with four occurrences.

Lewis reported six cases of decompression sickness with neurological involvement. The symptoms experienced included itches, chokes, bends, and visual disturbance. Two cases required hyperbaric therapy. While Lewis does not report the total number of flights or flight time for the period considered, 14 reported cases of decompression sickness over a 3-year period in Air Force operations represents a very low rate of occurrence.

Meader (1967) reviewed the incidence of decompression sickness in high altitude flight in the WU-2 aircraft over a 5-year period. He found 36 cases of decompression sickness, all of the bends type, experienced by 11 crewmembers in 950 flights. This represents an incidence of 17 percent (excluding from the data one individual who suffered 19 episodes). None of the cases reported caused a mission to be aborted, and only one required descent to a lower altitude to afford relief from pain. The majority of bends occurred during the first 3.5 hours of flight and affected the knee joints in almost two-thirds of the cases, with a tendency to recur in the same joint.

Table 3

Location of Bends Pain
1 January 1968 - 31 December 1971

	Lower Extremity					
	Hip		Knee		Ankle	
	One	Both	One	Both	One	Both
Number of Occurrences	1	0	3	3	1	0
Total Lower Extremity: 8						
	Upper Extremity					
	Shoulder		Elbow		Wrist	
	One	Both	One	Both	One	Both
Number of Occurrences	4	0	2	1	0	0
Total Upper Extremity: 7						

(Lewis, 1972)

Altitude Chamber Testing

U.S. Navy altitude training data relative to decompression sickness for the 10-year period 1959 through 1968 were recently reported by Furry (1973). These data indicated a low incidence of decompression sickness events among aircrew personnel: 266 incidents were reported in 252,564 man-exposures for an incidence of 0.1 percent.

Berry (cited in Billings, 1973) reported the incidence of bends, chokes, and central nervous system symptoms among 51,530 man-exposures in Air Force altitude chamber training flights. These data are listed in Table 4. Again, bends is the most frequent symptom, but the incidence of this and other manifestations of decompression sickness is still relatively low.

Table 4
Incidence of Dysbarism in Altitude Chamber Training
(N = 51,530 Exposures)

Type of Decompression Sickness	Incidence (percent)
Bends, alone or with other symptoms	2.41
Chokes	0.07
Central nervous system symptoms	0.03

(Data of Berry cited by Billings, 1973)

Avascular necrosis of the long bones is a late sequela to decompression. Bone lesions produced by silent bubbles (evolved gas undetected because it produced no symptoms during exposure to low barometric pressures) have been observed in Navy low pressure chambers by inside observers. Coburn (1970) examined X-rays for these individuals for the 1-year period 1954-1955, and reported that seven of 40 individuals, or 17.5 percent, showed bone change. Table 5 shows the distribution of the changes.

Helium Diving and Decompression Sickness

In the last decade, deep saturation and subsaturation diving with helium-oxygen mixtures have become commonplace for Navy and commercial divers. One of the new problems associated with the diving is the relatively high incidence of decompression sickness during the decompression phase when the diver is still under

Table 5

Distribution of Bone Lesions
in Forty Low Pressure Chamber Workers

	Lesion Distribution	
Bones Involved	Number of Lesions	Percentage
Femur		
Left	1	9
Right	3	27.0
Humerus		
Left	0	0.0
Right	2	18.0
Tibia		
Left	3	27.0
Right	0	0.0
Ulna		
Left	0	0.0
Right	1	9
Fibula		
Left	1	9
Right	0	0.0

(Coburn, 1970)

pressure. Between 1960 and 1970, 39.7 percent of the Navy's reported cases of decompression sickness associated with helium diving developed symptoms under pressure and 61.8 percent experienced symptoms either under pressure or within 15 minutes after surfacing. The number of such cases has increased progressively since 1960, paralling the activity and interest in deep diving (Summitt et al., 1971). Figure 3 shows the occurrence of decompression sickness under pressure expressed as a percentage of the cases reported during the time periods indicated.

Factors Affecting Susceptibility to Decompression Sickness

In considering the risk of decompression sickness in future space missions, a number of factors must be taken into account. Certain environmental parameters affect the degree of hazard. Among these, barometric pressure is, of course, most important. Also significant are the constituents of the breathing atmosphere. However, in a given environment, individuals respond differentially in terms of susceptibility to decompression sickness. For example, individuals with a higher percentage of adipose tissue are more likely than lean individuals to be susceptible to decompressure sickness. Younger persons are less susceptible than older persons. The following sections will describe the factors now known to be related to the incidence of decompression sickness.

Environmental Factors

The incidence of decompression sickness is affected by the following:

1. pressure-altitude at time of decompression;
2. altitude of exposure;
3. rate of ascent;
4. period of exposure; and
5. ambient temperature.

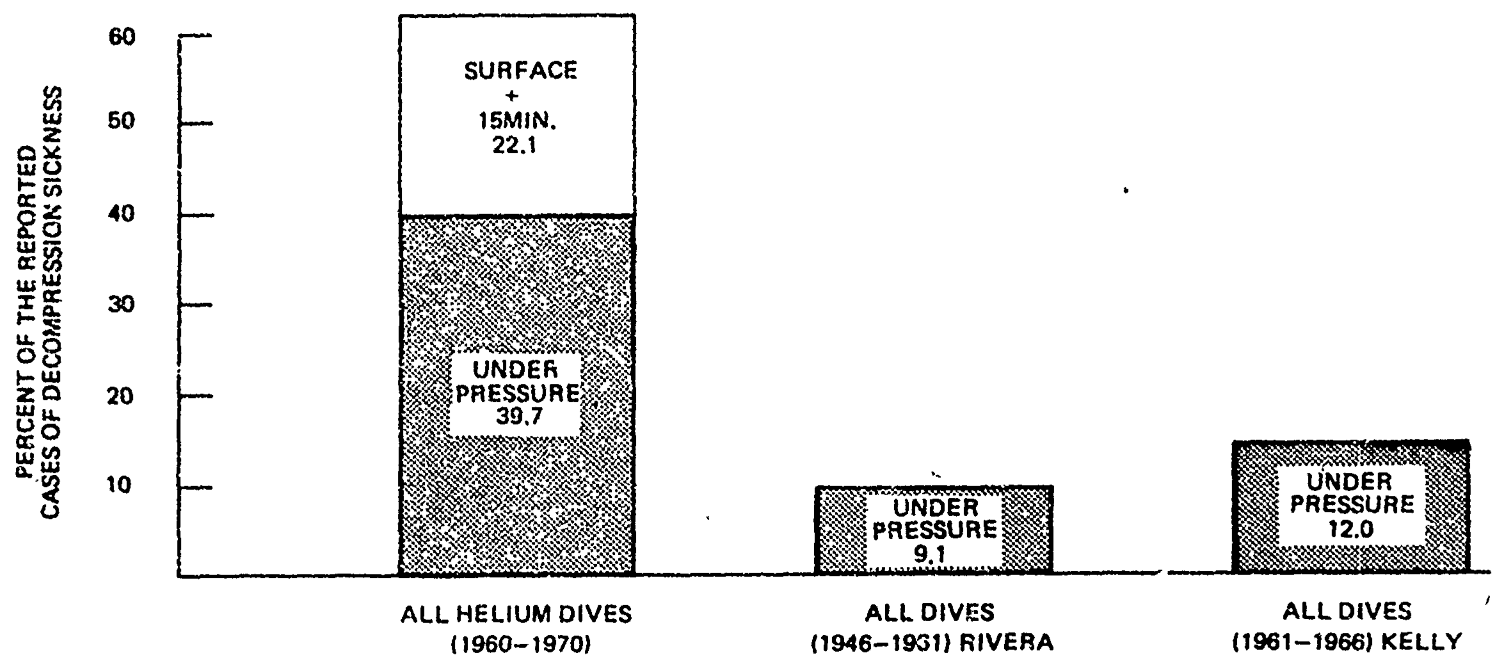

Figure 3. The occurrence of decompression sickness under pressure expressed as a percentage of the cases reported during the indicated periods of time. (Summitt et al., 1971)

