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WEIGHTLESS SIMULATION USING WATER IMMERSION TECHNIQUES: AN ANNOTATED BIBLIOGRAPHY

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WEIGHTLESS SIMULATION USING WATER IMMERSION TECHNIQUES: AN ANNOTATED BIBLIOGRAPHY

Compiled by
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ABSTRACT

This compilation contains 215 selected references pertaining to behavioral and biomedical research involving human subjects. The references are organized under three topics: (1) Physiological Studies, including acceleration stress tolerance and physiological responses to simulated weightlessness, (2) Human Engineering Studies of man's performance capabilities under neutral buoyancy conditions simulating weightlessness, and (3) Techniques and Personal Equipment Requirements for water immersion studies.

The references are arranged alphabetically by Author, or by Title if appropriate, under each of the three topics. An Author Index is included as an aid in locating the contributions of specific investigators.

The references cited were drawn from the literature published or privately distributed during the period from January 1951 through December 1967.

PREFACE TO THE THIRD EDITION

This edition of Weightlessness Simulation Using Water Immersion Techniques was sponsored by the Lockheed Independent Research and Development Programs entitled, "Zero-G Simulation of Astronaut Extravehicular and In-Space Maintenace Tasks," and "Neutral Buoyancy Simulation of Weightlessness." It supercedes the second edition published in February 1967.

At least as early as 1945 water immersion techniques were employed by investigators in the field of aviation medicine to study human responses to certain critical environmental stresses associated with flight to high performance aircraft. Water immersion has been used with increasing frequency and confidence in recent years to assess man's physiological and psychological responses to elevated and reduced gravity fields. Although the preponderance of this work has been concerned with the effects of acceleration, impact, and simulated zero-g conditions on human organ systems, the condition of neutral buoyancy in water has achieved wide acceptance as a method for studying man's capabilities to perform useful work in the free fall or "weightless" state. In a very real sense, then, this bibliography presents a concise history of the development of ideas, methodologies, and knowledge in a narrow but profoundly influential sector of research in aviation medicine and bioastronautics.

Publications abstracted in this bibliography are relevant to the development of countermeasures for minimizing the debilitating effects of prolonged exposure to weightlessness, to the design of manned spacecraft crew stations, extravehicular work places, locomotion aids and restraint devices, and to the evaluation of personal protective equipment. The reader will also recognize that some studies may be of particular interest to investigators concerned with man's ability to perform useful work under the sea.

Several staff members in the Lockheed Technical Information Center and Biotechnology Organization participated in searching and organizing the literature for this and the preceding editions. Helen M. Abbott, Research Information Specialist, compiled the first edition published in July 1965. Dennis M. Kowall, Associate Engineer, assisted the author in compiling the second edition. Virginia D. Caswell, Research Information Analyst, Arthur T. Vogt, Junior Research Engineer, and Olga T. Kallos, Research Information Analyst, participated in compiling the third edition; Mrs. Kallos prepared the final manuscript for publication. Their contributions were greatly appreciated. In each edition, evaluation of the literature was conducted by the author, a Human Factors Specialist in the Biotechnology Organization.

The following individuals submitted materials for inclusion in the third edition of the bibliography. Their interest and assistance is gratefully acknowledged.

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PART I: PHYSIOLOGICAL STUDIES

A. Acceleration Stress Tolerance

1. Beckman, E. L., R. M. Chambers, et al
PHYSIOLOGIC CHANGES OBSERVED IN HUMAN SUBJECTS DURING ZERO G SIMULATION BY IMMERSION IN WATER UP TO NECK LEVEL. Aerospace Medicine 32(11): 1031 – 1041, 1961.

To ascertain some of the effects of prolonged weightlessness on man, a series of experiments involving seven Ss immersed in water (an effective simulation of the weightless state with respect to proprioceptive responses) up to the neck level for periods of 5 to 23 hours was conducted. Weight changes on a tracking task, during exposure to a simulated space vehicle re-entry deceleration profile, attributable to water immersion were determined. Changes in tolerance to accelerative forces were also measured.

2. Benson, V. G., E. Beckman, et al.
EFFECTS OF WEIGHTLESSNESS AS SIMULATED BY TOTAL BODY IMMERSION UPON HUMAN RESPONSE TO POSITIVE ACCELERATION. Naval Air Development Ctr., Johnsville, Pa. Rept. No. NADC-MA-6132. AD 262 329. See also Aerospace Medicine 33(2): 198 – 203, Feb 1962.

Twelve members of Underwater Demolition Team No. 21 used underwater breathing equipment while completely immersed in water for 18 hours. Their response to positive acceleration was determined by observing the G level at which the limitation of ocular motility under acceleration (LOMA) occurred. This G level is approximately the same as when loss of peripheral vision or greyout occurs when subjects are exposed to positive acceleration. The period of immersion was well-tolerated. A small but statistically significant decrease in the G level at which LOMA occurred was found following the period of immersion.

(See also references 14, 16, 113, 114, 202)

3. Benson, V. G., E. L. Beckman, et al
WEIGHTLESSNESS SIMULATION BY TOTAL BODY IMMERSION. PHYSIOLOGICAL EFFECTS. Naval Air Development Ctr., Johnsville, Pa. Report No. NADC-MA-6134. AD-263 194, 1961.

Attempts have been made to simulate the weightless state by immersing subjects in water up to the neck level for varying periods of time. These subjects were exposed to acceleration forces on human centrifuges before and after immersion. A reduction in the ability to withstand these acceleration forces was noted following the immersion period. Immersion in water to the neck level produces a negative pressure breathing situation which in turn results in a profuse diuresis. An attempt was made to eliminate the negative pressure breathing and the diuresis by equipping the subject with a full face diving mask with a compensating regulator and completely immersing him in water for a period of twelve hours. Of the seven subjects tested, only three were able to tolerate the 12-hour period of water immersion. The remaining four terminated early in the study due to the stress of the underwater environment and were not exposed to acceleration forces following their immersion periods.

4. Bondurant, S., W. G. Blanchard, et al
EFFECT OF WATER IMMERSION ON HUMAN TOLERANCE TO FORWARD AND BACKWARD ACCELERATION. Aero Medical Lab., Wright Air Development Center, Wright-Patterson Air Force Base, Ohio. Rept. on Biophysics of Space Flight. Jul 1958, 10p. WADC Technical rept. no. 58-290. AD-155 808.

Accepted physical principles suggest that immersion of subjects in water should constitute effective protection against some of the effects of acceleration. This premise has been evaluated in a study of the duration of tolerance of immersed subjects to forward accelerations of 6 through 14 g. Respiration was maintained by the use of skin diver's breathing equipment. With proper positioning, acceleration time tolerances were observed which were in excess of twice any previously reported.

5. Coburn, K. R., P. H. Craig, and E. L. Beckman
EFFECT OF POSITIVE G ON CHIMPANZEES IMMERSED IN WATER. Aerospace Medicine, Vol. 36:3, Mar 1965.

A concept for the prevention of the deleterious effect of high acceleration forces upon animals by immersing them in water in a "constant volume" G capsule has been proposed by GRAY. A series of experiments were carried out to evaluate the validity of this concept by subjecting primates to acceleration of up to +31 g_z in such a system. Included is a discussion of the pathological and physiological findings.

6. Code, C. F., E. H. Wood, and E. J. Baldes
HYDROSTATIC ANTI-BLACKOUT PROTECTION: THE PROTECTION AFFORDED AGAINST THE EFFECTS OF POSITIVE ACCELERATION BY IMMERSION IN WATER. Abstracted in: Federation Proc., Vol. 4:1, Mar 1945.

7. Hardy, J. D.
ACCELERATION PROBLEMS IN SPACE FLIGHT. In XXI International Congress of Physiological Science, Buenos Aires, Argentina, Aug 1959.

8. Hyde, A. S. and H. W. Raab
A SUMMARY OF HUMAN TOLERANCE TO PROLONGED ACCELERATION. Aerospace Medical Research Lab., Air Force Systems Command, Wright-Patterson AFB, Ohio. Rept. No. AMRL-TR-65-36. Final Report Jan 1963 – Jan 1965.

Human subject tolerance to accelerations of greater than one second duration is summarized for the orthogonal X, Y, and Z axes. Because each investigator at each laboratory utilizes different restraint systems, body positions, ambient temperatures, etc. and most important, utilizes different criteria of "tolerance," the data are referenced and presented in tables and graphs for each major category (direction of acceleration. The points presented in the graphs and tables are usually the highest values achieved; in each series there were subjects who could not tolerate the given direction, amplitude, and duration.

9. Lindberg, E. F., et al
EFFECT OF PARTIAL IMMERSION IN WATER ON RESPONSE OF HEALTHY MEN IN HEADWARD ACCELERATION. Journal of Applied Physiology. Vol. 18:1171 – 1179, Nov 1963.

Protection against the effects of headward acceleration afforded by immersion in water was assayed in the human centrifuge on 15 subjects. The findings did not support the concept that impediment to venous return is the primary determinant of man's tolerance to headward acceleration. Visual symptons occurred at increased amplitudes of ear pulse, and presumably also at increased blood pressure at head level, during water immersion than during control runs.

10. Margaria, R., T. Gualtierotti, and D. Spinelli
PROTECTION AGAINST ACCELERATION FORCES IN ANIMALS BY IMMERSION IN WATER. J. of Aviation Medicine 29(6):433 – 437, Jun 1958.

Experimentally an animal immersed in water can stand acceleration forces more than ten times greater than in air, the probability of survival being very high even at 1,000 G. A limit to the resistance to acceleration forces is given by parts of the body having a specific weight different from that of the rest of the body, particularly the lungs for their air content, and the otoliths. Rat foetuses, having no air in their lungs, can survive impacts corresponding to accelerations higher than 10,000 G when the mother is floating in water.

11. Thiede, F. C., C. F. Lombard, and S. D. Bronson
EFFECT OF IMPACT ACCLERATION ON GUINEA PIGS PROTECTED BY A FLUID-FILLED BLADDER DEVICE AND BY TOTAL WATER IMMERSION. Aerospace Medicine, 1057 – 1062, Nov 1964.

Impact acceleration pathology in guinea pigs at 50 g, positioned either footward or transverse supine 12.5° from the horizontal, was not significantly different whether protection was afforded by full fluid immersion, a limit-stretch fluid-filled bladder or a fully contoured container. Intratracheal pressure pulses, however, indicated that intrapulmonic pressure build-up at impact is greater with fluid immersion and container only than with the bladder device. Pathology with 100 g headward

acceleration was extensive in the heavier organis with the container-only mode while lung pathology was much more severe in the immersed animals oriented footward and headward. This study may offer the same protection to man from impact accleration as full fluid immersion but with much less weight and without the compression effects on thorax and chest.

12. Webb, M. G. and R. F. Gray
PROTECTION AGAINST ACCELERATION BY WATER IMMERSION. Paper presented at the ARS semi-annual Meeting, 8 – 11 Jan 1959, San Diego.

A primary report on a relatively crude device for testing the principle of water immersion as a method of protecting man against the effects of acceleration. The authors believe that a practical immersion system is feasible from the engineering standpoint, and that such systems will be found in future space vehicles.

13. Wood, E. H., et al
PHOTOELECTRIC EARPIECE RECORDINGS AND OTHER PHYSIOLOGIC VARIABLES AS OBJECTIVE METHODS OF MEASURING THE INCREASE IN TOLERANCE TO HEADWARD ACCELERATION ($+G_z$) PRODUCED BY PARTIAL IMMERSION IN WATER, (The Mayo Clinic, Mayo Foundation, Rochester, Minn.) AMRL-TDR-63-106, Aerospace Medical Research Laboratories, Wright-Patterson Air Force Base, Ohio, Dec 1963.

The protection against the effects of headward acceleration afforded the human by his immersion in water to the level of the xyphoid and to the third rib at the sternum has been assayed in 15 trained centrifuge subjects. Variations in ear opacity, ear opacity pulse, heart rate, respiration and reaction times to auditory and visual stimuli were recorded continuously in a series of 15 subjects during 15-second exposures to acceleration while seated in a steel tub mounted in the cockpit of the Mayo centrifuge. The level of acceleration was increased by increments of 0.5 to 1.0 $+G_z$ until complete loss of vision (blackout) was produced when the tub was empty (control) and when filled with water to the level of the xyphoid and also to the third rib at the sternum. A total of 200 centrifuge exposures to accelerations ranging from 2.0 to 9.0 $+G_z$ were carried out.

No systematic alterations in the general pattern, characterized by a period of failure during the first 5 to 10 seconds followed by cardiovascular compensation and recovery from visual symptoms during the latter part of the exposure, were observed during immersion in water. The decrements in ear opacity associated with the various degrees of visual impairment were closely similar; however, the decrements in ear opacity pulse and increments in heart rate were significantly less during immersion in water than when in air. The average values for protection afforded by immersion in water to the third rib against loss of vision and the above three objective variables were 1.8 ± 0.1, 2.7 ± 0.2, and 2.9 ± 0.2 $+G_Z$ respectively. It is believed that at a head level a higher blood pressure is required to maintain vision during immersion in water than when no external pressure is applied to the lower part of the body; and that the protection afforded to blood pressure at head level and to maintenance of consciousness is greater than the protection afforded to vision.

PART I: PHYSIOLOGICAL STUDIES

B. Physiological Responses to Simulated Weightlessness

14. Abbott, H. M., J. H. Duddy, and D. M. Kowall
WEIGHTLESSNESS SIMULATION USING WATER IMMERSION TECHNIQUES: AN ANNOTATED BIBLIOGRAPHY. Lockheed Missiles & Space Col., Sunnyvale, Calif. Rept. no. LMSD-5-24-65-3, Sb-65-2-Rev. 1. Feb 1967. AD-649 861.

The compilation contains 141 selected references pertaining to biomedical and behavioral research involving immersion of human subjects. The references are organized under three principal topics: (1) Physiological Studies, including acceleration, impact protection and physiological responses to weightlessness simulation, (2) Human Engineering Studies, and (3) Techniques and Personal Equipment Requirements for immersion studies. The references are arranged alphabetically by author or title under each separate topic. An Author Index is included as an aid in locating specific investigators and publications. The references cited are considered to be the principal contributions to the literature during the period from 1951 through Jan 1967, including both open and government sources.

15. Agostoni, E., G. Gurtner, H. Rahn, and G. Torri
RESPIRATORY MECHANICS DURING SUBMERSION AND NEGATIVE-PRESSURE BREATHING. Department of Physiology, State University of New York at Buffalo, Buffalo, N. Y. and Istituto di Fisiologia Umana, Universita di Milano, Italy. Contracts: AF-33(616)-6823 and AF-61(052)-867. Journal of Applied Physiology 21: 251 – 258, Jan 1966.

During submersion up to the neck the expiratory reserve volume of the sitting subject is reduced to 11% of the vital capacity in air, the same decrease is obtained breathing from a tank at -20.5 cm H_2O. The decrease of lung volume is mainly due to the

(See also references 1, 3, 128, 143, 202)

cranial displacement of the abdomen; although at the end of spontaneous expirations during submersion the diaphragm is stretched almost as far as at full expiration, it is relaxed, whereas during a full expiration it contracts. The end-expiratory pressures across the rib cage, the diaphragm, and the abdominal wall are: -19, -14, and -13 cm H_2O during submersion, and -23.5, -11.5, and -12 during NPB. Notwithstanding the lack of the gravitational effect of the abdomen during submersion, the shape of the chest wall is almost the same as during negative-pressure breathing because of the low compliance of the rib cage. During submersion the airways resistance increases by 58% because of the lung volume decrease; during negative-pressure breathing it increases by 157%, the extra increase being due to the compression of the extrathoracic airways.

16. Beckman, E. L., K. R. Coburn, et al
SOME PHYSIOLOGICAL CHANGES OBSERVED IN HUMAN SUBJECTS DURING ZERO G SIMULATION BY IMMERSION IN WATER UP TO NECK LEVEL. Naval Air Development Ctr., Johnsville, Pa. Rept. No. NADC MA 6107. AD 256 727, 1961. (See also Aerospace Med. 32:1031 – 1041, 1961.)

Knowledge relative to the effects of prolonged weightlessness is needed in preparing man for space flight. The buoyant force exerted upon immersed bodies effectively simulates the weightless state with respect to proprioceptive sensory responses and perhaps in other ways. An investigation into the physiological effects of immersing subjects in water up to neck level was undertaken. A series of experiments involving 7 subjects immersed in water up to neck level for periods of 5 to 23 hours (5 subjects for 12 hours) showed a significant weight loss during the period of immersion, which was explained by the diuresis which occurred. Pulmonary volume measurements showed a decrease in the expiratory reserve volume and in the respiratory minute volume during immersion. There was no significant decrement in the performance of a tracking task, attributable to the water immersion, during exposure to a simulated space vehicle reentry deceleration profile. Exposure to 4.5 positive G for 15 seconds following water immersion revealed a decrement in tolerance in most subjects.

17. Benedikt, E. T., Editor
WEIGHTLESSNESS – PHYSICAL PHENOMENA AND BIOLOGICAL EFFECTS. New York: Plenum Press, 1961.

Contents include:

Levine, R. B.	"Zero Gravity Simulation,"
Simons, J. C.	"Current WADD Weightless Research,"
Brown, E. L.	"Human Performance and Behavior During Zero Gravity,"

18. Bourne, G. H., Editor
MEDICAL AND BIOLOGICAL PROBLEMS OF SPACE FLIGHT: PROCEEDINGS OF A CONFERENCE HELD IN NASSAU, THE BAHAMAS, NOVEMBER 1961. (Emory University, Dept. of Anatomy, Atlanta, Ga.) Academic Press, 1963.

Collection of papers dealing with medical and biological aspects of manned space flight. The vehicles and advanced manned space systems involved in launching operations are discussed, as are space vehicle simulators. Problems of weightlessness (especially cardiovascular adaptability), machines and attempts to simulate the weightless state, nutrition, the use of algae as food, water recovery in a space vehicle, and the problems of radiation are also considered.

19. Bourne, G. H.
(Emory University, Dept. of Anatomy, Atlanta, Ga.)
NEUROMUSCULAR ASPECTS OF SPACE TRAVEL. In: Physiology of Man in Space. New York, Academic Press, Inc., 1963, pp. 1 – 59.

Discussion of the muscular stresses in space flight resulting from weightlessness and high-g conditions. Radiation effects are also briefly noted. The macroscopic and microscopic structures of muscles and their methods of action and innervation are studied. The responses of sense organs to subgravity are tabulated. Illustrated are short-term water-immersion tanks, related equipment, and other zero-gravity simulators.

20. Bowers, J. A., W. B. Hood, et al
HEMODYNAMIC EFFECTS OF WATER IMMERSION. Aerospace Medical Research Lab. and Indiana Univ. Cardiopulmonary Lab. AMRL, Wright-Patterson AFB, Ohio. Paper given at Aerospace Med. Assoc. 36th Annual Meeting, Apr 1965, N. Y.

Five Air Force volunteers were studied during two separate eight-hour periods of supine water immersion and supine bed rest for changes in heart rate, blood pressure, and cardiac output (indicator dilution curves), and for alterations in blood volume (Evans Blue), urine volume and osmolarity. A dry suit with a free-breathing helmet was used for immersion. Blood sampling and measurement of hemodynamic variables utilized in dwelling arterial and superior vena cava catheters. In an attempt to evaluate cardiovascular deconditioning, the hemodynamic responses to 60° head up tilt, Valsalva, and venous occlusion cuffs were also studied pre- and post-immersion and bed rest. Immersion, compared with bed rest in the same subject, produced a consistent increase in urine volume (range, 173 – 670 per cent) with a fall in the ratio of urine to plasma osmolarity. These changes during immersion were accompanied by a decrease in plasma volume (range, -520 to -1085 cc), slight increase in plasma osmolarity (range, 7 to 12 milliosmoles/L), and minimal increases in blood hemoglobin (range, 0.1 to 2.0 gms/%). There were no consistant changes in blood pressure, cardiac output, or heart rate during water immersion or bed rest. Clear-cut evidence of cardiovascular deconditioning was not observed. Comparable changes in blood pressure, heart rate, and cardiac output occurred both pre- and post-immersion and bed rest in response to tilt, Valsalva, or venous occlusion cuffs.

21. Bowers, J. A., M. McCally, and R. H. Murray
WATER BALANCE AND PLASMA VOLUME DURING WATER IMMERSION. (Abstract) Aerospace Medicine, Mar 1966, p. 266.

During both manned space flight and water immersion, decreases in circulating plasma volume and diuresis have been demonstrated. In order to determine the duration and extent of these changes during water immersion. 15 neck level water immersion experiments were performed on AF volunteers for periods varying from 4 – 16 hours of immersion. Fluid intake was maintained at 200 cc/hr except for four experiments in which no fluid intake was allowed. Plasma volume was determined pre- and post-immersion. Urinary output and fluid balance (intake minus output) were determined. A progressive fall in plasma volume was observed over the entire 16 hours of immersion. The greatest decrease occurred during the first 6 to 8 hours, averaging 830 ml (p.05). After 8 hours of immersion only slight additional decrease in plasma volume were noted. Negative water balance was evident after 2 hour in all experiments. At the end of 8 hours of water immersion, water balance averaged

1215 cc. At the end of 12 hours, water balance was 1594 cc and after 16 hours 1582 cc. No significant differences were present between the response of the forced hydrated subjects and dehydrated subjects. It was concluded that during water immersion (a) circulating plasma volume decreased markedly in the first 8 hours, (b) a marked negative water balance is present for the first 12 hours after which a new equilibrium state is reached, and (c) the amount of fluid intake has only little effect on the above changes.

22. Brown, J. L.
ORIENTATION TO THE VERTICAL DURING WATER IMMERSION. Aerospace Medicine 32:209 – 217, Mar 1961.

Subjects were immersed in water at a depth of either 18 or 25 feet and then rotated in a tucked position on a rod through 3, 4, or 5 revolutions. Rotation was terminated with the head in one of 4 positions: upright, inclined forward, down, or back. Upon termination of rotation subjects were directed to point in the up direction, then to nod the head and correct the direction of pointing if necessary, and finally to swim toward the surface. There were errors in direction of initial pointing of as much as 180 degrees. Errors were greatest with the head down or back and least with the head up or forward. Nodding of the head was followed by consistent improvement in the direction of pointing. There was little indication of any difficulty in swimming in the upward direction. Greater density of the legs as compared to the trunk resulted in fairly rapid vertical orientation of the body upon release of the rod. The results are interpreted to reflect the relative inefficiency of the utricles as gravity sensors when the head is in certain positions. The simulation of zero gravity may be enhanced by utilizing these positions with water immersion.

