Engineering Man For Space
THE CYBORG STUDY

FINAL REPORT
NASw-512

TO: NASA (OART) BIOTECHNOLOGY AND HUMAN RESEARCH
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SUBMITTED BY: ROBERT W. DRISCOLL, CYBORG PROGRAM
APPROVED BY: RICHARD J. PRESTON, MANAGER, BIO-SCIENCES AND TECHNOLOGY

UNITED AIRCRAFT
CORPORATE SYSTEMS CENTER
FARMINGDALE, CONN.

The CYBORG study is the study of man. It concerns itself with the determination of man's capabilities and limitations under the unpredictable and often hostile conditions of space flight, and the theoretical possibility of incorporating artificial organs, drugs, and/or hypothermia as integral parts of the life support systems in space craft design of the future, and of reducing metabolic demands and the attendant life support requirements. By this approach it is hoped that the efficiency and longevity of the life process on board space flights may be increased. It covers these new areas in detail in order to determine whether their application or utilization can assure the continued contribution of man to the success of prolonged space flights or interplanetary exploration without threatening his safety during such flights. The idea of modifying man is an advanced concept which must supersede conventional thinking and which will, in the long run, provide us with basic research data in the fundamental physiology of man during the conditions of space travel.

The Phase I CYBORG study has two principal task areas. Task A is a detailed consideration of the availability and practicability of using artificial organs, hypothermia and/or drugs in adapting man to a space environment.

Task B is the collection and study of data relating to the operation of the human heart in a space environment. This has included the development of a mathematical and physical dynamic model.

This report is divided into seven major sections. The sections on artificial organs, hypothermia, drugs, sensory deprivation, and cardiovascular models represent the detailed discussion of the roles each may play in space flights of the future.

Section II thoroughly analyzes the history, development, state-of-the-art, and future directions in the fields of the artificial lung, the artificial heart, the artificial kidney and extracorporeal pump oxygenating equipment. All of the problems associated with the development of such units, physical, mechanical, and physiological, are considered in detail.Various existing models of each of the units used in present-day clinical procedures are illustrated and evaluated. Conclusions based on this information indicate limited application of artificial organs to space craft life support system design, with certain reservations however.

Section III follows the same general plan of analysis with great stress being placed in the physiologic aberrations and responses to artificially reduced body temperature. Methods by which body temperature can be lowered either by external means or electrical neurologic stimulation are covered thoroughly. The effect of this temperature reduction on the major organ systems and their physiologic functions is carefully analyzed. This work appears to indicate a potential role for hypothermia as a metabolic retarding element, both from the standpoint of space applications and terrestrial medical research contributions. The metabolic reducing effects of a hypothermic situation have been clearly demonstrated in many areas of clinical research. The ability, at some point in this research, to "suspend animation" by hypothermia becomes a significant possibility. In the preservation of red blood cells for instance, work under Navy contract has already shown that the storage of the erythrocyte is possible for periods up to four years. Tagging and reinjection of these stored cells into living systems has indicated that their predetermined life cycle of approximately 120 days has remained unchanged by the lengthy period of hypothermic preservation.

Section IV deals with a pharmacologic approach to the problems possibly to be encountered by space travelers. The use of drugs as adjunct or protective agents in human physiology for space flight considerations is not new. Extensive work has been done on the radioprotective properties of a variety of chemical agents. The section on drugs in this report limits itself, however, to a study of those agents considered applicable only in the areas of anxiety, depression, fatigue, acceleration protection, thermoprotection, metabolism reduction and motion sickness.

The use of chemical agents to alter physiologic function in space flights enables the operators to eliminate many variables in physiologic function and maintain precise and predictable control over these functions. However, although there is a great wealth of information on literally thousands of such agents, there is no central information source where the complete and varied effects of these agents, over and beyond those for which they were produced, may be obtained. It is felt that such an information base should be established immediately to fill this need. This agency would not only help the medical profession, but would also make its data available to those engaged in all forms of biomedical research.

The section on Sensory Deprivation (V) was heavily investigated because it is felt that this area can cause potentially debilitating effects on research pilots engaged in space exploration. It is considered a serious limitation on man's adaptability to space flights and, therefore, it has been emphasized in the **CYBORG** final report. In this area there has been extensive research and even the most preliminary analysis indicates that in hypodynamic situations where there is minimum sensory input, depending on the conditions, serious psychophysiologic deviations may occur in periods of less than one hour. This section discusses the aberrations resulting from exposure to hypodynamic conditions, identifies the environmental events associated with such effects and the sensory modality most susceptible to them, evaluates the characteristics of individuals most resistant or susceptible. In addition, it investigates methods of identifying and evaluating such characteristics and analyzes the hypodynamic aspects or possibilities of the space capsule and a space environment. It cannot be over-emphasized that the area of sensory deprivation must be actively pursued and that this area is worthy of continued, penetrating **CYBORG** research.