Relationship of Altitude to Decompression Events. Figure 4 indicates the relationship of decompression sickness to various pressure-altitudes. It should be noted that, in general, there is no danger for the resting subject below 30,000 feet. Above this altitude, however, symptoms may develop even if the rate of climb has been slow and the crew is breathing 100 percent oxygen. In rare cases, decompression sickness has been noted at lower altitudes. Fryer (1964) reported one case which began 2 hours after flight at 18,500 feet. Davis and coworkers (1971) reported two cases of neurological decompression sickness with no attendant vasomotor involvement at 19,000 and 28,000 feet, respectively. Fryer (1969) reports two other cases. These low altitude incidences notwithstanding, the syndrome is more serious at higher altitudes.

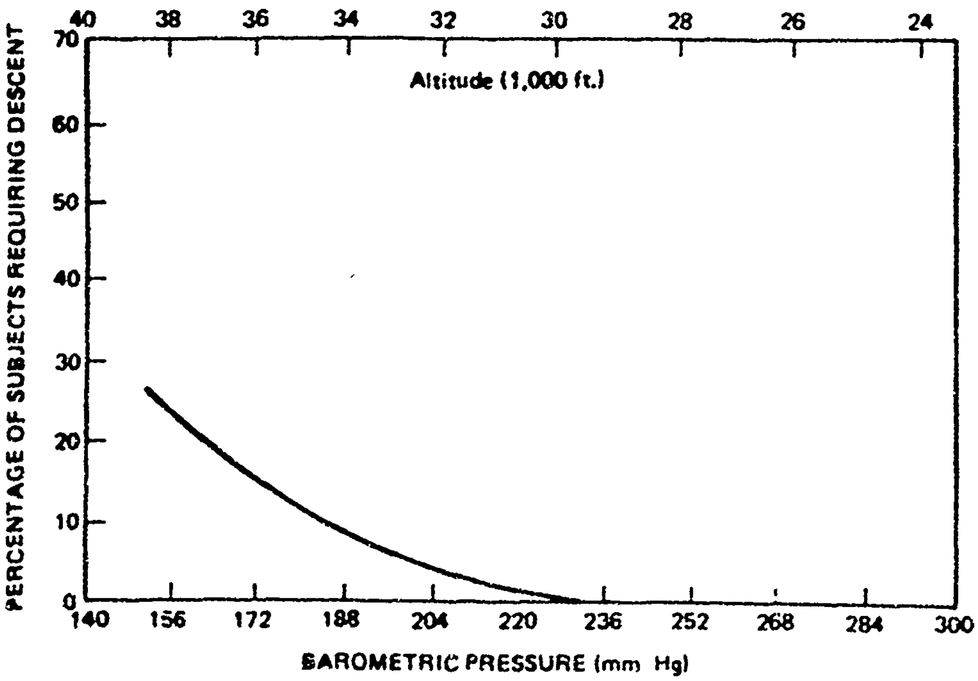

Figure 4. Incidence of decompression sickness at varying pressure-altitudes after 2-hour exposure in resting subjects. (Adapted from Fryer, in Ernsting, 1963)

The probability of bends symptoms depends not only upon the pressure-altitude to which one is exposed following decompression and upon the absolute reduction in pressure, but upon the initial altitude or ambient pressure at the time decompression began. Figure 5 illustrates this point for slowly desaturating and rapidly desaturating subjects, and for the general population range. Note, for example, that a decompression from 14.7 psia (the anticipated Space Shuttle operating pressure) to 4 psi (approximate current EVA suit pressure) would produce bends pain in about half the population. A decompression to the same pressure altitude from an ambient pressure of 11 psia, the typical airline cabin pressure, would produce no symptoms.

Rate of Ascent. It has long been assumed that if ascent rate is slow enough, blood and tissues desaturate with regard to an inert gas sufficiently to preclude the development of a degree of supersaturation likely to cause bubble formation on a scale associated with symptoms. In actual practice, however, it has been found that wide variations in ascent rates can be tolerated with no clear decompression sickness effect. Fryer (1969) states that Fraser could find no difference between ascents to 35,000 feet taking 15 minutes or 60 minutes, followed by a 2-hour sojourn at the full height.

Period of Exposure. Under standard conditions, the rate of appearance of decompression sickness symptoms is a function of exposure time. Meader (1967) studied bends in 958 U.S. Air Force WU-2 missions with pilots wearing partial pressure suits and flying at average cabin altitudes of 28,000 to 29,000 feet. Time of onset of symptoms was noted for 24 of the 36 reported bends episodes. Pain did not appear until 2 hours had elapsed. In some instances, symptoms became apparent as late as 7-1/2 hours after takeoff. Half the symptoms, however, occurred within the first