23. Campbell, P. A. and S. J. Gerathewohl
THE PRESENT STATUS OF THE PROBLEMS OF WEIGHTLESSNESS. Texas State Journal of Medicine 55(4):267 – 274, Apr 1959.

Reports weightless orientation studies made by immersing men in water. Man's ability to orient himself depends upon a variety of factors, and during weightless situations the eye becomes the only reliable organ.

24. Carlson, L. D.
CARDIOVASCULAR STUDIES DURING AND FOLLOWING SIMULATION AND WEIGHTLESSNESS. (Kentucky, University, Dept. of Physiology and Biophysics, Lexington, Ky.). In: Life Sciences and Space Research V; International Space Science Symposium, 7th, Vienna, Austria, May 10 – 18, 1966, pp. 51 – 54. (Symposium sponsored by the Committee on Space Research, the International Union of Biochemistry, the International Union of Biological Sciences, and the International Union of Physiological Sciences.)

Evaluation of the extent to which the simulation of weightlessness by bed rest and water immersion appears valid. The simulation of weightlessness is compared with the actual state, and it is found that major differences occur in the recovery time of the tilt response and in the extent to which venous filling occurs during a tilt. The application of lower body negative pressure during bed rest is the only measure which seems to have positive results in preventing post-simulation orthostatic intolerance.

25. Diringshofen H. von
IMMERSION IN WATER AS A PARTIAL SIMULATOR OF WEIGHTLESSNESS IN SPACE MEDICINE. Archiv für physikalische Therapie (Leipzig), 14(4):307 – 311, Jul – Aug 1962. (In German)

Research on weightlessness employing water-tank type simulators is reviewed in the light of Titov's experience in space flight. Certain disturbances in the physiological functions seen in the experiments were caused by the hydrostatic pressure of the water. A progressive muscular asthenia with increasing tendency to orthostatic collapse developed in the experimental subjects as a direct effect of the hypodynamic environment. This tendency still persisted two days after the seven-day experiment in the water-tank simulator. The lowered stress resistance was evidenced by lowered acceleration tolerance, lowered physical efficiency in the presence of unimpaired muscle strength, and in particular by lowered sensorimotor performance. The electroencephalogram showed a disturbance in the sleep-wakefulness cycle, i. e., frequent intervals of light sleep or lowered consciousness and only two hours of deep sleep. Recommendations include a program of systematic physical exercise aboard the space ship to maintain muscle and cardiovascular tonus, and training of spatial orientation to compensate for the non-function of the otoliths in zero-gravity conditions.

26. Diringshofen H. von
THE PARTIAL SIMULATION OF WEIGHTLESSNESS IN WATER (ZUR TEILSIMULATION DER GEWICHTSLOSIGKEIT IM WASSER). Zentralblatt fur Verkehrsmedizin, Verkehrs-Psychologie, Luft- und Raumfahrt-Medizin, 10:193 – 197, Dec 1964. (In German)

Investigation of the effects of prolonged partial and total immersion in water as a means of simulating some of the conditions of weightlessness and their effects on the human body. The otic mechanisms of equilibrium, however, remain subject to the effect of gravity. Moreover, there are significant differences between true weightlessness and the partial simulation of this condition in water since there are pressure gradients between internal lung pressure and external pressure on the breastbone and chest which are a function of the depth to which the body is immersed and the pressure of the air supplied to the subject when under a diver's helmet. Of particular importance is the difference between both sides of the diaphragm. For purposes of optimum simulation this pressure should be equalized.

27. DOUGLAS STUDYING OIL BATH WEIGHTLESSNESS. Missiles and Rockets, p. 36, 4 Oct 1965.

An article describing the use of silicone oil in place of water for performing immersion studies of the physiological responses of 12 subjects to simulated weightlessness.

28. Douglas, W. K.
(USAF, Missile Test Center, Patrick AFB, Fla.).
MEDICAL ASPECTS OF ASTRONAUT TRAINING.
In: Bioastronautics. Edited by Karl E. Schaefer. New York, Macmillan Co.; London, Collier-Macmillan, Ltd., 1964, pp. 307 – 313.

Discussion of (1) basic sciences, (2) physical fitness, and (3) conditioning for space flight. It is indicated that the stresses to which the pilot of a spacecraft is exposed are generally similar to more intense than those to which an aircraft pilot is exposed. In order to safeguard the spacecraft pilot from a hostile environment which contains noise, vibration, acceleration, high temperatures, and other stresses, it is thought to be important that he be made intimately aware of the physiology of cardiovascular, respiratory, and vestibular systems. In order to increase the self-reliance of crewmen in the event of illness or incapacity, it may be advisable, according to the author, to give them instruction in diagnostic and therapeutic techniques. The subjects of

dietetics and rest, immunizations, basic hygiene, and exercise are discussed, and it is suggested that experience with the use of the Self-Contained Underwater Breathing Apparatus (SCUBA) can help build stamina, give experience in voluntary respiratory control, and, to a degree, simulate weightlessness. Training devices such as the Multi-Axis Spin Test Inertia Facility (MASTIF) and the centrifuge are discussed and the role of the flight surgeon is outlined.

29. Downey, V. M. and C. C. Cain
Lockheed Missiles & Space Company,
Sunnyvale, California.
POSSIBLE PHYSIOLOGICAL EFFECTS OF LONG-TERM WEIGHTLESSNESS. Paper given at Aerospace Medical Association, 36th Annual Meeting, Apr 1965, N. Y.

Many unknowns remain in weightlessness. The major questions concern the long-term effects. Fully realizing the possibilities for error, a projection of the possible effects of prolonged weightlessness upon man will nevertheless give us some idea what to expect in future manned orbital flights.

Two sources of such information exist today. The first is the few "hard" data available from the reports of the Mercury and Vostok flights (lasting from one and one-half hours to five days), and the earlier animal suborbital and orbital flights, notably the six-day flight of Laika. These data showed that man can adapt to short-term zero-g exposures. However, extrapolation of the data is a hazardous scientific venture. For example, much of the information obtained from parabolic aircraft flights has been shown to be due to changing or transitional acceleration, rather than to weightlessness itself.

The other source of information at hand is the data from simulation devices. Laboratory experiments in analogues of weightlessness have shown some effects on various organs. All such analogues are open to question. Conclusions based on these experiments may be in error. It is simply impossible to simulate weightlessness in the laboratory.

Effects on each organ system will be examined separately. The possible effects during long-term exposure to weightlessness will be considered first. Next, the possible effects after exposure to long-term weightlessness will be presented.

30. FORCE FIELDS.
In: NASA Life Sciences Data Book (National Aeronautics and Space Administration, Washington, D.C.) (Contract NASr-89.) Jun 1962.

This handbook provides 29 pages of charts and summaries from the various force fields. Areas covered include: acceleration (experience, impact, transverse G limits, acceleration terminology, variations in G tolerance, G vector and consciousness, direction of force, maximum tolerable acceleration profiles, G protection by water immersion); tolerance to tumbling; deceleration (abrupt transverse, positive and negative G decelerations, tolerance to vertical impact, human impact sensitivity, impact tolerance); G fields in rotating space vehicles; vibration, (response, tolerances, physiological effects, psychophysical factors, performance functions, transmission, oxygen consumption, respiratory ventilation, and tracking performance); resonance of the abdominal wall; oscillations; high dynamic pressures; and blast injury.

31. Gauer, O. H., P. Eckert, D. Kaiser, and H. J. Linkenbach
FLUID METABOLISM AND CIRCULATION DURING AND AFTER SIMULATED WEIGHTLESSNESS.
(Berlin, Freie Universität, Physiologisches Institut, Berlin, West Germany). International Symposium on Basic Problems of Man in Space, 2nd, Paris, France, Jun 14 – 18, 1965. Preprint no. 11. (Symposium sponsored by the International Astronautical Federation, International Academy of Astronautics, UNESCO, International Atomic Energy Agency, International Telecommunication Union, World Health Organization, and World Meteorological Organization.)

Discussion of water-immersion experiments designed to simulate the condition of weightlessness. For immersion periods of 8 hr, the following results were obtained: (1) osmotic clearance is frequently increased in addition to the usual increase in free-water clearance; (2) by a single injection or a slow infusion of vasopress in the diuresis of water immersion can be interrupted or prevented in the same manner as a water diuresis of the same strength which has been induced by drinking water; (3) an average reduction in plasma volume of 16% is demonstrated by measurements with Evans Blue; and (4) infusion of vasopressin during water immersion in dosages that were too small to affect blood pressure prevented orthostatic collapse in 4 out of 5 subjects. It is considered that, for the interpretation of these results, it is helpful to take the upright rather than the supine position as the normal control state of man.

32. Gauer, O. H.
PHYSIOLOGICAL PROBLEMS OF WEIGHTLESSNESS AND BASIC RESEARCH. Papers given at International Symposium on Basic Environmental Problems of Man in Space, 1st, Paris, France, October 29 – November 2, 1962, Proceedings. Edited by H. Bjurstedt, Springer-Verlag, New York, 1965. pp. 160 – 168.

Some predictions on the hazards of the weightless conditions which were made jointly with Haber twelve years ago are reviewed in the light of today's experience and recent advances in basic research. An outline of recent work on the circulatory basis of fluid volume control through intravascular receptors is presented. Recent work indicates that the CNS performs an evaluation of the "competence" of the heart to deal with the load imposed on the circulation during a day. Loss of "competence" is accompanied by fluid retention, gain by diuresis. The application of this principle to the state of weightlessness as far as it could be produced in immersion experiments permits the explanation of observed changes in fluid and mineral metabolism which can in turn be related to current concepts of blood volume control.

33. Gauer, O. H.
RESEARCH ON VOLUME CONDITIONED STIMULI AFFECTING SALT AND WATER EXCRETION. Final Scientific Rept., 1 Feb 1965 – 31 Jan 1966. Berlin, Freie Universitaet Physiologisches Institut (West Germany). Contract: AF-EOAR 63-65, Jan 1966. AD-633 968.

Results of following investigations are given: effects of vasopressin on circulatory homeostasis during and after simulated weightlessness (water immersion); role of portal circulation in osmo- and volume control; vasopressin and lymph; reflex changes of the circulation during graded changes of transmural pressures.

34. Gauer, O. H.
RESEARCH ON VOLUME CONDITIONED STIMULI AFFECTING SALT AND WATER EXCRETION.
Rept. No. 2 (Final) for 1 Feb 1964 – 31 Jan 1965.
Berlin, Freie Universitaet Physiologisches Institut (West Germany). Contract: AF EOAR-64-16, Mar 1965. AD-614 912.

A bibliography is given of the six published papers, involving fluid volume control and the physiologic effects of water immersion, where generated under the auspices of the grant.

35. Gaume, J. G.
THE BIOLOGICAL EFFECTS AND IMPLICATIONS OF WEIGHTLESSNESS. (Martin Company, Denver Division) Apr 1962.

This research report explores the effects and implications of weightlessness on the human body for extended periods. It cites past research on weightlessness and compares bed rest and water suspension with actual weightlessness in outer space. The document suggests carefully planned muscle exercises as a possible means of preventing ill effects caused to the body by long periods of weightlessness.

36. Generales, C. D. J., Jr.
WEIGHTLESSNESS: ITS PHYSICAL, BIOLOGICAL, AND MEDICAL ASPECTS. In: Medical and Biological Problems of Space Flight: Proceedings of a Conference Hel in Nassau, The Bahamas, November 1961. Edited by C. H. Bourne, N. Y., Academic Press, 1963, pp. 123 – 187.

General discussion and review of the nature of weightlessness and its effects on biological systems. The geophysical aspects of gravity are considered, as are the gravity environments to be expected on the Moon and various planets. The physiological effects of the weightless environment are considered, including respiratory and cardiovascular effects in man. The requirements for a life-support system for a space vehicle are studied, including the microorganisms and algae needed, as well as sources of air and water. Methods of evaluating weightlessness effects are briefly described, including the use of simulators in which a man is immersed in water. Also considered are methods by which the astronaut can accustom himself to the

long-term effects of weightlessness. The advantages and disadvantages of the artificial gravity environment are analyzed, and the effects of rotation on man are outlined. The use of weightlessness in surgery is considered in relation to the influence on the body tissues and mechanisms of zero-g.

37. Gerathewohl, S. J.
RECENT EXPERIMENTS ON SUBGRAVITY AND ZERO-G STRESS. (Paper, 31st Annual Meeting, Aerospace Medical Association, May 1960, Miami Beach, Fla.).

Subgravity and zero-G have long been considered an unfavorable environmental condition. For about one decade, several experimenters in this country and abroad have studied the stress as involved in actual and simulated weightlessness on both animals and man. Since weightlessness actually produces a stressless situation, the immersion method has attracted special attention. In this case, no particular surface area has to carry the weight of the body, and the internal stress forces seem to be minimized. Moreover, the remaining stress within the body is isotropic, if the difference in hydrostatic pressure remains small. All this is true within certain limits for the homogenous and non-sensoric part of the organism. Gravity and acceleration changes directly act upon the specific gravireceptors. Stimulation of the vestibular system by angular acceleration will not occur in flight parabolas and orbits, if the subject is at rest, since the rotation of a vehicle around its y-axis does not produce vistibular Coriolis effects. Only rotations of the unrestrained subjects cause extreme disorientation after a few revolutions which, in fact, border on severe cases of vertigo, at times. However, with a visual frame of reference and experience in unrestrained floating, moving, and performing, the weightless condition does not appear to be a serious obstacle to space flight.

38. Gerathewohl, S. J. and J. E. Ward
PSYCHOPHYSIOLOGIC AND MEDICAL STUDIES OF WEIGHTLESSNESS. Physics and Medicine of the Atmosphere and Space. (Proceedings of the Second International Symposium on the Physics and Medicine of the Atmosphere and Space, held at San Antonio, Texas, November 10, 11, and 12, 1959, sponsored by the School of Aviation Medicine, Aerospace Medical Center (ATC) Brooks AFB, Texas). (New York: John Wiley & Sons, 1960). Chapter 26, pp. 422 – 434.

Reports study of group of 46 men and one woman for weightlessness tolerance at the USAF School of Aviation Medicine. Tabular account of results with psychological reactions.

39. Giovanni, Cleto Di, Jr. and R. M. Chambers
PHYSIOLOGIC AND PSYCHOLOGIC ASPECTS OF THE GRAVITY SPECTRUM. New England Journal of Medicine, 270:134 – 139, 16 Jan 1964.

A discussion is presented of the possible physiologic and psychologic effects of subgravity and weightlessness. Problems considered include excess calcium mobilization, muscular atrophy, and bone demineralization; disorientation, the oculogravic illusion, and vestibular disturbances; psychomotor performance, visual acuity, and sleep; and orthostatic intolerance. Pertinent evidence is presented from laboratory experiments, zero-gravity trajectory flights, and suborbital and orbital flights.

40. Giovanni, Cleto Di, Jr. and R. M. Chambers
PHYSIOLOGIC AND PSYCHOLOGIC ASPECTS OF THE GRAVITY SPECTRUM. New England Journal of Medicine, 270:88 – 94, 9 Jan 1964.

A discussion is presented of the possible effects of acceleration on psychomotor performance, and the effects of subgravity and weightlessness on the cardiovasular system. Pertinent data are presented from laboratory and clinical experiments and orbital flights. The human centrifuge is described, and techniques for the study of weightlessness are discussed, including the Keplerian trajectory, orbital flight, bed rest, and water immersion.

41. Giovanni, Cleto Di, Jr. and R. M. Chambers
PSYCHOPHYSIOLOGICAL ASPECTS OF REDUCED GRAVITY FIELDS, REPORT NO. 6. Naval Air Development Center, Johnsville, Pa. Aviation Medical Acceleration Lab. Rept. no. (NADC-MA-6305; AD-430095), N64-15753, 30 Dec 1963.

Considerable data have been collected concerning acceleration physiology from centrifuge, rocket sled, and drop tower studies but weightlessness has remained a poorly understood environment primarily because there is no way to duplicate it on earth. This report considers the various methods used to study or approximate the subgravity state, and the results and extrapolations that have been drawn from them. The

cardiovascular and musculoskeletal aspects of recent bed-rest and water-immersion studies are examined, and results are compared with the data from actual space flights. Real weightlessness apparently has been an innocuous environment thus far, and the only factor of concern has been a tendency toward postural hypotension detected immediately following recovery after missions of 9 and 34 hours. As longer missions are achieved, other problems, such as muscle atrophy and excessive calcium mobilization, may appear.

42. Goff, L. G., et al
THE EFFECTS OF TOTAL IMMERSION AT VARIOUS TEMPERATURES IN OXYGEN UPTAKE AT REST AND DURING EXERCISE. Journal of Applied Physiology, 9:59, 1956.

43. Goldman, J. K.
FREE FATTY ACID RESPONSES TO TILTING AFTER WATER IMMERSION. Aerospace Medical Research Laboratories, Wright-Patterson Air Force Base, Ohio, AMRL-TR-65-77, May 1965.

Water immersion is accompanied by decreased urinary excretion of noradrenaline and is followed by orthostatic intolerance. The latter has been postulated to result from impaired noradrenaline metabolism. Such an impairment would produce, in addition, a diminished rise in plasma free fatty acids in response to tilting. This response was measured in normals after office control, water immersion and exposure to a thermal environment identical to that found in the immersion facility. The plasma free fatty acid response to a tilt is impaired after water immersion as would be expected if sympathetic nervous system dysfunction is involved in postimmersion orthostatic intolerance.

44. Goodall, McC., M. McCally, and D. E. Graveline
URINARY ADRENALINE AND NORADRENALINE RESPONSE TO SIMULATED WEIGHTLESS STATE. American Journal of Physiology, 206:431 – 436, Feb 1964. (Contract No. AF-33(657)-10627).

Sixteen normal subjects were placed in a simulated weightless state, i.e., water immersion. After 6 hours of immersion, urine samples were collected and bioassayed for adrenaline and noradrenaline. The excretion of adrenaline was moderately

increased ($P < 0.15 > 0.10$), possibly related to the anxiety associated with the immersion. The excretion of noradrenaline was significantly ($P < 0.01$) reduced during immersion. Six subjects were also studied during passive vertical tilt following the immersion. The increase in pulse rate and decrease in pulse pressure were significantly greater than those observed during a control tilt. The results of these experiments indicate that the decrease in orthostatic tolerance following a simulated weightless state is probably related to a decrease in sympathetic nerve activity, which in turn is reflected by a decline in the urinary output of the sympathetic neurohormone noradrenaline.

45. Gooden, B. A.
BIO-MEDICAL PROBLEMS OF PROLONGED SPACEFLIGHT. Spaceflight, 7(3):98 – 103, May 1965.

The problems affecting the cardiovascular system is discussed and some methods are suggested for protecting astronauts during and after long space missions. Experimental procedures are noted for producing cardiovascular deconditioning in subjects on earth.

46. Graveline, D. E. and M. M. Jackson
DIURESIS ASSOCIATED WITH PROLONGED WATER IMMERSION. Report on Biophysics of Flight. Aerospace Medical Lab., Aeronautical Systems Div., Wright-Patterson Air Force Base, Ohio. ASD TR 61-651, Dec 1961. AD-273 201.
(See also J. Appl. Physical, 17:519, 1962.)

Utilizing complete water immersion, balanced respiration, and unrestricted activity, the diuretic response of five human subjects to 6-hour periods in this environment was studied. The results indicate that the low specific gravity diuresis which occurs in this situation is of the water-diuresis type, with decreased urinary concentrations of sodium, potassium, urea, and creatinine.

47. Graveline, D. E.
EFFECTS OF POSTURE ON CARDIOVASCULAR CHANGES INDUCED BY PROLONGED WATER IMMERSION. Rept.for Mar–May 1961, on Biophysics of Flight. (Aerospace Medical Lab., Aeronautical Systems Div., Wright-Patterson AFB, Ohio). ASD TR 61-563, Oct 1961. AD-270 869.

Previous hypodynamic research using water-immersion techniques was done with the subjects in a semi-reclining position. To evaluate the possible influences of posture and negative immobilization on the cardiovascular deterioration associated with prolonged water immersion, a technique was employed which allowed complete freedom of activity, position, and attitude. Five subjects were evaluated for functional change after 6 hours in this environment. The results indicate that postural factors play an insignificant role in the mechanism of cardiovascular alteration induced by water immersion.

48. Graveline, D. E.
MAINTENANCE OF CARDIOVASCULAR ADAPTABILITY DURING PROLONGED WEIGHTLESSNESS. Aeronautical Systems Div., Biomedical Lab., Wright-Patterson AFB, Ohio. Rept. no. ASD TR-61-707, Dec 1961 (Project 7222; Task 722201). AD-273 605. (See also Aerospace Med., 33:297, 1962.)

During prolonged zero gravity because of the absence of hydrostatic pressure influences, special techniques will be necessary to maintain cardiovascular adaptability and provide the orbiting astronaut with optimum tolerance for reentry stresses. A multiple tourniquet approach to intermittently obstruct venous return from the periphery has been devised, simulating the hydrostatic pressure effects of standing and thereby "triggering" compensatory cardiovascular reflexes. Following 6-hour periods of water immersion with tourniquet protection, the orthostatic tolerance of 5 subjects was determined and compared with that obtained following previous 6-hour immersion tests with no protection. In all subjects the tourniquet technique maintained normal or better than normal cardiovascular adaptability and measured by tilt-table testing.

49. Graveline, D. E.
MAINTENANCE OF CARDIOVASCULAR ADAPTABILITY DURING PROLONGED WEIGHTLESSNESS. Aerospace Medicine, Vol. 33, No. 3, Mar 1962, pp. 297 – 302.

50. Graveline, D. E.
MAINTENANCE OF CARDIOVASCULAR ADAPTABILITY DURING PROLONGED WEIGHTLESSNESS.
In: Medical and Biological Problems of Space Flight: Proceedings of a Conference Held in Nassau, The Bahamas, November 1961. G. H. Bourne, Editor. N. Y. Academic Press, 1963, pp. 115 – 122.

Brief description of a multiple tourniquet technique to maintain cardiovascular adaptability during prolonged zero-g exposure. The technique intermittently obstructs venous return from the periphery, simulating the hydrostatic pressure effects of standing, and thereby "triggering" compensatory cardiovascular reflexes. Following 6-hour periods of water immersion with tourniquet protection, the orthostatic tolerance of 5 subjects was determined and compared with that obtained following previous 6-hour immersion tests with no protection. In all subjects the tourniquet technique maintained normal or better than normal cardiovascular adaptability as measured by tilt-table testing.

51. Graveline, D. E. M. McCally, and M. M. Jackson
MECHANISMS OF THE WATER-IMMERSION DIURESIS.
In: 34th Annual meeting, Aerospace Medical Association, 1963. Aerospace Med., 34(3):256, 1963. (Abstract)

Paper given at 34th Annual Meeting Aerospace Med. Assoc. 1963.