Section IV discusses the operation of the human heart in a space environment. Complete understanding of the multitude of complex interactions of organs and organ systems in the human will be a long time in coming. However, careful analysis of several of the more obvious characteristics of these systems has shown that their properties can, in many cases, be expressed in mathematical terms. The subsequent ability to duplicate and simulate any or all of these functions in terms of mathematical analogues will lead to an improvement in our understanding of the basic mechanisms and controls which affect the human system operation. By employing hypothetical, mathematical equivalents for computer simulation and high-speed input variation analysis, we can begin to understand some of the complexities of human organ systems, their interface relationships, and, accordingly, be in a better position to predict function as influenced by new and changing environments.

Although the **CYBORG** study (NASw-512) has dealt specifically with hypothermia, drugs, artificial organs, and cardiovascular modules, we have expanded this concept to include other fields which cannot justifiably be reported in this document. However, it is felt that the area of calcium mobilization, a potentially severe limitation on man's physiologic adaptability to a space environment, should be investigated in detail. As was discussed in the interim **CYBORG** report presented to NASA-OART in January of this year, the calcium-excretion levels evidenced by the three U.S. orbital man space flights were significantly elevated to arouse the interest of United Aircraft's Bio-Science group into an active pursuit of the reasons for this phenomenon. It has been proposed that mineral dynamics, along with mathematical and physical models of biological systems and sensory deprivation, be continued in subsequent phases of the **CYBORG** program.

A. Introduction

The NASw-512 Contract is a biological design study of man, particularly in alien or extraterrestrial environments. It concerns itself with the systems requirements for the optimum life support, man monitoring control, and spacecraft configuration design which will insure his safe and continued contribution to extra-terrestrial and space explorations. By thorough study of man's systems and subsystems when subjected to the simulated and actual conditions of extraterrestrial environments, we will be able to make significant progress toward the better understanding of man as a space voyager.

In long-term space flights, the physiologic well-being of the pilot is of primary concern to the earth-bound medical monitors. While on such flights, the pilot/astronaut must be protected not only from all of the known hazards of the space environment, but must in addition receive protection from those that are suspected to be of a debilitating nature. By the same token, the conquest of space by man must not be delayed by hyperprotective measures adopted through an overcautious approach to the unknown which require elaborate and unnecessarily redundant system designs. Only by a complete understanding of man's psychophysiological reactions to these hazards can we be permitted to let such flights take place, and be in a position to predict with any degree of reliability the probable success of a given flight.

As this report indicates, only selected areas merit detailed experimental efforts in the Phase II portion of the CYBORG Program. These are mathematical models (Biocybernetics), Sensory Deprivation, and Mineral Dynamics.

B. Biocybernetics

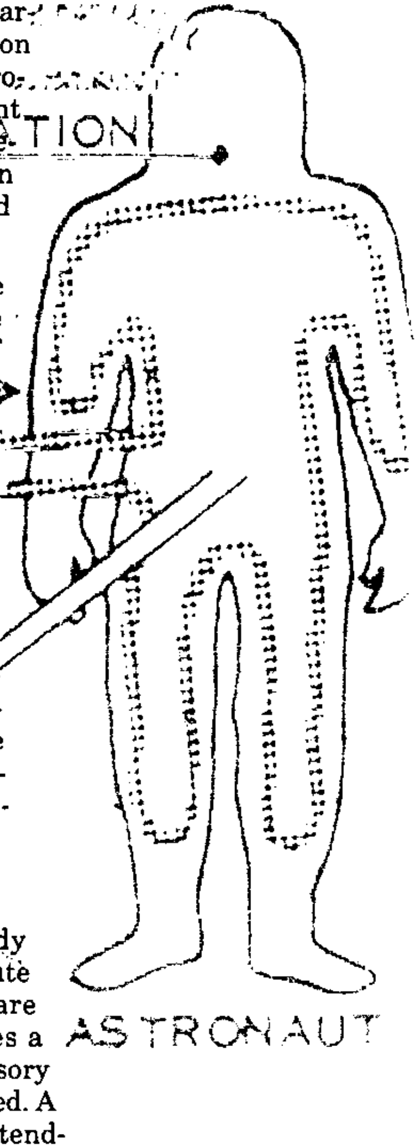
The ability to determine the performance of several aspects of the human organism while it is subjected to the stresses of space flight, without risking an astronaut's life, can be accomplished with a large measure of success by terrestrial simulation. Careful analysis of many aspects of human functions has shown that in many cases even the seemingly most complex systems can be reduced to mathematical relationships. By computer simulation and mathematical models of these systems we can develop an actual physical dynamic analog of the system under consideration. By subjecting these analogs to the environmental stresses of a space flight in terrestrial simulation laboratories we may be better able to gather a thorough understanding of the system dynamics involved and generate the design requirements for this aspect of manned space flight.