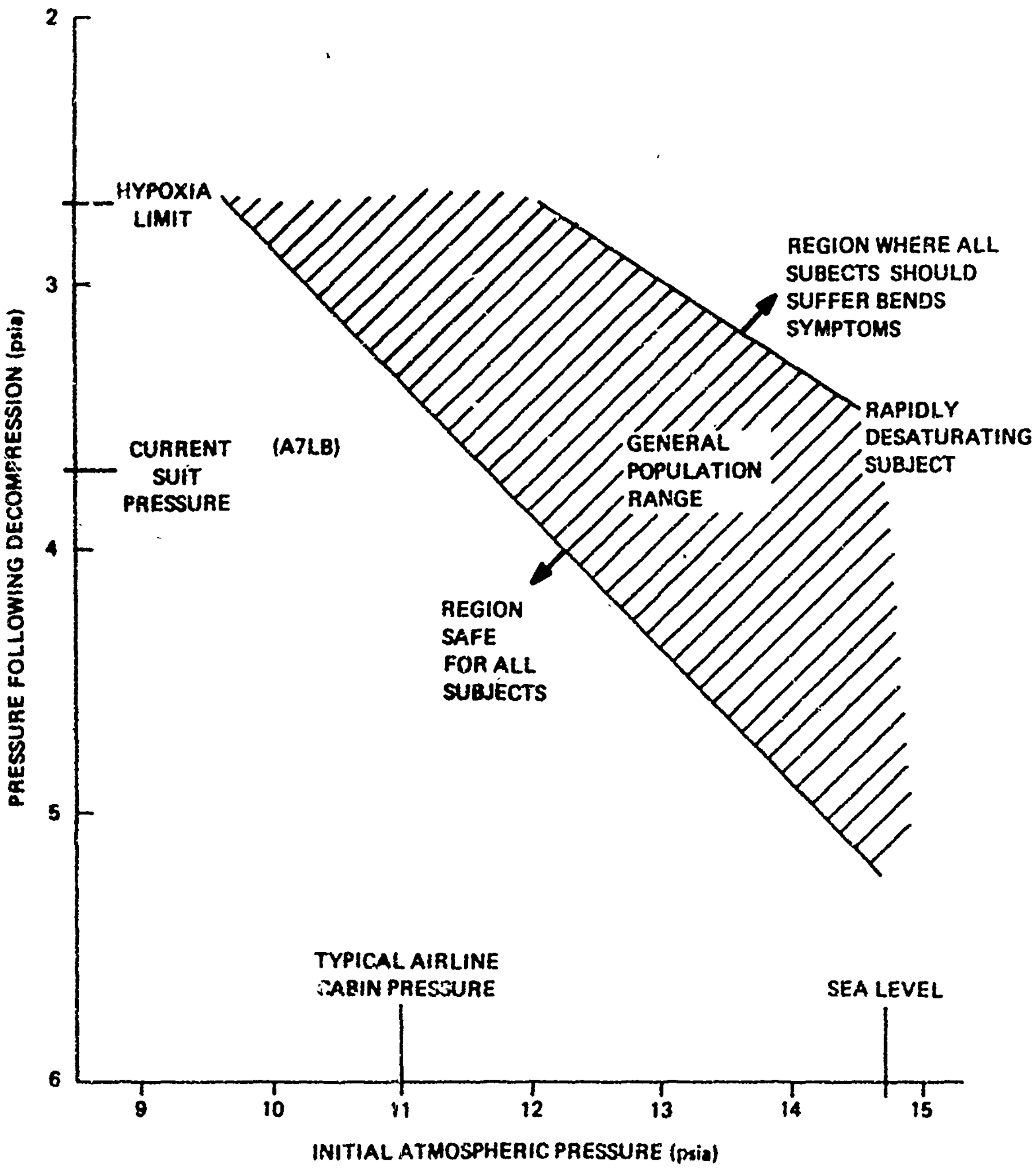

Figure 5. Effects of decompression from various pressure altitudes. (Adapted by Webbon, 1972, from data of others)

3-1/2 hours (Figure 6). Berry (1961) reported one case occurring 1 hour and 25 minutes after takeoff.

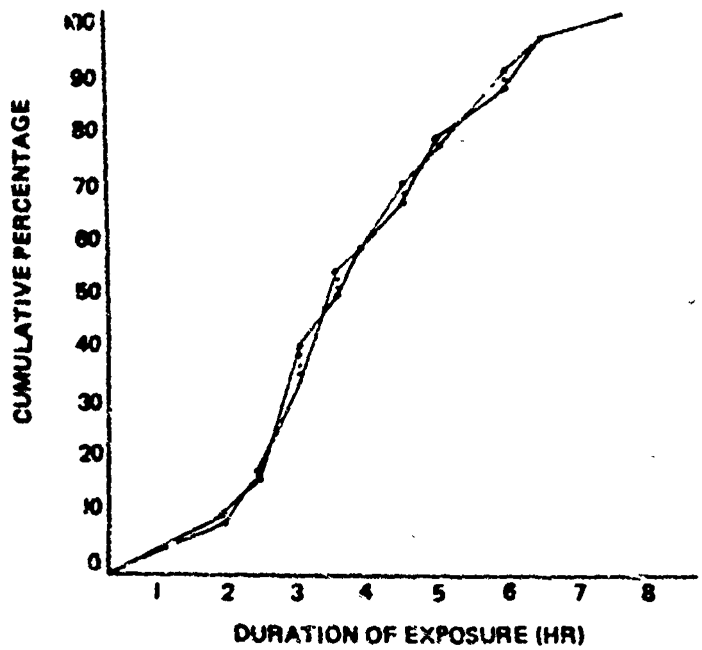

Figure 6. Time of onset of symptoms in 24 cases of bends reported in USAF pilots flying at average cabin altitudes of 28,000 to 29,000 feet. (Meader, 1967)

Climatic Conditions. Cold exposure may be related to the appearance of bends pain. In the cases studied by Meader (1967), more symptoms occurred in the winter (38 percent) than in any other seasons. Billings (1973) also notes the existence of evidence linking cold with decompression sickness episodes.

Breathing Gases. The incidence of decompression sickness is materially reduced if inert gases are "washed out" of the body prior to ascent and no inert gases are breathed during residence at altitude. However, breathing pure oxygen for prolonged periods of time is not without hazard. Atelectasis has been noted for individuals breathing 100 percent oxygen at low barometric pressures. Hemolysis of red blood cells may also occur. Engineering considerations dictated that a single gas atmosphere be used on early space missions. This approach was believed to present minimum physiological hazards for the crews involved because exposure times were relatively short. For the longer term missions of the future, two-gas atmospheres will be used. The U.S. Skylab mission will use an oxygen-nitrogen breathing atmosphere with the partial pressure of oxygen at 3.7 psia and that of nitrogen at 1.3 psia. The Space Shuttle atmosphere will comprise the same gases with partial pressures of approximately 10.5 psia for oxygen and 4.5 psia for nitrogen.

The presence of inert gas, while it minimizes or eliminates the oxygen toxicity problem, increases the risk of decompression sickness.

Predisposing Physiological Factors

There are a number of factors which tend to increase the susceptibility of an individual to decompression sickness. The most important of these are obesity, age, exercise, and previous episodes of decompression sickness.

Obesity. Nitrogen is highly soluble in fat (about five times as soluble as in water). Decompression sickness susceptibility is therefore correlated with body weight. If ten percent of any arbitrary unit of body weight consists of lipid in adipose tissue, a 70 kilogram man would have about 490 milliliters of nitrogen per atmosphere (P_{N_2} = 760 mmHg) dissolved in body fat (Behnke, 1971). Indeed, aviators reported to have experienced decompression sickness are often overweight. Fryer (1964) relates a case in which the striken aviator was 67 pounds overweight.

In a study of Air Force aviation personnel, Allen, Maio, and Bancroft (1971) verified the relationship between obesity and susceptibility to decompression sickness in 147 subjects. In this study, 40 men with less than 12 kilograms of body fat were found to suffer a lower incidence of Type I decompression sickness than 107 men with twelve or more kilograms of body fat. This was true both with and without preoxygenation (denitrogenation), for up to 3.5 hours. However after 4 hours of preoxygenation, 99 percent of all subjects were protected. Age as well as body weight was undoubtedly also operative as a factor since both students and veteran fighter pilots were included in the sample. It should be noted that only 11 percent of the student divers in the sample had over 12 kilograms of body fat as compared with 58 percent of the fighter pilots. The comparison of these two groups and a random sample with regard to body fat is illustrated in Figure 7.

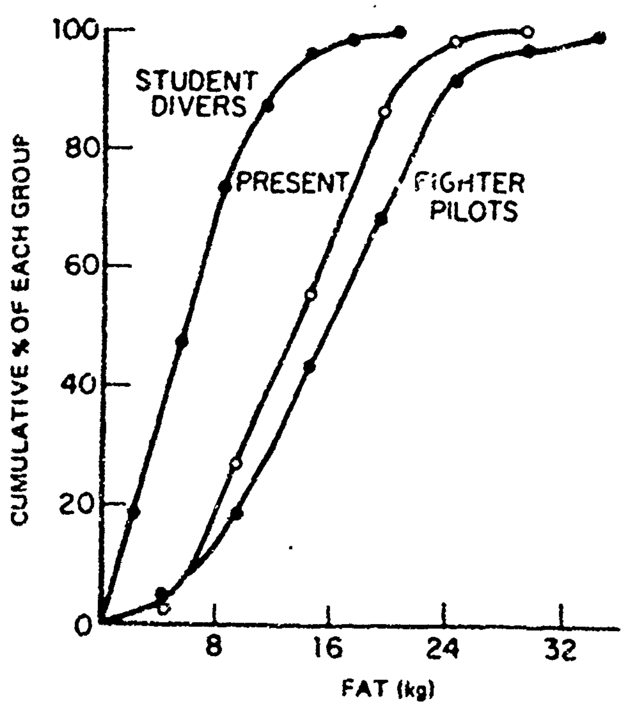

Figure 7. Comparison of body fat in student divers, random sample, and fighter pilots. (Allen, Maio, & Bancroft, 1971, from data of Kandel)