52. Graveline, D. E. and G. W. Barnard
PHYSIOLOGIC EFFECTS OF A HYPODYNAMIC ENVIRONMENT SHORT TERM STUDIES.
Aerospace Medicine 32(8):726 – 736, Aug 1961.
See also (Wright Air Development Division, Wright-Patterson AFB, Ohio) WADD TR 61-257; AD-262 992.

By a technique involving complete immersion in water, a hypodynamic situation was produced in which normal weight sensations were altered and movement was relatively effortless. Four subjects were evaluated after 6, 12, and 24 hours of this environment. Tilt table, centrifuge, and heat chamber studies demonstrated significant cardiovascular deterioration even after the 6-hour runs, becoming more severe with the 12- and 24-hour experiments. Pertinent psychomotor evaluations, anthropometric measures, and urine and blood studies also were done. The results of this study indicate that the cardiovascular adaptation to a hypodynamic environment of this type occurs early and the deterioration from even a 6-hour exposure is apparent.

53. Graveline, D. E. and B. Balke
THE PHYSIOLOGIC EFFECTS OF HYPODYNAMICS INDUCED BY WATER IMMERSION.
School of Aviation Medicine, Brooks AFB, Texas. Research Rept. 60-88, Sep 1960.
AD-247 163.

Body immersion in water was used to produce an experimental situation in which the normal weight sensation was altered and in which slow movements were effortless. The hypodynamic effects of such immersion on orthostatic tolerance, on cardiorespiratory adaptability to physical stress, and on other biologic and psychophysiologic parameters were studied on one human subject in experiments of 2 and 7 days duration, respectively. Pronounced functional deterioration resulted from the hypodynamic situation in both experiments; cardiovascular reflexes were severely disturbed and muscular tone was diminished. The extensive biochemical studies on blood and urine showed marked deviations from the normal. Psychomotor effectiveness, tested on a complex systems task, was impaired noticeably. The need for sleep appeared to be markedly reduced during the periods of water immersion.

This area of research is vital to the man-in-space program. Weightless or near-weightless conditions in space flight are expected to produce a similar hypodynamic effect on the organism as was caused by water immersion. Such loss of functional reserves may severely interfere with the astronaut's capability to adjust adequately to returning gravitational forces.

54. Graveline, D. E., B. Balke, et al
PSYCHOBIOLOGIC EFFECTS OF WATER-IMMERSION-INDUCED HYPODYNAMICS, Aerospace Medicine 32(5):387 – 400, May 1961.

A weightless environment in which movement was effortless was produced by whole body immersion in water. One subject was immersed for seven days. The data collected during that time indicated that serious functional impairment results from prolonged exposure to hypodynamic conditions.

55. Graveline, D. E. and M. McCally
SLEEP AND ALTERED PROPRIOCEPTIVE INPUT AS RELATED TO WEIGHTLESSNESS: WATER IMMERSION STUDIES. Aerospace Medical Research Labs., (6570th), Aerospace Medical Div., Biomedical Lab., Wright-Patterson AFB, Ohio. AMRL-TDR-62-83. AD-286 022. (Abstracted in Aerospace Medicine, v. 34, no. 1, p. 74, January 1963).

The "free-floating" condition of immersion is associated with substantial alterations in mechano-receptive feedback to the central nervous system in a manner similar to the free-floating condition of weightlessness. In this study electroencephalographic and electrooculographic recordings were made during sleep of completely immersed, neutrally buoyant subjects. Sleep records obtained while using both tether and clam-shell sleeping facilities were compared to each subject's normal bedrest sleep records. The results are presented, and their possible application to prolonged weightlessness is discussed.

56. Graybiel, A. and B. Clark
SYMPTOMS RESULTING FROM PROLONGED IMMERSION IN WATER: THE PROBLEM OF ZERO G ASTHENIA. (Naval School of Aviation Medicine, Pensacola, Fla.) (Proj. MR005.15-2001.1.4), 25 July 1960; AD-244 932. (See also Aerospace Medicine 32(3):181 – 196, Mar 1961).

In order to reduce the effects of G on the body, three subjects were floated in tanks of physiological saline solution for ten hours per day for two weeks while systematic attempts were made to eliminate any effects of sensory deprivation.

57. Graybiel, A. and B. Clark
SYMPTOMS RESULTING FROM PROLONGED IMMERSION IN WATER: THE PROBLEM OF ZERO G ASTHENIA. (U.S. Naval School Aviat. Med. Res., Pensacola, Fla.) Jun 15, 1960. Rep. MR005.15-2001, (Subtask 1, Rep. 4:1–27).

58. Guyatt, A. R., F. Newman, F. F. Ankotai, J. I. Palmer, and M. L. Thomson
PULMONARY DIFFUSING CAPACITY IN MAN DURING IMMERSION IN WATER. Journal of Applied Physiology, in press.

59. Haines, R. F.
POSTURAL ORIENTATION IN A HYPODYNAMIC ENVIRONMENT: I. THE EFFECT OF PRIOR EXPERIENCE. Paper given at Midwestern Psychological Assoc. Annual Meeting, May 4, 1963, Chicago, Illinois.

This paper deals with postural orientation to the vertical under water. The role of prior underwater swimming experience on the ability to place oneself in the vertical position without the aid of vision is assessed. The major conclusions were that: (1) prior SCUBA experience has little effect on the ability to place oneself in the

vertical position without vision, (2) a certain amount of habituation occurs to the initial side of tilt and is most likely due to water resistance to body movement, (3) subjective estimates of starting tilt tend to be correct for direction but overestimated and, (4) the present methodology is sound for subjects able to hold their breath for at least 45 seconds.

60. Hammer, L. R.
AERONAUTICAL SYSTEMS DIVISION STUDIES IN WEIGHTLESSNESS: 1959 – 1960. Aerospace Medical Laboratory, Aeronautical Systems Division, W-P Air Force Base, Ohio. Dec 1961. (Proj. 7184; Task 71595). WADD TR 60-715. AD-273 098.

Facilities and techniques used at Aeronautical Systems Division to study the effects of weightlessness are described; completed experiments and those started before January 1961 are discussed. Topics are grouped under two main headings: aerospace medical studies and aeromechanics studies. Specific problem areas and methods of experimentation are emphasized. Findings are briefly stated.

The Biomedical Laboratory Water Submersion Task is discussed in Section 11, Facilities and Methodology. Studies of the Psychophysiological Effects of Prolonged Weightlessness employing the water submersion tank are discussed in Section 111, Aerospace Medical Studies.

61. Hong, S. K., H. Rahn, D. H. Kang, S. H. Song, and B. S. Kang
DIVING PATTERN, LUNG VOLUMES, AND ALVEOLAR GAS OF THE KOREAN DIVING WOMAN (AMA). Department of Physiology, Yonsei University College of Medicine, Seoul, Korea, and Department of Physiology, State University of New York at Buffalo, New York. Grant: G-8794, National Science Foundation. Journal of Applied Physiology, 18:457 – 465, May 1965.

Lung volumes and alveolar gases during actual dives were studied in the Korean diving women, or ama. These women dive without assistance. Average descent and ascent velocities are 0.6 m/sec. Maximal depth and duration of dive observed were 17 m and 82 sec, respectively. However, typical sustained diving activity is to a depth of 5 m for 30 sec, averaging 60 dives/hr. This diving pattern is compared with the assisted

dives of the Japanese ama lasting 60 sec and reaching a depth of about 20 m. Prior to diving the lung is filled to 85% of vital capacity. About 700 ml of this gas are lost upon return to the surface. A slight hyperventilation before dive reduced the P_{CO_2} to 28. At the bottom the fractional composition of O_2 as well as CO_2 is less than before dive indicating that both gases are removed by the circulation. The compression of the gases accounts for the reversal of CO_2 transport. Upon return to the surface CO_2 leaves the blood and reaches normal values while the O_2 is very low. At the bottom O_2 pressure is high due to compression but falls rapidly upon ascent. The detailed pattern of gas exchange is discussed.

62. Hong, S. K., S. H. Song, et al
SEASONAL OBSERVATIONS ON THE CARDIAC RHYTHM DURING DIVING IN THE KOREAN AMA.
J. Appl. Physiol. 23(1):18 – 22, 1967.

Electrocardiograms were obtained from five ama in the summer (water temperature of 27° C) and the winter (water temperature of 10° C) during each of the following apneic maneuvers: (1) breath holding (BH) in air, (2) BH in water, (3) surface swim with head submerged underwater, and (4) diving to a depth of 5 meters. Although a sinus bradycardia was noted in all cases, the extent of this bradycardia was least during BH in air and was greatest during BH in water as well as during surface swim. Moreover, the bradycardia during diving was less severe than during BH in water. Cardiac arrhythmias were uniformly noted in all apneic maneuvers. On the basis of these findings, it is concluded that the diving bradycardia is mainly attributable to both breath holding and water submergence and the cardiac arrhythmia during diving to breath holding alone.

63. Howard, P., J. Ernsting, and D. M. Denison, et al
EFFECT OF SIMULATED WEIGHTLESSNESS UPON THE CARDIOVASCULAR RESPONSE TO PASSIVE TILTING. Aerospace Medicine. (Abstract) Mar 1966.

In an effort to identify some of the factors concerned in the production of cardiovascular deconditioning, the response to passive tilting (to 70° for 12 minutes) was measured in five men before and after immersion for 6 hours in salt water at a temperature of 34° C. The subjects were immersed in a supine position. Orthostatic tolerance was not affected by immersion. The response of the arterial blood pressure during the second tilt was not significantly different from the controls. Urine output during the test was normal or decreased and no significant change of plasma volume was observed. The absence of diuresis and of a decrease in the plasma volume suggests that the pressure/volume relationship of the intrathoracic circulation remained normal throughout. This supports the conclusion that the decondition demonstrated by others was due to the negative breathing pressure selected for their experiment. Theoretically considerations indicate that although the reference level chosen will profoundly affect the results,

the choice must be arbitrary, and that a realistic simulation of weightlessness in the pulmonary circulation is impossible.

64. Howard, P., J. Ernsting, D. M. Denison, D. I. Fryer, D. H. Glaister, and G. H. Byford
EFFECTS OF SIMULATED WEIGHTLESSNESS UPON THE CARDIOVASCULAR SYSTEM.
(Royal Air Force, Institute of Aviation Medicine, Farnborough, Hants., England). Aerospace Medicine, vol. 38, Jun 1967, pp. 551 – 563.

The effects upon the cardiovascular system of weightlessness simulated by immersion in brine for six hours were studied in five subjects. Measurements of the blood pressure, heart rate, plasma volume, urine excretion, and metabolic gas exchange failed to reveal any abnormality resulting from the immersion. The response to passive tilting to an angle of 70° from the horizontal for twelve minutes was recorded before and after the exposure. No syncopal reactions occurred, and the slight changes in the reactions after immersion could be attributed to other factors. It is postulated that the failure to demonstrate cardiovascular deconditioning was related to the absence of a diuretic response, and that both were the result of essentially normal thoracic pressures. The selection of a reference level for the respiratory system is discussed in relation to the effects of weightlessness upon the peripheral circulation. It is concluded that no entirely satisfactory reference can be defined.

65. Hunt, N. C., III
A FACTORIAL STUDY OF IMMERSION DIURESIS AND ITS INHIBITION BY POSITIVE PRESSURE.
(USAF School of Aerospace Medicine, Brooks AFB, Texas.) Paper given at Aerospace Medical Association 36th Annual Meeting, April 1965, N. Y.

This study was sought fo further define the nature of a water immersion diuresis and to attempt to counterbalance the negative pressure breathing (NPB) inherent to water immersion with properly applied positive pressure. In this manner, a simulated weightlessness environment is presented in which water pressure counterbalances the usual hydrostatic gradients of the vascular system, without the artefactural NPB element.

A panel of subjects has been submitted to a factorial analysis to compare urine volume and composition during routine activity, recumbency, and water immersion (semi-supine with headout). A continuous-flow respiratory system using weighted spirometers was evaluated for (a) absence of intrinsic diuretic stimuli at zero pressures,

which have been noted even in low resistance respiratory equipment, and (b) ability to produce antidiuresis at positive pressures. These standards were attained. Measurements of the negative pressure imposed by head out immersion were made.

Current analysis includes four subjects, with an anticipated total of ten. The subjects were dehydrated and sumitted to six hours of the various regimens, with urine collected hourly for volume and composition. Using the urine of routine activity as control, the volumes during recumbency and immersion increase 230 per cent and 354 per cent, respectively. Application of 15 cm H_2O respiratory pressure to immersed subjects reduced the volume to 254 per cent. Sodium values, presented as above were 204 per cent and 294 per cent, respectively, returning to 199 per cent during positive pressure, application. Comparison of recumbency and immersion urines reveals a qualitatively similar composition, the implication of which will be discussed. Absolute amounts of creatinine excretion revealed minimal differences between treatments, in contrast to previously reported findings; standard GFR studies are being initiated. Finally, comparison of immersed subjects with and without respiratory counterpressure will be presented.

66. Hunt, N. C., III
IMMERSION DIURESIS. (Duke Hospital, Dept. of Medicine, Durhan, N. C.). Aerospace Medicine, vol. 38, Feb 1967, pp. 176 – 180.

The effect of water immersion on urine composition was studied in twelve dehydrated subjects. Acting as their own controls, the subjects were submitted to three separate six-hour periods of (1) routine daily activity, (2) water immersion to neck level, reclining in a deck chair, and (3) reclining in a deck chair, nonimmersed. Reclining in a deck chair, relative to routine daily activity, was associated with a natruresis accompanied by a small volume of osmotically obligated water. Water immersion, relative to reclining in a deck chair, was associated with a marked diuresis, consisting primarily of nonsolute obligated water, and secondarily of water obligated to a significantly increased sodium excretion. In six subjects, Pitressin treatment tended to suppress immersion diuresis. Whereas the release of nonsolute obligated water is best explained by ADH inhibition accompanying the negative pressure breathing inherent to immersion, another reason must be sought for the enhanced sodium excretion. The mechanism for natruresis was not defined by indirect measurements of glomerular and tubular activity; possible mechanisms are discussed.

67. Hunt, N. C., III
POSITIVE PRESSURE BREATHING DURING WATER IMMERSION. (USAF School of Aerospace Medicine, Brooks AFB, Texas.) Aerospace Medicine, Vol. 38, Jul 1967, pp. 731 – 735.

Continuous positive pressure breathing was applied to twelve volunteers during water immersion, in an attempt to overcome the diuresis and tilt table intolerance associated with immersion. During the six-hour treatment period the subjects reclined in a deck chair, immersed to neck level in water, and breathed a continuous 20 cm H_2O positive pressure. The resultant urine composition and tilt table tolerance were compared to that associated with six hours (a) immersed, and (b) non-immersed in the same position and without positive pressure. The use of positive pressure respiration inhibited the diuresis associated with water immersion; this inhibition applied to both non-solute obligated water and excretion of sodium salts. Tilt table tolerance following positive pressure surpassed that seen in the non-immersed control. It was concluded that the diuresis was inhibited by the action of positive pressure respiration on volume receptor sites. Possible mechanisms for tilt table protection are discussed.

68. Jarrett, A. S.
EFFECT OF IMMERSION ON INTRAPULMONARY PRESSURE. Journal of Applied Physiology, 20, Nov 1965.

Immersion resulted in an increase in intrapulmonary pressure. The significance of this to the positioning of the diver's demand valve is discussed.

69. Jarrett, A. S.
EFFECTS OF IMMERSION ON LUNG VOLUME. Flying Personnel Research Committee, R.A.F., Institute of Aviation Medicine, Farnborough, Hants, England. Publication No. 1221, Dec 1963.

70. Knight, L. A.
AN APPROACH TO THE PHYSIOLOGIC SIMULATION OF THE NULL-GRAVITY STATE.
J. Aviation Medicine 29(4):283 – 286, Apr 1958.

While studying the physiological effects of prolonged weightlessness the similarities between the condition of a body floating in space and that of a body floating in water were noted, and the conclusion was drawn that weightlessness is the absence of external forces acting on the body. It was assumed that a physiologic condition approaching that observed in the null-gravity state could be simulated by obscuring vision, immersing the subject in water to eliminate tactile and proprioceptive cues, and positioning him in the supine, head-down orientation. A preliminary experiment (three subjects acquainted with conditions of null-gravity) was conducted to investigate the matter of spatial orientation during immersion in water, and to establish values for the threshold of sensitivity of the otolith organ to change in position.

71. Lambertsen, C. J.
PROCEEDINGS OF THE SYMPOSIUM ON UNDERWATER PHYSIOLOGY (3RD), 23, 24, AND 25 MARCH 1966, WASHINGTON, D.C., National Academy of Sciences-National Research Council, Washington, D.C., Committee on Undersea Warfare. 1967. Contract No. Nonr-2300(08). AD-652 315. Pub. by The Williams and Wilkins Co., Baltimore, Md.

Contents: Recent Naval Experiences in Extending Useful Diving Depth; The Problem of Fire; Saturation Diving; Special Problems in the Etiology and Treatment of Decompression Sickness; Potential Advances in Deep Diving; Limitations of Physiological Performance at Extreme Ambient Pressures; Physical and Cellular Mechanisms.

72. Lawton, R. W.
THE PATHOPHYSIOLOGY OF DISUSE AND THE PROBLEM OF PROLONGED WEIGHTLESSNESS: A REVIEW. Report for Dec 1960 – Mar 1963. Jun 1963, 46p. General Electric Co., Philadelphia, Pa. (Proj. 7222, Task 722201). AMRL TDR63-3. AD-417 395.

The physiological implications of zero-G as encountered in space flight are discussed and the available research concerning the physiological effects of weightlessness is reviewed. The purpose of this review is to proceed from the present state of knowledge of normal human physiological systems, particularly as their structure and function are affected by gravity, to a consideration of the possible physiological consequences of prolonged human exposure to zero-G. Methods used to produce and to simulate zero-G are briefly reviewed. The data suggesting that prolonged weightlessness will be a deconditioning environment is presented. This data is considered for possible untoward effects of prolonged exposure to weightlessness, and for methods of prevention of undesired effects. The problem of artificial gravity by rotation of a space vehicle is briefly considered. Areas of needed future investigation are suggested.

73. Lawton, R. W.
PHYSIOLOGICAL CONSIDERATIONS RELEVANT TO PROBLEM OF PROLONGED WEIGHTLESSNESS.
Astronautical Sciences Review 4(1):11 – 18, 31 – 38, Jan – Mar 1962.

Review of studies of inactivity and confinement to determine effects of immobilization and bed rest, and submersion in water; cardiovascular effects, bone demineralization; muscle atrophy; otolith functions; semicircular canal phenomena; slow rotation room and selection and training of astronauts.

74. Loftus, J. P. and L. R. Hammer
WEIGHTLESSNESS AND PERFORMANCE: A REVIEW OF THE LITERATURE, Aerospace Medical Laboratory, Wright-Patterson Air Force Base, Ohio, Jun 1961, ASD-TR-61-166.

The implications of weightlessness as encountered in space flight are discussed, and the known research dealing with the psychological and physiological effects of zero gravity is critically reviewed. Topics are grouped under the headings of orientation,

psychomotor performance, and physiological functions, with a special section of methods of research. The major problem area indicated is the effect of weightlessness on gravity oriented sensory mechanisms, particularly the vestibular apparatus, and consequently on both physiological functions and psychomotor performance. An extensive bibliography is included.

Immersion techniques are discussed in the section devoted to Methods of Research, pp. 5 – 6, and a review of immersion studies reported in the literature published prior to April 1961 is presented in the section devoted to Physiological Functions, pp. 21 – 22.

75. Margaria, R. and G. A. Cabagna
HUMAN LOCOMOTION IN SUBGRAVITY. Milano, Universita, Instituto di Fisiologia Umana, Milan, Italy). Aerospace Medicine, vol. 35, pp. 1140 – 1146. Dec 1964. (Research supported by the Italian National Research Council.)

Discussion of the effectiveness of experimental models for simulating subgravity conditions of the Earth. Methods for studying locomotion in subgravity, based on the use of (1) simulation techniques, such as sustaining the subject by means of springs or gas-filled balloons, or immersion in water, and (2) a quantitative analysis of the mechanics of locomotion at G = 1, with subsequent extrapolation of the data to G < 1, to determine the possible changes in the mechanics of locomotion, are examined and compared.

76. McCally, M.
BODY FLUID VOLUMES AND THE RENAL RESPONSE OF HUMAN SUBJECTS TO WATER IMMERSION, AMRL-TR-65-115. Aerospace Medical Research Laboratories, Aerospace Medical Division, Wright-Patterson Air Force Base, Ohio, Aug 1965.

Immersion of human subjects in water is used to simulate various aspects of the aerospace environment, including weightlessness. However, little is known of the physiological cardiovascular and renal responses to immersion. Such data are necessary before responses to immersion can be related to other environments, such as aerospace. The excretion of water and solute by the kidney is the fundamental mechanism for preserving the constancy of the mammalian extracellular fluid. The mechanisms by which the kidney is notified to retain or excrete water and solute in response to changes in the environment have been defined in considerable detail in recent years.

The response of the kidney to water immersion of human subjects, as measured by water and solute excretion, provides a fascinating model for the study of body fluid volume regulation. The Ama divers of Japan and Korea represent specific problems of body fluid volume regulation during immersion as dictated by the depth, duration, temperature, and respiratory mechanics of their particular immersion pattern. This report includes: (1) a brief review of the physiological mechanisms of body fluid volume regulation as we now understand them, (2) a description of the renal responses to neutral or indifferent temperature immersion, (3) a consideration of the role of pulmonary mechanics and water temperature in the renal response to immersion, (4) a summary of the possible mechanisms of the immersion diuresis and, (5) speculations about the renal response to Ama diving.

77. McCally, M. and J. Goldman
FREE FATTY ACID RESPONSE TO TILTING FOLLOWING IMMERSION. Aerospace Medical Research Laboratories, Wright-Patterson AFB, Ohio. Paper given at Aerospace Medical Association 36th Annual Meeting, Apr 1965, N. Y.

Orthostatic intolerance is seen in human subjects following prolonged bed rest and water immersion. Serum free fatty acids are released by noradrenaline and rise rapidly during the normal response to passive vertical tilt. Blood pressure, heart rate, plasma glucose and free fatty acid responses to a six degree vertical tilt for thirty minutes were studied in six subjects following six hours of complete water immersion, six hours of heat exposure simulating the thermal characteristics of the immersion and six hours of office activity control. Heart rate response to tilt was least after heat, greatest after immersion and significantly different in both cases from that following office control ($P < 0.01$ paired samples). During tilt after heat and office control, free fatty acids rose normally. After immersion the free fatty acids fell 20 per cent ($p < 0.01$) and then rose slowly toward control levels. Plasma glucose levels did not change significantly in response to any of the tilts. The impaired fatty acid response to tilt after immersion supports the hypothesis that the known diminished urinary excretion of noradrenaline during water immersion reflects decreased sympathetic vasomotor activity in turn contributes to the orthostatic intolerance. The possible relationships of disuse and inactivity to the metabolism of noradrenaline are discussed.