Phase I of the CYBORG Study has been concerned with the basic problem of conceptualizing and defining specific system components of man and the functioning of these components in an extra-terrestrial environment.

As part of CYBORG, considerable effort has been devoted to the synthesis of a non-linear mathematical model of the human cardiovascular system designed to reproduce the salient features of its functioning under several environmental conditions and, possibly, under certain types of psychological inputs. In the continuation of the CYBORG concept in Phase II, efforts will continue to be devoted to the development and exploration of a cardiovascular system model and will be extended to other human systems and subsystems. It is recognized that the experimental verification of this analytic model in all detail cannot be undertaken without access to a gravitation-free environment. It is possible, however, to perform significant experimental work in animals which have been subjected to surgery in which their carotid sinuses and other baroceptors have been denervated. These animals can be thus regarded as "pseudoweightless" from the cardiovascular viewpoint, and hence can be used in studies designed to evaluate the response of the cardiovascular system to certain standard inputs such as would be encountered in rapid re-entry from a deep space mission.

Since one ultimate objective of this program is the design of sensing and processing systems, it must be emphasized that ultimately some aspects of this work must be performed under actual operational conditions in man. It is not possible or desirable, at this time, however, to do more than point out the necessity for this ultimate test. Additional understanding of human cardiovascular dynamics can be expected to improve the precision with which we can specify more nearly optimum sensor-processing systems. For example, blood flow or vascular current is an important but difficult to measure physiologic parameter. It is conceivable, as shown by F. Cope, that blood flow can be determined indirectly from data on blood pressure and blood-vessel compliance.

Relationships such as the one indicated above have been investigated as part of Phase I and should certainly be further studied in this proposed program. The availability of molecular integrated circuit techniques makes it entirely conceivable that once a set of rational requirements has been generated, small sensor-processor units can be designed which will handle the data in a manner which will permit the display of more meaningful cardiovascular variables. Even in those cases where it is not feasible or desirable to incorporate the data processing elements in the sensor packages themselves, the processing methods can still be incorporated in suitable computing devices for remote handling and display. After this objective is accomplished, studies will be undertaken to explore the utility of preparing analog packages of the human vascular system. Such packages, once developed, would prove useful in both terrestrial experimentation and in the preliminary exploration of the extra-terrestrial environment.



C. Sensory Deprivation

This area has been included in the CYBORG Study because many reported effects of sensory deprivation constitute a serious modification of normal functioning, and there are grounds for supposing that the space capsule constitutes a restricted environment which provides significantly less sensory stimulation than that to which humans are usually accustomed. A major contingency which must be guarded against on any extended space mission is the induction of hypodynamic conditions as a result of a failure of any component. For example, loss of power could result in the cutting of communications with earth station. In order to maximize the probability of survival, it is essential that design requirements be specified and devices be incorporated which will maintain the sensory environment at a high dynamic level.

The major purpose of the proposed study is the identification and evaluation of the means by which man can be prepared to cope successfully with the many psychological stresses which may affect him during long-term space missions. The need for this work arises because man is basically a biological organism designed to operate within the parameters defined by the earth environment. Despite a remarkable degree of overdesign, there are many areas in which man's capabilities fall short of requirements posed by such missions.

On the basis of the present analysis, time-structuring events such as programs of moving displays, sound, and recorded material of interest to the crew seems to merit investigation. Other activities such as problem-solving requirements and sequential tests may be promising. The design requirements of such devices should receive the highest priority. By presenting to the pilot changing patterns of sensory inputs, we may be able to control his possible lapse into a state of sensory deprivation and prevent its attendant incapacitating effects from ever occurring. In addition, it is felt essential that means be formulated which will have the capacity to monitor the status of the Central Nervous System. Such a device would be able to determine the level of Central Nervous System reactivity to a marginal signal input and determine whether quite unconsciously the pilot is gradually losing control of his conscious mental processes.