According to Goldman (1971), aging and increases in body fat are parallel phenomena, even in individuals who maintain an activity level with advancing age comparable to that maintained in youth. Endocrine changes which accompany aging result in a reduced caloric demand which is rarely adequately balanced by a voluntary reduction in the caloric intake of food. As body weight increases as a result of this imbalance, with any increase in a given individual almost certainly fat, the percentage of body fat in man nearly doubles between age 20 to 24 and age 70. A standard reference 50-year-old male shows body weight increasing from 70 kg at age 20 to 78.6 kg at age 50 and body density decreasing from 1.070 (referenced to 12 percent of body weight as storage fat at age 20) to 1.051 (referenced to 21.4 percent of storage fat at age 50). With the increase in body fat, susceptibility to decompression sickness will, of course, also increase.

In the study conducted by Allen et al. (1971), younger men were found to have consistently less body fat than older subjects. More than one-half of the younger subjects had less than 12 kilograms of body fat, and only eight men between the ages of 20 and 35 years had more than 24 kg of fat. In the third and fourth decades of life, proportionally fewer individuals had less than 12 kg of body fat, and, by the fifth decade, all had more than 12 kg.

Figure 8 shows the incidence and mean grade of bends for 835 individuals exposed in the Allen et al. study who had more than 12 kg of body fat and less than 12 kg of fat. Subjects prebreathed oxygen for up to 4 hours and were decompressed according to three schedules (see figure legend). With all breathing gases and pressure differentials tested, persons with greater amounts of body fat suffer more episodes of bends and more severe cases than leaner individuals.

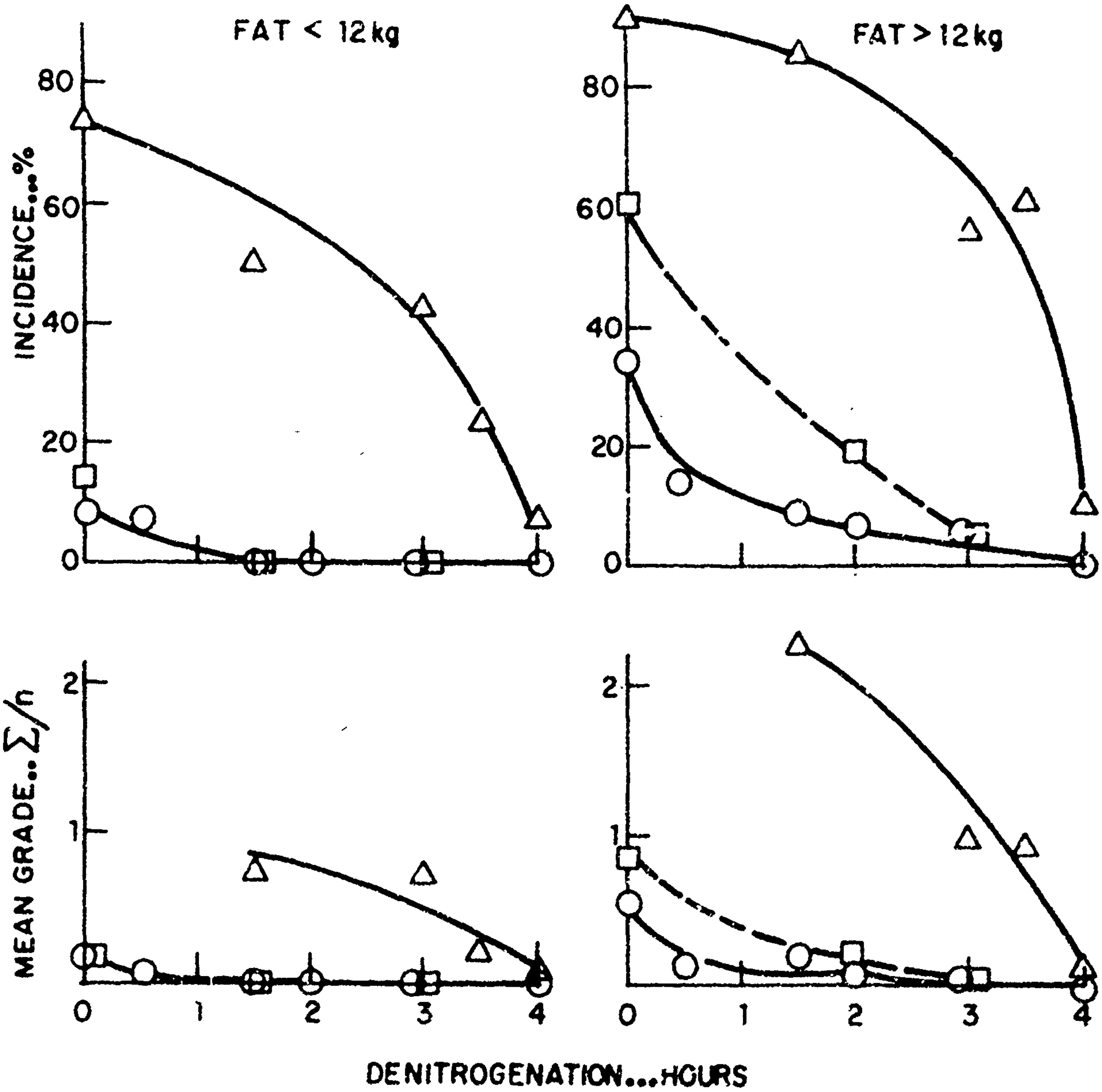

Figure 8. Effect of denitrogenation on incidence and mean grade of bends in men with less or more than 12 kg of body fat. Decompression from 14.5 psia O_2 to 3.5 psia O_2 (triangles), 14.5 psia O_2 to 5 psia O_2 (circles), 14.5 psia O_2 to 5 psia $O_2:N_2$ mixtures (squares). (Allen, Maio, & Bancroft, 1971)

In the study of U.S. Navy decompression sickness incidence in conjunction with deep helium dives (Summitt et al., 1971), a correlation was found to exist between the severity of bends symptoms and the weight of the individuals involved. A statistically significant correlation was found in the study between weight-to-height ratio and type of decompression sickness, indicating that the obese diver is more likely to suffer Type II bends than is the nonobese diver.

Age. A clear relationship between age and susceptibility to decompression sickness has been demonstrated. Gray (reported in Gersh & Catchpole, 1951) in analyzing the results of thousands of altitude chamber decompressions during World War II, discovered that relative susceptibility to decompression sickness increases by about 11 percent per year between the ages of 18 and 28 years.

Age also has been found to affect the outcome of treatment for bends. Summitt et al. (1971) found, in a population of U.S. Navy divers, that the older the diver, the more likely it was that he would not obtain complete relief from bends symptoms or that he would suffer a recurrence of symptoms. These correlations were statistically significant.

Figure 9 presents the age distribution of individuals experiencing decompression sickness symptoms in the study, showing that individuals at any age may be overcome. However, within this group, the authors found a tendency for age to affect the severity of decompression sickness and, as noted, the successful outcome of treatment. It can be assumed that the average age of scientists participating in the Space Shuttle mission will be higher than the average of the divers in this study. One would expect to see an age effect similar to that noted here but of greater magnitude.