78. McCally, M.
PLASMA VOLUME RESPONSE TO WATER IMMERSION: IMPLICATIONS FOR SPACE FLIGHT. Aerospace Medicine 35(2):130 – 132, 1964. AD-441 410.

Change in plasma volume of 5 subjects was measured during 6 hours of complete water immersion and during 6 hours of office activity control by hemoglobin and hematocrit

dilution and with radio-iodinated serum albumin (RISA) techniques. The mean plasma volume increased 9% during the first 25 minutes of immersion and then decreased over the next 4 to 6 hours to approximately 11% less than the zero time value. The repeated injection and sampling of RISA is not a suitable technique for the measurement of acute changes in plasma volume. The mechanisms of the water immersion diuresis and post-immersion orthostatic intolerance are discussed and inferences made to human exposure to weightlessness.

79. McCally, M., J. K. Goldman, and G. W. Barnard
SYMPATHOADRENAL RESPONSE TO WATER-IMMERSION HYPODYNAMICS. (In: 34th Annual Meeting, Aerospace Medical Association, 1963.) Aerospace Medicine 34(3):262, 1963.

80. McCally, M. and D. E. Graveline
URINARY CATECHOLAMINE RESPONSE TO WATER IMMERSION. U.S. Air Force Tech. Doc. Rept. AMRL-TDR-63-20. 1 – 10, 1963. AD-407 741.

The urinary excretion of adrenaline and noradrenaline was measured by bioassay for 16 normal human subjects during 6 hours of complete water immersion. The excretion of adrenaline was moderately increased, possibly related to the anxiety associated with the immersion. The excretion of noradrenaline was significantly ($p < 0.01$) reduced during immersion. Six subjects were studied during passive vertical tilt following immersion. Orthostatic intolerance was demonstrated and the increase in pulse rate and decrease in pulse pressure were significantly different from the control tilt. The probable mechanisms of the reduced noradrenaline excretion during immersion and its relation to the postimmersion impairment of orthostatic tolerance are discussed.

81. McCally, M. and D. E. Graveline
URINARY ADRENALINE AND NORADRENALINE RESPONSES TO WATER IMMERSION. Federation Proceedings 22(2 Pt. 1):508, 1963. Paper given at 47th Annual meeting of the Federation of American Societies for Experimental Biology, 1963.

82. McCally, M. and D. E. Graveline
SYMPATHOADRENAL RESPONSE TO WATER IMMERSION. Aerospace Medicine, 34, 1007 – 1011. (1963)

Urinary excretion of adrenaline and noradrenaline was measured by bioassay of 16 subjects during 6 hours of complete water immersion. Excretion of adrenaline was moderately increased with immersion (possibly due to anxiety). The excretion of noradrenaline was significantly decreased ($p = 0.01$) during immersion. During passive vertical tilt following immersion orthostatic intolerance was demonstrated and the increase in pulse rate and decrease in pressure were significantly different from the control tilt. The possible mechanism of the decrease noradrenaline excretion during immersion and its relation to post immersion impairment of orthostatic tolerance is discussed.

83. McKenzie, R. E., B. Hartman, and D. E. Graveline
AN EXPLORATORY STUDY OF SLEEP CHARACTERISTICS IN A HYPODYNAMIC ENVIRONMENT. School of Aerospace Medicine, Brooks AFB, Texas. Rept. SAM 60-68, Oct 1960. AD-250 042.

Sleep characteristics were monitored and evaluated by eeg technics during an exploratory study of biologic hypodynamics produced by body immersion, three kinds of changes in sleep characteristics were seen: (a) a reduction in the total amount; (b) a constriction in the range of sleep states; and (c) a progressive improvement in the stability of sleep states. The hypothesis is advanced that the biologic function of sleep may be to provide a recovery period from the neuromuscular debt acquired from the effects of counter-acting the forces of gravity. This has several implications for space travel in the weightless state.

84. Meineri, G.
THE EFFECTS OF SUBGRAVITY AND THE METHODS FOR REPRODUCING IT ON THE GROUND AND IN FLIGHT. Rivista di medicina aeronautica e spaziale (Roma), 26(1):80 – 98. Jan – Mar 1963. (In Italian, English summary (p. 94)).

A review of the literature is presented which deals with experiments on the physiological effects of subgravity. The chief methods used to simulate subgravity conditions are described and a distinction is made between ground methods (immersion of all or part of the body in water, high acceleration exposure), and the more

cumbersome methods through which actual or complete subgravity can be attained (parabolic flight, suborbital and orbital launching). The accomplishments are reported of the Center of Studies and Researchers in Aerospace Medicine, Rome, which uses a subgravity tower for experiments. This tower is of great value in obtaining data on the physiological effects of short-term subgravity similar to that encountered in space flight, such as transition between the active and passive stage of flight, the effects on psychomotor behavior, the role played by the labyrinth and its components, etc. The possible extension of these methods into worldwide space research projects is discussed.

85. Miller, P. B.
PHYSICAL DECONDITIONING DURING PROLONGED SPACE FLIGHT. (USAF, Systems Command, Aerospace Medical Div., School of Aerospace Medicine, Brooks AFB, Tex.). American Institute of Aeronautics and Astronautics, Air Force Logistics Command, and Aeronautical Systems Division, Support for Manned Flight Conference, Dayton, Ohio, Apr 21 – 23, 1965, AIAA Paper 65-281.

Discussion of anticipated medical problems of prolonged space flight, including postural intolerance to gravity after landing, diminished physical work capacity, decreased blood volume, excessive excretion of calcium in the urine, and muscular weakness. An excessive urinary loss of calcium may predispose the astronaut to kidney stones and, eventually, to weakened bones. No significant change is expected in tolerance to the transverse acceleration of reentry. Prolonged bed rest, analogous in several respects to prolonged space flight, has been used to evaluate the efficacy of various countermeasures adaptable to space flight. No procedure to date (including intermittent inflation of blood pressure cuffs on the extremities, positive pressure breathing, various types of in-bed exercise programs, and lower body negative pressure) has been completely effective in preventing the loss of postural tolerance during bed rest. Preliminary studies suggest that lower body negative pressure may become an effective procedure. In subjects with postural intolerance after bed rest, the wearing of an anti-G suit prevents postural fainting. Physical work capacity can be maintained by vigorous exercise on a bicycle ergometer. No measure to prevent excessive urinary calcium excretion has been found. Muscular strength can be preserved by isometric exercise. It is noted that the observation of postural intolerance after space flights has intensified interest in possible medical problems of prolonged space flight. Postural intolerance had been predicted earlier on the basis of a presumed similarity in several respects of prolonged space flight to prolonged bed rest. In both environments, the need for physical activity is greatly diminished, significant positional changes in hydrostatic pressure in the body fluids are absent, and weight bearing in the erect position is not present. As the body adjusts to the diminished stresses of bed rest, a number of physiological events occur, including

changes in the heart and blood vessels, changes in the volume of the blood, changes in muscular strength, and changes in the calcium content of the bones and urine.

86. Morway, D. A., R. G. Lathrop, R. M. Chambers, and L. Hitchcock, Jr.
THE EFFECTS OF PROLONGED WATER IMMERSION ON THE ABILITY OF HUMAN SUBJECTS TO MAKE POSITION AND FORCE ESTIMATIONS. Naval Air Development Center, Medical Acceleration Lab., Johnsville, Pa. 24 Jul 1963. NADC-MA 6115. AD-414 349.

Twelve subjects using underwater breathing apparatus were immersed in water for 18 hours. Each subject's responses to two general psychomotor tasks: (1) the ability to reach and position the arm and hand accurately and (2) the ability to estimate prelearned level of force, were measured before, during and after water immersion. Analysis of variance performed upon the target aiming task showed no significant difference in the horizontal aiming component. However, a highly significant (P less than .01) bias upwards was observed in the vertical aiming component. Comparisons between trial means using the Duncan Q' test indicates that the bias upwards declined as a function of immersion time. An analysis of variance performed upon the force estimation data showed a significant interaction between trials within blocks and test conditions. Duncan's Q' test ordered means comparison revealed no significant difference between the pre- and post-immersion force estimations. The mean estimation obtained during immersion was significantly different (P less than .01) from the pre- and post-trials. The force data showed no tendency to adapt as a function of time immersed.

87. Nelson, J. G.
THE EFFECTS OF WATER IMMERSION AND BODY POSITION UPON PERCEPTION OF THE GRAVITATIONAL VERTICAL. U.S. Naval Air Development Center, Aerospace Medical Research Department, Johnsville, Pa. NADC-MR-6709, Report No. 10, 18 Jul 1967.

This study concerned the accuracy, particularly the sensitivity or short-term repeatability with which humans can use their vestibular sense to perceive the gravitational vertical, and how this ability varies with body (head) position. Subjects were restrained upon an underwater 2-axis tilt table, and required to position themselves in one of 6 cardinal positions of the body (head) with respect to gravity. The results showed

some large and significant contast error, most notably a pitch-forward bias shared (unequally) by all of the medial-plane positions, exceeding 30° in the nominal head-down position. The classical concept of reduced sensitivity in the head-down as compared with the head-up positions was supported. However, probable error ranged from 15° to 40°, indicating only a marginally useful sensitivity in any position. In addition, sensitivity at any one position was not necessarily symmetrical as to direction of deviation, and some sensitivities at intermediate values of tilt overlapped head-up or head-down sensitivities.

88. Nixon, C. W. and C. E. Waggoner
SELECTED SPEECH DURING WEIGHTLESSNESS. (Final Report, June 1960 – June 1961.) Aerospace Medical Research Lab., (6570th), Aerospace Medical Div., Wright-Patterson AFB, Ohio. May 1962. MRL-TDR-62-45. N62-16589.

Certain characteristics of human speech exhibited under 1-g conditions may be different under weightless conditions. If such differences exist, they might interfere with satisfactory speech communication under conditions of zero gravity. Standard speech materials recorded under conditions of 0 g, 1 g, and 2-1/2 g's were evaluated by both objective and subjective methods. Results indicate that speech production is not significantly altered by brief periods of zero gravity. Reception of speech also seems to be unaffected. Both speakers and listeners indicate good speech intelligibility under conditions of weightlessness.

89. Reeves, E. J., J. W. Weaver, and J. J. Benjamin
COMPARISON OF PHYSIOLOGICAL CHANGES DURING LONG TERM IMMERSION TO NECK LEVEL IN WATER 95 – 85 AND 75° F. Naval Medical Research Institute, Bethesda, Md. Aug 1966. NAVMED-MF 911.99-1001-9. AD-636 989.

The experiment was designed to evaluate the physiological changes which result from immersion of subjects in water to neck level for 24 hours at water temperature of 95 – 85 and 75° F. It was previously determined that immersion of subjects in water below 95° F resulted in heat loss from the body which was compensated for by an increase in metabolic rate. Other changes in blood morphology and blood electrolytes had been shown to occur concomitantly with increases in urinary excretion of water and electrolytes. Since the previous studies had been carried out over a relatively short period of time, the present experiments were designed to evaluate such changes over a 24 hour period not only at 95° F water temperature but at lower water temperatures as well. It was found that the three subjects increased their metabolic rate

when immersed in 85° F water and were able to maintain normal deep body temperature over a 24 hour period. When immersed in 75° F water, the increased O_2 consumption due to shivering was insufficient to maintain deep body temperature. In addition the physiological discomfort of immersion at 75° F and the "spiritual failure" of the subjects caused the experiment to be terminated after 12 hours.

90. Reeves, E., E. L. Beckman, and R. E. DeForest
PHYSIOLOGICAL EFFECTS RESULTING FROM DIFFERENT TYPES OF FLUID REPLACEMENT DURING WATER IMMERSION. Aerospace Medicine, 34:3, 264, 1963. (Paper given at 34th Annual Meeting, Aerospace Medical Association, 1963.)

The investigation was concerned with the study of the magnitude of diuresis which resulted during water immersion, and how to replace this water loss. Data was collected concerning body temperature, pulse, respiration, blood pressure, oxygen consumption, blood morphology and urinary output.

91. Rubiowsky, John
MAN IN A TUB. Space World, 1:14 – 15, Jul 1960.

Discussion of Capt. Graveline's seven days in 400 gallons of warm water.

92. Stone, R. W. Jr. and W. Letko
SOME OBSERVATIONS DURING WEIGHTLESSNESS SIMULATION WITH SUBJECT IMMERSED IN A ROTATING WATER TANK. National Aeronautics and Space Administration. Langley Research Center, Langley Station, Va. Sep 1964, 22p. (NASA-TN-D-2195). N64-30094.

An investigation was made with a rotating water tank to determine the feasibility of the water-immersion technique for weightlessness simulation, including an attempted elimination of the otolith cues by rotation. Because of the early orbital flights the experiments were not continued and the technique was not fully evaluated; however, the experiences encountered are believed to be of general interest and of some possible physiological consequence.

93. Thach, J. S., Jr.
BEHAVIORAL TECHNIQUE, PART II. Naval School of Aviation Medicine, Pensacola, Fla. (In: NASA, Washington, The Role of the Vestibular Organs in Space Exploration, 1966, pp. 276 – 282.) N67-15145.

Behavioral measures were obtained from two squirrel monkeys under two-degree-of-space simulation conditions in order to evaluate the adequacy of the design. Relationships were established between work requirements and diet and water intake, weight, and efficiency of work. Extended and severe isolation appeared to reduce locomotor activity. When the monkeys lived under continuous light, their activity cycles increased to longer than 24-hour periods. The behavioral technique was sensitive yet stable, but limited by persisting problems with liquid diets.

94. Thompson, L. J., M. McCally, and A. S. Hyde
THE EFFECTS OF POSTURE, BREATHING PRESSURE, AND IMMERSION IN WATER ON LUNG VOLUMES AND INTRAPULMONARY PRESSURES. Report on Biophysics of Flight, Aerospace Medical Research Lab., Biomedical Laboratory, Wright-Patterson Air Force Base, Ohio. AMRL-TR-66-201, May 1967.

Lung volumes were measured by spirometry and single breath helium dilution in five subjects under various combinations of posture, breathing pressure, and headout neutral temperature immersion. Tidal volume was unaltered. Vital capacity was reduced significantly only by negative pressure breathing during seated immersion. Seated immersion decreased total lung capacity and functional residual capacity, but the supine posture underwater partially restored these decreases. Positive pressure breathing increased total lung capacity and residual volume for the seated subject in both air and water. A wide range of transthoracic pressure gradients is subjectively more comfortable than a slight increase in the transpharyngeal pressure gradient, suggesting that during immersion, intrapulmonic pressures are selected by the subject to minimize the transpharyngeal pressure gradient.

95. Thompson, L. J. and M. McCally
ROLE OF TRANSPHARYNGEAL PRESSURE GRADIENTS IN DETERMINING INTRAPULMONARY PRESSURE DURING IMMERSION. (Indiana University, Cardiopulmonary Laboratory, Bloomington, Ind.; USAF, Systems Co Command, Aerospace Medical Div., Aerospace Medical Research Laboratories, Environmental Medicine Div., Wright-Patterson AFB, Ohio.) Aerospace Medicine, vol. 38, Sep 1967, pp. 931 – 935. Research sponsored by the Indiana University Foundation; Contract No. AF 33(616)-8378.

The role of transpharyngeal pressure gradients in setting intrapulmonary pressures was studied in eight seated subjects, immersed in thermally neutral water (33 to 34° C). When breathing through a mouthpiece or a facemask, subjects chose pressures which were negative relative to the sternal notch (range 0 to -8 cm H_2O). When a helmet alone was used, breathing pressures ranged from -5 to +20 cm H_2O, suggesting that when no transpharyngeal pressure gradient is present, discrimination in choosing a breathing pressure is reduced. When breathing from a mouthpiece inside a helmet, an increase in breathing pressure resulted in the subject choosing an increased helmet pressure thus minimizing the transpharyngeal gradient (mean range 1 to 7.5 cm H_2O). A wide range of transthoracic pressure gradients (-30 to +40 cm H_2O) is subjectively more comfortable than a slight increase in transpharyngeal gradient (up to 7.5 cm H_2O).

96. Ting, E. Y., S. K. Hong, and H. Rahn
LUNG VOLUMES, LUNG COMPLIANCE AND AIRWAY RESISTANCE DURING NEGATIVE-PRESSURE BREATHING. Department of Physiology, The University of Buffalo, Buffalo, N. Y. Journal of Applied Physiology, 15:550 – 553, Jul 1960.

Lung volumes, airflow resistance and lung elastance were measured in seven subjects during various degrees of continuous negative-pressure breathing in the supine posture. At -30 cm H_2O the expiratory reserve is reduced to about 30% of its normal value and the resistance to airflow is more than doubled. On the other hand, the pressure-volume curve of the lung measured with the aid of an esophageal balloon was not significantly altered by either negative-pressure or postivie-pressure breathing.

97. Torphy, D. E.
EFFECTS OF IMMERSION, RECUMBENCY, AND ACTIVITY ON ORTHOSTATIC TOLERANCE. Aerospace Medicine, 37:119 – 124. (Feb 1966). AD-632 856.

The effect of water immersion for 6 hours without negative breathing pressure was studied in 5 subjects. Heart rate during all conditions as well as blood pressure were measured. No statistically significant decrement in heart rate or blood pressure response was found, although immersion resulted in a tendency toward increased heart rate and blood pressure as well as greater narrowing of the pulse pressure with tilting.

98. Torphy, D. E.
EFFECTS OF SHORT TERM BED REST AND IMMERSION ON PLASMA VOLUME AND CATECHOCAMINE RESPONSE TO TILTING. Aerospace Medicine, 37:383 – 387. (1966).

A study of the effects of 6 hours of bed rest or immersion on plasma volume and catecholamine excretion of subjects undergoing tilting tests. It was found that the urinary excretion of norepinephrine and epinephrine under all conditions studied showed the expected increase. This suggested that the vasconstriction responses to orthostasis is not impaired by 6 hours immersion. Plasma volume measured before and after all treatments showed that recumbency decreased plasma volume and immersion decreased it still further. The fluid volume loss was considered as a possible primary cause of the orthostatic intolerance found following the water immersion experience.

99. Vallbona, C., et al
THE EFFECT OF BEDREST ON VARIOUS PARAMETERS ON PHYSIOLOGICAL FUNCTION: PART I. Review of the literature on the physiological effects of immobilization. NASA CR 171, Mar 1965.

A review of the literature (up to 1963) on the effects of immobilization reveals that bed rest was evaluated in 83 subjects (30 of whom were allowed to sit up) and water immersion in 33 subjects. There is a wide variety of experimental conditions in each study. This precludes pooling of data to evaluate the significance of the findings. It is concluded that bed rest deserves further study with special attention to include wider variety of subjects in regard to age, training habits, and physical condition;

identification of physiological rhythms during bed rest; definition of changes in body composition; study of the mechanism of orthostatic hypotension following bed rest.

100. Vanyushina, Yu. V., M. A. Gerd, and N. Ye. Panferova
THE CHANGE OF CERTAIN INDICES OF THE FUNCTIONAL CONDITION OF THE ORGANISM UPON PROLONGED STAY BY MAN IN THE POSE OF "AVERAGE PHYSIOLOGICAL REST." Joint Publications Research Service, Washington, D.C. (In its Probl. in Aerospace Med. 21 Oct 1966, pp. 107 – 108.) N67-11457.

The pulse and respiratory rates, blood pressure magnitudes, and body temperatures of human subjects immersed in water (or in chairs of special design) were measured at 2 hr intervals during waking hours to determine the changes occurring in physiological indices that occur during a prolonged stay in the pose of average physiological rest characteristic under weightlessness conditions. The basal metabolisms of the tested individuals were determined by the Douglas-Holden method each morning immediately after sleep. Periodic measurements of the maximum strength and endurance of the right and left hand muscles were made. It was found that the pulse and respiratory rates remained practically unchanged throughout the course of the tests, and that the level of maximum and minimum arterial pressure dropped progressively. The biological activity of the blood changed in the direction of a decrease in the chronotropic effect and increase of the inotropic effect. The basal metabolism was reduced during the course of testing, and the respiratory coefficient rose. Other comments on the fundamental transformation of functional systems under the conditions of physiological rests, are also made.

101. Vanyshina, Yu. V.
FUNCTIONAL CHANGES IN THE CARDIOVASCULAR SYSTEM AFTER EXPOSURE TO HYPODYNAMIA. National aeronatucis and Space Administration, Washington, D.C. In: Aviation and Space Medicine, Dec 1964, pp. 76 – 78. N65-13653.

An attempt was made to determine how the cardiovascular reflexes that resist gravity might change in human beings required to remain a long time in circumstances that limit reflex impulses from the muscles and cardiovascular system. Experiments involving subjects immobilized for 5.5 to 10.5 days in a special armchair in a position of maximum muscular relaxation and involving subjects who remained suspended in a

tank of water for 5.5 to 11.5 days were performed. It was found that in human beings remaining for a long period of time under conditions of limited mobility, the adaptive reactions of the cardiovascular system to the force of gravity decrease. The weakening of the mechanisms was manifested during orthostatic testing, by a sharp acceleration of the pulse, a drop in systolic and pulse pressure, and slight cerebral anemia.

102. Vogt, F. B., W. A. Spencer, D. Cardus, and C. Vallbona
THE EFFECT OF BEDREST ON VARIOUS PARAMETERS OF PHYSIOLOGICAL FUNCTION. PART XIII. A REVIEW OF POSSIBLE MECHANISMS OF ORTHOSTATIC INTOLERANCE TO PASSIVE TILT. NASA, Washington, Contract NAS9-1461, NASA-CR-183, May 1966. N66-23846.

This is a review of possible mechanisms of orthostatic intolerance to passive tilt, which includes observations from water immersion and bedrest experiments. The review relates the observation on cardiovascular function, intravascular volume, and transfer of fluids and electrolytes into and out of the vascular system to orthostatic intolerance to passive tilt. Experimental procedures are suggested which would test the meaning of the observations to account for the intolerance to passive tilting after prolonged bedrest.

103. Vogt, F. B.
EFFECT OF EXTREMITY CUFF-TOURNIQUETS ON TILT TABLE TOLERANCE AFTER WATER IMMERSION. Aerospace Medicine, 36:442 – 447, May 1965 (NASA-sponsored research).