D. Mineral Dynamics

On each of the three United States manned orbital flights, collected in- and post-flight urine specimens showed significantly elevated levels of excreted calcium. This is a phenomenon which has been frequently observed in the past in cases of hospital patients subjected to extended periods of immobilization, in sensory-deprivation studies, certain stress situations, and in simulated weightlessness experiments involving water immersion. It remains to be determined, however, whether this increase reflects potentially serious drainage of calcium from the skeletal system. In order to monitor and appraise the significance of alterations in calcium output, it is necessary that a detection system be devised which will permit the tracing of the mineral through the several metabolic compartments.

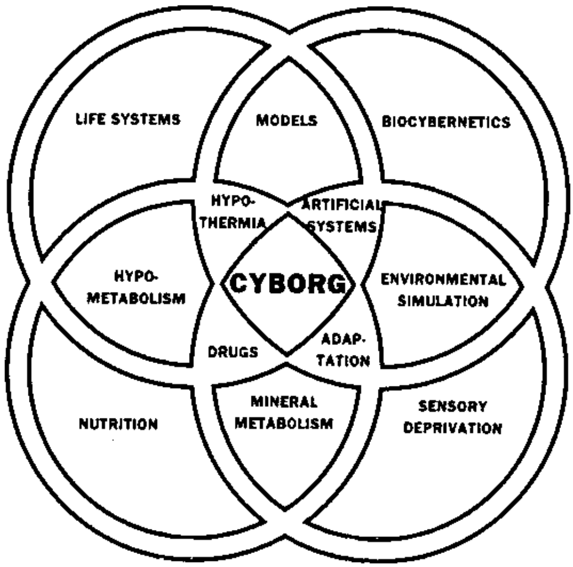
It can be unequivocally stated that no method is known today for determining calcium movement other than those methods involving some type of tracer. It is to be emphasized that passive neutron-activation methods are capable only of "static estimates of calcium." The elucidation of the dynamics of the mineral requires the use of distinguishable but chemically identical atomic species. Therefore, a suitable system for the detection of calcium dynamics must involve:

1. The use of a tracer,
2. A suitable sensor, and
3. The application of correct data processing techniques to the information collected.

In the course of this proposed program, we shall continue the investigation of calcium dynamics in man and animals from the viewpoint of the changes which occur as a result of immobilization and/or psychological stress and establish the requirements for a detection system to determine and display changes and predict trends in the pilot's calcium dynamics.

The CYBORG program is expected to be a long-range program of study and experimental efforts. The experimental phases are intended to develop both mathematical and physical-dynamic models of important human systems. These will include the cardiovascular, endocrine, gastrointestinal, cutaneous, and pulmonary systems. The physical models will be verified by actual laboratory experiments and relating mathematical formulae will be developed to describe interaction of the systems. These models will be simulated in the UAC computer facility and dynamically tested, ultimately, in space environmental extremes. Firm design requirements will be established for an optimized physiologic monitoring system as well as for the design requirements for a life-support environmental control system. Such systems will be integrated to provide a total man-machine complex with man in the control loop as the forcing function. Space-capsule design requirements will be delineated, as well as a result of sensory-deprivation experiments and man-augmentation mechanism design constraints.

These design requirement "groups" will be developed in such a way that a relatively simple modification scheme will allow the requirements to change and update the state of the art as time progresses. This will prevent the necessity of having to fund an entirely new program every few years to redevelop design requirements as the changing state of the art makes existing requirements groups obsolescent.



Out of the CYBORG program we will be able to understand considerably more about man, his systems and his subsystems. Methods for augmenting and extending his limitations, which will be compatible with the state of the art and the applicability of man in a space mission will be derived from CYBORG in an effort to obtain the maximum integration of man into a man-machine complex.

Hopefully we will evolve a model of the central nervous system during this period. This is an ambitious task, but must be earnestly assaulted if such a worthy undertaking is ever to be completed.

A significant number of experiments will be performed on animals and man throughout this program to verify the modeling concepts which have evolved from the CYBORG theory. In this way, CYBORG will accomplish its mission by providing a better understanding of the biological design of man and relating the impact of this understanding to compatible hardware systems.