In Gray's study of decompression sickness patterns among U.S. Army Air Force aviators during World War II (cited in Edel,

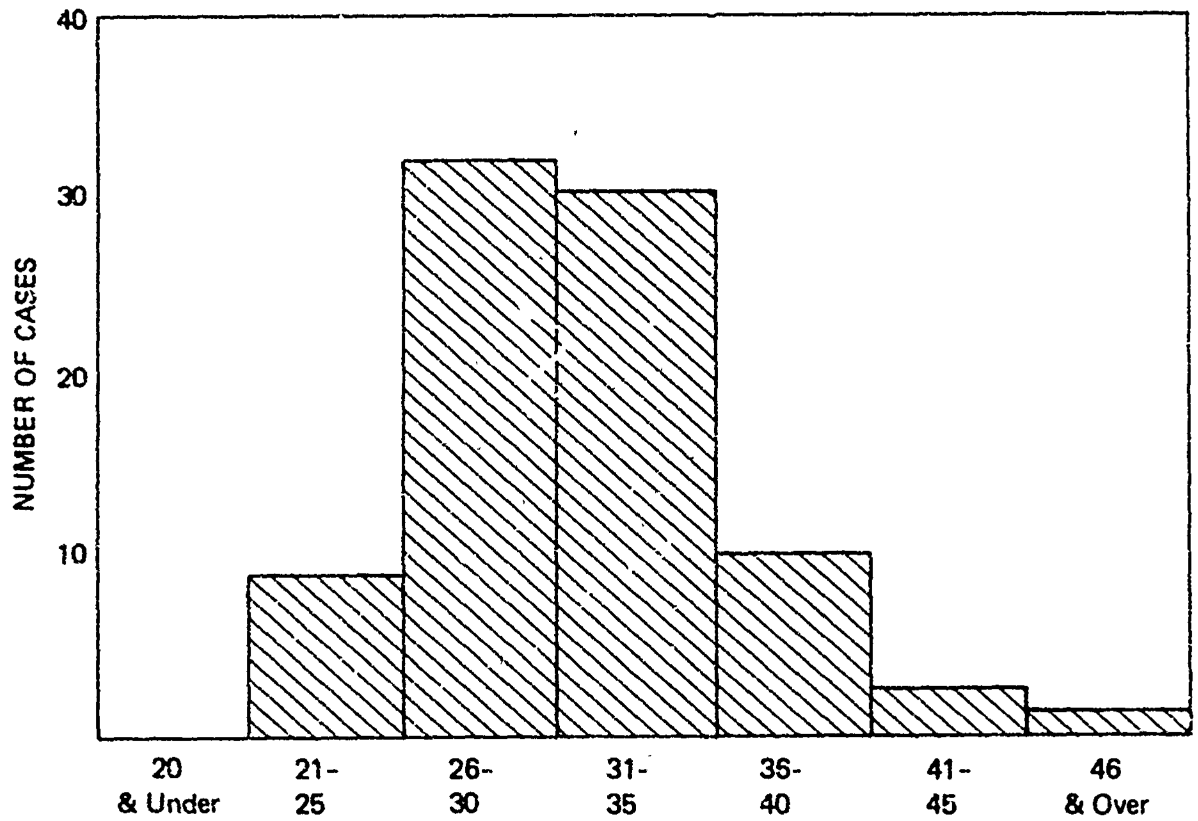

Figure 9. Age distribution of Navy divers experiencing decompression sickness (Summitt et al., 1971)

1968) it was found that younger men were not only more resistant to bends at altitude but also required less preoxygenation time for protection against bends than older crewmembers did.

Exercise. Strenuous physical activity increases susceptibility to decompression sickness. Fryer and Roxburgh (cited in U.S. Naval Flight Surgeon's Manual, 1968) reported that the incidence of decompression sickness at 34,000 feet was three times as great in persons exercising as in those that rest (Figure 10).

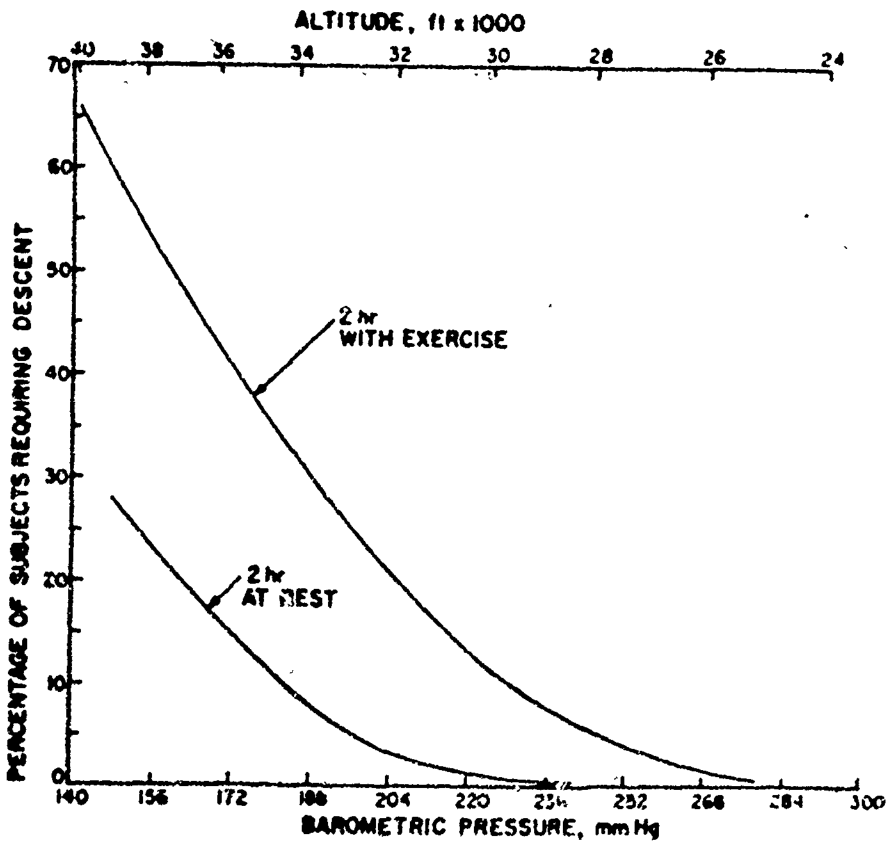

Figure 10. Incidence of decompression sickness at varying pressure altitudes. (U.S. Naval Flight Surgeon's Manual, data from Fryer & Roxburgh, 1956)

Adler (1964) reports that exercise is one of the most important factors influencing bends and chokes at altitude. According to this author, deep knee bends, pushing, and other strains influenced bends at altitude as much as would adding 3,000 to 5,000 feet to the altitude of exposure. Further, while exercise promotes symptoms in all parts of the body, the region most often affected is the part which is exercised. Exercise increases not only the probability of bends but the rapidity of their development (Edel, 1968, citing other sources).

A preoxygenation schedule that provides protection against bends for 80 percent of subjects at rest while exposed to a given altitude may be effective for only 60 percent if they perform strenuous exercise at the same altitude (Edel, 1968).