Experimental investigation of the tilt-table intolerance of four healthy adult young males in two water-immersion tests of 6-hours duration, in an effort to reproduce a previous study reporting a protective effect from cuff-tourniquets applied to the extremities during immersion. Body weight, fluid intake, urine output, and leg circumference measurements were made and recorded. After the first period of six hours of water immersion, three of the four subjects experienced syncope during a tilt-table test. Compared to pre-immersion tilt tests, all subjects experienced marked changes in heart rate or blood pressure during tilting after immersion. A significant diuresis was not noted. During the second period of immersion, cuff-tourniquets were applied to the four extremities and inflated to a pressure of 60 mm Hg, with a cycle of 1 min on, 1 min off. Some degree of protection against tilt-table intolerance after immersion was provided in the test; none of the three subjects

experienced syncope or showed the marked blood pressure changes they had shown on the previous immersion test without cuffs.

104. Vogt, F. B.
PLASMA VOLUME AND TILT TABLE RESPONSE TO WATER IMMERSION DECONDITIONING EXPERIMENTS USING EXTREMITY CUFFS. Aerospace Medicine, 38:460 – 464, May 1967. (NASA Contract No. NAS9-5821.)

The plasma volume and tilt table response of six healthy adult male subjects was evaluated before and after six periods of water immersion deconditioning. The immersion periods were of 12-hour duration. A Latin Square experimental design was utilized employing six different water immersion treatments: (1) no cuff, (2) arm cuffs, (3) arm cuffs 1-minute-on, 1-minute-off, (4) arm cuffs 2-minutes-on, 4-minutes off, (5) arm cuffs 5-minutes-on, 10-minutes-off, (6) leg cuffs 5-minutes-on, 10-minutes off. The cuffs were inflated to an effective pressure of 60 to 70 mm Hg. The subjects were immersed in a sitting position, head out, with the water temperature maintained at 93° F. The results of the study indicate that cardiovascular deconditioning occurred during immersion as is evidenced by a decline in plasma volume and in tilt table manifestations of orthostatic intolerance. There was no statistically significant difference in the tilt table response or plasma volume changes for any of the experimental treatment conditions. The results thus indicate that in this group of subjects, under well controlled experimental conditions, a protective effect was not noted with the use of extremity cuffs. The mechanism for the apparent protection afforded by cuffs in other experiments, and not in this study, is not evident.

105. Vogt, F. B. and P. C. Johnson
STUDY OF EFFECT OF WATER IMMERSION ON HEALTHY ADULT MALE SUBJECTS – PLASMA VOLUME AND FLUID-ELECTROLYTE CHANGES. Aerospace Medicine, 36:447 – 451, May 1965. (NASA-sponsored research.)

Experimental investigation of four healthy adult males during two water-immersion experiments of 6-hours duration. During the second experiment, cuff-tourniquets were applied to all four extremities of each subject to test the effect in preventing or lessening the cardiovascular deconditioning associated with water immersion. The use of the cuff-tourniquets was found to be partially effective. Repeated plasma volume, hemoglobin, hematocrit and serum sodium, potassium, osmolarity, and protein determinations were performed and are reported. Measurements of fluid intake, urine output, and body weight are reported. An increased transfer rate of

intravascular compartment is suggested as one of the possible factors responsible for the symptoms observed during tilt-table tests after water immersion.

106. Vogt, F. B.
TILT TABLE AND PLASMA VOLUME CHANGES WITH SHORT TERM DECONDITIONING EXPERIMENTS. (Texas Institute for Rehabilitation and Research; Texas, University, Graduate School of Biomedical Sciences, Houston, Tex.). Aerospace Medicine, vol. 38, Jun 1967, pp. 564 – 568. NIH Grant No. FR-00254; Contracts No. NAS 9-1461; No. NAS 9-5821.

The tilt-table response of nine experimental subjects was evaluated before and after short-term periods of deconditioning, including chair rest, bedrest, water immersion, and water immersion with cuffs. Twelve-hour deconditioning experiments were conducted utilizing the following eight experimental conditions: (1) water immersion, (2) water immersion with arm cuffs only, (3) water immersion with leg cuffs only, (4) water immersion with arm and leg cuffs, (5) bedrest, (6) chair rest, (7) water immersion with leg cuffs the last 4 hours, and (8) water immersion with leg cuffs 15 min/hr. In water-immersion experiments, the subjects were immersed in a sitting position, head out, with a water temperature of 94° F. Cuffs were inflated in cycles, with inflation to 70mm Hg for 2 out of every 6 minutes. The results indicate that definite cardiovascular deconditioning occurred with water immersion, as evidenced in the plasma volume decline and the tilt-table response. There was a significant decline in plasma volume during all experimental conditions except chair rest. The results of this study do not indicate a definite protective effect from the use of intermmittently inflated extremity cuffs.

107. Vorob'ev, B. N., Editor
MECHANICS IN BIOLOGY – SIMILARITY OF ORGANISMS AND DEVIATION FROM IT (MEKHANIKA V BIOLOGII – PODOBIE ORGANIZMOV I UKLONENIE OT NEGO). In: K. E. TSIOLKOVSKII – COLLECTED WORKS. VOLUME IV – NATURAL SCIENCE AND TECHNOLOGY (K. E. TSIOLKOVSKII – SOBRANIE SOCHINENII. VOLUME IV – ESTESTVOZNANIE I TEKHNIKA). Moscow, Izdatel'stvo "Nauka," 1964, pp. 161 – 263. (In Russian)

Application of the concept of similarity to a study of the work done by living creatures in various situations. The work output in a number of situations requiring muscular activity is ascertained, a distinction being made between the energy and power of various organisms. An estimate is made of the relative work done by various creatures as a function of height. The role of the temperature of animals on the mechanical energy of their muscles is taken into account. The development of the brain and the thinking power of living creatures and of man, in particular, is considered in some detail. An account is given of the rise of religion and of the reasons for its persistence. The effect of various environmental factors on body functions and motor activity is assessed. Motion under conditions of weightlessness is discussed, with special reference to motion in water. A study is made of the mechanics of wings in flying creatures and of flight in calm and moving media. The effect of changes in the height of humans on their muscle power is ascertained.

108. Walawski, J.
OBSERVATIONS ON HEART RATES AND CARDIODYNAMICS DURING PROLONGED WEIGHTLESSNESS SIMULATED BY IMMERSION METHOD. (Medical Academy, Dept. of Pathophysiology, Warsaw, Poland) and Z. Kaleta (Military Institute of Aviation Medicine, Warsaw, Poland.) In: International Symposium on Basic Environmental Problems of Man in Space, 1st, Paris, France, Oct 29 – Nov 2, 1962, Proceedings. 1965, pp. 179 – 185.

Among the numerous methods proposed for the investigation of phy siological effects of weightlessness in laboratory conditions the immersion method seems to be most advantageous. Although no true state of weightlessness is attained, nevertheless long-term observations in subgravity are made possible in this way. Certain human experiments indicate that in such conditions slight disturbances in ECG and blood pressure may become manifest. These results were not confirmed by other authors. The aim of the present work was to investigate the effect of long-term weightlessness simulated by immersion on ECG and blood pressure in rabbits. The animals were under urethane narcosis to eliminate the influence of the central nervous system. The experimental animals were submerged in 1% solution of NaCl at temperatures ranging from 34 to 35° C. Respiration was made possible by tracheotomy tube connected with respiratory valve. Blood pressure from the carotid artery was registered kymographically using a mercury manometer. ECG electrodes were introduced under the skin of the fore and hind extremeities. All incisions were sutured carefully to avoid contact of electrode with the immersion fluid. The immersion period ranged from 12 to 24 hours. No apparent changes were seen in the electrocardiograms. The heart rate registered hourly was about 230 per minute and did not change during the whole observation period. No significant changes in ECG were observed. The conduction time remained in the normal range for rabbits. In some instances a slight depression of QRS

complexes was noted. Sometimes QRS complexes were elevated even in final stages of the experiments. The arterial blood pressure remained during the whole experiment nearly at a constant level showing only slight deviations. The above results indicate that 24 hours weightlessness simulated by the immersion methods does not induce any significant circulatory disturbances and is fairly well tolerated by rabbits. Supplementary experiments now under way using further physiological tests seem to confirm the foregoing conclusions.

109. Walker, J. L. C.
PLASMA 17 HYDROXYCORTICOSTEROIDS IN HEALTHY SUBJECTS AFTER WATER IMMERSION OF TWELVE HOURS' DURATION. (Texas Institute for Rehabilitation and Research; Baylor University, College of Medicine, Dept. of Rehabilitation and Dept. of Biochemistry, Houston, Tex.). Aerospace Medicine, vol. 38, May 1967, p. 459. PHS Grant No. FR-00129; VRA Grant No. RT-4.

The Plasma 17 hydroxycorticosteroids were measured by the Nelson and Samuels method in six healthy subjects before and after water immersion at 93° F of 12-hr duration. The test was repeated several days after the first immersion. There was no significant difference in the concentration of 17 hydroxycortiocosteroids in the plasma withdrawn before or after water immersion.

110. Warren, B. H.
A COMPARISON OF PHYSIOLOGICAL CHANGES OCCURRING DURING WATER IMMERSION AND BED REST. Paper: 34th Annual Meeting of the Aerospace Medical Association, Statler-Hilton Hotel, Los Angeles, Calif., Apr 28 – May 2, 1963.

Human water immersion experiments have been performed by several investigators under the assumption that the resulting "hypodynamic" environment simulates certain conditions of weightlessness. Bed rest has also been used as a method for studying the hypodynamic state. In the present investigation a controlled comparison of these techniques was made. Twelve healthy male volunteers took part in these experiments. Each subject was studied during two 6-hour water immersion periods and one 6-hour bed rest period. Physical and psychological variables were kept as constant as possible. Electrocardiograms were traced continuously and blood pressures were recorded automatically. Blood and urine samples were collected for physical and

chemical determinations. A tilt table was used to produce gravitational stress for measuring cardiovascular responses before and after each hypodynamic period. An analysis of the data revealed that the direction of change of a physiological parameter during water immersion coincided with the direction of change of the same parameter during bed rest. The biological relationship of the above hypodynamic factors to weightlessness can only be hypothesized. Further evaluation of physiological changes occurring during water immersion and bed rest appear warranted, however, before either is accepted as a better tool than the other for studying the hypodynamic state in man. In over thirty hypodynamic periods above, no significant differences were noted in the physiological parameters measured during water immersion and bed rest which could not be attributed to factors other than an increased hypodynamic state during water immersion.

111. WATER IMMERSION STUDIES: A REPORT BIBLIOGRAPHY. Defense Documentation Center, Cameron Station, Alexandria, Va. Report No. ARB-035224, Jun 1965.

A report bibliography requested from Defense Documentation Center. It contains 25 references pertaining to the use of water immersion studies to simulate weightlessness.

112. Webb, P., and J.F. Annis
SILICONE SUBMERSION, A FEASIBILITY STUDY. Webb Associates, Yellow Springs, Ohio. Oct. 1966. MF022.03.02.7002-9. Contract: N622269-3212. AD-645 080.

The report details a study which demonstrated the feasibility of maintaining men totally and continuously submerged for five days by using silicone fluid in a specially designed tank. Five submersions were tried, 3 were in water for 6 hours for training purposes and 2 were in silicone; one for 16 hours and the final run which lasted a full five days (120 hours) with complete submersion for about 60% of the time and head out immersion for the remaining 40%. It was found that silicone fluid can be used as a weightless simulation medium in prolonged immersion and that subjects can be kept free of skin irritation or maceration for long periods of time if diligent quantity control of the fluid is maintained. It was also found that long submersion need not result in a negative water balance due to diuresis.

113. WEIGHTLESSNESS SIMULATION USING WATER IMMERSION. A bibliography covering the period: 1965 to 22 August 1967. NASA Literature Search Number 4826. National Aeronautics and Space Administration, Scientific and Technical Information Division, Bethesda, Md.

This is a report bibliography requested from NASA. It contains 38 references pertaining to the use of water immersion studies to simulate weightlessness.

114. Wunder, C. C.
A SURVEY OF CHRONIC WEIGHTLESSNESS SIMULATION IN BIOLOGICAL RESEARCH. Virginia Univ., Charlottesville. 1964, 122p. (Contract AF18 600 2057). AD 607052. Prepared in cooperation with Iowa State Univ., Iowa City, the National Institutes of Health, and the American Cancer Society.

The central emphasis of the survey concerns the status of research involving various methods of effecting chronic weightlessness for organisms. Three general types of approach are considered: (1) accelerations that oppose the Earth's gravity, (2) indirect reduction of gravitational effects, and (3) indirect information from increases of gravitational load. After initiation of this survey, the Air Force requested particular consideration of immobilization as one type of approach to the problems of weightlessness simulation. Immobilization (by means of casts, splints, tenotomy, and denervation) is considered as one aspect of the second category listed above. Other aspects of that category are bed rest, support by frictionless devices, buoyant support (during water immersion), and tumbling.

PART II: HUMAN ENGINEERING STUDIES

115. AIREPORTER, Publication of the Garrett Corp., "Life Science Conducts Zero Gravitation Study." Nov 1966.

Report on a project, titled, "Study of Astronauts Capabilities to Perform Extravehicular Maintenance and Assembly Function in Weightless Condition," is being done for Otto Trout, Langley Research Center, National Aeronautics and Space Administration, Langley Station, Virginia. The originator of the underwater approach to zero gravity simulation. The tests will consist of measurements of metabolic rates in tasks underwater in pressurized suits.

116. Beckman, E.L.
A REVIEW OF CURRENT CONCEPTS AND PRACTICES USED TO CONTROL BODY HEAT LOSS DURING WATER IMMERSION. AD 614241.
Naval Medical Research Inst., Bethesda, Md. 1964, 33p. Research rept. no. MR-005.13-4001.06, R-3.

Presented to the Aerospace Medical Panel General Assembly of Advisory Group for Aeronautical Research and Development (14th), held at Lisbon, Portugal, 12 Sep 64. Available copy will not permit fully legible reproduction. Reproduction will be made if requested by users of DDC. Copy is available for public sale.

The problem of providing adequate clothing for personnel who either during normal operations or accidentally are immersed in cold water has continued to challenge clothing manufacturers. In the past decade the development of foamed plastics and other clothing materials has offered new possibilities. Likewise advances in energy conversion and storage systems offer new solutions to this critical operational problem. The basic physical and physiological concepts which relate to the problem of limiting thermal loss from the immersed human will be reviewed. Newer technical developments in insulative clothing and supplemental heating systems will be discussed with relation to these basic concepts.

(see also references 209, 210, 213)

117. Beckman, E.L., E. Reeves and R.F. Goldman
CURRENT CONCEPTS AND PRACTICES APPLICABLE TO THE CONTROL OF BODY HEAT LOSS IN AIR CREW SUBJECTED TO WATER IMMERSION. Aerospace Medicine. (Apr 1966). Research report no. MR005.13-4001.06; AD-635 052.

The problem of providing adequate clothing for personnel immersed in cold water is discussed. The basic physical and physiological concepts which pertain to the problem of limiting thermal loss from immersed humans is reviewed.

118. Beckman, E.L. and E. Reeves
PHYSIOLOGICAL IMPLICATIONS AS TO SURVIVAL DURING IMMERSION IN WATER AT 75°F. Aerospace Medicine, 37:1136-42, (Nov. 1966). Research report no. MF-011.99-1001; AD-646 826.

The investigation was designed to study the physiological responses of subjects immersed to neck level in 75°F water for periods of 12 hours. It was found that water immersion could not be tolerated by all subjects for various reasons. Changes in blood, urine and O_2 utilization during immersion, in addition to physiological changes, were also found to be related to the tolerance of immersion.

119. Bulk, G.K. and C.R. Adams
AN EMPIRICAL STUDY OF DEVICES AND TECHNIQUES TO IMPROVE THE ASTRONAUT'S PERFORMANCE IN AN ORBITAL SPACE ENVIRONMENT. Paper given at Human Factors Society, 8th Annual Meeting, Washington, D.C., 20 Oct 1964. Douglas Aircraft Company, Inc., Santa Monica, Calif. Douglas Paper No. 3035.

This paper describes a study utilizing a hydrostatic tank for conducting manned operations in a simulated weightless environment. A MORL-Type space station mockup was used under water by three subjects and an observer as an aid for investigating and recording techniques of locomotion, restraint, sleeping and exercise. Results of the study indicate that the underwater technique used provides a useful but limited means to acquire information concerning man's performance in an orbital space environment.

120. Bulk, G.K. and C.R. Adams
ZERO-BUOYANCY: SIMULATION OF WEIGHT-LESSNESS TO EVALUATE THE PSYCHO-PHYSIOLOGICAL AND ANTHROPOMETRIC PARAMETERS THAT AFFECT SPACE STATION DESIGN. Paper No. 3263, Douglas Aircraft Company, Inc., Santa Monica, Calif. (See also Aerospace Medicine, 38:518-520, May 1967.)

This paper summarizes some progress in the use of neutral-buoyancy for study of space crew performance. Included are descriptions of some of the psychophysiological, man-machine and anthropometric parameters as they affect space-station design. A number of general conclusions based upon the underwater simulation operations (e.g., techniques of locomotion, restraint, body orientation, rescue operations, (extravehicular activities) EVA, assembly and repair operations, exercise) with reference to a six-degrees-of-freedom motion simulation are described. Full-pressure-suit underwater locomotion and mobility studies directly relevant to EVA are discussed. Various sleeping positions in reference to orientation to the deck were studied. Simple restraint devices were investigated.

121. Chaffee, J.W., A.F. Emanuel, and J.E. Mabry
NEUTRAL BUOYANCY AS A MEANS OF SIMULATING O-G EFFECTS ON HUMAN PERFORMANCE. The Boeing Company, Aero-Space Division, Seattle, Washington. Paper given at Aerospace Medical Assoc. 36th Annual Meeting, Apr 1965, N.Y.

By ballasting space systems operators to neutrally buoyant in water, it is possible to simulate many of the effects upon man's gross motor behavior in the zero gravity environment. To the extent that these are analogous with those to be encountered when weightless in space, the systems designer is provided with important pre-launch information descriptive of human capabilities and requirements in systems operation, maintenance and assembly.

This paper describes the experimental techniques, facility requirements, and experimental results of an exploratory program directed toward acquiring an operational description of simulated zero-gravity effects on the operation performance. Quantitative data and films will be presented.

(see also references 17, 74, 111, 208, 212)

122. Chambers, R.M., D.A. Morway, et al
CHANGES IN PERFORMANCE PROFICIENCY UNDER CONDITIONS SIMULATED BY WATER IMMERSION AND CENTRIFUGATION. (Paper, 32nd Annual Meeting of the Aerospace Medical Assoc., Palmer House, Chicago, Illinois, Apr 24-27, 1961).

123. Chambers, R.M., D.A. Morway, et al
THE EFFECTS OF WATER IMMERSION ON PERFORMANCE PROFICIENCY. Aviation Medical Acceleration Lab., Naval Air Development Center, Johnsville, Pa. 22 Aug 1961. Rept. no. NADC-MA-6133. AD-267 665.

In an attempt to study a wide range of human performance abilities associated with weightlessness and the transition from weightlessness to a high G reentry environment, the technique of water immersion and centrifugation was used to simulate these conditions. Six male subjects were immersed in water to the neck level for a 12-hour period and one subject for a 23-hour period. Eight selected performance tasks were administered: (1) before immersion, (2) during immersion, (3) after immersion and centrifugation so that gross motor and perceptual behavior could be sampled. It was found that behavior was not apparently affected by prolonged water immersion followed by reentry type accelerations.

124. Clark, C.C. and R.F. Gray
A DISCUSSION OF RESTRAINT AND PROTECTION OF THE HUMAN EXPERIENCING THE SMOOTH AND OSCILLATING ACCELERATIONS OF PROPOSED SPACE VEHICLES. U.S. Naval Air Development Center, Aviation Medical Acceleration Lab., Johnsville, Pa. Rept. No. NADC-MA-5914, Dec 28, 1959. (Project TED ADC AE 1412).

The thesis of this paper is that it is not the forces generated by acceleration or deceleration (at least to somewhat beyond 30G) which damage man, but rather the body distortions which can result from an unbalanced action of these forces. By proper

"packaging" of the human tolerance will depend on the consequences of local tissue compression or extension rather than on the consequences of gross tissue and organ displacements and distortions. The acceleration time histories to accelerate to and decelerate from the velocities suitable for space travel are presented with emphasis that presently attained velocities are only a beginning. Minimum travel time involves acceleration for half the trip and deceleration for the other half. Techniques of centrifuge simulation of these accelerations are presented. The dependence on vehicle configuration of vehicle decelerations be reentry into an atmosphere is noted. Vehicle oscillations induced by motor and by lift misalignments are described. The ability of the human to make body motions while under acceleration determines the minimum necessary restraint for the head and limbs. To minimize involuntary pilot control inputs, a simultaneous designing of restraints and controls is necessary. A moulded body form "contour couch" provides a broadened support and reduces body distortion. In such a couch, man has reached +25 G_x (chest-to-back) as the peak acceleration of a versine waveform with a 40-second period. Tight bandaging of the body and particularly training in techniques of complete body straining are important aspects of these experiments.

125. CREW SYSTEMS SIMULATION RESULTS OF A WATER IMMERSION SIMULATION PROGRAM. General Electric Missile and Space Division, Philadelphia, Pa. Doc. No. 67SD4306. 10 June 1967.

The General Electric Company conducted a series of manned space simulation studies at its underwater test facility. Preliminary feasibility studies were conducted in a Saturn vehicle S-IVB stage mockup. Later passivation tasks and equipment transfer tasks were investigated. Also, lunar traverse tasks were conducted at 1/6-gravity levels over an underwater course. Task times were recorded and subjective comments of the two pressure-suited subjects were noted. Drag measurements were recorded for equipment models, suited and nonsuited subjects during erect and prone transport.

126. David, H.M. ZERO-G SLOWS ASTRONAUT PERFORMANCE. Missiles and Rockets, pp. 34-36, Nov 8, 1965.

A review of the work that was done by General Electric in simulating weightlessness by the water immersion technique. It discusses the facility and equipment used in their effort to develop new tethering devices.

127. Dean, R.D. and R.P. Langan.
SIMULATED WEIGHTLESSNESS UNDER
NEUTRAL BUOYANCY. Boeing Co., Seattle,
Wash. (In: NASA Marshall Space Flight Center,
Proc. of the Interdisciplinary Symp. on Apollo
Appl. Programs. 12-13 Jan. 1966, Dec 1966,
pp. 229-240.) N67-24278.