The fact that exercise increases susceptibility to decompression sickness is of great relevance in specified missions of the future, since activity profiles for these missions includes exercise of a rather rigorous nature. Exercise is encouraged during weightless space flight because of its beneficial effects both in the psychological and physiological spheres. U.S. space crews have expressed concern about physical deterioration in weightless space and have, in fact, returned with decreased exercise capacity and reduced limb volumes (Berry, in press). The etiology of these changes is as yet uncertain, but they appear to be related in part to the elimination of the need for countergravitational stresses in zero G. Exercise, particularly using exercise devices, provides the opportunity for exertion of the type of force inherent in ordinary activities in a one g field. A bicycle ergometer device will be used in the Skylab mission to provide for exercise that raises the heart rate to levels which help to preclude cardiovascular deconditioning, heart rates of 120 beats per minute or more.

Exercise is known, as noted earlier, to induce bends at altitude in the area most heavily exercised. It has been suggested that exercise exerts its influence in the causation of bends symptoms by increasing body core temperature, or by creating local "hot spots" (Bigelow et al., 1972). When an individual is exercising, localized small temperature rises can add to any temperature increase which may simultaneously occur in the general core temperature. Thus, certain areas become hottest and most likely to incur bubble formation. One means of decreasing the incidence of bends during exercise would, therefore, be to employ means to decrease the rise in body core temperature. Minimizing exercise has been suggested. Because exercise is useful in counteracting cardiovascular deconditioning in weightless space flight, exercise should not be eliminated entirely but refrained from in periods prior to extravehicular activities. Properly cooled environments and the wearing of sufficiently light clothing may also be helpful. Finally, the use of certain drugs and acclimatization of individuals to heat prior to exposure to low pressures have been suggested (Bigelow et al., 1972).

Previous Episodes of Decompression Sickness. Some evidence exists that suggests an individual becomes more susceptible to decompression sickness following an episode (Adler, 1964). Most individuals, however, do not demonstrate a particular change in susceptibility. On the other hand, once an individual has experienced multiple episodes of bends pain, there is a tendency for pain to recur in the same location. Table 6 demonstrates this for three of four subjects experiencing recurrent symptoms in a study of U.S. Air Force pilots engaged in high altitude flight (Meader, 1967).

Table 6

Site of Recurrence of Bends

Subject	Number of Episodes	Location	Number of Occurrences
Subject B	3	Right knee	2
		Left knee	3
Subject H	4	Right knee	4
		Left knee	1
Subject I	16	Left arm	1
		Left wrist	1
		Right knee	8
		Left knee	7
		Right ankle	3
		Left ankle	4
		Right foot	2
Subject K	2	Right shoulder	1
		Right knee	1
		Right ankle	1

(Meader, 1967)

Denitrogenation (Preoxygenation). "Washout" of inert gases from tissues by means of prebreathing oxygen is a highly effective means of preventing decompression sickness. Denitrogenation is accomplished by establishing a "gradient" or nitrogen partial pressure difference between the tissues and the alveolar gas, such that alveolar P_{N_2} is low. Tissue P_{N_2}, therefore, diffuses readily to blood and thus to alveoli. If the exterior supply of nitrogen to the alveoli is kept low or nonexistent, and if the exhaled gas is vented overboard, eventually almost all the tissue nitrogen can be removed. The time required for complete denitrogenation is, however, about 12 hours, and the length of time required is the same regardless of the original gradient.

One limiting factor in nitrogen excretion is pulmonary washout rate. In the example given in Comroe (1965) of a man given

100 percent oxygen to breathe, the functional residual capacity was 3,000 milliliters; anatomical dead space 150 ml, and alveolar ventilation 350 ml/breath. Each inspiration dilutes the nitrogen in the alveolar gas by 10 percent. The alveolar nitrogen, therefore, on the first respiration decreases from 80 to 72 percent. At the end of the second respiration, the alveolar nitrogen is 64.8 percent. This continues until alveolar nitrogen is washed out and the lung contains only O_2, CO_2, and H_2O vapor. The pulmonary nitrogen may be washed out in a few minutes, but tissue and, therefore, blood nitrogen are eliminated much more slowly because the nitrogen must diffuse from the tissue to the blood, be transported to the lung, and then diffuse from blood to alveoli, then be expelled from the lung on exhalation.

However, as tissue P_{N_2} decreases, the diffusion rate decreases since the gradient is decreased. In addition, blood supply to fatty tissue is rather low and tissue perfusion rates are correspondingly low. Therefore, the denitrogenation curve is not a straight line, as reference to Figure 11 shows. Indeed, even after 6 hours breathing 100 percent oxygen to achieve the optimal gradient, nitrogen still remains in the tissue in small quantities (U.S. Naval Flight Surgeon's Manual, 1968).

The greater the pressure under which the oxygen is delivered, the briefer the preoxygenation time required to accomplish nitrogen washout. Figure 12 illustrates the effect of suit pressure on the preoxygenation time required to prevent bends with 90 percent certainty (lower curve) and 99 percent certainty (upper curve) (Webbon, 1972, from data of others). Note that at the 8 psi suit pressure contemplated for the Space Shuttle, virtually no oxygen prebreathing time should be required prior to suit operations.

All Skylab missions will employ a 3.75 psi EVA suit. Operating suit pressures for other future missions are not as yet known. The goal for Space Shuttle missions is an 8 psi suit. Should suit technology development not meet this goal in time for early Shuttle missions, the issue of denitrogenation schedules will still be a relevant one.

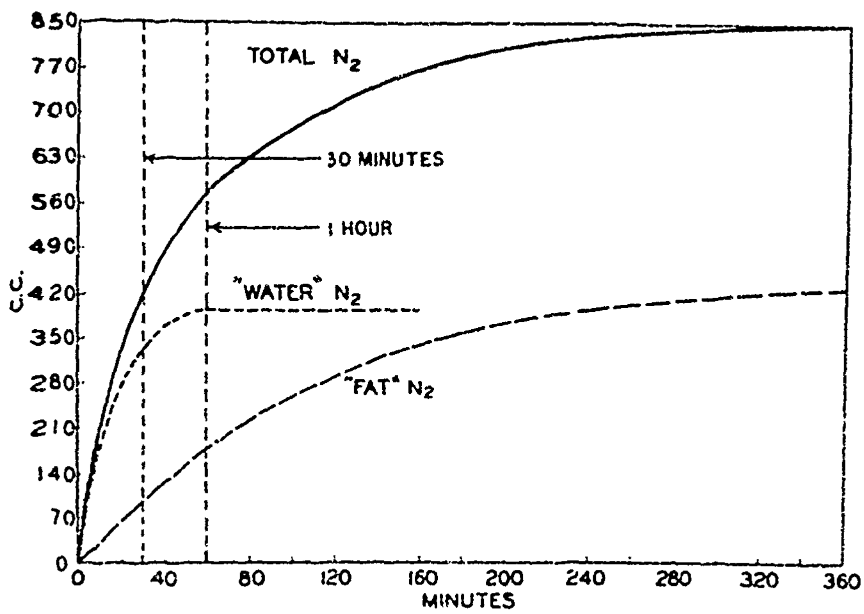

Figure 11. The rate at which nitrogen is eliminated from the body at sea level when pure oxygen is breathed. (U.S. Naval Flight Surgeon's Manual, 1968)

Allen and Maio (1971) suggest a denitrogenation technique which would reduce the period of oxygen breathing required prior to liftoff. They recommend the use of intermediate altitude crew quarters for effecting denitrogenation. The schedule shown in Figure 13 was found to provide sufficient protection for subsequent exposure to a 5 psi $70:30::O_2:N_2$ atmosphere. Eighteen subjects spent eight hours overnight (2100 to 0500 hours) at 15,000 feet pressure altitude in a $40:60::O_2:N_2$ "shirtsleeve" environment. This enriched oxygen concentration maintained a ground level alveolar P_{O_2} equivalent. The first hour or so was spent relaxing, but for the most part of the eight hours, the men reported later

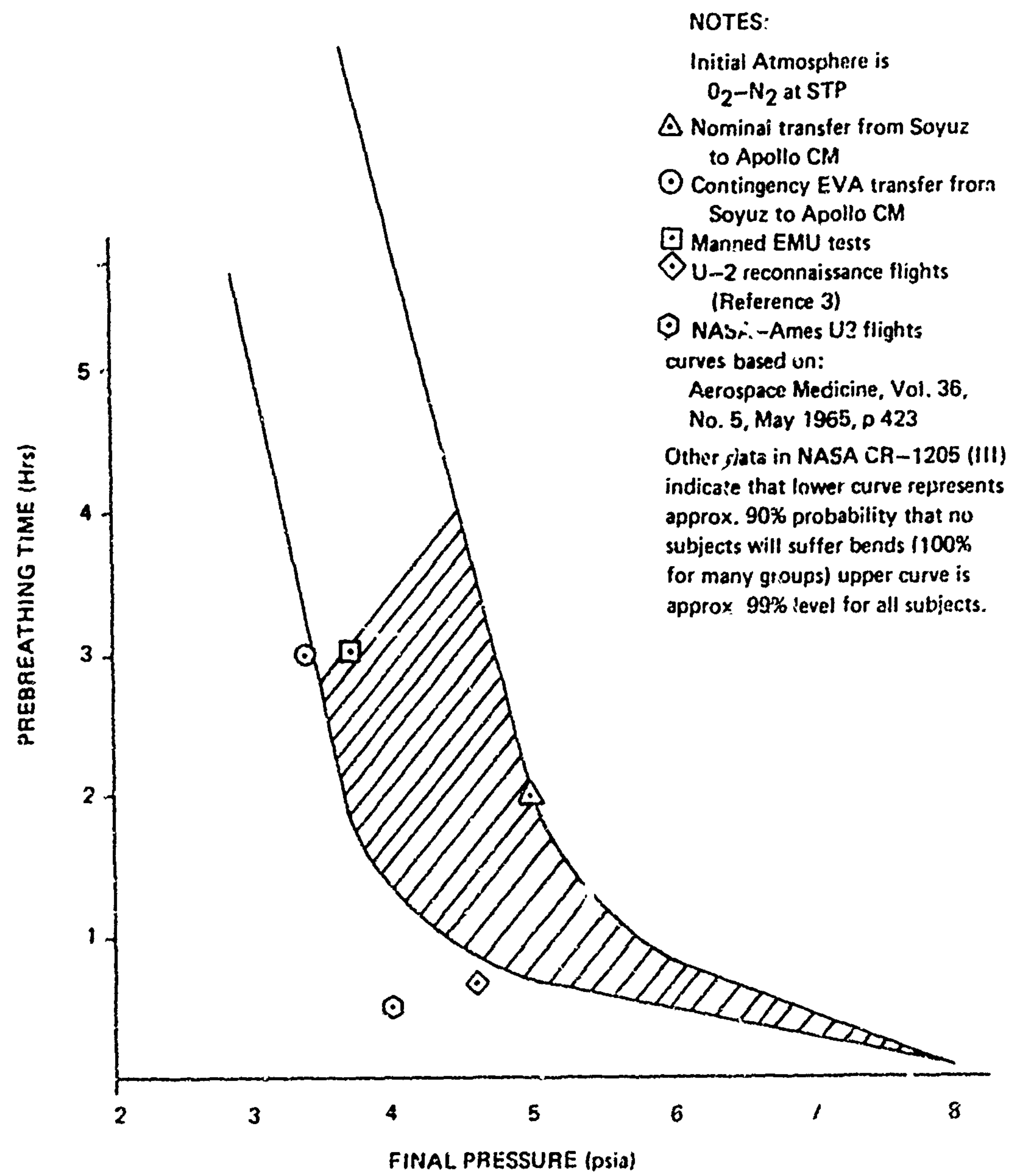

Figure 12. Effect of suit pressure and preoxygenation time on bends incidence. (Webbon, 1972)

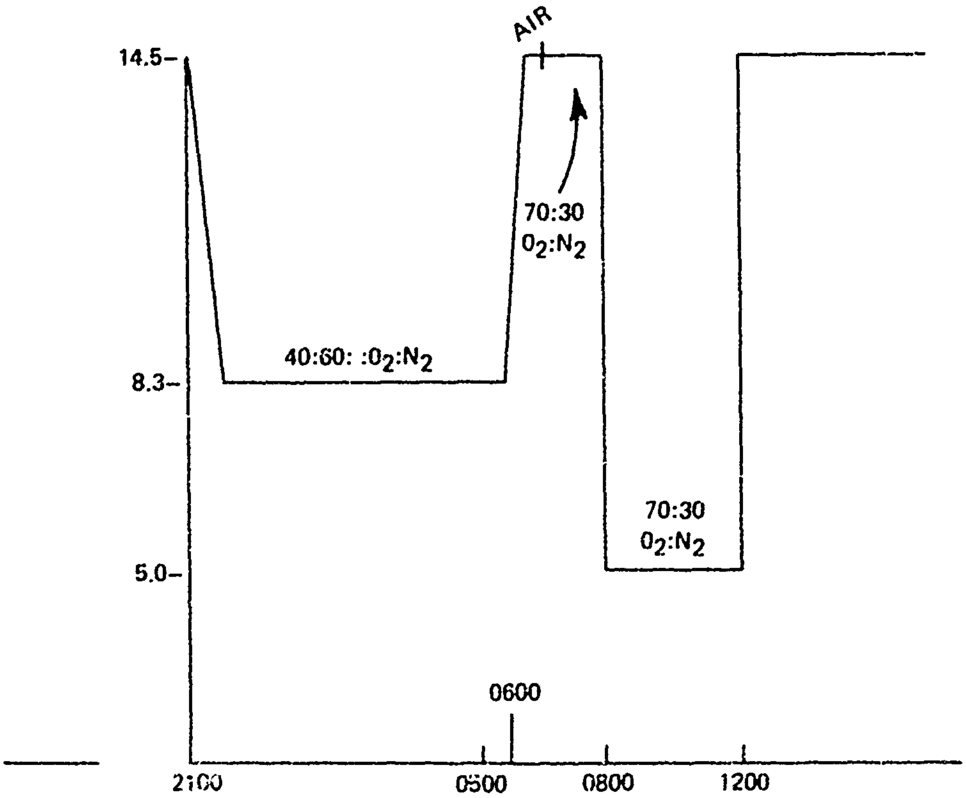

Figure 13. Chamber flight profile used to study intermediate altitude crew quarters concept as a denitrogenation method. (Maio & Allen, 1971)

that they slept confortably on mattresses. Near the end of the eight hours at 15,000 feet, the men were awakened and at 0500 hours recompressed with ambient air to ground level pressure. During the next hour in air at ground level (0500-0600 hours), the men were fed breakfast consisting of two scrambled eggs and an 8 to 10 ounce steak, toast, coffee, and juice. At 0700 hours, after being carefully fitted with masks and helmets, the men then breathed $70:30::O_2:N_2$ for 2 hours at ground level. This latter phase simulated the prelaunch check period in the space vehicle with $70:30::O_2:N_2$ as the cabin environment. Following this, the six men were decompressed directly to a pressure altitude of 5 psia with $70:30::O_2:N_2$, where they remained for 4 hours, exercising by marking time for 30 seconds every 15 minutes. This same schedule was repeated on separate nights for the remaining two groups of six men each. There were no cases of decompression sickness observed in any of the 18 subjects with this schedule.