Limitations and advantages of the new neutral buoyancy zero-gravity simulation technique are discussed, and studies conducted in neutrally buoyant environments which were designed to evaluate the potentiality of this technique are reviewed. Reported are results of studies of the effects of neutral buoyancy on the time required to traverse 20- and 28-inch circular hatches; the effects of neutral buoyancy on man's ability to manipulate hand tools such as wrenches and screw drivers; the extravehicular assembly; restraint concepts; and a prototype airlock design. It is concluded that in spite of the inherent limitations of neutral buoyancy, the method can provide an inexpensive and reliable means of evaluating designs for space vehicle hatches, compartments, airlocks, restraints, and transfer devices; and can also provide an invaluable training aid, in that it permits practice on performance in an environment that approximates true zero gravity.

128. Delattre, M. and G. Dubois
DEVELOPMENT OF THE ONERA WEIGHTLESSNESS FACILITY (MISE EN PLACE A L'O.N.E.R.A.
D'UNE INSTALLATION D'ESSAIS EN
IMPESANTEUR). La Recherche Aerospatiale,
no. 110, Jan.-Feb. 1966, p. 19-28 (in French).

Description of the ONERA laboratory for tests on weightlessness developed to conduct further research on the behavior of liquids and on very sensitive accelerometers by means of the free-fall method. The effect of aerodynamic braking on the simulation of weightlessness is determined, the particular solution adopted is defined, and the first experimental results are summarized.

129. Diefenbach, W.S.
THE ABILITY OF SUBMERGED SUBJECTS TO SENSE THE GRAVITATION VERTICAL.
Cornell Aeronautical Lab. Inc., Buffalo, N.Y.
OM-1355-V1, Jan 1961, 39p. AD-445 369.

The ability of human subjects to perceive the vertical when submerged in a buoying fluid and subjected to varying amounts of body tilt was studied in a series of pilot experiments. Experimental equipment employed attempted to minimize positional cues other than those arising from the vestibular apparatus and visceral sources. Gross errors in perception of the vertical were made by all subjects. These errors were repeatable within subjects, and had a high linear correlation with the amount of body tilt. In addition, evidence was found that precision in positioning an unseen control may vary with body tilt. Possible simulation of weightlessness and implications for design of space controls are briefly discussed and further research studies are suggested.

130. Duddy, J.H., G. Fahlman, and L.R. Meisky
DIVER TRAINING, PROFICIENCY AND QUALIFICATION REQUIREMENTS FOR NEUTRAL BUOYANCY SIMULATIONS OF WEIGHTLESSNESS. Biotechnology Dept., Lockheed Missiles & Space Company, Sunnyvale, Calif. 8 May 1967.

This document establishes training, proficiency, and qualification requirements for personnel participating in neutral buoyancy simulations of weightlessness as test subjects, safety divers, and underwater test engineers and observers.

131. Ferguson, J.C. and R.M. Chambers
PSYCHOLOGICAL ASPECTS OF WATER IMMERSION STUDIES Report No. 7. Naval Air Development Center, Johnsville, Pa., Aviation Medical Acceleration Lab. 30 Dec 1963, 28p. (NADC-MA-6328; AD-429 523). N64-15755.

The purpose of this paper was to review the recent water immersion literature, placing special emphasis on the psychological aspects of these studies. The adequacy of water immersion as a technique for simulating weightlessness was discussed, and

water immersion facilities and procedures were described. The areas of perceptual and motor performance, boredom and fatigue, sleep, orientation, and personality and emotional aspects of water immersion were selected as being of special psychological interest.

132. Fisher, H.T.
DIVER TASKS AND TOOL REQUIREMENTS FOR UNDERWATER OPERATIONS FINAL REPORT
Lockheed Missiles & Space Co., Biotechnology Organization, Sunnyvale, Calif. 6-70-67-3, 24 July 1967

This report presents the results of an investigation of diver tasks and tool requirements for underwater operations related to man-in-sea operation and experimental objectives of ocean systems programs at LMSC. The effort was funded under the company's 1966 Independent Development Programs for the Ocean Systems organization.

133. Fowler, F.D., M.V. McLean and D.G. Penkoff
CURRENT AND FUTURE APPLICATIONS FOR UNDERWATER WEIGHTLESSNESS SIMULATION (UWS). (McDonnell Douglas Corp., Douglas Aircraft Division, Missile and Space Systems Division) (Paper, Human Factors Society Convention, Boston, Mass., Sept 25-28, 1967.)

Current and projected uses for the UWS technique include development testing, procedures verification, and training for all manned space programs. The reality of the large space station will shortly be manifested in the Orbital Workshop (OWS). This is where working in space will really begin. Astronaut mobility aids must allow the men to not only move around safely and efficiently within the Saturn S-IVB, but the aids must also allow them to bring in life support and mission equipment and install it. The tank was originally designed as a hydrostatic proof test tower for the Saturn and it has since been used for the previous studies. The reliability, convenience, and economy of the UWS technique provides the following advantages to participating companies and their personnel: it enables the engineers to obtain first-hand information about the effects of weightlessness on human performance and equipment design. It provides a close working environment with the astronauts and provides immediate feedback during test situations. In companies which are development man-in-the-sea programs, the UWS training provides them with groups of engineers and scientists who can relate to both areas and can more readily apply aerospace techniques to hydrospace problems.

134. Goldstein, S.E. and U.R. Alvarado
A METHOD FOR OBTAINING HIGH FIDELITY UNDERWATER SIMULATION OF MANNED SPACE ACTIVITIES. General Electric Co., Philadelphia, Pa. (Paper given at AIAA 4th Annual Meeting and Technical Display, Anaheim, Calif., Oct 23-27, 1967. AIAA Paper no. 67-925.)

Scaling laws and the model design techniques for increasing the fidelity of underwater simulation of zero and partial g environments are described. Attention is focused on the vital part that hydrodynamic mass plays in the underwater simulation of accelerating bodies. The proposed model design technique, wherein the model mass plus the hydrodynamic mass equals the mass being simulated, results in more accurate acceleration response to a given applied force. Coast histories can be made more representative by employing a large ratio of mass to C_DA. The foregoing model design techniques also apply to rotational motions wherein the analogous parameters are moment of inertia, hydrodynamic moment of inertia, and rotational damping. Test results employing these principles compared favorably with the motions which would have occurred in space. Several constraints associated with applying these principles are considered. These include the limitations of underwater simulation and the hydrodynamic characteristics of a man. Practical design aspects are considered such as the incorporation of instrumentation for measuring man's ability to maneuver objects. These model design and instrumentation techniques can be extended to simulate the motions of unmanned systems such as lunar or planetary soft landers.

135. Hall, A.L., Z.E. Jones, R.J. Shavelson, and G.A. Albright
ZERO GRAVITY SIMULATION AND COUNTERMEASURES EVALUATION. Biotechnology Dept., Lockheed Missiles & Space Company. Rept. No. LMSC-677337. 15 Dec 1966.

Four men were used in a bed rest, water immersion study to determine cardiovascular and muscular deconditioning and the effectiveness of deconditioning countermeasures (exercise and LBNP) developed by LMSC. The results show that deconditioning of cardiovascular, respiratory and muscular systems occur after 36-48 hours in bed rest or water immersion situations. Exercise combined with LBNP device prevented this general deconditioning normally found, but did not prevent plasma volume loss or orthostatic hypotension. It was shown that after each exposure, men regained their cardiovascular conditioning within 48 hours and their muscular conditioning within 96 hours.

136. Hanna, T. D.
PSYCHOMOTOR PERFORMANCE DURING TOTAL BODY WATER IMMERSION FOR MASSED AND SPACED LEARNING ON A COMPLEX TASK.
Aerospace Med. 34(3):256, 1963. Paper given at 34th Annual Meeting Aerospace Med. Assoc., 1963.

An analysis is presented of learning curves for a complex psychomotor task acquired by two equally matched groups of water immersed subjects under conditions of either massed or spaced practice. The task consists of a constant demand, multiple stimulus learning situation requiring immediate decisions making and different motor responses. Whereas the shape of the two learning curves was similar, significant differences were observed between the elevation of the two groups and the differences between early and late trials. The within session decrease in performance between initial and final values for the 30 minute massed trials was not found during the 10 minute spaced trials. It was concluded that under the experimental conditions, massed sessions incur attentional drifts rather than fatigue. The implications are discussed.

137. Hartman, B., R.E. McKenzie and D.E. Graveline
AN EXPLORATORY STUDY OF CHANGES IN PROFICIENCY IN A HYPODYNAMIC ENVIRONMENT. School of Aviation Medicine, Brooks Air Force Base, Texas. Report No. 60-72, Jul 1960. AD-244 121.

Simulated weightlessness for a prolonged period was produced by the body immersion technique. Changes in psychomotor efficiency was assessed during immersion and after return to the normal environment of 1 G. Systematic changes in a relatively simple task were obtained during immersion. Gross disruptions in psychomotor behavior on return to the normal environment were observed. Accompanying this were increased response times on three different kinds of task in a systems operator simulator. These results suggest that the functional capabilities of a man, while adequate during prolonged weightlessness, will be seriously impaired during the re-entry phase of space flight.

138. Hauty, G.
PSYCHOPHYSIOLOGICAL PROBLEMS IN SPACE FLIGHT. (Federal Aviation Agency, Aeromedical Service, Civil Aeromedical Research Institute, Oklahoma City, Okla.). (In: Bioastronautics. New York, Macmillan Co. 1964, pp. 196-224.)

Review and discussion of the problems of weightlessness, vigilance, and sensory deprivation. Prolonged simulated weightlessness was studied by immersing a subject (clad in a rubber suit) in a tank of water up to his neck for 7 days, removing him for only brief periods once each day. During immersion, operator performance exhibited a slight progressive decline which the author attributes to a decline in motivation. Little physiological impairment was noted although the nature and duration of the sleep states were said to have changed markedly. In the studies of vigilance and sensory deprivation, subjects were assigned the problem of flying a simulated space mission. The investigation of vigilance required the subject(s) to perform without interruption a complex series of tasks over a 30-hour period. Objective and subjective reactions to changes in the work load were monitored. In both the vigilance and the sensory-deprivation experiments the comments of the test subjects were recorded.

139. HUMAN FACTORS ENGINEERING TRAINING AND PROFICIENCY REQUIREMENTS FOR NEUTRAL BUOYANCY SIMULATION. National Aeronautics and Space Administration. Marshall Space Flight Center, Huntsville, Ala. R-P & VE-VAH-67-78.

This report provides training requirements, proficiency tests, and classifications of Neutral Buoyancy operating personnel. Operating personnel are classified by test function into four categories (i.e., Test Observer, Auxiliary Personnel, Test Subject, and Safety Diver) by degree of exposure to hazard and task difficulty.

140. Kent, P.R. and S. Weissman
VISUAL RESOLUTION UNDERWATER. U.S. Naval Submarine Medical Center, Research Lab., Submarine Base, Groton, Conn. Rept. No. 476, Research Work - Unit MF022.03.03-9019.09, 5 May 1966.

Visual resolution in air and underwater were compared using Landolt Ring targets and a self-luminous, water- and pressure-proof target mount. SCUBA diving masks were worn during the tests, both in water and in air. Comparisons were also made while

viewing above and below surface targets through a periscope from a surface position. In both instances, visual resolution in clear water was better than in air at the same actual target distance, when apparent luminances were equated for the two conditions. In most cases the improvement while wearing the SCUBA mask fell below predictions based on the magnification of the target image underwater. The reasons for this were ascribed to fogging of the mask underwater, and the lack of sufficiently small targets for some observers. The difference in resolution between air and underwater viewing through the periscope was nearer that predicted by theory.

141. King, B.G., C.T. Patch and P.G. Shinkman
WEIGHTLESSNESS – TRAINING REQUIREMENTS AND SOLUTIONS. U.S. Naval Training Device Center, Port Washington, New York, 3 Mar 1961, NAVTRADEVCEN 560-1.

Physical principles and biological mechanisms relevant to human performance under conditions of weightlessness have been explained in order that the trainee can develop an appreciation of how the unaccustomed environment will affect his behavior. Special emphasis has been given to (a) changes of man's center of mass as various parts of the body are moved with respect to each other, and the significance of CM for body movement, (b) the mechanisms of postural reflexes, including experimental observations of response of pigeons to postural disorientation by tilting during weightlessness, and (c) anticipated changes in the sensory input spectrum and implications of such changes. Models have been proposed as visual aids in providing for cognitive learning aspects of training. The different effects of weightlessness on motor-perceptual and perceptual factors have been identified and solutions proposed for separately training each of these effects.

...Normally a body in contact with the earth is supported against gravity at localized sites and the body is provided with sensory mechanisms for referring sensations to the point of contact of the supporting force. This aspect of weightlessness can be simulated in an "earth trainer" by providing trainees with suitably-designed clothing and submerging them in a water tank... In this situation the supporting force of the body is distributed over a large surface area and the body would feel much as it would in weightlessness... The stimuli that are associated with maintenance of body posture that are experienced by the utricle and the visceral afferent nerve endings will be identical with those experienced on a rigid support, and the trainee will probably be able to orient himself with respect to gravity even in the absence of visual and tactile cues. The disadvantages of such a device (water tank) will be the greater density of the medium and the pressure gradient with respect to depth.

142. Levine, R.B.
NULL-GRAVITY SIMULATION. (Lockheed-Georgia Company, Marietta, Ga.) Paper given at Aerospace Medical Association 31st Annual Meeting, May 9-11, 1960.

143. Loats, H.L., Jr., Jacobs, D.L., and G.S. Mattingly
COMPARISON OF ACTUAL GEMINI EXTRAVEHICULAR EXPERIENCE WITH PREFLIGHT WATER IMMERSION SIMULATION. Environmental Research Associates, Randallstown, Md., and National Aeronautics and Space Administration, Manned Spacecraft Center, Houston, Texas. (Paper delivered at XVIIIth International Astronautical Congress of the International Astronautical Federation (IAF), held in Belgrade, Yugoslavia, 24-30 Sep 1967.)

The water immersion simulation of the Gemini EVA utilized full-scale mockups of the Gemini vehicle including portions of the Agena Target Docking Adapter with valid replicas of ancillary EVA equipment such as tools, astronaut maneuvering unit, etc. All important items were maintained in a neutrally buoyant condition. Bioinstrumentation was incorporated into the Gemini flight suits and continuous biomedical, voice and film records were made. A post flight run was made to permit further evaluation of the water immersion technique.

144. Loats, H.L., Jr. and G.S. Mattingly
A STUDY OF THE PERFORMANCE OF AN ASTRONAUT DURING INGRESS AND EGRESS MANEUVERS THROUGH AIRLOCKS AND PASSAGEWAYS Final Phase I. Environmental Research Associates, Randallstown, Md. (Contract NAS1-4059) 31 Aug 1964, N67-23328 (NASA-CR-66340; ERA-64-8.)

A time-displacement analysis using motion pictures was performed to assess experiments involving pressure-suited astronaut egress under balanced gravity conditions. A full scale airlock with three distinct hatch configurations and a cylindrical passageway was used at Langley Research Center. The experiments were performed in three modes: (1) ground/normal gravity; (2) water immersion/neutral buoyancy; and

(3) aircraft/balanced gravity. Comparative parameters for the three modes were suit pressure, subject, and suit type. Egress maneuvers using the water immersion and aircraft modes could be correlated as regards psychological and operational considerations. The major dissimilarity of the ground tests was in the total times of egress and in discrete task performance times and modes, all due to mobility decrement caused by the pressure suit and by normal gravity effects. Valid experiments of egress under balanced gravity require water immersion tests backed up with a number of aircraft tests. Ground/normal experiments are additionally required for control and procedure determinations.

145. Loats, H.L., Jr., G.S. Mattingly, and C.E. Brush
A STUDY OF THE PERFORMANCE OF AN ASTRONAUT DURING INGRESS AND EGRESS MANEUVERS THROUGH AIRLOCKS AND PASSAGEWAYS.
Final Report, NAS1-4059, Phase II, Volume I, Summary. 30 Apr 1965. Environmental Research Associates, Randallstown, Maryland.
Contract: NAS1-4059. Report no. ERA 65-3.

The performance characteristics of a pressure-suited astronaut during ingress-egress through a cylindrical, manually operated airlock were studied by water immersion simulation techniques. The buoyancy force induced by water displacement of a totally immersed subject was used to counteract his adjusted total weight to provide the simulated weightless environment. The subject performed a real-time ingress-egress maneuver as determined by functional task analysis of a representative mission.

The following airlock operational characteristics were investigated by factorial replication: the effect of airlock geometry and volume on total performance; the effect of hatch geometry, diameter and operation direction on performance; the contribution of torque requirements, hardware placement and motion aids to the problems and procedures comprising ingress-egress and manned replenishment. Correlation to actual weightless conditions was provided by similarity comparison with experiments performed aboard zero gravity research aircraft.

146. Loats, H.L., Jr., G.S. Mattingly, and C.E. Brush
A STUDY OF THE PERFORMANCE OF AN ASTRONAUT DURING INGRESS AND EGRESS MANEUVERS THROUGH AIRLOCKS AND PASSAGEWAYS.
VOLUME II: TECHNICAL DISCUSSIONS
Environmental Research Associates, Randallstown, Md. (Contract NAS1-4059) 31 Apr 1965, N67-23342 (NASA-CR-66342; ERA-65-3, Vol. II).

The performance characteristics of a pressure-suited astronaut during ingress-egress through a cylindrical, manually operated airlock were studied by water immersion simulation techniques. Position-velocity time profiles of the maneuvers were analyzed for three simulation modes: ground-normal gravity, aircraft-zero gravity, and water immersion-neutral buoyancy. Data for the following replicated parameters are presented: subject, suit type, suit pressure level, hatch configuration, hatch diameter, and hardware location. Demonstrations of the problems and procedures comprising the application of torque during ingress-egress, manual replenishment through the airlock, and the employment of external motion aids such as fixed bar and tethers were accomplished.

147. Loats, H.L., Jr., G.S. Mattingly, and C.E. Brush
A STUDY OF THE PERFORMANCE OF AN ASTRONAUT DURING INGRESS AND EGRESS MANEUVERS THROUGH AIRLOCKS AND PASSAGEWAYS.
VOLUME III: APPENDICES Final Report.
Environmental Research Associates, Randallstown, Md. (Contract NAS1-4059) (NASA-CR-66343; ERA-65-3, Vol. III) 31 Mar 1965 N67-23343.

Subject anthropometric data, an experiment summary, a statistical analysis, subject/suit calibration data, and drag estimations are presented as supporting material to an astronaut performance study. Also included is a glossary of physiological and technical terms which are related to the ingress and egress experiments.

148. LOG OF THE AQUANAUTS.
Naval Research Reviews, pp. 16-17, 19-25, Sep 1964.

A discussion of the operational phase of Project Sealab 1. This is a recorded version of what transpired during 11 days of working both inside and outside of the 40 foot long chamber maintained at a pressure equal to that of the surrounding water and while breathing from an atmosphere consisting mostly of helium.

149. MAN IN SPINNING TANK OF WATER WILL TEST EFFECTS OF WEIGHTLESSNESS IN SPACE.
Army Navy Air Force Journal, 97:21, 23 Apr 1960.

150. Marton, T., S.R. Hunt, T. Klaus and C.R. Cording
NEUTRAL BUOYANCY SUBMERSION FOR THE ANALYSIS OF HUMAN PERFORMANCE IN ZERO G.
Paper given at AIAA 4th Manned Space Flight Meeting St. Louis, Mo., Oct 11-13, 1965. (See also Missiles and Rockets, Nov. 8, 1965, pp. 34-37.)

Since man's capability to perform controlled force emission tasks while weightless is dependent on his being physically restrained, three modes of restraint were developed for evaluation under both the submergence and Keplerian modes. Phase I dealt with the collection of base line control data in the normal or 1g environment. This paper summarizes the findings of Phase II during which the same data was obtained under a neutrally buoyant condition for each of the three restraint modes. Phase III will, providing the analysis of the results gained from I and II demonstrate the need for continuance, examine the same tasks, utilizing identical restraints during Keplerian trajectories.

151. Marton, T. and A.H. Merritt
THE USE OF NEUTRAL BUOYANCY SUBMERSION AS AN AID TO STUDY OF HUMAN PERFORMANCE IN ZERO GRAVITY. (General Electric Company, Missile and Space Division, King of Prussia, Pa.).
Paper given at National Conference on Space Maintenance and Extravehicular Activities, Mar 1-3, 1966, Orlando.

152. Mattingly, G.S.
REDUCED GRAVITY SIMULATION USING WATER IMMERSION TECHNIQUES. Paper given at Human Factors Society, 9th Annual Meeting, Dayton, Ohio, Oct 18-21, 1965.

153. Molesko, N.M., Editor
A COLLECTION OF PAPERS ON SPACE-SUITS AND HUMAN PERFORMANCE
Chrysler Corp., New Orleans, La. Space Div., 16 Aug 1965. (REL-HFG-65-1). N66-17386.

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9. Roth, H.P. (Chrysler Corp.), "Work and Thermal Loads on Men Working in Space Suits."
10. Roebuck, J.A. (N. Am. Aviation, Downey, Calif.), "Transcription of Discussion at Symposium on Space Suits and Human Performance."
11. Schwartz, S.A. (Grumman Aircraft Engr. Corp.), "Transcription of Discussion at Symposium on Space Suits and Human Performance."

154. Morway, D.A., R.G. Lathrop, et al
THE EFFECTS OF PROLONGED WATER IMMERSION ON THE ABILITY OF HUMAN SUBJECTS TO MAKE POSITION AND FORCE ESTIMATIONS.
Aviation Medical Acceleration, Lab., Naval Air Development Center, Johnsville, Pa. 24 Jul 1963, 21p. NADC MA6115-5. AD-414 349.

Twelve subjects using underwater breathing apparatus were immersed in water for 18 hours. Each subject's responses to two general psychomotor tasks: (1) the ability to reach and position the arm and hand accurately and (2) the ability to estimate a prelearned level of force, were measured before, during and after water immersion. Analysis of variance performed upon the target aiming task showed no significant difference in the horizontal aiming component. However, a highly significant (p less than 0.1) bias upwards was observed in the vertical aiming component. Comparisons between trial means using the Duncan q' test indicates that the bias upwards declined as a function of immersion time. An analysis of variance performed upon the force estimation data showed a significant interaction between trials within blocks and test conditions. Duncan's q' Test Ordered Means Comparison revealed no significant difference between the pre- and post-immersion force estimations. The mean estimation obtained during immersion was significantly different (p less than .01) from the pre- and post-trials. The force data showed no tendency to adapt as a function of time immersed.

155. Nordby, F.J.
PREPARATION FOR LUNAR ENVIRONMENT WITH MEANS OF VARYING GRAVITATIONAL ENVIRONMENT. SAE – Paper 758A for meeting Sep 23-27, 1963, 3p.

Paper describes method which may be used to investigate, test, or evaluate functions, operations, or performance of man/machine systems under various (or varying) gravitational environments; method could be employed to acquire information on time required to accomplish functions, developing methods of performance, verification of design, personnel selection, etc; method is immersion technique based on controlled variations of density (specific gravity) of fluid mass. It was developed as part of a research experiment – to supplement existing techniques.

156. Pauli, D.C. and G.P. Clapper
AN EXPERIMENTAL, 45-DAY UNDERSEA SATURATION DIVE AT 205 FEET, SEALAB II PROJECT GROUP. Report on Project Sealab. Summary rept. Office of Naval Research, Washington, D.C. 8 Mar 67, Rept. no. ONR-ACR-1245, AD-651 999.

Sealab II demonstrated that: The concept of ocean-floor habitation to accomplish a wide range of salvage and scientific tasks is compatible with man's ability to perform useful work at these depths: No significant short-time physiological changes occur which resulted in deterioration of the aquanauts physical condition: There is a degradation of human performance which increases with the complexity of the task being accomplished.

157. Pauli, D.C. and G.P. Clapper
AN EXPERIMENTAL 45-DAY UNDERSEA SATURATION DIVE AT 205 FEET, SEALAB II PROJECT GROUP. Report on Project Sealab. Office of Naval Research, Washington, D.C. 8 Mar 67, Rept. no. ONR-ACR-124. AD-652 374

The Sealab II operation was conducted between Aug. 28 to Oct. 14, 1965, 300 ft off Scripps Pier at La Jolla, California, in a depth of water of 205 ft. Using a synthetic breathing gas of helium, oxygen, and nitrogen, each of the three aquanaut teams lived under pressure approximately 15 days in an ocean-floor habitat, making forays into the 48F, 5 to 30 ft visibility bottom waters for periods ranging from a few minutes to an extended dive of 3 hours. Excursion no-decompression dives to 266 ft and 300 ft were accomplished. Diving from the habitat was accomplished using both semi-closed-circuit breathing apparatus and hookah (habitat-connected-hose) breathing apparatus. A decompression complex new to the Navy consisting of a personnel transfer capsule mating with a deck decompression chamber was used for accomplishing recovery and decompression of aquanauts Sealab II demonstrated that: (1) The concept of ocean-floor habitation to accomplish a wide range of salvage and scientific tasks is compatible with man's ability to perform useful work at these depths. (2) No significant short-line physiological changes occur which resulted in deterioration of the aquanauts physical condition. (3) There is a degradation of human performance which increases with the complexity of the task being accomplished.

158. Peebles, J.A.
HUMAN FACTORS SIMULATION TEST PLAN
LH_2 TANK ENTRY AND INSPECTION. Systems
Design Branch (BECO memo.). 22 Dec 1966.

This test plan has as its purpose, a validation and evaluation of hardware design and support equipment. It also proposed to evaluate extravehicular task requirements, accessability and transfer technique. In addition to these primary objectives, this test situation was to validate the task operation sequence.

159. Peeler, D.J., and R.C. Smith
FULL PRESSURE SUIT FAMILIARIZATION
AND TRAINING FOR NEUTRAL BUOYANCY
OPERATIONS. Biotechnology Dept.,
Lockheed Missiles and Space Company,
Sunnyvale, Calif. 14 July 1967.

This document presents preliminary training materials relating to the operation and malfunctions of the U.S. Navy MARK IV aviator's full pressure suit manufactured by the Arrowhead Rubber Company and modified for use underwater. It was prepared to meet the specific requirements of neutral buoyancy simulations of weightlessness conducted in the Ocean Biotechnology Research Tank at Lockheed Missiles and Space Company.

160. Pierce, B.F. and E.L. Casco
CREW TRANSFER IN ZERO G AS SIMULATED
BY WATER IMMERSION. General Dynamics/
Astronautics, San Diego, Calif., 15 Apr 1964,
GDA-ERR-AN-502.

...The essential characteristic of man that makes water immersion a feasible method of weightless simulation for analyzing this (the relationship of man to equipment)... is that the specific gravity of the human body is equal to about one. Having approximately neutral buoyancy, the subjects representing the crew can assume positions and movements relative to the mockup which are similar to those that would occur in weightlessness, but which would be unattainable under one-G conditions.

The major limitation of this technique results from the fact that water offers considerable resistance to movement, and the resultant restriction to body mobility (as well as the possibility of using this resistance for self propulsion) must be taken into consideration. Nevertheless, water immersion provides the best simulation of weightlessness for periods of unlimited duration and with equipment of unlimited size.

161. Pierce, B.F., R.L. Wolf and E.L. Casco
THE USE OF SPACESUITS IN WATER IMMERSION STUDIES. General Dynamics/ Convair. Life Sciences Section, San Diego, Calif. (In: Chrysler Corp. A Collection of Papers on Spacesuits and Human Performance.) 16 Aug 1965, N66-17390.

Since water immersion has been demonstrated to be a satisfactory method of simulating various physical effects of zero gravity, a review of two related studies and consideration of future research operations are discussed. The suit system and breathing equipment are the two basic systems that studies must consider; and development of adequate communications with the underwater subjects is deemed essential. It is pointed out that with presently available techniques, underwater space-suit operations have already presented information for practical, manned space vehicle design problems.

162. Reid, G.
ZERO "G" SIMULATION AND ITS RELATIONSHIP TO EXPANDABLE STRUCTURES.
Paper given at 3rd Aerospace Expandable and Modular Structures Conference, Carillon Hotel, Miami Beach, Florida. May 16-18, 1967.

This paper discusses the simulation of the null gravity state and its application to human factors engineering for space experiments. Water immersion/neutral buoyancy was utilized as aids in the design of, and procedures determination for, several space experiments (e.g., Power Tool for Space Maintenance, Expandable Airlock Experiment, and Modular Structures for Assembly). The objective of the simulation effort was to minimize the operational difficulties that might be encountered with the astronaut/equipment interface. The relative value and specific applications of the neutral buoyancy simulations are discussed.

163. Santa Maria, L.J., M.J. Damato, and M.H. Radliff
A PHYSIOLOGICAL EVALUATION OF THE DIVERS' WET SUIT IN SIMULATED FLIGHT AND EMERGENCY ENVIRONMENTS.
Aerospace Medicine, 35(2):144-147, 1964.

The results of the physiological responses concerning skin and rectal temperatures of subjects wearing the divers' wet suit during exposure to different levels of environmental conditions are presented. Exposures were of 4 generic types: (1) two-minute immersion followed by life raft occupancy, (2) a constant immersion state, (3) dry-cold exposure, and (4) exposure to ambient conditions of moderate temperature. Results indicate that usage under most acceptable laboratory conditions only may constitute basis for favorable comparison with current exposure suit assemblies in regard to body temperatures and tolerance times. Reduction of water leakage and the introduction of ventilating capabilities might enhance its acceptability as a constant-wear protective assembly for the fixed-wing pilot and aircrewman.

164. Schultz, D.C. and J.H. Covington
(PRELIMINARY) OPERATIONAL ASPECTS OF SIMULATING WEIGHTLESSNESS BY THE USE OF THE WATER IMMERSION TECHNIQUE.
Flight Crew Support Division, NASA Manned Spacecraft Center, Houston. June 1967.

This report provides an introductory source of information on operational aspects of applying the water immersion technique to the simulation of weightlessness. This information is based on experience with the technique in simulation of extravehicular activity (EVA) during the Gemini program. The report emphasizes those areas of the Gemini experience associated with the simulation of the total EVA. It is concluded that if careful attention is given to providing and maintaining the crewman in a condition of neutral stability in translation and rotation, and to the fidelity considerations of EVA equipment and vehicles involved in the EVA, performance of the EVA underwater can be considered a pre-run of the inflight experience.

165. Schuster, D.H.
EVALUATION OF REPLACEMENT TIMES OF SPACECRAFT RADIOS UNDER SIMULATED WEIGHTLESSNESS. Collins Radio Co., Cedar Rapids, Iowa. (In: Chrysler Corp. A Collection of Papers on Spacesuits and Human Performance, 16 Aug. 1965) N66-17391.

Mechanical aspects of maintaining two prototype radios for spacecraft communications systems were evaluated under two simulated weightlessness conditions: (1) subjects worked on dry land without gloves and (2) scuba divers worked underwater with gloves on neutrally buoyant radio mockups. It was found that on dry land, the VHF unit required 530 seconds to remove and replace, while 1009 seconds were needed underwater; the SHF unit took 375 seconds on dry land and 644 seconds underwater. It is noted that the main effects of environment and unit were considerably more important than this interaction between environment and radio unit. Further, it was noted that time required was considerably shortened by practice. Two multiple regression analyses were made; and in the nonlinear case, a multiple correlation coefficient of 0.873 was obtained for predicting maintenance time. Comments of subjects regarding design of the wrench used and stress conditions are noted.

166. Schwinghamer, R.J.
TOOL EXPERIMENTS FOR ASSEMBLY, MAINTENANCE AND REPAIR IN SPACE. (George C. Marshall Space Flight Center, Huntsville, Alabama). Paper given at National Conference on Space Maintenance and Extravehicular Activities, Mar 1-3, 1966, Orlando. N67-12716.

The future need for high power in space assembly, maintenance and repair operations is pointed out, and the advantages of energy storage and the pulse power concept are discussed. A typical solar charged pulse power system is described, and some typical pulse power tools which already exist are shown. Applications for space assembly and maintenance and repair are considered. Experiments are described which are intended to develop apparatus and techniques for creating at will cohesion and perhaps even adhesion in vacuum environments of 10^{-9} Torr or less. The system will ultimately use magnetomotive force as the driving mechanism, and promises to be an ideal joining technique in space. Actual tool performance and operational simulation experiments are treated. Preliminary neutral buoyancy simulation studies of tool performance are also described. Conclusions are drawn, regarding ordinary hand tools, certain types of lanyards and tethers, large or complicated vehicle structural

assembly, maintenance and repair tasks, and the mechanical advantages associated with pulse, and ordinary power tools. Also included are comments denoting the benefits associated with neutral buoyancy immersion techniques in the development of space tools, tool systems and applications, and the contention is further made that working with the actual one-to-one ratio hardware, preferably under neutral buoyancy immersion conditions, constitutes a decided advantage.

167. SEALAB 1

Naval Research Reviews, pp. 5-8, Jul 1964.

Sealab 1 is sponsored by the Office of Naval Research in collaboration with the Bureau of Ships and the Naval Medical Research Laboratory, New London, Conn. The Sealab capsule was designed and constructed at the Navy Mine Defense Laboratory, Panama City, Fla.

The project was undertaken to help determine the extent to which man can adjust to the undersea environment and carry out useful assignments there.

168. Shurley, J.T.

PROFOUND EXPERIMENTAL SENSORY ISOLATION. American Journal of Psychiatry, 117(6):539-545, 1960.

This is a description of the sensory deprivation experiments conducted at Oklahoma City Veterans Administration Hospital. In order to simulate weightlessness, the subject was placed in a large tank filled with water slowly flowing at a constant temperature. The rest of the system consisted of automatic controls and continuous tape recorders. The subjects were volunteers who had been pre-selected on the basis of capacity for memory, ability to communicate freely, and self-observation. Light, sound, vibration, odor, and taste inputs were highly restricted. The chronological report is based on tape recordings by a subject in isolation for 4-1/2 hours. The water immersion test was not perceived as unpleasant. The subjects feeling states varied during post-exposure.

169. Smith, H.E.
COMMUNICATIONS SYSTEM FOR ZERO-G SIMULATION IN WATER. National Aeronautics and Space Administration, Marshall Space Flight Center, Huntsville, Ala. 6 Dec. 1966, N67-22844; NASA-TM-X-53547.

This report presents a description of a two-way communications system connecting nine personnel stations and a public address system. The system includes underwater speakers that can be heard by the safety divers. Operating instructions for the system are also given.

170. Smith, J.R.
TEST REPORT: BASELINE DATA WATER IMMERSION FACILITY PRESSURE SYSTEM. Flight Crew Support Division, Water Immersion Facility, NASA Manned Spacecraft Center, Houston, Texas. WIF 67-2, 27 June 1967.

The pressurization system which was designed and fabricated for manned operation in the Water Immersion Facility (WIF) was tested in an unmanned mode as a first step toward proving the system operational. The results were found to be acceptable for use in the WIF. The test plan and test results are included in this report.

171. Stone, R.W., Jr. and W. Letko
SOME OBSERVATIONS DURING WEIGHTLESSNESS SIMULATION WITH SUBJECT IMMERSED IN A ROTATING WATER TANK. NASA TN-D-2195, 1964.

172. Streimer, I.
MANUAL FORCE-PRODUCTION CAPABILITIES IN THE UNDERWATER ENVIRONMENT. North American Aviation, Inc., Ocean Systems Operations, Anaheim, Calif. SID 66-1562, October 1966b.

This report discusses the results of a research program which investigated force-producing capabilities of underwater workers. The force and torque outputs of four male subjects were obtained via a memory torque wrench mounted on a testing device located six feet below the surface of the water. Three hand wheels and three shafts of different diameters were used for torque measurements. A horizontal bar was used for force measurements. The results indicate generally that force-producing capabilities are significantly degraded in the underwater tractionless mode. The results are discussed in terms of their implications to underwater system design.

173. Streimer, I.
ENERGY CONSIDERATIONS AS DETERMINANTS OF UNDERSEA SYSTEM DESIGN. North American Aviation, Inc., Ocean Systems Operations, Anaheim, California.

A conceptual approach is developed to the sizing of man-machine systems intended for deployment in "exotic" environments. The approach is predicated upon the efficiency with which available system energy is converted into useful goal-directed work. Systems are generically categorized as a function of their energy replacement characteristics and three classes of efficiency degradations are delineated which can adversely affect system capability, reliability, and cost. The effects of alterations in operator performance characteristics upon system design are detailed in terms of engineering changes, and suggestions are advanced as to the nature of the future research necessary to obtain maximum cost effectiveness in future systems.

174. Streimer, I.
ERGONOMIC FACTORS IN THE DESIGN OF EXTENDED DURATION MANNED UNDERWATER SYSTEMS. Paper given at Institute of Environmental Sciences' 1966 Annual Technical Meeting.

The utilization of man in the research and exploitation of the continental shelves will entail the employment of human operators as a source of force and power during the execution of diverse tasks prerequisite to program success. Anticipated performance decrements in control, construction, maintenance, assembly and scientific experimentation functions are discussed in terms of their impact upon such system variables as environmental control system design and sizing, manning requirements, life support system requirements, work-rest cycles, etc. A six point program of experimentation is suggested which it is believed will enable the attainment of information which will facilitate both realistic and economical system design.

175. Streimer, I., D.P. Turner, and K. Volkmer
TASK ACCOMPLISHMENT TIMES IN UNDERWATER WORK. North American Aviation, Inc., Ocean Systems Operations, Anaheim, California.

This report discusses an experimental program initiated to establish the ratio of task accomplishment times between normally tractive land work and underwater work during the performance of a selected maintenance task. All the test and training sessions of the three male subjects were conducted in the NAA Apollo Drop Test Facility, Downey, California. All tasks were performed at a depth range of 12-18 feet. The results indicated that work underwater was more time-consuming than dry-land work with the mean increase of 35 percent. Differences were observed in the percentage of time increase in subtasks, which seemed attributable to the type of work performed.

176. A STUDY OF THE PERFORMANCE OF AN ASTRONAUT DURING INGRESS AND EGRESS MANEUVERS THROUGH AIRLOCKS AND PASSAGEWAYS. Final Report, NAS1-4059, Phase III, Dec 1966. Environmental Research Associates, Randallstown, Maryland. Contract: NAS1-4059. Report no. ERA 66-3.

Phase III of NAS1-4059 was initiated in July, 1965. Its purpose was to generate additional quantitative data on refined experiments and to expand the experiment scope to include rescue, replenishment and general maneuvers exterior to the airlock. Evaluation of the astronaut's capabilities to conduct manual ingress-egress were made by comparative time-task analysis. A series of demonstrations were performed to develop information for evaluation of future research areas such as rescue operations, the effects of sub-earth normal gravity levels, replenishment through airlocks and human ability to produce torque forces.

177. STUDY OF ASTRONAUT CAPABILITIES TO PERFORM EXTRAVEHICULAR MAINTENANCE AND ASSEMBLY FUNCTIONS IN WEIGHTLESS CONDITIONS. Statement of work L-632, NASA Langley Research Center, Langley Station, Hampton, Va., Nov 2, 1965.

The NASA is currently planning extended duration space missions during which extravehicular operations will be required. Extravehicular operations will permit the performance of tasks such as maintenance and repair of equipment, assembly of large equipment and assembly of modular units. In order to better understand the capabilities, limitations and level of performance of the astronaut in performing these extravehicular tasks and to develop techniques and equipment for accomplishing them prior to flight dates, it is necessary to provide a means of realistic simulation.

Water immersion weightless simulation of the maneuvers of the pressure-suited astronaut has recently been developed into a useful research tool for studying his capabilities in a zero gravity environment. By this means of simulation an astronaut can operate in six (6) degrees of freedom in a neutrally balanced condition for extended periods of time. This means of simulation has been effectively used to study ingress and egress techniques of the pressure-suited astronaut through airlocks and passageways of a space vehicle. Past experiments performed in this area have shown that the technique is applicable in studying certain of the required extravehicular activities of the pressure-suited astronaut. It is therefore possible to investigate, in greater

depth than previously possible, those tasks which the astronaut must perform on the exterior of a space vehicle in a pressurized suit. Accordingly, a combined theoretical and experimental program for simulation of the astronaut performing extravehicular maintenance and erection techniques, beginning with simple tasks and increasing in complexity to include the assembly of large equipment and modules, is required.

178. A SURVEY OF CHRONIC WEIGHTLESSNESS SIMULATION IN BIOLOGICAL RESEARCH. Virginia U., Charlottesville. (HQARSC-TDR-64-1; AD-607 052) N65-13216. (Contract AF 18(600)-2057). 1964, 114p.

The experimental simulation of weightlessness by prolonged, quiet bed rest, by water flotation, and by body and/or limb immobilization is evaluated. The value of the simulation of a low-gravity environment by immobilization was found questionable because it produces the type of low activity characterized by reduced external motion, whereas a true weightlessness environment would not necessarily prevent external motion and might even permit greater amounts of such motions. It was found that studies of immobilization can be related to the restrictions that are imposed by the size of the existing space capsules, but should not be used to predict the effect of true weightlessness.

179. Trout, O.F., Jr. INVESTIGATION OF MAN'S EXTRAVEHICULAR CAPABILITIES IN SPACE BY WATER IMMERSION SIMULATION TECHNIQUE. American Institute of Astrospace Meeting Nov 29 – Dec 2 1966. Boston, Mass. NASA Langley Research Center, Langley Station, Hampton, Va. (See also J. Spacecraft Rockets 4, no. 6, pp. 806-808. AIAA Paper No. 66-903.

A discussion of the use of the water submersion technique to simulate partial and zero gravity operations to determine the capabilities of man in space, determine the man-machine interface and to obtain design data. The application of this method to ingress-egress operations thru airlocks systems together with applications to manual locomotion, maintenance and assembly processed, crew and cargo transfer functions, rescue and repair tasks were also discussed.

180. Trout, O. F., Jr.
WATER-IMMERSION TECHNIQUE FOR SIMULATION OF INGRESS-EGRESS MANEUVERS UNDER CONDITIONS OF WEIGHTLESSNESS
NASA. Langley Research Center, Langley Station, Va., "Selected Papers on Environment and Attitude Control of Manned Spacecraft," p79-87, Dec 1966. N67-14251.

A water-immersion technique has been developed whereby a pressure-suited subject, unrestrained by connecting lines and hoses, can simulate maneuvers under conditions of weightlessness in six degrees of freedom. This simulation has been applied to a series of ingress-egress experiments; and the results of these experiments indicate that the technique has application to the study of human factors and capabilities in extravehicular space operations and to a determination of design criteria for advanced manned space vehicles and related equipment.

181. Trout, O. F., Jr., H. L. Loats, Jr., and G. S. Mattingly
A WATER IMMERSION TECHNIQUE FOR THE STUDY OF MOBILITY OF A PRESSURE-SUITED SUBJECT UNDER BALANCED-GRAVITY CONDITIONS. (NASA Langley Research Center and Environmental Research Associates, Randallstown, Md.) NASA TN D-3054, National Aeronautics and Space Administration, Washington, D.C., Jan 1966. (Technical Film Supplement L-849 available on request.)

A technique for simulating zero-gravity performance of an astronaut in a pressurized spacesuit by complete water immersion has been developed and investigated. The technique allows the pressure-suited subject to move in six degrees of freedom without the encumbrance of connecting lines or hoses or other supports and further permits performance simulation of long duration tasks.

Experiments were made to demonstrate the relationships between the maneuvers performed by a pressure-suited subject under weightless conditions produced by water-immersion and zero-gravity aircraft flights and those performed under full-gravity conditions. An overall description of the test procedures, pressure suit and modifications, self-contained gas-supply breathing system, and methods for obtaining neutral buoyancy is provided.

The tests demonstrated that the simulation technique is useful for pre-mission determinations of critical operational characteristics relating to spacecraft and spacesuit design under conditions of zero-gravity. In addition, the physical capabilities of man and his ability to perform useful work and maneuvers in a pressurized suit under simulated zero-gravity conditions can be demonstrated by this technique. Test variables included time, suit pressure, and simulation mode. Comparison of the subject's motion behavior between the aircraft and water-immersion tests showed that the water-immersion technique is valid where velocities are low.

182. Trout, O.F., Jr.
WORK PERFORMANCE IN SPACE.
(Paper presented at ad hoc Working Group Meeting Extravehicular Technology and Space Maintenance, Ames Research Center, Moffett Field, California, 21-22 Sept 1967.)

Paper discusses three broad categories of work performance: (1) manual locomotion and maneuvering; (2) crew and cargo transfer; (3) maintenance and equipment assembly. Most of the work presented in paper was done by neutral buoyancy simulation.

183. VIRGIN ISLANDS TEST FACILITY: FOR EVALUATION OF ASTRONAUT AND EQUIPMENT PROCEDURES, 12 Dec 1966. General Electric Missile and Space Division, Philadelphia, Pa.

The manual describes the neutral buoyancy test facility being used for underwater zero gravity simulation work by General Electric. It provides a discussion of safety regulations, equipment, and operational procedures to be followed in the functioning of their open ocean test facility.

184. Weltman, G., R. A. Christianson and G. H. Egstrom
A DIVER RESTRAINT DEVICE FOR UNDERWATER EXPERIMENTATION. Biotechnology Lab., Univ. of California, Los Angeles. Rept. Nos. TN-30; 65-5, Feb 1965, 6p. AD 463 097.