Because it may be necessary to interrupt the oxygen prebreathing period to allow for donning of EVA gear and so forth, the effect of such interruption in the denitrogenation process and the protection against bends afforded must be considered. Webbon (1972) using data compiled by Roth (1968), constructed the curves shown in Figure 14. The curve indicates that the incidence of decompression sickness increases with increasing air breathing after a given preoxygenation period. However, with longer preoxygenation periods, body tissues are more thoroughly saturated. Consequently, nitrogen gases are less likely to go into solution in an individual who has prebreathed pure oxygen for 3 hours than one who has breathed oxygen for 1 hour.

Summary and Conclusions

The purpose of this study was to examine recent technical literature in an attempt to gain insight into the relative

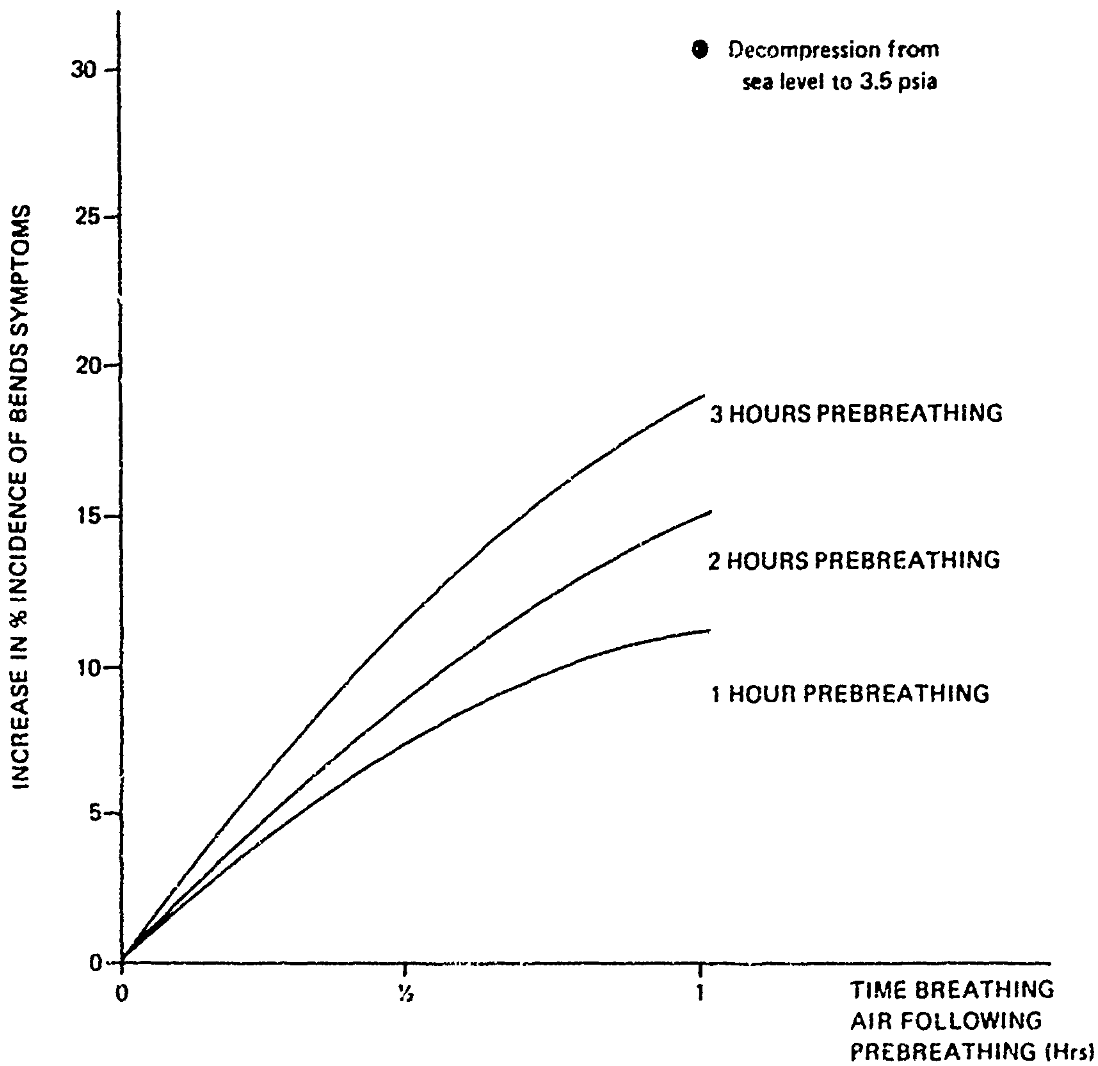

Figure 14. Effect of interruptions in oxygen prebreathing on bends incidence. (Webbon, 1972)

importance of personal factors such as age, physical condition, and obesity in determining susceptibility to decompression sickness. As scientists and other nonastronaut types venture into space aboard the Space Shuttle, and as men of all ages spend increasing amounts of time in underwater habitats for scientific, recreation, and commercial purposes, it becomes quite important to be able to assess their capability to remain healthy in an environment of changing pressures.

Technical literature was examined which dealt with decompression sickness episodes inflight, in low pressure chamber operations, and in diving activities. Particular attention was given to recent work by the U.S. Navy in which personal characteristics (age, weight/height ratio) were recorded for 136 cases of decompression sickness in oxygen/helium dives. A review of literature from the three above fields of activity leads to the following conclusions:

1. There is a definite and positive relationship between increasing age and weight and the likelihood that an individual will suffer from decompression sickness as he changes pressures in an atmosphere containing an inert gas. In general, one can say that any decline in physical condition results in increased susceptibility to decompression sickness. However, for predictive purposes, the relationship is low. For example, Summitt et al. (1971) found a correlation between age and treatment outcome of 0.20; and a correlation between weight/height ratio and the type of sickness experienced of 0.36 (with heavier individuals having the greater difficulty). While ambitious starts have been made toward development of predictive models (Bigelow et al., 1972), it will be quite difficult to build any kind of predictive model at this time upon which one could predicate exact standards for accepting or rejecting individuals for space flight or for diving. The relationship, as represented by the above correlations, is much too low for prediction.

2. Presuming that missions of the future require participation of scientists who are of less than optimum physical condition, there are a number of cautions which can be observed which should negate the increased risk brought about by degraded physical condition. First, exercise of any real extent should be avoided immediately after changing pressures. Second, the temperature should be kept at the low end of the comfort zone. Third, for space activities, changes of over 6 to 7 psi should be avoided. Even for relatively obese passengers, there are no recorded instances of decompression sickness inflight until the flight altitude reaches 18,500 feet or higher. This altitude represents a pressure change of 7.5 psi from that of sea level. It seems, then, to represent a conservative and safe level for pressure change which should be appropriate for all persons.

3. Prospective passengers for missions of the future such as those of the Space Shuttle should not be excluded on the basis of age, certainly to age 60, if their general physical condition is in any way reasonable. However, if the candidate is particularly heavy, for example, in the order of 70 pounds or more above the norm for his height and age, consideration should be given to rejecting him. Although a precise indication of his increase in susceptibility to decompression sickness cannot be made, all statistical and rational considerations would lead one to believe such an individual would be a prime candidate for a decompression sickness episode. This would be particularly true, of course, in the event of some emergency in which the decompression was relatively rapid and in which the change was 7 psi or greater.

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