There is currently a great deal of interest on many fronts concerning man's inhabitation of the sea. If this interest is a valid indication of future effort, as it seems to be, one may expect a significant increase in the number of experimental studies dealing with human work and task performance underwater. It seems reasonable to assume that the goals of these new studies will match the goals of previous investigations in other work environments. That is, there will be a similar emphasis on the psycho-physiological effects of environmental variations, and on the ways in which equipment and workplace design influence performance level. For the underwater studies to be of equal practical value, however, they will also have to match the care and control of previous experimentation. This means that in many instances, because of the novel aspects of operating underwater, investigators will have to evolve, perfect, and communicate modified techniques for handling subjects, establishing work tasks, acquiring data, and so forth. Some brief remarks on the design and use of a diver restraint device applicable to several types of underwater study are presented.

185. White, P.D., L.M. Nyberg, and W.J. White
A COMPARATIVE STUDY OF THE PHYSIOLOGICAL EFFECTS OF IMMERSION AND BED REST. Doublas Aircraft Company, Inc., Santa Monica, Calif. Advance Biotechnology (Contract NAS9-4166).

Physiological responses of 10 subjects, each serving as his own control, were compared during alternate 10 day periods of silicone immersion and bed rest. The major findings of this study were: (1) the detrimental effects of prolonged immersion and bed rest on orthostatic tolerance and extracellular fluid were reconfirmed; (2) the incidence of presynocopal reactions on the tilt table was higher and occurred earlier during immersion than during bed rest; (3) during immersion the daily solute load excreted by the kidney, osmolar clearance, and urine output were higher than during bed rest; (4) a negative free-water clearance was seen in all subjects, during immersion and bed rest; (5) except for two subjects, the skin problems encountered during immersion were trivial; and (6) the silicone fluid, immersion tanks, filtration, and cooling equipment met requirements of the experiment.

186. Whiteside, T. C. D.
HAND-EYE COORDINATION IN WEIGHTLESSNESS.
Aerospace Medicine 32(8):719 – 725, Aug 1961.

To study hand-eye coordination under conditions that would eliminate the variable of visual monitoring of performance yet with eye movement controlled, Ss were required to point at graph paper situated some 20 to 25 inches from his chest at chest level. A thimble with a point was worn on the index finger so that accurate measurements could be made. A mirror was located in such a manner that the S saw a target situated to one side but could not see his hand and arm. The aiming task was performed under normal conditions, under simulation of subgravity (immersion in water up to neck), under zero g in an aircraft flying the well-known parabola, and under acceleration (2g) on the centrifuge. Practical implications of the findings were indicated.

187. Wolf, R. L.
THE USE OF FULL PRESSURE SUITS FOR UNDERWATER STUDIES TO SIMULATE WEIGHTLESSNESS. General Dynamics/ Astronautics, San Diego, Calif., 1 Apr 1964, GDA-ERR-AM495.

For evaluating some of the effects of a weightless environment, the approximately neutral buoyancy of the human body in water provides a suitable simulation. One of the most difficult problems in the use of full pressure garments in underwater testing is their positive buoyancy when inflated to normal pressures with air. For proper simulation it is necessary to have the underwater characteristics of the full pressure suit similar to those encountered in outer space. Any weights used to gain neutral buoyancy will add mass to particular points, making it difficult to control the center of gravity and to make normal body movements. For this test the technique of pressurizing the suit with water, although not of the most desirable quality, did provide a satisfactory means for partial simulation and gave valuable information for modification necessary for future tests.

188. Wortz, E. C., L. E. Browne, W. H. Shreck, et al
STUDY OF ASTRONAUT CAPABILITIES TO PERFORM EXTRAVEHICULAR MAINTENANCE AND ASSEMBLY FUNCTIONS IN WEIGHTLESS CONDITIONS.
NASA Langley Research Center, CR-859. Prepared by AiResearch Manufacturing Company, Los Angeles, Calif., Sept. 1964. N67-36491.

Experiments were conducted on man's capabilities to perform manual work in the weightless environment. More than 200 experimental conditions were studied. The independent variables were simulation techniques, tasks, locomotion aids, restraint devices and tools. This document describes the final results of both the analytical and experimental studies. Conclusions are drawn with respect to the effects of the independent variables, the human engineering observation, quantitative analyses and physiological parameters. Hypotheses are advanced concerning the improvement of work in the weightless environment.

189. Wright, N. P., Editor
PROCEEDINGS FIFTH ANNUAL CONVENTION OF THE UNDERWATER SOCIETY OF AMERICA held in Mexico City, Jun 17 – 21, 1964. Published by C. E. D. A. M., Carlos B. Zetina 20, Mexico City 18, Mexico.

The prupose of this Congress was to discuss the latest developments in every branch of underwater activity. Section 11 of the proceedings is on Manned Undersea Stations.

190. Yuganov, Ye. M., P. C. Isakov, et al
MOTOR ACTIVITY OF INTACT ANIMALS UNDER CONDITIONS OF ARTIFICIAL GRAVITY.
(Akademiya nauk SSSR. Isvestiya., Seriya Biologicheskaya, no. 3, 455 – 460), 1962.

The minimal effective value of artificial gravity necessary to maintain the body posture and coordination of movements of mice and rats under conditions of weightlessness as in the parabolic flight of an aeroplane was determined. Artifical gravity was created in a small size contrigure which produced radial accelerations varying from 0.05 to 1.0 g. Accelerations of 0.28 to 0.3 g were sufficient for prophylaxis of the unfavorable effect of weightlessness upon the motor reactions of the animals.

191. Zaleski, J. R.
TEST REPORT: BASELINE DATA APOLLO A5L PRESSURE SUIT. Flight Crew Support Division, Water Immersion Facility, NASA Manned Spacecraft Center, Houston, Texas. WIF 67-1, 23 June 1967.

A pressurized A5L (005) suit was measured for design of a quick release weight harness. Helmet blow off and suit depressurization methods were explored. It appears that 1/2 psig in the suit is the maximum at which the helmet can be reliably removed. Suit subject injury at this pressure is quite possible. Depressurizing the suit rapidly to below 1/2 psi is required. Depressing the "basket" in an unused suit connector appears to be the best method for depressurizing the suit.

192. Zaleski, J. R. and L. G. Richard
WATER IMMERSION FACILITY PROCEDURES BROCHURE. Flight Crew Support Division, NASA Manned Spacecraft Center, Houston. 25 Jan 1967.

This brochure deals with the development of necessary safety procedures and practices for the neutral buoyancy zero-g simulation facility, Building 5, NASA Manned Spacecraft Center. It also deals with diver training, operational procedure and emergency situations which will prevent confusion, panic and possible employee injury.

PART III. TECHNIQUES AND PERSONAL EQUIPMENT REQUIREMENTS

193. Beagles, J. A. and E. F. Coil.
DIVERS' BODY HEAT LOSS: describes a study of the endurance of underwater swimmers wearing a variety of foam neoprene wet suits and immersed at 30-32F in the NEL Arctic pool. Navy Electronics Lab, San Diego, Calif. 10 Oct 1966, Rept. No. NEL-1408, Proj. SR-011-01-01, Task 0401. AD-652-405.

A study was made primarily to obtain data applicable to the design of an optimum protective suit for divers in arctic environments. The experimental method employed swimmers who performed shallow dives in the NEL Arctic Pool at 30-32F. Skin temperature was recorded by the use of suitably located thermistors, and other data were obtained from blood samples drawn immediately before and after each dive. Results suggest that a four-piece foam neoprene wet suit consisting of a 1/8-inch tight-fitting inner suit and a 1/4-inch snug-fitting outer suit along with two pairs of neoprene socks and mittens would provide the optimum combination of protection and mobility for divers in arctic waters.

194. Beckman, E. L.
THERMAL PROTECTIVE SUITS FOR UNDERWATER SWIMMERS. Naval Medical Research Inst., Bethesda, Md. Rept. No. 8. Task: MF011.99-1001. July 1966. AD-485-871.

An analysis of the problems of maintaining the thermal balance of underwater swimmers is presented. Current and planned developments to provide the necessary thermal protective equipment are described. A satisfactory garment for maintaining the thermal balance of underwater swimmers during a 4-hour work period in water at temperatures down to 29 degrees F must include both an insulative layer and a source of supplemental heating. The insulative layer must be as effective at depth as the popular 1/4 inch unicellular, foam neoprene skin divers wetsuit is a shallow

(see also references 14, 19, 28, 40, 60, 113, 116, 122, 143, 160, 163, 184, 187, 189, 210)

water. A fabric in which the insulative value is independent of pressure change must be developed. In addition, a system of supplemental heating must be developed to supply the swimmer with approximately 350 to 500 thermal watts per hour. An electrical, resistance-wire heating system with a silver zinc battery for power was integrated with a 'constant volume,' pressure-compensated, insulative garment for use by Sealab 2 Aquanauts. This development will be described in addition to the planned thermal protective garments for use by Sealab 3 aquanauts which include a liquid heating system powered by an isotopic thermal generator.

195. Bolger, P. H. and Radnofsky, M.I.
NASA/DOD/INDUSTRY EXTRA VEHICULAR ACTIVITY PROGRAMS & CAPABILITIES.
Working paper. NASA/OMSF, Advanced Manned Missions Program, July 1967.

This paper presents in concise form (186 pages) and makes available in a single document, a resume of the overall efforts in the field of Extravehicular activities. It is a working document, a source of information to interested workers to commence with adequate background information, areas now being investigated and logical sources for some additional data. Neutral buoyancy facilities of NASA, Department of Defense, and Industry are described. Also the programs being carried out are deliniated.

196. Casco, E. L., Pierce, B. F., and Wolf, R. L.
THE USE OF SPACE SUITS IN WATER IMMERSION STUDIES. General Dynamics/Astronautics, San Diego, Calif. Report No. GDA-ERR-AN-566, 13 Nov 1964.

197. Dzendolet, E. and Rievley, J. F.
MAN'S ABILITY TO APPLY CERTAIN TORQUES WHILE WEIGHTLESS. USAF Aeromedical Labs., Wright-Patterson AFB, Ohio. 19 Apr 1959. WADC TR 59 94. Proj. 7184 Task 71586.

198. Fisher, H.T.
STATUS TO DATE OF BIOTECHNOLOGY INPUTS TO THE UNDERWATER WORK SYSTEMS AND TOOLS INDEPENDENT DEVELOPMENT PROGRAM. Lockheed Missiles & Space Co. Interdepartmental Communication. Limited distribution. 8 Sep 1966. (55 – 60).

The memorandum has been prepared to present the status of the work accomplished to date relative to the following topics: The human factors considerations for Ocean System Program concerning diver work output, gas mixture, physiological interaction, and human engineering. A brief discussion of four major diver problem areas; visual surveillance, communication, navigation, and motor manipulation. Additionally, the utilization and design of tools in relation to underwater use. This discussion is followed by a section that specifies the next major effort to be accomplished by the organization in support of the oceans systems program.

199. Gerathewohl, S.J.
ZERO-G DEVICES AND WEIGHTLESSNESS SIMULATORS. National Academy of Sciences, National Research Council, Washington, D.C. Publication No. 781, 1961.

This report concerns the devices, methods, and techniques which have been used for the investigation of the effects of zero-G and weightlessness by many investigators. The report is not a scientific treatise of the problem of weightlessness and the effect of sub- and zero-gravity upon the organism, but rather a description of research equipment techniques.

Concerns the devices, methods, and techniques, which have been used for the investigation of the effects of zero-G and weightlessness by many investigators. Part I deals with devices which can be used for producing sub- and zero-gravity, viz., vertical-motion devices, aircraft, and ballistic missiles. A simple-mathematical treatment of the physical parameters involved in sub- and zero-G conditions precedes

the discussion of each of these three methods. In Part II, instruments and techniques for the simulation of weightlessness are described. The objective of this survey is to assure maximum usefulness of such devices and optimum cooperation between agencies and to guarantee that new requirements of the future be incorporated in research proposals on bioastronautics.

200. Goldman, R.F., Breckenridge, J.R., Reeves, E. and Beckman, E.L.
"WET" VERSUS "DRY" SUIT APPROACHES TO WATER IMMERSION PROTECTIVE CLOTHING.
(U.S. Army, Research Institute of Environmental Medicine, Natick, Mass.; National Naval Medical Center, Naval Medical Research Institute, Bethesda, Md.). Aerospace Medicine, vol. 37, May 1966, p. 485-487. AD-638-92.

Discussion of immersion protection flight clothing, which can be either a wet-type suit or waterproof dry suit. A waterproofed manikin was used to study the insulative properties of both types of suits in air and also during water immersion. The bulkier characteristics of the dry suit studies provided greater insulation in air than either a 1/4 in. or 3/16 in. unicellular sponge, neoprene wet suit. However, during water immersion, compression of the dry suit by the water reduced the insulation by 75%. The insulation of the wet suits was also reduced, but these suits are less compressible, and thus during water immersion provide significantly more insulation than the dry suit.

201. Goodman, M.W.
CARBON DIOXIDE ABSORPTION SYSTEMS FOR SCUBA. 1. QUANTITATIVE CONSIDERATIONS OF DESIGN AND PERFORMANCE OF CYLINDRICAL CANISTERS. Navy Experimental Diving Unit, Washington, D.C. Interim rept. Research rept. RR-3-64. (Proj. S F011 06, 03, Task 3380). AD-615 771.

Cylindrical SCUBA canisters, packed with granular Baralyme, were tested with a mechanical respirator. Breathing resistance was observed to vary linearly and in direct proportion to the length-diameter ratio when airflow was of less than critical or pre-critical magnitude. Duration of useful canister life (end-point at 0.5% CO2) was determined to be a function of canister size, i.e., volume and quantity of absorbent. Efficiency, however, correlates closely with the packed granular column length of iso-diameter, adequate-size canisters. Dimensions of low-flow-impedance, minimal-capacity canisters are governed by the absorptive wave-reactive-zone volume and the empirically-stipulated diameter. Methods for determining size capacity and dimensional ratios of low resistance, efficient, duration-specific canisters are considered, together with the gas flow and composition parameters, the specific environmental hazards facing closed-circuit oxygen swimmers, and related factors of significance in these respects.

202. Gray, R.F. and Webb, M.G.
HIGH G PROTECTION. Aviation Medical Acceleration Lab., Naval Air Development Center, Johnsville, Pa. 12 Feb 1960, 18p. (Proj. TED No. ADC AE 1411; rept no. NADC-MA-5910). (Task MR005. 12-0007.2, rept. no. 7). AD-235 338.

These advantages, problems, and limits of older types of G protective systems are discussed in this report. Theories are presented for methods of using liquid or form-fitting external supports for the body along with respiratory pressurization to counteract the distorting forces. Actual devices which were worked out to apply these

theories are shown. These devices include: (a) the Mayo Tank first used in 1942 to test G protection by submersion in water. This has been slightly modified to bring about a substantial increase in G protection, (b) The G-Capsules and associated equipment, which most thoroughly of all devices so far built, is an application of these new theories of body support, and (c) the Moulded Couch built by the National Aeronautics and Space Administration according to some of these ideas and incorporating several other devices or procedures such as partial supination to avoid chest pain. Through the use of these various devices during the past year, several new records of tolerance to centrifugal acceleration have been established, indications have been gained for improvements on these devices, and it is expected that higher levels of G tolerance will be attained.

203. Gray, R.F. and Webb, M.G.
TESTS ON WATER-FILLED CAPSULES IN THE PRONE POSITION. Letter Report No. TED ADC AD-1411, MA-5, Serial 2933. 14 Apr 1959.

204. Haber, F. and Haber, H.
POSSIBLE METHODS OF PRODUCING THE GRAVITY-FREE STATE FOR MEDICAL RESEARCH. USAF School of Aviation Medicine, Randolph AFB, Texas. 1951.

205. Johnston, R.S. and Hays, E.L.
DEVELOPMENT OF EXTRAVEHICULAR EQUIPMENT. International Astronomics Federation (17th). Madrid, Spain. Oct 9 – 15, 1966.

206. Levine, B.
A DEVICE FOR SIMULATING WEIGHTLESSNESS.
(Lockheed-Georgia Co., Marietta, Ga.) In:
Medical and Biological Problems of Space Flight,
pp. 85 – 113. Proceedings of a Conference held
in Nassau, the Bahamas, Nov 1961. Ed. by
Geoffrey H. Bourne, New York and London:
Academic Press, Inc., 1963.

Design and instrumentation for a successful weightlessness simulator are discussed in terms of the three major effects it must produce: (1) deprive the subject of all important sensory cues (visual, mechanical, balance) to the existence of a gravitational field; (2) produce as many as possible of the important physical and physiological effects (on vestibular function, respiration, diurnal rhythms, locomotion, manipulation skill, muscle, bone, and cardiovascular function, cause motion sickness) of a true gravity-free state; and (3) appeal psychologically (exhilaration, isolation, physical contact loss) to the subject as a true representation of actual space flight conditions in as many modes as possible. The Lockheed null-gravity simulator gives promise of fulfilling these conditions. It consists of a large tank filled with water in which the subject is immersed: the tank and its contents are rotated rapidly at a constant speed. Basic experimental procedures in using the simulator (subject fitting, positioning system, breathing air system), and safety measures are discussed.

207. Levine, R.B.
NEW APPROACH TO ZERO GRAVITY TESTS.
Aircraft & Missiles, 4:26 – 29, Jun 1961.

In order to simulate the environment, Lockheed's Null-Gravity Simulator utilizes the process of immersing a man in water. Water immersion gives the following desired effects: (1) the subject loses the ability to detect gravitational support, (2) muscular effort for maintaining posture is reduced, (3) previously stretched, soft tissues no longer perceive the direction and magnitude of the gravitational field, (4) the force of friction between the vessel walls and the subject decreases to zero, and (5) hydrostatic pressures in the circulatory system are nearly equaled by the water pressure. Also included is a physical description of the simulator.

208. MAN IN SEA HELPS SPACE RESEARCH

Undersea Technology, 6(3):16, Mar 1965.

General Electric uses the facilities of Philadelphia's Aquarama to simulate weightlessness in tests of man working at consoles of its version of the MOL.

209. Miller, E.S., Norman, D.G., and Miller, G.
HUMAN PERFORMANCE FOR MAINTENANCE
AND REPAIR IN ZERO GRAVITY
General Electric Missile & Space Div.,
Valley Forge, Pa.
Paper given at AIAA "Space Program Issues
of the 70's Meeting," Seattle, Wash.,
28 – 30 Aug 1967.

Results of an experimental program developed to provide basic human engineering performance data for use by engineers designing equipments for manned space systems are presented. Neutral buoyancy submergence techniques for the simulation of zero gravity conditions were utilized with the test subjects in pressurized Apollo state-of-the-art suits. In the initial experiment, the ability of the pressure-suited test subject to generate impulsive and sustained forces was measured objectively under a variety of conditions which simulated various modes of restraint and accessibility. The second experiment provided subjective and objective evaluations of the effects of object volume and mass, and attachment point to the subject on the maneuvering, transporting, and manipulation of such objects in zero g. The effects of hydrodynamic mass and drag were measured and compensated for in the experimental protocol, equipment design, and resultant test data.

210. Rasquin, J.R.
UNDERWATER OPERATION EXPERIMENTS EVALUATION. NASA, Marshall Space Flight Center, Huntsville, Alabama. NASA-TM-X-53614. 29 May 1967.

The results of three evaluation studies of operations in a zero "G" engineering mockup facility are combined. The requirements to modify a standard impact wrench for underwater operations are presented. A regulator valve used in the exhaust part of a high altitude suit to maintain working pressure under a hydraulic head is described. The results of an evaluation of three types of hatches used to provide ingress and egress to the S-IV-B workshop are given.

211. Schock, G.J.D.
PERCEPTION OF THE HORIZONTAL AND VERTICAL IN SIMULATED SUBGRAVITY CONDITIONS. USAF Aeromedical Field Lab., Holloman AFB, New Mexico. Jun 1959. Proj. 7851, AFMDC TN 59-13.

212. Seeler, H.W.
UNDERWATER PRESSURE-COMPENSATED BREATHING CONTROL VALVES FOR PROLONGED WATER IMMERSION. Aerospace Medical Research Labs., Wright-Patterson AFB, Ohio. Final Rept. for Feb 1960 – Jun 1962, AMRL-TR-64-130. AD-611-807.

Two water-pressure-compensated breathing devices for prolonged immersion have been designed, fabricated, and tested underwater. One valve is a continuous-flow regulator and the other is a demand regulator. Both valves allow exhalation through a hose directly into the surface atmosphere for air analysis. One of the two valves has been used extensively during prolonged weightlessness simulation. immersion.

213. Taggart, R.
AUXILIARY POWER FOR MAN IN THE SEA.
Robert Taggart Incorporated, Fairfax,
Virginia.

This paper discusses the problems involved in working in an underwater environment and points out potential methods of efficiently supplying the auxiliary power essential to the performance of this work. Auxiliary power sources from the surface are compared with sources on the ocean floor. It was concluded that electric power used for an underwater operation should be restricted to a single power cable leading to a central location from the surface vessel and that electric power should be used only for equipment which is fixed in this central location for the duration of the operation. Also all hand power tools and other equipment which is moved about the site should be driven by compressed air stored in portable tanks.

214. WATER PRESSURIZED SPACE SUITS HELP SOLVE FATIGUE PROBLEM IN EVA (EXTRA-VEHICULAR ACTIVITY). Research Bulletin, General Dynamics; Convair Division. 1.3, fourth quarter, 1966.

215. WEIGHTLESSNESS – UNDERWATER FOR OUTER SPACE.
Product Engineering, 52, 4 Jan 1965.

A brief article on underwater studies made by Boeing Company, Seattle, Washington. The test chamber used is 15 ft deep, 19 ft long and 14 ft wide, big enough to test mockups of proposed space vehicles. The research program is OGER (O-Gravity Effects Research).

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13. ABSTRACT

This compilation contains 215 selected references pertaining to behavioral and biomedical research involving human subjects. The references are organized under three topics: (1) Physiological Studies, including acceleration stress tolerance and physiological responses to simulated weightlessness; (2) Human Engineering Studies of man's performance capabilities under neutral buoyancy conditions simulating weightlessness; and (3) Techniques and Personal Equipment Requirements for water immersion studies.

The references are arranged alphabetically by Author, or by Title if appropriate, under each of the three topics. An Author Index is included as an aid in locating the contributions of specific investigators.

The references cited were drawn from the literature published or privately distributed during the period from January 1951 through December 1967.

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14. KEY WORDS: Key words are technically meaningful terms or short phrases that characterize a report and may be used as index entries for cataloging the report. Key words must be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location, may be used as key words but will be followed by an indication of technical context. The assignment of links, rules, and weights is optional.